DISSERTATION

DEFINING AND ENGINEERING SOLUTIONS FOR AGROECOLOGICAL IMPACTS OF SALINITY AND WATERLOGGING IN AN IRRIGATED RIVER VALLEY

Submitted by

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WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY JOHN PHILIP BURKHALTER ENTITLED "DEFINING AND ENGINEERING SOLUTIONS FOR AGROECOLOGICAL IMPACTS OF SALINITY AND WATERLOGGING IN AN IRRIGATED RIVER VALLEY" BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

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ABSTRACT OF DISSERTATION

DEFINING AND ENGINEERING SOLUTIONS FOR AGROECOLOGICAL IMPACTS OF SALINITY AND WATERLOGGING IN AN IRRIGATED RIVER VALLEY

Through extensive field data collection and finite-difference modeling of groundwater flow, solute transport, and mass balance in the unsaturated zone, salinity and waterlogging problems are investigated in a 50,600 ha study area within an irrigated reach of the Lower Arkansas River Valley in southeastern Colorado. The established data collection program is described and rich data sets, including water table depth, water table salinity, surface water salinity, and soil water salinity are presented for a three-year (1999 – 2001) study period. From these data and other collected or estimated aquifer and unsaturated zone data, models were constructed, calibrated, and tested. The development and application of these models are presented in a series of published articles that are included along with more detailed descriptions of the model components and calibration procedures. These presented components include the unsaturated zone mass balance approach, aquifer recharge estimation, use of geographical information systems (GIS) tools, and special procedures used in the Groundwater Modeling System (GMS version 3.1) interface software to create MODFLOW and MT3DMS models of the investigated alluvial aquifer.

The calibrated models were used to investigate a wide range of regional alternatives to mitigate salinization and waterlogging problems. These alternatives incorporated various configurations of solution measures including recharge reduction through increased irrigation efficiency, canal seepage reduction, sub-surface drainage installation, and pumping volume increases. Results indicate that significant reductions in average regional water table elevation (as large as 1.93 m), soil water salinity (up to 950 mg/L), and crop yield increase over the irrigation season can be achieved. Potential for marked reduction in salt loading to the river and in net water consumption was also confirmed. The presented research demonstrates the progression and wide range of activities involved in the irrigation-stream-aquifer modeling process. These activities included field data collection, initial model development, model refinement from the steady-state to transient configuration, creation of an original unsaturated zone mass balance model, model calibration and testing, and model application to investigate proposed solution alternatives.

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PREFACE

The research described herein is part of a larger effort to create a basin-scale decision support system (DSS) for the Lower Arkansas River Valley located in the southeastern portion of Colorado. The purpose of this document is to detail the aspects of the development of this DSS of which the author was directly involved. Specifically, the author was responsible for the original construction of the regional-scale groundwater flow and salinity transport models and for the formulation of an unsaturated zone salinity model. Additionally, the author was a part of the original data collection team and aided in the associated field work and program management. The author was not responsible for the development of the modified drainage model used to evaluate a subset of the considered solution alternative scenarios or for the lab testing of collected soil and water samples.

The progression of the author's research is documented in three independent journal papers (Chapters 3 – 5). These papers were published or are in press of the American Society of Civil Engineers' (ASCE) *Journal of Irrigation and Drainage Engineering.* The papers are presented in chronological order and demonstrate the increasing level of complexity of the modeling effort. In addition to these papers, a review of the available literature is given in Chapter 2, a description of model calibration and results is provided in Chapter 6, additional conclusions (beyond those detailed in the presented papers) and recommendations for future work are presented in Chapter 7, and a number of supplemental appendices are included.

Please note that the lists of tables and figures provided in the following pages do not include those that are contained within the published papers (Chapters 3 –5). The tables and figures in these documents are considered to be part of the self-contained whole of each paper, and exclusion of them from the lists avoids repetition of some similar items that were necessary in presenting each paper individually.

For my wife Kristy

"There is no more lovely, friendly, or charming relationship,
communion, or company than a good marriage."
- Martin Luther

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CHAPTER 1

INTRODUCTION

> *"All things in the world are two. In our minds we are two – good and evil. With our eyes we see two things – things that are fair and things that are ugly... We have the right hand that strikes and makes for evil, and the left hand full of kindness, near the heart. One foot may lead us to an evil way, the other foot may lead us to a good. So are all things two, all two."*
>
> *Eagle Chief [Letakots-Lesa]*
> *Pawnee*

In her book *Pillar of Sand,* author Sandra Postel describes the two sides of irrigation as representing a Faustian bargain that modern society has inadvertently struck with nature (Postel 1999, p. 91). The enormous benefits of increased food production and economic gains are obvious and attractive; but, the destructive consequences of altering the cycles of nature lurk beneath the surface, threatening to emerge if we fail to recognize them. Jan van Schilfgaarde observes that throughout history, "Civilizations have risen and fallen with the growth and decline of their irrigation systems..." (1989, p. 204).

Two major problems that inherently stem from irrigation practices, and that may very well have contributed to the decline of several ancient civilizations, threaten the vitality of many of today's agricultural regions of the world. *Salinization* of the soils and irrigation water and *waterlogging* of fields due to high groundwater tables have caused significant adverse socio-economic and large scale environmental problems across the globe (van Schilfgaarde 1989, p. 204). Daniel Hillel, a Professor Emeritus of Soil, Water, and Plant Sciences at the University of Massachusetts, recently reported on behalf of the World Bank that, "Waterlogging and salination, along with other degradation processes, have not only caused the collapse of irrigation-based societies in the past, but are indeed threatening the viability of irrigation at present." He continues, "The problem is global in scope" (Hillel 2000).

1.1 THE WORLDWIDE EPIDEMIC

Joe Wambia, a senior financial analyst with the South Asia Rural Development Unit at the World Bank, has stated, "Waterlogging and salinity remain Pakistan's top environmental challenges and the principal threat to Pakistan's vitally important irrigated agriculture." He goes on to report, "Each year, Pakistan loses about 25 percent of its potential crop production equivalent to US$2.5 billion due to salinity " (World Bank 1997). Unfortunately, this situation is not unique. China, India, Central Asia, and the United States, as well as Pakistan, are losing vast quantities of production due to salinity and waterlogging problems (Postel 1999, p. 92).

The magnitude of the current crisis, though hard to accurately quantify, is undeniably immense. The United Nation's Food and Agriculture Organization (FAO) reports that in 2002 the worldwide total area of irrigated agricultural land was 276.7 million hectares. The FAO has also reported that of the four countries with the largest amounts of irrigated agriculture, the effects of salinity are evident on 28 percent of the irrigated lands in the United States, 23 percent in China, 21 percent in Pakistan, and 11 percent in India (Umali 1993). It is estimated that 47.7 million hectares, nearly one-fifth of the total irrigated land, is damaged by salinity build-up – this damage translates to an estimated US$11 billion in reduced farmer income (Postel 1999, p. 92). In 1991, a study conducted in India concluded that since its independence in 1947, India had accumulated around 8 million hectares of land damaged by waterlogging and salinity due to irrigation and that as many as 1.5 million farmers had been displaced as a result (FAO 1995). Unfortunately, the problems continue to expand, and a reported 1.5 million ha (3.7 million ac) of irrigated land are taken out of production annually due to waterlogging and salinity (UNEP 1992).

1.2 HISTORICAL DEVASTATION

Throughout history, a great number of irrigation-based civilizations have arisen only to ultimately disappear. In the Tigris-Euphrates basin of present-day Iraq, the Sumerians, Babylonians, and Assyrians all once thrived. In the western hemisphere, Central Mexico, Peru, and the American Southwest, each once supported advanced societies heavily reliant on irrigation. Although numerous factors played a role in the rise and decline of each of these ancient cultures, the importance of irrigation appears undeniable.

In 1957, the Iraqi government sponsored an archeological study of the southern Mesopotamian plains in an attempt to understand the importance of irrigation and its associated salinity problems. The evidence uncovered indicated three major episodes of salinization – the first of which corresponds directly with the fall of the Akkadian (Sumerian) empire (around 1700 B.C.). Following this event, the demographic centers of societies moved northward, away from the Persian Gulf, and history saw the rise of two more empires: Babylon and Assyria. Both of these also saw significant problems associated with their irrigated agriculture (Postel 1999, p.19-27). Postel concludes concerning the history of this region, "While archeologists and Near East specialists do not agree on the full extent of salinization's role in ancient Mesopotamian history, it was a destabilizing force, if not a proximate cause of societal decline" (Postel 1999, p. 19). Following Assyria, the region saw thriving occupation by Sassanians and later by the Arabians; however, the plight of this region is described as follows:

> By the sixteenth century, the Fertile Cresent of Mesopotamia, from which human civilization had sprung and reached unprecedented heights, was little more than a salty wasteland. These societies had given the world writing, mathematics, and unparalleled feats of engineering. But they had not created a system of agriculture that could sustain their people (Postel 1999, p.27-28).

In Mesoamerica, settled villages arose around 2000 B.C. These villages were sustained through domesticated corn production. Large-scale irrigation saw its rise beginning around 300 B.C. in the Tehuacán Valley of Mexico. In Peru, the Chimú Empire spanned for 2,500 years and relied on irrigated corn agriculture as a food source. In North America, the Hohokam civilization thrived for over 1,000 years in the south-central Arizona area, utilizing the Gila and Salt Rivers to irrigate crops. The Hohokam built over 500 kilometers of main canals and practiced a variety of agricultural techniques which may have enhanced the societies overall stability (Postel 1999, p.37 –38). Ultimately, however, each of these great societies fell victim to the vulnerability of an irrigation-based existence and the accompanying environmental devastation.

1.3 THE PROBLEMS EXPLAINED

Our fight with salinity and waterlogging derives from the basic fact that we are trying to grow crops in arid regions where nature never intended water to flow as it does in our man-made systems. Water in these areas always has some natural salt content deriving from contact with soil and rocks; however, in most instances, man's use is the primary cause of the high salinity levels which have created the environmental and potential economic crises that are now upon us. When water is used for irrigation, its natural salt content is intensified as crops utilize pure water in the transpiration process and as pure water is evaporated from reservoirs, canals, ditches, and flooded fields. Thus the problems associated with salinity are twofold – there is an increase in water salinity as you move downstream due to dissolution associated with return flows, evaporation, and consumptive use, and there is a buildup of salt in the soils as plants use pure water.

Waterlogging, the raising of the water table and its capillary fringe to an elevation at which it encroaches within the root zone of the crops, is also a product of our attempt to 'tame the desert'. Excess aquifer recharge, which can be greatly reduced by effective management of system performance, contributes significantly to high water table levels. Generally, factors that drive aquifer recharge include deep percolation of excessive irrigation applications (i.e. low irrigation efficiency), canal and reservoir seepage, excess precipitation, and, in less common instances, natural seepage from rivers and tributaries. Additionally, in many areas, inadequate drainage exists to maintain the water table at desired levels. Subsurface drainage systems are often ineffective due to poor design or are too costly to install. Vertical drainage from pumping is often inadequate to effectively lower water tables on a regional scale and can have significant effects on water rights administration and surface water quality. In many instances, anthropogenic changes in the system, such as reservoir construction, will yield results that inadvertently exacerbate high water table problems.

A fundamental three-way link exists between salinity, waterlogging, and irrigation which must be broken in some way for problems to be adequately controlled. Richard Rapaport explains this process as it occurred in California, "The buildup of crop-damaging salt which concentrates in marginally-productive arid lands has plagued farmers of the western San Joaquin Valley for over a century...The application of large amounts of water reduced the buildup of salts in the soils, but also created the need to construct an agricultural wastewater drainage system to reduce the resultant high water tables" (Rapaport 1986). A system diagram showing the important salinization processes is given in Figure 1-1. Within this diagram, a high water table scenario is shown along with the major water balance components.

As is illustrated in this system diagram, when water is removed from the water table through upward flow (upflux) and from the root zone through evapotranspiration, the build-up of salts results. Also impacting salinity levels is the natural dissolution process that occurs when water is in contact with soils and aquifer materials. This process generally contributes salts into the system in proportion to the aquifer volume. A lack of adequate drainage exacerbates high water table conditions, which consequently results in

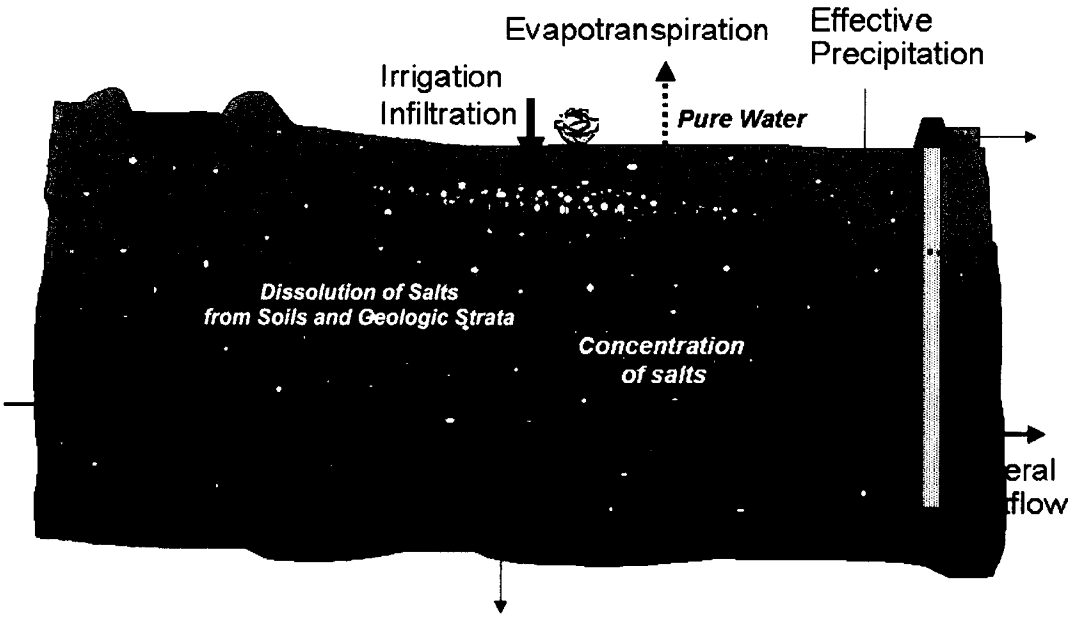

Figure 1-1. System Diagram Showing Salinization Under High Water Table Conditions

continued upflux and salt concentration increases and larger dissolution contributions. To break this three-way link, yet still provide adequate soil water for crops along with sufficient water for the leaching of salts, a delicate balance must be established. Accurate simulation models of groundwater flow and salinity transport are needed to support regional management decisions and to aid in regional system design.

As noted above in the estimated global statistics, the impacts of high water tables and increased soil and groundwater salinity are significant and include:

- Reduced crop yield due to waterlogging
- Reduced crop yield due to soil salinity above threshold levels

- Reduced farmer income due to reduced crop yields or required change to lesser valued crops
- Reduced produce quality
- Arable land losses
- Downstream effects on water quality

Undoubtedly, effective modeling can be an invaluable tool in solving the current inter-related problems of high water table levels and high soil and groundwater salinity.

Within the state of Colorado, where crop production accounted for around US$1.3 billion in gross income in 2003 (Colorado Agricultural Statistics Service 2005), there are indications that the intensity of waterlogging and salinity problems are increasing significantly. According to the Colorado Agricultural Statistics Service, the agricultural industry in Colorado has taken approximately 800,000 ha (2 million acres) of land out of production over the last ten years (2005). A significant portion of land losses that have been occurring are believed to be directly related to waterlogging and salinity (Valiant 1997). Within the irrigated Lower Arkansas River Valley, where visible evidence of the problems exists (see Appendix G), water table elevations rose from 0.3 to 1.3 meters (1.0 to 4.3 feet) on average between the years 1969 and 1994 (Cain 1997). Also, according to the US Environmental Protection Agency, many areas in the Valley are classified with the highest salinity hazard rating and salinity levels in the river have been on the rise (Lewis 1998, Whittemore 2000). In response to this current crisis, a study was initiated by the Colorado Agricultural Experiment Station (CAES) to monitor and model waterlogging and salinity problems on a regional scale within the Lower Arkansas River Valley of Colorado. Although the anecdotal evidence suggested that problems were widespread within the region, a program was needed to quantify the magnitude of the problems and to provide a basis upon which to prescribe solution alternatives. The research documented herein is in support of and utilizes data collected for this study.

1.4 DESCRIPTION OF STUDY AREA

Early explorers of the American plains noted that the waters of the Arkansas River were affected by a natural salinity source. The Long Expedition noted in 1820 that, "At the mountains the water was transparent and pure, but soon after entering the plains it becomes turbid and brackish" (Long's Journal: July 18, 1820). In 1845, as part of the Frémont Third Expedition, Lieutenant James William Abert commented on a pool of water found near the present day city of La Junta, Colorado, as being, "...so highly impregnated with common salt and sulphate of soda as to be nauseous and bitter to the taste" (Carroll 1941). After irrigation was introduced within the region in the 1870's, saline high water tables began to develop in the early part of the twentieth century (Miles 1977). Since that time, the problems have fluctuated in severity in response to a variety of changes within the river basin. In the 1930's, a large-scale effort to install subsurface clay tile drains achieved some success in easing high water table problems. During the 1950's, installation and operation of a large number of pumping wells penetrating the alluvial aquifer had the indirect effect of maintaining lower groundwater levels.

Recently, however, changes within the Lower Arkansas basin have caused the waterlogging and salinity problems to seemingly worsen. Construction of two major reservoirs (Pueblo and John Martin) has not only allowed a much larger and more consistent supply of irrigation water (and, therefore, caused the overall application amount to increase), but also has changed the sediment transport and peak flow characteristics of the river. Reduced sediment load in river water diverted to canals is suspected of causing a reduction in canal "sealing" and an associated increase in seepage. Additionally, the reduction in peak river flow has caused a gradual aggradation of the river bed, thereby elevating river water levels and reducing the potential return flow drainage gradient from irrigated lands. Also, recent court decisions concerning the Arkansas River Compact between Colorado and Kansas have required that the utilization of existing pumping wells be significantly curtailed. Evidence also exists indicating that much of the subsurface drainage installed in the 1930's is no longer functional. Likely, all of these factors have played some role in the recent intensification of problems in this region.

The CAES effort was initiated with the specific goal of developing a decision support system (DSS) and associated database to evaluate management options within the Lower Arkansas River Valley. The study area examined in the presented research is specified as the "Upstream Study Region" within the larger basin-scale project. It is comprised of approximately 26,400 ha (65,300 ac) of irrigated land within Otero and Bent Counties, Colorado, and stretches along a 62 km (38.5 mi) reach of the Arkansas River (see Figure 1-2). The western boundary lies just west of the town of Manzanola, and the eastern

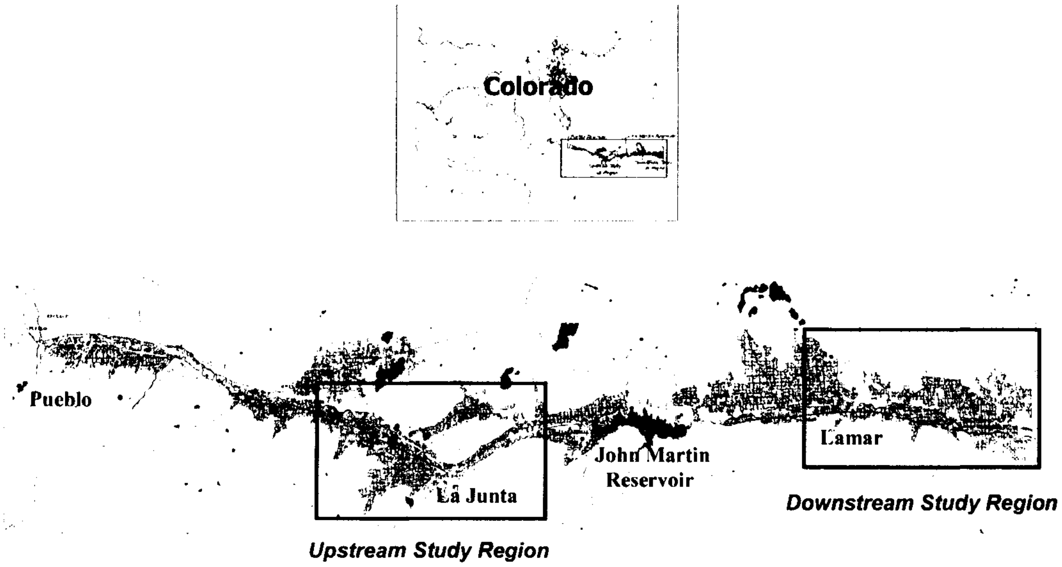

Figure 1-2. Study Area Located in the Lower Arkansas Valley, Colorado

boundary is defined by Adobe Creek. The cultivated crops consist of alfalfa, corn, grass, sorghum, wheat, cantaloupe, watermelons, onions, and various other vegetables (FSA 2001).

The prominent irrigation system employed in the study area is open-ditch furrow irrigation, although there are a significant number of farms now using gated pipe in lieu of the traditional open-ditch and siphon tube technique. The number of center pivot sprinkler and drip irrigation systems is still very small. Soils in the area are principally alluvial deposits dominated by silty-clay-loam surface layers and loam-to-sandy loam substrata (USDA 1972a, 1972b). The study area was made as large as possible under the given budgetary and personnel constraints, and this particular region was selected for study because it is considered representative in terms of hydrogeology, cropping patterns, irrigation infrastructure and management techniques of the Lower Arkansas Valley upstream of John Martin Reservoir. Also, this area is interesting because it contains a smaller subregion east of La Junta which has been the focus of some limited modeling analysis by the US Geological Survey (Konikow and Bredehoeft 1974, Person and Konikow 1986, Goff 1998). Ultimately, study results should provide sound guidance in prescribing solutions for the entire Valley area upstream of John Martin Reservoir.

1.5 POTENTIAL SOLUTION METHODOLOGIES

In addressing high water table and salinity problems, the general methodologies consist of:

- The "do nothing" approach
- Allowing individual farmers to solve problems as needed (localized approach)
- Attempting to develop solution alternatives based on anecdotal evidence
- Collecting required data and developing a simulation model to use as a tool for solution alternative design (to varying levels of detail for field or regional scales)

It is assumed that the "do nothing" approach is unacceptable and could potentially lead to the collapse or severe crippling of the crop-based economy in the Lower Arkansas Valley. The localized approach may prove effective to some extent; however, the financial burden on individual farmers may be too large for most to bear, and regional impacts would be ignored during design. Attempting to solve the problems based solely on anecdotal evidence might also yield some success in mitigating the problems, but the potential for efficient designs and effective regional management would be greatly diminished. Also, the important issue of problem quantification would be ignored and the direct impacts of projects would be difficult to evaluate.

Instead, it is the premise of this research (and a concept incorporated into the study objectives) that a modeling approach, supported by intensive data collection, is the most appropriate course of action to take in addressing the current high water table and salinity problems in the Lower Arkansas Valley. The focus of the research is on the development and application of a regional-scale groundwater flow and salinity transport model; however, efforts are also currently underway (by others) to look at field-scale and basin-scale models and their potential linking in an overall management decision support system.

The primary objective of the described research is to produce information and tools that will enable the *generation of effective solution alternatives* for reducing high water table and salinity problems and reducing salt loads to the river within the project sub-region. The developed models should be flexible enough so that a wide range of solution options can be examined, and they should be accurate enough to provide reasonable confidence in predicted system responses. Specifically, the identified objectives of the research effort are:

- To collect relevant data that will enable accurate characterization of the current conditions and problems within the study region.
- To construct a set of modeling tools that accurately represent the dynamics of the irrigation-stream-aquifer system and will be useful in predicting the impacts of changes imposed upon the system.
- To develop a model which will predict the transport of salts in the unsaturated zone which lies above the aquifer system.
- To examine a broad range of potential solution strategies using the developed modeling tools and provide comparative results which could be very valuable in developing a plan for real-world implementation.

Hopefully, fulfilling these research objectives will lead to the ultimate protection of the Arkansas River water resource and the sustainability of irrigated agriculture within the Lower Arkansas River Valley.

Included within this documentation of the conducted study is a review of relevant available literature, the series of research papers produced, a chapter describing model calibration procedures and results, a chapter presenting conclusions and recommendations, and a number of appendices described below:

> Appendices A and B relate to the data collection program initiated for this study. Appendix A presents expanded discussion of the field methods employed and the results of the data collection effort over the study period (1999 – 2001). It is

intended to supplement the information presented within the research papers; however, some repetition was unavoidable. Appendix B provides summary tables of the principal collected data sets. The values presented within these tables have undergone quality control to the extent that they represent the field-measured values, but they include a limited number of values that were omitted from incorporation within the model analysis due to suspected bias (likely related to human or instrumentation errors).

Appendices C, D, and E relate detailed information on the developed unsaturated zone salinity model. Appendix C presents the underlying modeling approach, associated governing equations, important assumptions, and a model coding schematic diagram showing the logical pattern that was utilized during model development. Discussion of specific modeling parameters is also provided. Appendix D presents the model code (in FORTRAN90 language) of the developed MT3DMS unsaturated module, and Appendix E describes the associated unsaturated module input file requirements and format.

Appendices F provides the general procedures and notes on the development of the water table recharge input data set. A step-by-step presentation of the utilized analysis is given along with discussion of underlying assumptions.

Appendix G consists of photographs taken during the course of the research. They provide documentation of the visual anecdotal evidence of the waterlogging and high soil salinity problems within the project region. Pictures are also included that show various aspects of the data collection program.

Appendix H describes model input preparation methods with an emphasis on the use of Geographic Information Systems (GIS) technologies. Several applications of GIS that were utilized are presented including the processing of satellite data to create imagery of the region and the creation of a field polygon data set that was used to translate data onto the finite-difference model grid.

Appendix I presents specific notes on model input preparation using the GMS software package (version 3.1). It provides descriptions and associated screenshots of the software of specific techniques that were developed by the author to efficiently and accurately produce the required model input data. It is included because these techniques are not intuitive from the standard software manuals and may be valuable to others who wish to conduct similar studies.

Appendices J and K present additional model calibration results to supplement those presented in Chapter 6. Spatial plots showing the water table depth calibration results of all observed time steps are given in Appendix J. Appendix K includes similar plots for the groundwater salinity model calibration results.

Appendix L includes summaries of additional model output beyond what the author was able to present within the published research papers (due to space constraints dictated by the publishers). Tables of final results along with color plots of the important model output are provided.

Appendix M presents an investigation into stochastic modeling feasibility that was conducted by the author during the course of the research. This investigation involved the generation of a number of stochastic realizations of a model data set and the subsequent running of the developed models under a Monte Carlo approach to evaluate output uncertainty. The analysis is presented as a trial only and is intended to be demonstrative of the viability of potential future work.

Lastly, a CD is provided that includes electronic versions of the unsaturated zone module code, the modified MT3DMS code and executable file, baseline model input files, various data analysis spreadsheets, and additional model output.

CHAPTER 2

LITERATURE REVIEW

The review of existing literature relevant to the current research is presented below. Seven pertinent areas have been identified, and the related studies/references have been categorized accordingly. These categories are general and meant only to serve organizational purposes. Many works reviewed could have fit into more than one defined category, but were placed only in one to avoid repetition. Under each topic, there are three sections. The first of these is a section entitled *Most Relevant Works* in which selected studies having the most similarity to or impact on the presented research are identified and described. The second section is the *Discussion* section where items of importance are summarized. The final section under each category is a *Bibliography* of all works reviewed.

2.1 GROUNDWATER MODELING/DECISION SUPPORT SYSTEMS

Numerous groundwater modeling studies of various scales have been conducted for a variety of purposes. Many were useful in providing guidance to the presented research. A few of these are highlighted below because they are similar in scope or have utilized similar tools in model development. The current move toward integrating geographical information systems (GIS) technology and groundwater modeling (often in the context of a decision support system [DSS]) is demonstrated in several studies; however, only two examples of studies that employ the Groundwater Modeling System (GMS) software package for purposes similar to the present research were discovered. Also, there is a notable lack of studies that incorporate numerical modeling tools to simulate salt transport on the region/sub-regional scale.

2.1.1 Most Relevant Works

Belitz and Phillips (1995) developed a transient, three-dimensional groundwater flow model using MODFLOW for investigation of regional agricultural drainage management. The study area investigated is a 1427 km^2 (550 mi^2) cultivated region located in the San Joaquin Valley, California, where the occurrence of high levels of selenium in drainage water is problematic. The developed MODFLOW model consisted of a three-dimensional grid defined by 36 rows, 20 columns, and five vertical layers. The horizontal model cell dimensions were specified as square with each side being one mile. The vertical model dimensions ranged from a uniform dimension of 6.1 m (20 ft) and 9.1 m (30 ft) in the upper two layers to three-sixteenths, five-sixteenths, and one-half of the remaining aquifer thickness for the third, fourth, and fifth layers, respectively.

The model was calibrated using hydrologic data from 1972 to 1988 and utilizes not only water table elevation, but also changes in underlying semi-confined aquifer heads and bare-soil evaporation area. Calibration results indicated a difference between the mean observed and the mean simulated water table elevation change of 0.1 m (0.4 ft). Additionally, the predicted bare-soil evaporation area was used as a calibration measure, and the simulation results indicated results generally within the range of the observed, but with notable over-prediction occurring after year 1985. Recharge and pumping were modeled as spatially variable, but temporally constant. Various management alternatives, including land retirement options, recharge reduction measures, and vertical drainage through increased groundwater pumping, were considered and evaluated over a 50-year planning horizon using an annual time-step. Results indicated that reducing recharge and/or increasing pumping were required to effectively reduce drainage flows while maintaining the viability of irrigated agriculture.

A study by Purkey and Wallender (2001) utilized a two-dimensional, vertical-transect, deforming finite-element model to examine the same study area in the San Joaquin Valley. They considered a variety of land retirement alternatives, including the retirement of large contiguous areas, the retirement of a patchwork of areas, and retirement of lands with and without drainage. They also modeled the baseline conditions. The model was formulated as a 11.38 km-long vertical transect using a daily time step and was intended to produce results that can be extrapolated to represent regional conditions. Calibration and testing procedures were not presented, and the authors make the point that the developed model was intended for comparative purposes only. Results were representative of a 50-year planning horizon and indicated that the retirement of large contiguous tracts of land was the best means to reduce drainage flows.

Jyrkama et al. (2002) presented a developed model that incorporates GIS tools to estimate recharge derived from precipitation for input into a sub-regional MODFLOW model for a 138 km^2 area within New Jersey. In this study, a hydrologic model known as HELP3 was used in conjunction with ArcView to create the transient, spatially-varied recharge boundary condition. The modeled period extended from January 1970 to September 2000 and used a monthly time step (although daily recharge values were calculated, they were aggregated into monthly totals to reduce computer processing requirements). Using GIS layers of soil type and land use/land cover (LULC), over 684 combinations were identified and used to generate the MODFLOW recharge input. Sensitivity analysis indicated that important factors in recharge estimation include the rooting depth and the leaf area index (LAI). Calibration was performed by adjusting uncertain parameters, such as curve number and evaporation zone depth, used in the adopted recharge estimation calculations. Analysis of calibration results demonstrated a much higher degree of accuracy (+/- 0.5 m for water table elevation prediction) using the presented recharge estimation technique versus a spatially-averaged approach (+/- 2.0 m). No testing of the calibrated model using an independent data set from another time period was presented. The overall conclusion of this study was that using a physically-based (soil type, LULC data, etc.) recharge estimation approach is the preferable method for transient groundwater modeling.

A study by Qureshi et al. (2004) combined a MODFLOW/MT3DMS model with an unsaturated zone model known as the Soil-Water-Atmosphere-Plant (SWAP) model to evaluate tube well operations and associated irrigation techniques for a field-scale site in the Pakistani Punjab region. Long-term impacts to soil salinity and crop productivity were examined to develop recommendations on how tube well networks should be utilized. The developed MODFLOW/MT3DMS models (formulated as a 23 row, 23 column, 9 vertical layer finite-difference grid) simulated conditions over a small plot (89m X 89m, 100 m depth) of maize that contained a 16-strainer skimming well. Calibration and testing of these models were performed; however, results are not presented. Output from these models was used as input into the SWAP model. The SWAP model was not calibrated versus known conditions, but was intended as a comparative tool only. Impacts of various pumping scenarios on soil water salinity levels and on crop yield were estimated using the SWAP model output. This study concluded that the current irrigation practices within the study area are not sustainable and that pressurized irrigation methods should be adopted in lieu of the widely-used skimming wells. Although limited in size and scope, this study provides a good example of combining groundwater flow and contaminant transport modeling with an unsaturated zone model.

A 0.42 million hectare region in the arid Punjab area of the northwestern part of Haryana, India, was investigated by Kumar and Singh (2003) through the development and application of a DSS that integrated groundwater flow and unsaturated zone models (included within sub-models of a software package known as SImulation of WAter management in Arid REgions [SIWARE]) with GIS applications. The DSS was utilized to investigate waterlogging impacts across the region. Salinity modeling was not included as a part of this study. The models used a 24-day time step and were calibrated and tested using data from 1977 to 1990. The main calibration parameters included the horizontal hydraulic conductivity and the aquifer specific yield. Model formulation consisted of a grid of 60 nodes (each representing a 10 km by 10 km area) that was used to evaluate two water management scenarios as well as a baseline case. The first modeled scenario considered a change in water pricing policy from a flat rate per parcel to a pay-per-volume scheme to increase overall water use efficiency. The second scenario involved modeling a change in water delivery policy from an area-based demand estimate to a demand estimate that also considers crop type. Although the employed models are very simplified and the actual effects on the investigated scenarios on aquifer recharge are highly uncertain, this study represents another example of integrating groundwater and unsaturated zone models into a basin-wide DSS to examine the regional impacts of management alternatives.

Chen (2004) presented a DSS that incorporates groundwater modeling, GIS applications, and expert systems to investigate groundwater management within a 1,800 km^2 basin in Taiwan. The focus of this study was to enable the management of groundwater resources with a goal of preventing aquifer overdraft. The Processing MODFLOW (PMWIN) simulation system was incorporated into the designed DSS and applied to the Choushui River basin. The specified model grid size and time step were not presented in the paper. The groundwater model was calibrated to 1997 data; however, only pumping rates were varied to achieve water table elevation matching. Emphasis was placed on the development of an expert system for administering groundwater pumping permits. No modeling of salinity was attempted. This study demonstrates the need for better groundwater modeling and supporting data, and provides a good example of incorporating modeling into a basin-wide DSS.

Another example of a developed basin-wide DSS, similar in scope to the ultimate product within which the present research will be included, is found in Al-Zubi et al. (2002) where the Analytical Hierarchy Process (AHP) was incorporated with an underlying groundwater simulation model. Additionally, stochastic models relating groundwater recharge to climatic parameters were used to generate model input. The DSS was applied to a 12,710 km^2 agricultural basin in Jordan (the Azraq Basin) to evaluate the sustainability of various investigated water management scenarios. Little detail is given concerning the underlying simulation model and its calibration, and salinity was not modeled; however, this study provides an indication that stochastic techniques are being considered and implemented to aid in water management decisions.

A simplified groundwater flow and salinity model was developed by Al-Senafy and Abraham (2003) and applied to a 30 km^2 area known as the Al-Wafra region within southern Kuwait . This area is a predominately agricultural district that relies solely on groundwater pumping to supply irrigation water. Although the models were based on several simplifying assumptions (such as uniform aquifer parameters, constant recharge rate, and single-cell salinity model structure) that limit the value of the conclusions, this study does provide an example of an attempt to address salinity issues on the regional scale.

Two studies, Heebner and Toran (2000) and Chen et al. (1999), are of interest because they present models that were constructed, like the presented research, using the Groundwater Modeling System (GMS) software package. Heebner and Toran (2000) developed a set of field-scale MODFLOW models that simulate a spray irrigation system. Two-dimensional, three-dimensional, steady-state, and transient configurations were investigated. Calibration and testing were not performed due to a lack of field data. Results showed that the three-dimensional, transient modeling offers significant accuracy improvements. Chen et al. (1999) used GMS to formulate a FEMWATER model to simulate contaminant transport and migration at a Superfund site in Florida. Calibration was performed using the visualization tools available in GMS; however, no results from the calibration analysis or model testing are presented.

2.1.2 Discussion

A large number of groundwater flow and contaminant transport models have been developed and successfully applied over the years; however, there have been surprisingly few that deal directly with regional shallow water table and salinity problems. Also, there have been very few attempts at comprehensive models that include groundwater flow, salinity transport, and unsaturated zone simulation capabilities. In cases where attempts have been made to consider the comprehensive range of physical processes that contribute to waterlogging and salinity problems, there often were inadequate data to properly calibrate and test the underlying models. In fact, one unique aspect of the present research is the extensive data collection program that enabled the detailed calibration, validation, and application of the modeling components over a high-resolution spatial and temporal domain.

Many studies have been centered around the modeling of highly-regulated contaminants and have considered local-scale modeling domains. Many others have addressed salt transport, but have modeled systems only at the field-scale. Others provided regional-scale DSS tools, but the underlying models were simplified to the point that there was an undesirably high level of uncertainty in simulation output. The present research provides a set of models at an appropriate level of detail that are supported by an extensive data set. It is believed that the current study is one of the most comprehensive regional/subregional-scale groundwater flow and salinity transport modeling efforts to date.

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2.2 SALINITY MANAGEMENT

General references and studies on salinity management were researched to identify possible solution alternatives and to examine river basins that face similar waterlogging and salinity problems. Also, the existing research was investigated to validate the measurement techniques and conversion methodology employed in the current study.

2.2.1 Most Relevant Works

Hoffman et al. (1990) presented a general overview of salinity management issues. They describe water management principles and practices for growing crops under high salinity conditions. Measurement techniques and diagnosis were discussed, along with management issues such as crop selection, irrigation system selection, irrigation management for salt leaching, and conjunctive use strategies. This resource is invaluable in understanding the relevant salinity issues and management challenges that are addressed in the present research.

Two studies of interest by Greeff (1994) and Acworth and Jankowski (2001) identified and attempted to quantify unknown salinity sources. In the study by Greeff (1994), a situation similar to that in the Lower Arkansas River Valley was presented. Within the Breede River basin in South Africa, a noted increase in salinity was observed, but the source of the salinity was unclear. After much study, including oxygen isotope analysis within the basin, it was concluded that the salinity derived from newly cultivated areas consisting of thin soil layers that overlay decomposed shale. A salt balance model was developed and presented. Acworth and Jankowski (2001) considered a basin in Australia and identified an atmospheric salinity source for unaccounted dryland salinity. Both of these studies provide examples where salinity levels are higher than can be accounted for by transport processes alone (similar to the current study region in the Arkansas River Basin).

Herrero et al. (2003) investigated soil water salinity on the field-scale with the purpose of validating the use of the Geonics EM-38 measurement tool (as was used in the present research). A one-hectare plot of olives in Spain was used to compare EM-38 measurements with traditionally collected and measured soil samples. A total of 141 locations were measured with the EM-38 meter and were compared with soil samples taken at 22 corresponding sites (6 samples taken per site). A large range of salinity levels existed across the studied plot, and one area revealed an inverted salinity profile, indicative of a high water table. Relationships between the horizontal EM-38 reading (EM_H) and soil extract electrical conductivity (EC_e) and between the vertical EM-38 reading (EM_V) and EC_e were developed for six soil depths. For the depth range 0-150 cm, the relationship between EM_V and EC_e was reported to be: $EC_e = -0.74 + 5.44EM_V$ with a correlation coefficient (r^2) of 0.86. Overall, the standard soil samples confirmed the validity of the EM-38 measurements. This study concluded that the EM-38 is most useful for measuring and mapping the horizontal soil water salinity distribution – where the vertical profile distribution of salinity is important, standard sampling methods are recommended. This research confirms the usefulness and validity of the EM-38 tool for regional salinity studies such as conducted in the present research.

2.2.2 Discussion

In general, salinity management techniques (such as providing adequate drainage to improve leaching of salts and prevent waterlogging, improving irrigation efficiency to reduce non-beneficial excess recharge, and employing system-wide improvements such as canal lining to reduce seepage) are fairly well understood; however, the formulation of effective solution strategies is often complex. It is expected that the present research, coupled with field-scale and economic modeling, will provide a sound basis for solution alternatives. The investigated references provided insight into what the most likely components of the solution alternatives should be. They also support the approach and soil water salinity data collection techniques of the current research.

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2.3 REGIONAL-SCALE MODELING OF IRRIGATION AND DRAINAGE PROCESSES IN SALINITY-AFFECTED AREAS

Review of published studies revealed that there have been a very limited number of regional-scale modeling efforts that directly simulate waterlogging and salinity effects within irrigated areas. The studies that do exist were useful in providing guidance in overall methodology and in identifying areas where improvements over previous research could be accomplished. Additionally, reviewed works provided verification that a regional-scale approach is feasible in light of data requirements and modeling resources.

2.3.1 Most Relevant Works

Gates and Grismer (1989) developed a regional-scale, finite-difference model for an irrigated area in the western San Joaquin Valley of California that experiences saline high water table conditions similar to the present study region. A grid composed of 60 cells, each representing approximately 32 ha, was used to model a hypothetical 20 km^2 area of cotton production. Uniform thicknesses were assigned to the aquifer and the underlying perching layer, and the computational time steps were varied from 3.7 to 41 days depending upon the season being modeled. The total simulation period investigated was 12 years. The authors employed mass balance models to simulate water and salt movement in the root zone. They also defined and utilized models that approximated the leaching of salts out of the root zone and upflux of water and salts from the water table. Subsurface drainage was also approximated and included in the analysis. Flow and salt transport in the aquifer were modeled using a modified version of the 2-D Methods of Characteristics (MOC) model (Konikow and Bredehoeft 1974). Because the developed models were intended as a feasibility stage planning tool, the authors also provided means by which the relative crop yield and net economic benefits could be approximated. They also attempted to quantify uncertainty through stochastic modeling methods. Four input variables were modeled stochastically by generating 100 realizations each and employing the Monte Carlo simulation technique. Two optimization methods, response surface methodology and the stochastic quasi-gradient technique, were also investigated and were reported in more detail in Gates et al. (1989). Sample output for the modeled hypothetical region were provided and included contours of the expected value and coefficient of variation for water table depth, water table salinity, soil water salinity, and relative yield. Predicted regional net benefits based on the optimization modeling were also reported. This study demonstrates the validity of the regional approach and the value of adopting an integrated unsaturated/saturated zone model for planning purposes; however, it also reveals the limitations of analysis on the regional scale due to the extensive data requirements.

A regional-scale study by Corwin et al. (1999) describes the integration of a GIS application with unsaturated zone flow and salt transport modeling applied to an area (2,396 ha) of tile-drained agriculture also located in the San Joaquin Valley. The predicted temporal and spatial changes in salt loading were calibrated previously to measured tile-drain outflow salinity data for the study period of 1991 to 1996. No calibration or testing results were presented in the paper. The unsaturated zone transport model TETrans, described as a "transient-state, mass-balance, layer-equilibrium" model, was used to predict salt load to the water table, and the GIS software package ARC/INFO was used to create model input for several depth increments and to produce visualizations of spatial data and results. Soil water salinity data were collected using a Geonics EM-38 at 2,368 locations across the study area. Soil samples were obtained from soil-core sampling at 315 of the 2,368 locations for calibration and characterization purposes. Only the historical period (baseline) scenario was modeled and presented. In general, the results of this study validate the TETrans model predictions and demonstrate the value of GIS applications in spatially variable, regional-scale problems.

Saysel and Barlas (2001) developed a regional-scale salinization model (root-zone domain) based on simple mass balance principles for a hypothetical irrigated area. No attempt was made to calibrate or validate the model with field data under actual conditions. The goal of the authors was to simply describe the theoretical system behavior based on the governing solute transport dynamics. The model used an annual time step and assumed homogenous conditions. Long-term, regional impacts of increasing levels of irrigation were investigated. This study is interesting because of the attempt to model soil water salinity on the regional-scale using a simple mass balance approach. This is similar to what was ultimately incorporated within the present research; however, in the case of Saysel and Barlas' (2001) study, no spatial or significant temporal variation was considered, and the accuracy of the model output was not evaluated.

Goff et al. (1998), Person and Konikow (1986), and Konikow and Bredehoeft (1974) produced a series of studies that investigated a 17.7 km reach of the Arkansas River, extending east from La Junta to the Otero-Bent County line within Colorado. This area is of particular interest because it is fully contained within the study region described herein. These studies described the development and application of the 2-D MOC model which simulates groundwater flow and solute transport. Reported model outputs included water table elevation, groundwater salinity, and groundwater return flows to the river. A 24-year period of record was used for model calibration based on these outputs. Two management scenarios, including reduction in groundwater pumping and complete cessation of irrigation, were considered. Although these studies were valuable in providing insight into the specific conditions within the study region, the quality of their results were very limited by the utilized historical data sets that typically included only annual readings from pumping wells conducted during fallow (winter) periods. Also, they were limited by the small number of management scenarios considered and because soil water salinity impacts were not investigated.

Peck and Hatton (2003) provided an interesting critique of previous regional-scale salinity modeling studies for dryland farming areas located within western Australia. Although this study did not consider irrigated areas similar to the present study region, it did offer the interesting conclusion that most regional-scale models break down in accuracy due to a lack of available data for model validation. This is not a problem in the present research.

2.3.2 Discussion

The reviewed regional-scale modeling studies of irrigation and drainage processes that have been conducted generally point to available data as the main constraint to scope and ultimate model utility. Studies such as Gates and Grismer (1989), although wide-ranging in scope, are limited by the extensive data requirements needed for practical application of the model. The previous work in the Arkansas River Valley revealed apparent limitations in scope based largely on inadequate available data. The present research overcomes the data limitation through the establishment of the data collection program, and, therefore, improvement over previous work is anticipated. The approach demonstrated by Corwin et al. (1999) could be attempted in the Arkansas River Valley study area with very little additional data collection (although much more analysis of collected soil samples would be required); however, the effort involved in developing the highly-detailed unsaturated zone model that they presented would be beyond the scope of the current research, and is best left for future consideration.

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2.4 MODELING IRRIGATION AND DRAINAGE PROCESSES IN THE UNSATURATED ZONE

This area of research was investigated for two reasons: 1) to discover potential approaches to the unsaturated zone salinity modeling, and 2) to discover potential shallow water table depth and salinity solution alternatives. The presented research provided the opportunity to link an appropriate unsaturated zone model to a regional-scale groundwater flow and salinity transport model. Numerous studies incorporating various approaches to modeling the unsaturated zone were reviewed, and, ultimately, helped shape the methodology utilized in the presented research.

2.4.1 Most Relevant Works

Ali et al. (2000a and 2000b) presented field-scale research that demonstrates the validation and application of the unsaturated zone model LEACHC. This model is a leaching and soil water chemistry model developed by Hutson and Wagenet (1992) that uses crop cover information to separate the evaporation and transpiration components of crop demand. It is a one-dimensional finite-difference model that models salt movement through the unsaturated zone using the Richards convection-diffusion equation. The developed study model was first validated using data from previous studies, and it was concluded that the model performed well in predicting the soil EC_e and water content profiles. The model was then applied to soil salinity modeling under shallow water table conditions. A number of management scenarios were simulated including various irrigation application amounts coupled with various irrigation intervals. Possible conditions modeled included two different soil and crop types with two different water table EC conditions present. In total, 96 scenarios were modeled. Results provided the best irrigation strategy for the modeled conditions.

Pohll and Guitjens (1994) conducted a study where a two-dimensional, vertical profile MODFLOW model was created to simulate tile drains on a field scale. The profile represents a 550 m-long vertical transect and was modeled with a grid consisting of a single 1-meter thick layer of cells with a uniform dimension of 2.5 m by 0.5 m in the vertical plane. Both transient flow and advective transport were investigated using a daily time step. Seventy-eight piezometers were installed and monitored for 20 days after an irrigation event. Slug tests were also performed at these locations to estimate horizontal saturated hydraulic conductivity (K). The model was calibrated to the observed data by varying K, the anisotropy factor, and the steady-state recharge rate over several iterations. Hydraulic head contours along with advective velocity gradients were generated for the modeled subsurface drainage scenario that represented existing conditions. No other scenarios were investigated in this study.

A Monte Carlo simulation approach presented by Hopmans et al. (1991) was applied to the use of a one-dimensional, finite-difference, unsaturated zone flow model named SWATRE. Three furrow and trickle irrigation scenarios applied to a 650 ha study area were investigated for purposes of comparing the use of hysteresis as opposed to the main drying curve in drainage estimates. No salinity modeling was attempted. A total of 50 realizations were conducted for the purposes of capturing soil spatial variability over the modeled field. No calibration or testing of the model was reported. Results indicated that the applied unsaturated zone flow model is not sensitive to the use of hysteretic soil properties as opposed to typical drainage curves in irrigation simulations.

Wahba et al. (2002) conducted a field-scale study using DRAINMOD-S to simulate conditions for an irrigated plot located in Egypt. The authors model both free-flowing and controlled subsurface drainage conditions which were implemented over the study field. No other scenarios were investigated. Although the model application was implemented over a small area (2.54 ha), the results of this research are interesting because a detailed calibration was performed. Calibration results for water table depth, drainage outflows, soil salinity, and relative crop yield are presented, and provide insight into the model accuracy that might be expected for simple systems.

Another field-scale study, conducted by Sarwar and Bastiaanssen (2001), demonstrated the relationships between waterlogging, soil water salinity, and crop evapotranspiration by implementing the SWAP model on a field within the Fourth Drainage Project (FDP) area of the Punjab basin in Pakistan. The SWAP model is described as a transient, one-dimensional unsaturated zone flow and solute transport model. The flow modeling component is based on the Richards equation, and the solute transport modeling component is based on the general convection-dispersion equation. Although the results apply only to the field-scale and ignore regional impacts, they revealed irrigation scenarios that were effective in reducing soil salinity. Calibration and testing of the model were performed previously by the authors and were not presented in the reviewed paper. Results also showed that the reduction in crop transpiration (and, therefore, crop yield) related to soil water salinity conditions. The general conclusions of this study concerning irrigation methods, however, are not necessarily valid on a regional scale.

2.4.2 Discussion

Much of the examined research concerning the modeling of the unsaturated zone flow and salt transport dynamics is not transferable to the proposed research because it exceeds the level of detail appropriate for regional/subregional groundwater flow and transport models. The reviewed research does, however, generally confirm the suspected link between high water tables and high soil water salinity. In general, previous studies of irrigation and drainage processes in the unsaturated zone have lacked the necessary salinity data required for adequate model calibration and validation.

2.4.3 Bibliography of Related Works on Modeling Irrigation and Drainage Processes in the Unsaturated Zone

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Sharma, D. P., and Singh, K. 1998. "Effect of Subsurface Drainage System on Some Physiochemical Properties and Wheat Yield in Waterlogged Saline Soil." *Journal of the Indian Society of Soil Sciences,* Vol. 48, No. 2, 284-288.

Wahba, M. A. S., El-Ganainy, M., Abdel-Dayem, M. S., Kandil, H., and Gobran, A. 2002. "Evaluation of DRAINMOD-S for Simulating Water Table Management Under Semi-Arid Conditions." *Irrigation and Drainage,* Vol. 51, 213-226.

2.5 MODELING UNDER UNCERTAINTY

General concepts related to modeling under uncertainty were investigated to ensure an adequate understanding of the fundamental principles and to discover potential approaches that might warrant consideration. Studies within this category provided guidance on how best to estimate the uncertain aquifer parameters and other model inputs required for the present research.

2.5.1 Most Relevant Works

Two studies that addressed general uncertainty concepts are of particular value. In the first, Carrera (1993) presents an overview of uncertainty in groundwater solute transport modeling predictions. Uncertainties related to anthropogenic stresses, model parameter values, and conceptual model formulations are addressed. Carrera goes on to recommend a stochastic modeling approach, but warns against assigning a stationary nature to hydraulic conductivity stochastic representations. The second study, by Lal (2000), presents an analysis of numerical errors contained within models such as MODFLOW. Proposed methods to reduce numerical errors, namely the refinement of spatial and temporal discretizations, are presented and demonstrated in an application to the South Florida Water Management Model. This study defines a useful set of formulas which aid in establishing model dimensions to limit numerical errors.

Studies by Dou et al. (1995, 1997a and 1997b) presented a methodology based on fuzzy set theory to reduce model uncertainty in steady-state groundwater flow and contaminant transport models. This method involves the incorporation of imprecise parameters into the underlying model algorithms. A radial flow case was examined and solved using two different solution techniques. These studies successfully applied fuzzy set theory to simple problems, but acknowledged the limitations when dealing with highly variable or large-scale problems such as the one addressed in the current study.

Connell (1995) presented an analysis of perturbation-based methods. The first-order second moment and the McLaughlin and Wood perturbation methods (1988a, 1988b) were investigated as alternatives to the Monte Carlo approach. Detailed mathematical derivations were developed and methods were compared with uncertainty restricted to hydraulic conductivity. Results indicated that perturbation methods are more computationally efficient than Monte Carlo methods.

2.5.2 Discussion

The general studies of sources of modeling uncertainty are useful in confirming that the current research addresses the correct issues and that the utilized approach is valid. The reviewed studies confirm that the best means of reducing uncertainty center around improving data density. The data collection program established for the current research directly addresses this issue. Calibration of field instruments also aided in reducing overall uncertainty by improving overall data quality.

Also of particular interest are the selected spatial and temporal discretizations of the modeling domain and how these might affect numerical error. There is an underlying assumption in the current study that the selected finite-difference grid size and modeled time step are appropriate and will not be changed during the course of the research. Confirmation that the chosen values are adequate is provided by the Lal (2000) study. Specifically, as suggested in Lal, the defined model dimensions were checked using the following equation: $X = 0.5(Te/t)^{0.5}$. In this equation, X represents the selected horizontal cell dimension (assuming a square cell geometry), T represents the aquifer transmissivity, e represents the specified acceptable percentage level of error in the predicted water table, and t represents the selected stress period interval. In the current study, the level of expected numerical error under the defined model configuration is typically within 5%, although in areas with particularly low transmissivity values (i.e. locations with low hydraulic conductivity values or thin aquifer thickness), this value can be larger.

2.5.3 Bibliography of Related Works on Modeling Under Uncertainty

Carrera, J. 1993. "An Overview of Uncertainties in Modeling Groundwater Solute Transport." *Journal of Contaminant Hydrology,* Vol.13, 23-48.

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Ratkovich, D. Y. 2000. "Current Problems of Stochastic Hydrology." *Water Resources*, Vol. 27, No. 6, 585-593.

Zhang, D., and Lu, Z. 2002. "Stochastic Analysis of Flow in a Heterogeneous Unsaturated-Saturated System." *Water Resources Research*, Vol. 38, No. 2, 1-15.

2.6 MODEL PARAMETER ESTIMATION, INVERSE MODELING, AND MANUAL CALIBRATION PROCEDURES

These topics were investigated to determine which calibration approach would be appropriate for the present research. Following the investigation described below, it was decided that a manual model calibration method was the most appropriate. Therefore, ultimately, the investigated parameter estimation and inverse modeling techniques were not employed; however, as computing resources improve, the concepts described within these works will become viable for project implementation. Likely, the parameter estimation and inverse modeling methods will enable improved model calibration to some degree in the near future; but, currently, they prove to be overly complex to be effectively applied.

2.6.1 Most Relevant Works

For guidance with appropriate manual calibration techniques, a couple of resources proved invaluable. The American Society for Testing and Materials (ASTM) (1996) has produced specific guidelines for model calibration. As mentioned later in Chapter 6, these guidelines were ultimately followed for model calibration purposes. Additional insight on manual model calibration was gained from Pinder (2002). Following execution of the adopted model calibration procedures, a report by Reilly and Harbaugh (2004) was discovered and considered as confirmation of the adopted calibration procedures and of the final calibrated model formulation. In general, studies of specific projects did not detail manual calibration techniques, although some did provide calibration results and provided insight into the expected model performance. A number of studies were available, however, that detailed attempts at automatic calibration methods. These are described below.

A three-dimensional, regional-scale groundwater flow model for the Death Valley region is presented in D'Agnese et al. (1999). The emphasis in the report of this study was on using parameter estimation techniques during model calibration. The region was divided into several homogeneously represented zones to foster the non-linear regression inverse modeling technique. Additionally, techniques to incorporate spatial data into model development using GIS were presented. Application of MODFLOWP to develop the associated MODFLOW model was utilized. An input parameter sensitivity index was presented and applied to aid in model calibration. The study ultimately concluded that, coupled with constraining parameters within a reasonable range, inverse modeling techniques can improve the general accuracy of regional flow models.

Barlebo et al. (1998) presented a three-dimensional inverse groundwater flow and transport model fitted simultaneously to hydraulic head and groundwater salinity concentration data. A non-linear regression approach was used to investigate two issues: 1) the accuracy of the transport model if the inverse model is fitted to hydraulic head only and 2) the advantages and disadvantages of using a two-dimensional vertical cross-sectional model opposed to a three-dimensional modeling approach. The models were applied to a landfill site in Denmark and were based on data collected at over 100 locations every six weeks from August 1992 to December 1993. Results indicated that the accuracy of the transport model was greatly reduced when inverse modeling was performed on hydraulic heads only. Also, it was concluded that the three-dimensional modeling was strongly preferred over the two-dimensional modeling formulation.

A study that emphasizes the efficient and responsible use of prior information when employing inverse modeling techniques was reported by Weiss and Smith (1998). A simple two-dimensional example was used to demonstrate the general prior-knowledge parameter estimation methods examined, and these methods (referred to as "parameter space" methods) were applied to a regional groundwater model for the San Juan Basin, New Mexico. This model is a cross-sectional flow and transport model and was calibrated based on 56 observation sites. The researchers identified 10 uncertain model parameters that needed to be estimated, and tested the parameter space methods by applying inverse modeling in two stages. One stage attempted to estimate all 10 parameters, while the other stage fixed four of the parameters and only attempted to estimate six. Results demonstrated that utilizing prior information along with inverse modeling can yield significantly improved model accuracy.

Medina and Carrera (1996) developed a methodology for simultaneously estimating flow and solute transport using inverse modeling techniques based on the maximum likelihood theory. The approach was constructed for estimating parameters around the transient case (flow and transport). Both a laboratory test and a field test were investigated. The field test was comprised of a subregional-scale flow and transport model of the Lower Llobregat River Valley near Barcelona, Spain. Only limited success was achieved in model calibration using the presented techniques. The authors attribute this to a lack of adequate spatial variability incorporated into the models.

2.6.2 Discussion

The automatic calibration methods presented in this area of research are valid for modeling situations where there is very limited data. Correct application of these methods, as demonstrated in the studies above, can reduce uncertainty effectively; however, the degree of reduction is restricted based on the low level of spatial variability that is computationally feasible. Also, there is, to some degree, additional uncertainty introduced by the potential for non-uniqueness of parameter estimations. In considering the rich spatial data sets that were collected as part of the present study, inverse modeling techniques were eliminated from consideration due to their inability to adequately handle spatial variability [as admitted in Medina and Carrera (1996)] and due to current computational limitations.

2.6.3 Bibliography of Relevant Works on Model Parameter Estimation, Inverse Modeling, and Manual Calibration Procedures

American Society for Testing and Materials. 1996. "Standard Guide for Calibrating a Ground-Water Flow Model Application". *ASTM Standard D 5981-96.*

Anderman, E. R., and Hill, M. C. 1999. "A New Multistage Groundwater Transport Inverse Method: Presentation, Evaluation, and Implications." *Water Resources Research,* Vol. 35, No. 4, 1053-1063.

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Poeter, E. P., and Hill, M. C. 1997. "Inverse Models: A Necessary Next Step in Ground-Water Modeling." *Ground Water*, Vol. 35, No. 2, 250-260.

Reilly, T. E., and Harbaugh, A. W. 2004. "Guidelines for Evaluating Ground-Water Flow Models." *US Geological Survey Scientific Investigations Report 2004-5038.*

Sun, N.-Z., Yang, S.-L., and Yeh, W. W.-G. 1998. "A Proposed Stepwise Regression Method for Model Structure Identification." *Water Resources Research*, Vol. 34, No. 10, 2561-2572.

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2.7 CROP YIELD AND ECONOMIC ANALYSIS OF WATERLOGGING AND SALINITY PROBLEMS

Economic analysis studies of waterlogging and salinity problems and their potential solution alternatives were investigated to aid in model formulation and to help devise realistic modeling scenarios. Of particular interest were the effects of salinity and waterlogging on the crop evapotranspiration (*ET*) rates and the resultant crop yields. Two economic studies specifically related to the Arkansas River Basin were discovered and are included here because they provide insight into potential long-term impacts of salinity and water management within the project region. Additionally, an economic analysis of salinity and waterlogging problems within the present study region was conducted as a part of a doctoral dissertation for the Department of Agricultural and Resource Economics at Colorado State University by Houk (2003). This analysis incorporated preliminary results from the presented research and helped direct subsequent modifications to the crop *ET* modeling.

2.7.1 Most Relevant Works

A number of resources published by the Food and Agriculture Organization (FAO) of the United Nations were useful in developing and verifying some of the underlying assumptions maintained in the present study. In particular, FAO Irrigation and Drainage Paper No. 56 (Allen et al. 1998) provided important information concerning the relationship between soil water salinity and crop yield, and on the relationship between crop yield and crop *ET*. Within this report, a linear relationship between decreasing crop yield and increasing soil water salinity levels is presented. More detailed information regarding this relationship for specific crops is given in FAO Irrigation and Drainage Paper No. 29 (Ayers and Westcot 1985) and in FAO Irrigation and Drainage Paper No. 48 (Rhoades et al. 1992). Smedema and Rycroft (1983) also provide similar relationships.

The general relationship between the crop yield and the crop *ET* is also presented in FAO Paper No. 56. This relationship is defined as follows:

$$\left[1-\frac{Y_a}{Y_m}\right]=K_y\left[1-\frac{ET_{cadj}}{ET_c}\right] \tag{2-1}$$

where : Y_a = actual crop yield (kg/ha)

Y_m = maximum expected crop yield under no salinity stress (kg/ha)

K_y = yield response factor (dimensionless)

ET_{cadj} = adjusted (actual) crop ET (mm/day)

ET_c = crop ET for standard conditions (mm/day)

The value of K_y ranges from 0.70 to 1.35 for various crop types, but is typically close to 1.0; therefore, for the presented research, it was assumed that the crop yield-salinity and crop yield-waterlogging relationships could be used directly to establish *ET* adjustment factors required in modeling. In other words, based on the equation presented above, it was assumed that the estimated soil water salinity and waterlogging adjustment for crop yield is equivalent to the adjustment that should be applied to the crop *ET* rate. Houk (2003) provides a summary of the yield-salinity and yield-waterlogging relationships that were ultimately used to modify the crop *ET* modeling in the present research. Additionally, Houk conducted economic analyses of a number of potential solution measures, many of which are incorporated into the modeled alternatives presented in Chapters 3 – 5.

Datta et al. (2002) present a detailed cost-benefit analysis for a localized subsurface drainage project within the Trans-Gangetic region of India. Results were extrapolated to the regional scale. Extensive historic economic data were utilized, and results indicated long-term (calculated over a 30 year period) benefit-cost ratios near or greater than one. The authors make a strong economic case for the effectiveness of subsurface drainage in addressing waterlogging and high soil salinity problems. Datta and de Jong (2002) performed a similar study, based on extensive interviews with local farmers, for the area of Haryana, India. Within this study, they also concluded that subsurface drainage was a viable solution alternative from an economic standpoint.

2.7.2 Discussion

The studies investigated provide support for adopted modeling assumptions and for the feasibility of investigated solution alternatives. The reviewed research provided direction and support for the assumptions made during the development of modifications to crop *ET* modeling. Ultimately, it was determined that crop yield relationships with salinity and waterlogging could also be used to adjust crop *ET* rates. Also, a few studies analyzed specific solution measures in terms of economics, and subsurface drainage options, in particular, have been demonstrated to be beneficial. Based on these conclusions, the presented research incorporates subsurface drainage alternatives within the scope of the investigated scenarios, despite what might seem at first to be a potentially exorbitant capital cost.

2.7.3 Bibliography of Relevant Works on Crop Yield and Economic Analysis of Waterlogging and Salinity Problems

Allen, R. G., Pereira, L. S., Raes, D., and Smith, M. 1998. *Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and Drainage Paper 56.* Food and Agriculture Organization of the United Nations, Rome, 300 pages.

Ayers, R. S. and Westcot, D. W. 1985. *Water quality for agriculture. Irrigation and Drainage Paper 29, Rev. 1.* Food and Agriculture Organization of the United Nations, Rome, 174 pages.

Datta, K. K., and de Jong, C. 2002. “Adverse effect of waterlogging and soil salinity on crop and land productivity in northwest region of Haryana, India.” *Agricultural Water Management*, Vol. 57, 223-238.

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Houk, E. E. 2003. *Economic assessment of water management in agriculture: Managing salinity and waterlogging in the Arkansas River Basin and environmental water shortages in the Platte River Basin.* PhD thesis, Dept. Ag. Resour. Economics, Colorado State University, Fort Collins, Colo.

Goodman, D. J. 2000. "More Reservoirs or Transfers? A Computable General Equilibrium Analysis of Projected Water Shortages in the Arkansas River Basin." *Journal of Agricultural and Resource Economics,* Vol. 25, No. 2, 698-713.

Letey, J., Dinar, A., and Knapp, K. C. 1985. "Crop-water production function model for saline irrigation waters." *Soil Sci. Soc. Am. J.*, Vol. 49, 1005-1009.

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CHAPTER 3

MONITORING AND MODELING FLOW AND SALT TRANSPORT IN A SALINITY-THREATENED IRRIGATED VALLEY

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3.0 ABSTRACT: Saline high water tables pose a growing threat to the world's productive irrigated land. Much of this land lies along arid alluvial plains, where solutions must now be developed in the context of changing constraints on river management. Findings are presented from the preliminary phase of a project aimed at developing, through well-conceived data collection and modeling, strategies to sustain irrigated agriculture in the salinity-threatened lower Arkansas River Basin of Colorado. Extensive field data from a representative subregion of the valley reveal the nature and variability of water table depth and salinity, irrigation efficiency and salt loading, and soil salinity. The shallow water

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table had an average salinity concentration of 3100 mg/l and an average depth of 2.1 m, and was less than 1.5 m deep under about 25% of the area. Evidence reveals low irrigation efficiencies and high salt loading under each of six canals serving the subregion. Water table depths less than 2.5 to 3 m contributed to soil salinity levels that exceed threshold tolerances for crops under about 70 % of the area. Preliminary steady-state modeling indicates that only limited improvement can be expected from vertical drainage derived from increased pumping, or from decreased recharge brought about by reduced overirrigation. Investments in canal lining, horizontal subsurface drainage, and improved river conditions also will need consideration.

3.1 INTRODUCTION AND BACKGROUND

Waterlogging and salinization are age-old nemeses of irrigated agriculture, and continue to plague irrigated regions around the world. About 20-25% of the world's irrigated land, including 27% of that in the United States, is affected by saline high water tables (Tanji 1990, Ghassemi et al. 1995). The threat to global crop production is serious (Postel 1999) and losses, measured in economic terms, can be substantial. Ghassemi et al. (1995) estimated that worldwide productivity loss is valued at about $10 billion per year. These losses, although high, must be weighed against the cost of facilities required for adequate management of these problems. There is also concern that long-term damage to the environment may occur due to saline return flows to rivers, downward percolating saline waters, and disposal of saline drainage water. Arresting this degradation of the world's most productive land, while protecting the broader natural resource base, may prove one of the great challenges of the coming decades. The study described herein focuses on one of the most salinity-affected irrigated regions in the United States, the lower Arkansas River Basin in Colorado (Figure 3-1). As such, it provides a fitting arena for one of the most comprehensive studies of irrigation-induced salinization yet undertaken.

Salinity and drainage problems usually appear in intensively-irrigated alluvial valleys within a few decades to about a hundred years after the commencement of large-scale irrigation. Eventually, the high rate of application of water to land exceeds the natural rate of drainage, the water table rises, and artificial drainage is often needed to regain an acceptable water and salt balance (Gates and Grismer 1989). In the lower Arkansas Basin in Colorado, irrigated since the 1870s, saline high water tables began to develop in the early part of the twentieth century (Miles 1977). Through the years, the problems have advanced and ebbed in response to sporadic human intervention and varying climatic conditions. Subsurface drains, installed in the 1930s, seemed to remedy the problems for a while. Since the 1970s, however, due to a variety of interacting factors, conditions have progressively worsened. These factors include gains in seepage losses from earthen canals due to increased diversions from the river and reduced sediment sealing of the canals; excessive application of water to fields; failure of subsurface tile drains laid in the 1930s; reduced groundwater pumping; and changes in river operations. Groundwater pumping serves to lower the water table in addition to supplying irrigation

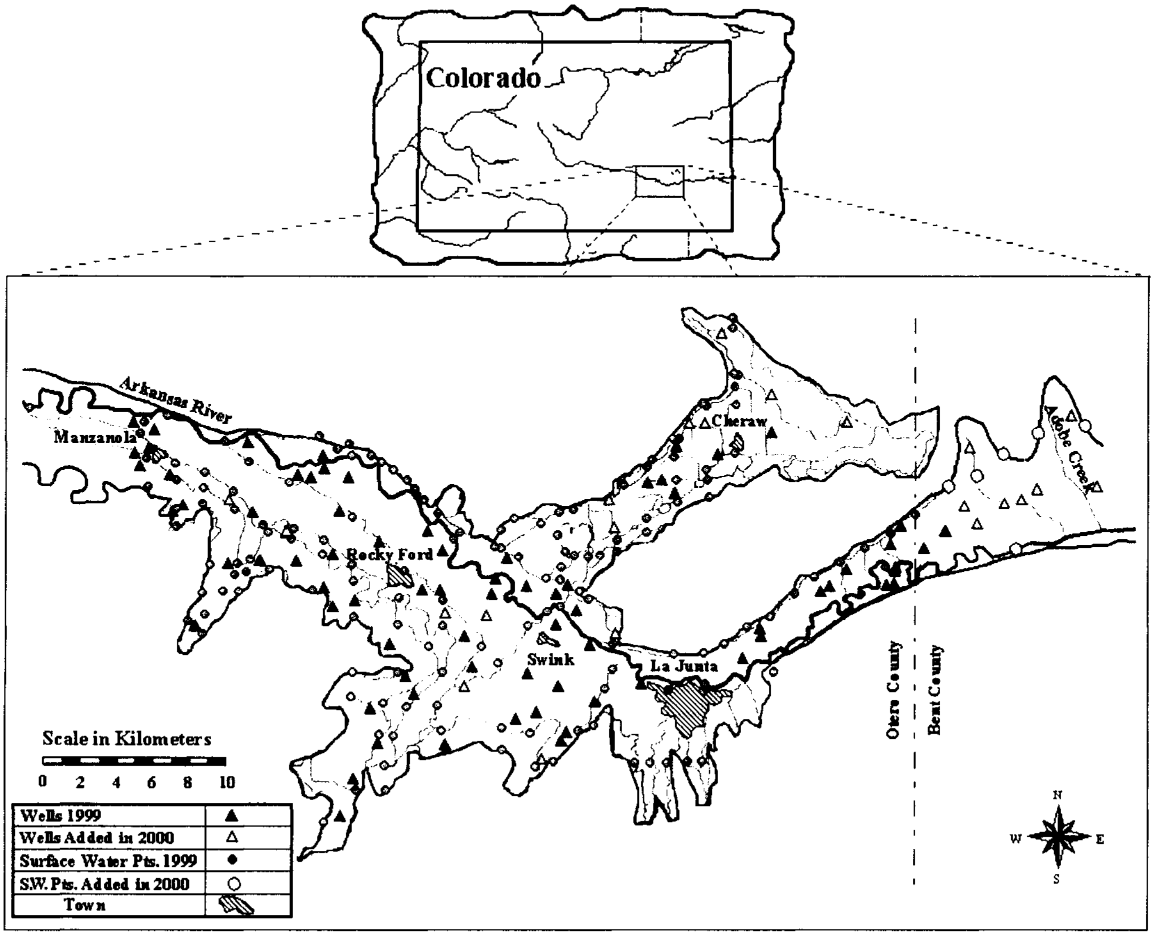

Figure 3-1. The study subregion in the Lower Arkansas River Basin near La Junta, Colorado

water, but has diminished in response to increased surface water availability. In addition, pumping has been curtailed in compliance with a recent court ruling requiring reparations to Kansas for Colorado's failure to comply with the Arkansas River Compact. Reduced velocities and elevated backwater conditions in the river, due primarily to two large on-stream reservoirs (Pueblo and John Martin), have caused the river channel to widen, sediments to deposit on the bed, and the river level to rise, thereby reducing the gradient driving drainage flows from irrigated lands to the river.

The United States Geological Survey (USGS) has a long history of stream-aquifer modeling studies in the lower Arkansas River Basin in Colorado. Goff et al. (1998) recently extended and augmented previous USGS studies by Konikow and Bredehoeft (1974) and Person and Konikow (1986). A two-dimensional groundwater flow and solute transport model was implemented for evaluating potential impacts of changes in irrigation practice along a 17.7 km reach of the river, extending east of La Junta to the Otero-Bent County line. A 24-year period of record was used for calibration of the model to predict both water-table elevation and salinity concentrations, as well as return flows to the river. Model calibration was based on water-table elevation and salinity data available from a limited number of pumping wells only, and these data were collected only during the fallow season (typically, the months of February and March). This represents a major limitation of this study, since measurements taken during the irrigation season would better reflect conditions impacting agricultural production in the study area. Only two changes in irrigation management were considered: (1) a reduction in groundwater pumping for irrigation, and (2) a complete cessation of all irrigation from groundwater and surface water sources in the study area. A more extensive set of alternatives, representing incremental changes in water management, needs to be considered.

Studies in other parts of the world have focused on optimization of groundwater pumping to manage piezometric levels in order to control problems of waterlogging, and indirectly, salinization. These include studies by Punthakey et al. (1994) and Ramana et al. (1995), but in each case, salinity was not directly modeled. Mudgway et al. (1997)

and Nathan and Mudgway (1997) explored scale issues in extrapolating detailed, field-scale investigations on estimating salt loadings to surface drainage to regional salt loading estimates using a lumped conceptual model. There is a need to extend these studies into a regional and sub-regional modeling structure to better incorporate more realistic stream-aquifer interactions based upon a rich set of field data.

This paper describes results of the first phase of a multi-year project, focusing on diagnosis of the scope and severity of the problems and preliminary assessment of control measures. Beyond the need to accurately describe the problems for farmers and relevant state and regional agencies, a reliable database and methodology are needed to aid in prescribing solutions. The data reported herein form one of the most comprehensive descriptions of irrigation-induced salinity and drainage problems currently available. Extensive field measurement and data collection have been conducted regarding water table depth and salinity, irrigation efficiency, salt loading, soil salinity, and other properties over a large representative subregion of the lower Arkansas River Valley, and their interrelationships explored. Plausible causes of the problems and promising directions for addressing them are also considered. Results of preliminary steady-state modeling of alternative solution strategies are presented. Subsequent papers will describe continued data collection, a fuller exploration of solutions using unsteady flow and mass transport models, and broader implications for similar problems worldwide.

3.2 REPRESENTATIVE STUDY SUBREGION AND APPROACH

The scope and extent of this study is to examine flow and salt transport processes over a subregional scale (order of 10^3-10^4 m in dimensions) and, eventually, over the larger basin scale (order of 10^4-10^5 m). Complementary studies, not reported herein, also are being conducted at the field scale (order of 10^2-10^3 m). In the initial phase, focus has been on a representative subregion extending eastward about 62 km, from just west of the town of Manzanola in Otero County to Adobe Creek in western Bent County (Figure 3-1). The study area covers about 53,100 ha (131,200 acres) of which about 26,400 ha (65,300 acres) are irrigated. This study area is sufficiently large to encompass the variety of soils, hydrogeology, irrigation and drainage infrastructure, and crops that characterize the valley upstream of John Martin Reservoir, yet small enough to be manageable, given available resources. Soils in the study subregion are principally alluvial deposits dominated by silty-clay-loam surface layers and loam-to-sandy loam substrata (USDA 1972a, 1972b). Primary crops are alfalfa, corn, grass, beans, sorghum, wheat, melons, and vegetables. Six main canals serve the study area, distributing water to command areas ranging from about 1100 ha to 6900 ha.

A numerical finite-difference model, developed using the Groundwater Modeling System (GMS) software package (BYU 1999), is applied to analyze and predict water table elevations and salinity; and flow of water and salts in and between the shallow aquifer, the river, and the irrigation-drainage system. The portion of the subregion initially modeled extends about 53 km eastward along the river course to the Otero-Bent county line, encompassing about 22,000 ha (54,400 acres) of irrigated land. The finite-difference grid cells define homogeneous areas in the model that have a size of 6.25 ha (about half the average field size in the subregion). The vertical dimension of the model extends downward a total of 1 to 30 m across subsurface layers to bedrock. Lines defining streams, canals, and drains typically are discretized at scales of about 200 to 300 m. Hence, model variables and parameters are defined as average values over point-definition scales on the order of 10^2 m. There are thousands of such points (i.e., grid cells) where variables and parameters require estimation. Estimation involved careful sampling of data at a number of field locations, as described below.

3.3 DIAGNOSIS OF FIELD CONDITIONS

3.3.1 Water Table Depth and Salinity

Since the behavior of the shallow unconfined aquifer within the top three meters below ground surface is of particular interest in this study, numerous monitoring wells were drilled to a depth of three meters at locations distributed throughout the study subregion. For consideration of flow and salt transport at greater depths, data on deeper aquifer characteristics were obtained from reports published by the USGS (Weist 1965, Wilson 1965, Hurr and Moore 1972, Nelson et al. 1989).

A total of 74 monitoring wells were installed (or adopted) and monitored during the first year (1999). Stratified random sampling (Cressie 1991) was applied to minimize bias in placement of the wells, while accounting for the need to describe an expected salinity gradient along the river. Slotted PVC pipes with 0.064-m (2.5 inch) inside diameter were used to case the wells. The 74 sites provided a data density of approximately one well per 640 ha within the portion of the study subregion to be initially modeled (Figure 3-1). The minimum distance between any two sites was approximately one kilometer, with the average distance approximately two kilometers. Data collected during the first year led to the deepening of 21 wells and the addition of 23 new wells (eight of these in western Bent County) in the second year (2000) of the study.

Measurements of water table depth and salinity were taken weekly during the peak irrigation period, and biweekly to approximately monthly during the remainder of the year. Water table depths were measured manually using a metal tape and a float, considered accurate to within about 0.03 m. Groundwater salinity was measured indirectly using calibrated specific conductance meters to measure temperature compensated (25° C standard) electrical conductivity (*EC*). Three measurements of *EC* were made at each well for each reading - one just below the water table, one at an intermediate depth, and one near the bottom of the well. These measurements were averaged to obtain a representative *EC* value for the well site. Measurements of *EC* were converted to total dissolved solids, *TDS* (mg/l), using a relationship derived from analysis of groundwater samples collected at 17 different well locations:

$$TDS = 882.2EC \ (r^2 = 0.98) \qquad (3\text{-}1)$$

Figure 3-2 shows example contours of the measured water table depth below ground surface [interpolated between data points using the inverse distance weighted method (Shepard 1968)] for the early season (May 11-12, 1999), the middle season (July 14-17, 1999), and the late-season (September 16-17, 1999). Based on these estimated contours, the seasonal average water table depth under the entire subregion was about 2.1 m.

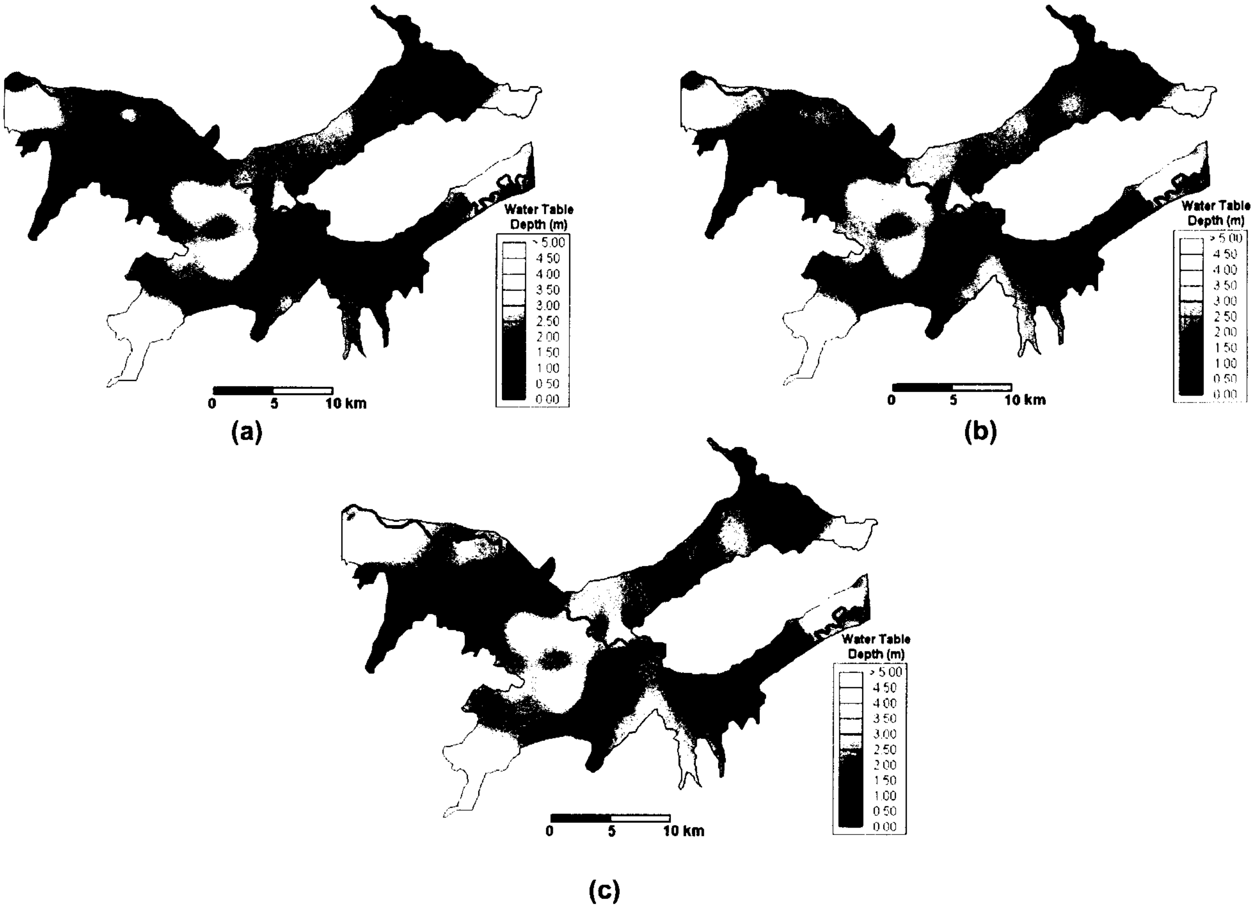

Figure 3-2. Estimated contours of water table depth based upon monitoring well readings for (a) May 11-12 1999, (b) July 14-17 1999, and (c) September 16-17 1999.

Seasonal-average depth under about 25% of the subregion was less than 1.5 m, while the water table was deeper than 3 m under about 20% of the area. Such shallow depths are indicative of possibly significant waterlogging effects in the overlying root-zone (Evans and Fausey 1999). The water table rose to a relatively stable level by mid May under most of the subregion, and did not decline substantially until mid November.

A statistical summary of water table depth for each measurement period is given in Table 3-1. Readings in twelve wells were consistently dry throughout the season, while another twelve wells were periodically dry. When a well was found to be dry on a given date, the water table depth was estimated based on previous readings and/or by correlation to readings taken at corresponding times in the first half of the 2000 season, after these wells were deepened. However, Table 3-1 shows analysis for measured values only; when a particular well was found dry, it was excluded from this statistical analysis. Generally, the water table depths at each reading were skewed over the subregion, typically fitting a gamma or Weibull probability distribution. Table 3-1 summarizes the 90th, 75th, and 25th percentile values of depth; the minimum recorded depth, the maximum recorded depth, the mean of the recorded depths over the subregion, and the spatial coefficient of variation (absolute value of the ratio of spatial standard deviation to spatial mean), CV_s, for each reading date. Values of CV_s ranged from about 0.33 to about 0.66, indicating a moderate degree of spatial variability about the mean. Values of the temporal coefficient of variation, CV_t, for individual wells ranged from about 0.05 to about 1.05.

Table 3-1. Statistical Summary of Water Table Depths Measured Over the Study Subregion in 1999

				Statistics of Observed Water Table Depths (m)						
Observation Period (1)	Best-Fitted Probability Distribution (2)	Total No. of Wells Measured (3)	No. of Dry Wells Measured (4)	90th Percentile (m) (5)	75th Percentile (m) (6)	25th Percentile (m) (7)	Minimum (m) (8)	Maximum (m) (9)	Mean (m) (10)	CV_s (11)
Apr 5 – 24 1999	Logistic	52	19	2.35	1.97	1.22	0.23	3.05	1.59	0.39
May 11 – 13 1999	Gamma	63	20	1.99	1.53	0.78	0.28	2.57	1.21	0.48
May 26 – 27 1999	Gamma	63	16	2.09	1.69	0.99	0.46	2.69	1.38	0.39
Jun 1 - 8 1999	Pearson	29	7	1.89	1.50	0.95	0.74	2.74	1.28	0.38
Jun 9 – 11 1999	Gamma	64	19	2.54	1.87	0.82	0.08	5.08	1.43	0.58
Jun 17 - 18 1999	Gamma	66	18	2.45	1.85	0.87	0.20	4.04	1.43	0.53
Jun 23 – 24 1999	Gamma	66	19	2.12	1.64	0.84	0.20	2.59	1.29	0.48
Jun 29 - Jul 1 1999	Gamma	68	14	2.55	1.97	1.02	0.25	3.99	1.56	0.47
Jul 6 – 8 1999	Rayleigh	68	21	2.48	1.92	0.88	0.28	3.89	1.45	0.52
Jul 14 - 18 1999	Beta	71	20	2.55	2.03	0.70	0.10	3.10	1.39	0.58
Jul 21 – 23 1999	Lognormal	71	19	2.44	1.69	0.76	0.23	3.86	1.35	0.66
Jul 28 - 29 1999	Weibull	73	23	2.30	1.85	0.93	0.30	2.97	1.42	0.46
Aug 3 – 5 1999	Gamma	67	20	2.62	1.86	0.71	0.11	4.22	1.39	0.66
Aug 10 - 14 1999	Rayleigh	72	24	2.26	1.76	0.80	0.20	2.84	1.32	0.52
Aug 17 – 19 1999	Weibull	70	18	2.82	2.19	1.01	0.23	4.11	1.65	0.52
Sep 4 1999	Gamma	68	24	2.55	1.91	0.88	0.27	4.04	1.47	0.55
Sep 16 – 17 1999	Weibull	69	18	2.69	2.14	1.05	0.23	4.14	1.64	0.48
Oct 1 - 6 1999	Logistic	60	17	2.19	1.88	1.25	0.28	2.87	1.56	0.33
Nov 12 - 13 1999	Gamma	68	22	2.50	2.01	1.16	0.41	3.12	1.63	0.40

An example of salinity concentrations, interpolated across the study area, is shown for the middle season (July 14-17, 1999) in Figure 3-3. Average groundwater salinity was found to decline slightly by about 0.28 dS/m (250 mg/l) over the subregion over the course of the irrigation season, likely due primarily to dilution effects as recharge from excess irrigation filled the aquifer. Areas where a substantial decrease occurred include the northwest area of the study subregion (just east of the town of Manzanola), where salinity concentrations decreased by about 3.4 dS/m (3000 mg/l), and the central area (just north of Swink) where a reduction of about 2.3 dS/m (2000 mg/l) was observed. Interestingly, however, there were three areas with a noticeable increase in salinity: just east of La Junta along the river; in the northeast, just southwest of Cheraw; and just south of Swink.

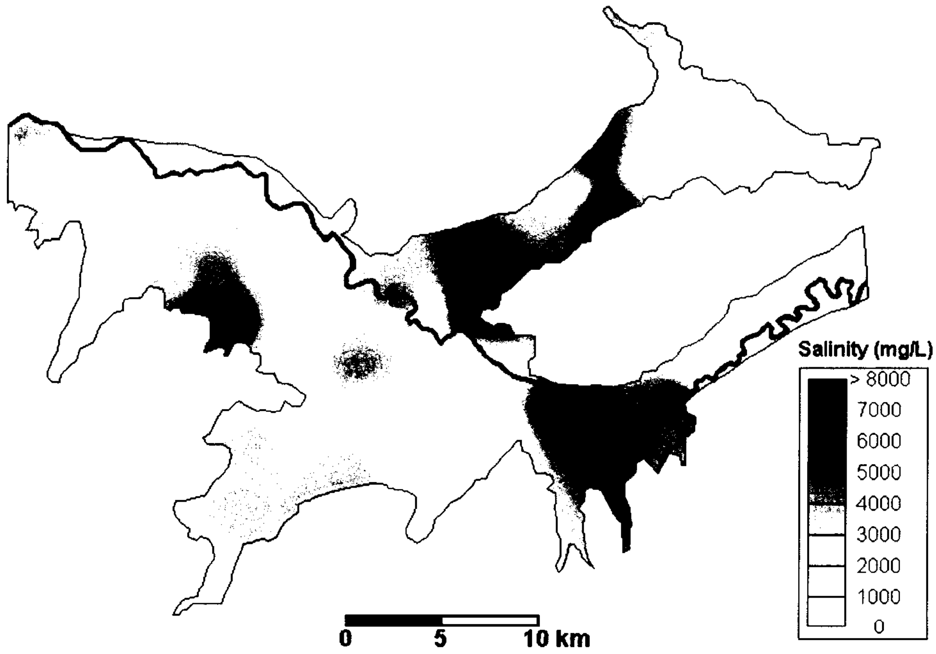

Figure 3-3. Estimated contours of water table salinity based upon specific conductance readings in observations wells for July 14-17 1999.

Groundwater salinity concentrations increased in these three areas by about 1.13 dS/m (1000 mg/l), 1.70 dS/m (1500 mg/l), and 1.70 dS/m (1500 mg/l), respectively. A possible cause is higher dissolution of native salts from salt-bearing soil layers, derived from marine shales (Zielinski et al. 1995) in these areas.

Water table salinity (measured as *EC*) statistics are summarized for each measurement period in Table 3-2. Data for each period generally fit a Pearson or lognormal probability distribution over the subregion. The table gives the 90th, 75th, and 25th percentile values; the minimum and maximum groundwater salinity values, the mean value, and the CV_s for each reading date. The overall maximum *EC* value recorded was 21.70 dS/m (19,144 mg/L). The minimum value recorded was 0.22 dS/m (194 mg/L), probably associated with direct dilution from a recent rainfall event. The seasonal-average electrical conductivity of the shallow water table measured over the study subregion was about 3.5 dS/m (3120 mg/L).

3.3.2 Irrigation Efficiency and Salt Loading

The *EC* of surface water in the study area was monitored at 163 sites, as shown on Figure 3-1, including 91 locations within the six main canals, 14 locations in a canal conveying water to a reservoir, 16 locations in six lateral canals, 25 locations in twelve drainage channels, nine locations in two reservoirs, and eight locations along the river. Measurements began in June 1999 and thereafter were made at a frequency closely corresponding to that for the data collection at the monitoring wells. *EC* values were

Table 3-2. Statistical Summary of Electrical Conductivity of Shallow Groundwater Measured Over the Study Subregion in 1999

		Statistics of Measured EC[1]							
Measurement Period (1)	Best-Fitted Probability Distribution (2)	Total No. of Wells Measured (3)	90th Percentile (dS/m) (4)	75th Percentile (dS/m) (5)	25th Percentile (dS/m) (6)	Minimum (dS/m) (7)	Maximum (dS/m) (8)	Mean (dS/m) (9)	CV_s (10)
Apr 5 – 24 1999	LogLogistic	33	6.41	4.47	2.59	1.52	21.70	4.11	1.36
May 11 – 13 1999	Pearson	43	8.95	5.64	2.18	0.42	21.50	4.68	0.98
May 26 - 27 1999	Lognormal	47	8.31	5.54	2.25	0.85	20.13	4.41	0.75
Jun 1 – 8 1999	Lognormal	23	8.41	5.61	2.28	0.71	19.37	4.47	0.80
Jun 9 – 11 1999	Pearson	45	7.60	4.73	1.79	0.22	17.27	3.95	1.03
June 17 - 18, 1999	Lognormal	47	5.97	4.15	1.85	0.77	10.39	3.32	0.66
Jun 23 - 24 1999	Pearson	47	6.66	4.70	2.32	0.70	15.26	3.88	0.63
Jun 29 – Jul 1 1999	Pearson	54	7.53	4.82	1.92	0.66	14.07	3.98	0.92
Jul 6 - 8 1999	Pearson	49	7.93	5.01	2.17	1.03	14.79	4.35	1.05
Jul 14 – 18 1999	Lognormal	52	7.06	4.57	1.74	0.45	12.04	3.64	0.82
Jul 21 - 23 1999	Pearson	52	7.16	4.59	1.82	0.71	17.86	3.78	0.91
Jul 28 – 29 1999	Inverse Gaussian	50	7.82	5.09	1.97	0.83	14.66	4.03	0.76
Aug 3 – 5 1999	Pearson	48	8.40	5.06	1.75	0.46	19.71	4.23	1.14
Aug 10 – 14 1999	Pearson	48	6.49	4.47	2.09	1.02	15.98	3.68	0.70
Aug 17 - 19 1999	Pearson	51	7.28	4.87	2.15	0.99	13.89	4.01	0.78
Sep 4 1999	Pearson	46	7.11	4.59	2.06	1.06	15.16	3.94	0.94
Sep 16 – 17 1999	Pearson	51	7.78	4.86	2.07	1.06	15.16	4.24	1.12
Oct 1 - 6 1999	Pearson	43	7.76	5.01	2.25	1.16	15.30	4.31	0.94
Nov 12 - 13 1999	Pearson	48	8.56	5.45	2.40	1.08	16.61	4.71	1.00

[1] 1 dS/m = 882.2 mg/L TDS

converted to *TDS* using a relationship derived from analysis of surface water samples collected at 28 locations in the system:

$$TDS = (1479.2)EC^{0.668} - 617.8 \quad (r^2 = 0.97) \tag{3-2}$$

For the period prior to June, salinity concentrations in the canals were estimated using regression relationships to salinity concentrations measured in the Arkansas River (USGS 1999) at the Catlin dam gauging station (just downstream of the diversion to the Catlin canal). Downstream increases in salinity, associated with diversions and with accumulation of saline surface and subsurface return flows, were typical for the river and the canals. Spatial variability in salinity along the river was moderate, as indicated by values of CV_s ranged from about 0.10 to 0.45 over the season. Values of CV_t ranged from about 0.20 to 0.35 for individual measurement locations along the river, indicating moderate temporal variability in salinity. In the main canals, values of CV_s varied over the season from 0.00 to 0.60. Insufficient measurement locations were available for estimating CV_s for drains. Values of CV_t for individual measurement locations in the main canals ranged from 0.10 to 0.70, while values for locations in major drains varied from 0.10 to 0.60.

The seasonal-average *EC* measured at the eight locations along the Arkansas River ranged from about 0.85 dS/m (720 mg/L) at the upstream end of the study reach to 1.50 dS/m (1322 mg/L) downstream near the Otero-Bent county line, with the overall-reach average being about 1.00 dS/m (861 mg/L). Seasonal-average *EC* measured along each of the six main canals ranged between 0.70 (548 mg/L) and 1.35 dS/m (1190 mg/L). The overall average *EC* measured in the irrigation canals was 0.93 dS/m (791 mg/L). Seasonal-average *EC* measured over all points in open drains, returning to the river, was about 2.6 dS/m (2183 mg/L).

Analysis of diversion records for the six main canals in the study subregion over the period 1 March to 20 October 1999 indicate total seasonal depths of water diverted ranging from about 1.10 m to 1.85 m with an average of 1.40 m. Pumped wells supplied between 0.02 m and 0.16 m to the command areas in the subregion. Seasonal effective rainfall was estimated from climatic and hydrologic data as about 0.19 m. Accounting for net crop water requirements, these data indicate irrigation efficiencies (product of conveyance and application efficiencies) of about 30 to 50% over the subregion. The total salt load to the land through infiltration and canal seepage was estimated to range from 10,300 to 17,900 kg/ha among the six canals, based on temporal measurements of salinity concentration near the canal inlets.

3.3.3 Soil Salinity

Soil salinity to a depth of about 1 m (encompassing the bulk of the roots for most crops in the subregion) was estimated by measuring electromagnetic induction at a number of sites within selected fields (individually-managed agricultural areas) using four electromagnetic induction probes (Geonics$^{\text{TM}}$ EM38). Two sets of readings were taken at each field location representing: (1) early-season conditions (i.e. data collected in late May to mid June), and (2) representing late-season conditions (i.e. data collected in early to mid August). Fields selected in 1999 (excluding the fields in Bent County) were a subset of fields containing monitoring well sites.

Within each field in 1999, EM38 measurements were taken at about 30 - 90 locations (corresponding to a data density of around one point per 0.10 ha) distributed over the entire field or, in cases where the field was large (> 20 ha), covering a portion of the field containing (or adjacent to) the monitoring well. Measured values of electromagnetic induction were converted to bulk soil salinity and soil saturation extract salinity, EC_e , using relationships presented in Rhoades et al. (1989). Preliminary analysis of soil samples collected for EM38 calibration supports the general validity of these relationships.

In the early-season reading, 73% of the sampled fields had 25% or more of their measured sites with soil salinities above the threshold, which is the approximate level above which the crop will experience yield loss (Maas 1990). The overall spatial average EC_e for the study area was estimated as 2.6 dS/m (2330 mg/l) for the early season. For the late-season readings, 68% of fields had at least 25% of measured points above the salinity threshold, and the overall spatial average increased slightly to 2.9 dS/m (2550 mg/L). Estimated contours of soil salinity, based upon these late-season measurements, are shown in Figure 3-4 along with box-and-whisker plots of the measurement statistics. These results are similar to spatial average values of 2.3 dS/m (2050 mg/L) and 3.1 dS/m (2720 mg/L) measured early and late, respectively, under 30 fields in 1998.

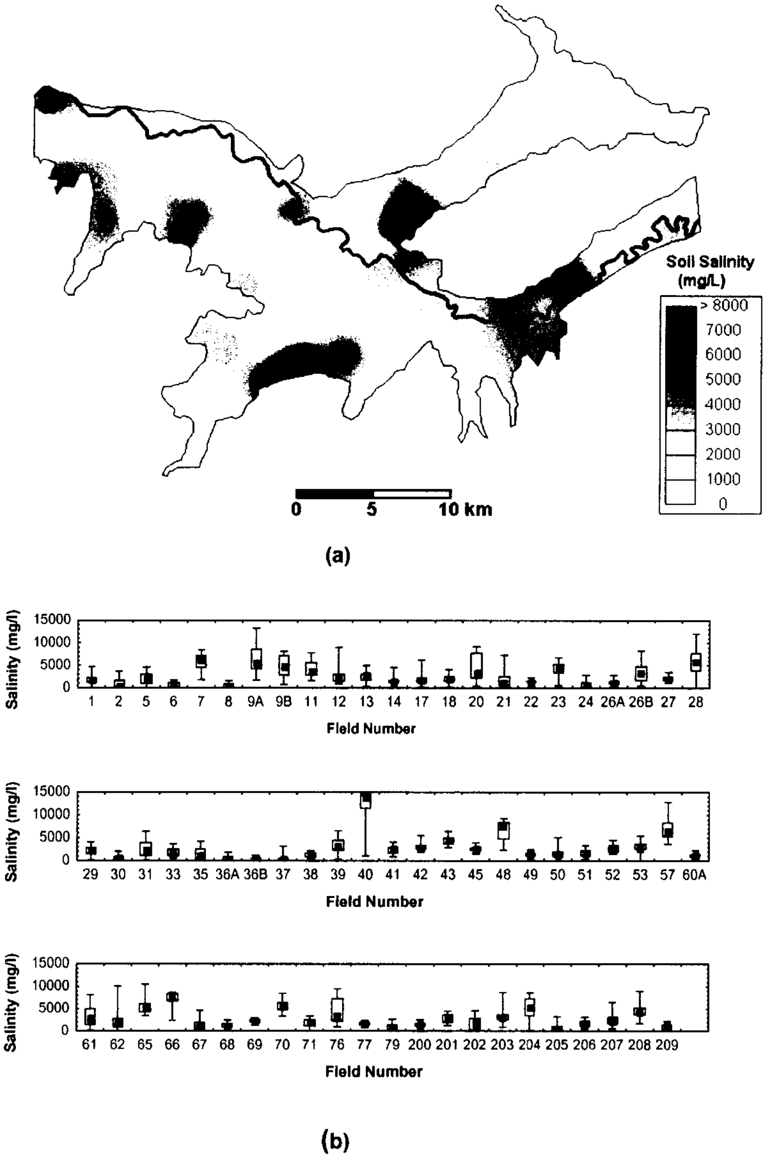

Figure 3-4. (a) Estimated contours of late-season saturated extract soil salinity based EM-38 readings taken in 68 fields in August 1999 and (b) Box and Whisker plots of measured salinity in each of the 68 fields (square represents median value, upper side of rectangle represents 75th percentile value, lower side of rectangle represents 25th percentile value, upper whisker represents maximum value, and lower whisker represents minimum value).

The relationship between saline high water tables and salinity of the overlying soil is evident in Figure 3-5. Plotted is the late-season field-averaged soil salinity versus water table depth averaged over the four weeks prior to the late-season soil salinity measurement The fitted equation indicates a significant non-linear trend suggesting that, under current irrigation practices, average water table depths greater than about 2.5 to 3 meters are needed to prevent exceeding a reference threshold salinity level of 2 dS/m (approximate threshold for alfalfa and corn, the predominant crops) in overlying fields (Maas 1990, Maas and Grattan 1999) .

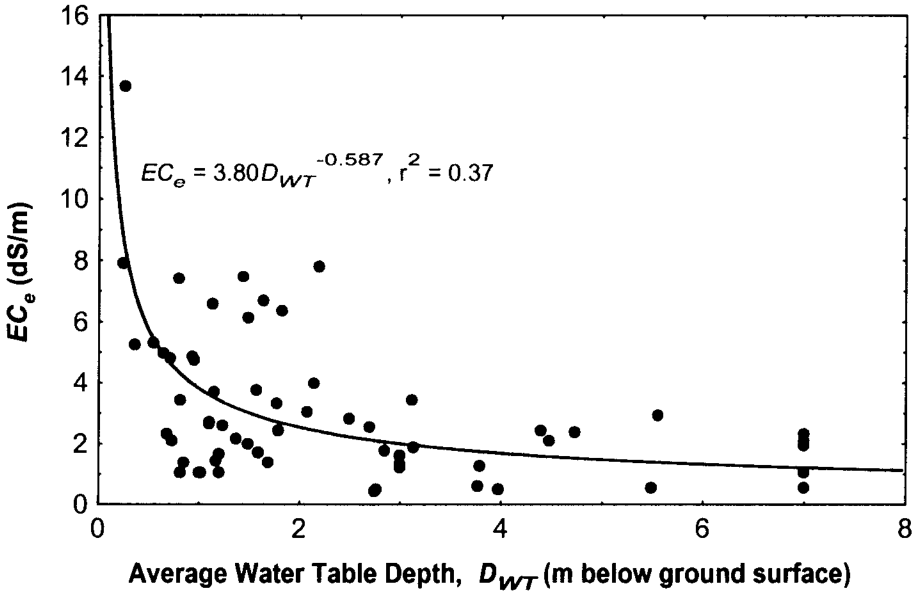

Figure 3-5. Trend in average measured late-season soil salinity with measured water table depth averaged over four-week period prior to late-season soil-salinity measurement.

3.4 PRELIMINARY INVESTIGATION OF SOLUTIONS

3.4.1 Conceptual and Numerical Models

The GMS software package was used to create a flow and salt transport model of the study subregion. GMS acts as a graphical "GIS-style" interface for several different models. The interface is divided into modules that allow the user to enter and analyze the various data types for the particular models being utilized. The two models within the GMS package applied in this study were the MODFLOW (McDonald and Harbaugh 1988) groundwater flow model, and the MT3DMS (Zheng and Wang 1999) contaminant transport model. Both MODFLOW and MT3DMS are modular three-dimensional finite-difference models (Wang and Anderson 1995) that approximate the governing non-linear partial differential equations for flow and mass-transport with a set of non-linear difference equations applied at a large number of finite-difference cells superimposed on the modeled region. In the current study, a finite difference grid of about 7550 active cells, each 250 m by 250 m (6.25 ha) in size, was superimposed on a conceptual model of the study subregion. The grid consisted of two layers: a shallow layer extending from the ground surface to a depth of 3.5 m, and a deep layer extending from a depth of 3.5 m to the bedrock (up to 30.4 m). The conceptual model was constructed from a LANDSAT7 satellite image (dated 19 July 1999) and from aerial photos of fields obtained from the USDA Farm Services Agency in Rocky Ford.

In this preliminary phase, MODFLOW and MT3DMS were applied to conditions of steady flow to explore the comparative order of magnitude of effects to be expected from scenarios associated with strategies requiring relatively low levels of structural intervention in the system. Such strategies could be achieved primarily through improved management of existing facilities without requiring substantial capital investment. These alternatives include: (1) increasing vertical drainage by modest boosting of pumping rates from existing wells to draw the water table down, and (2) improving irrigation management to achieve moderate reduction in recharge to the water table from overirrigation. Any incremental pumped flow would be routed through open drains back to the river to preclude violation of state and interstate laws. A feasibility-stage approach was taken that used steady-state simulation under constant seasonal-average properties and boundary conditions (average of conditions representative of those measured from early April through late October 1999). The purpose of this approach was to make a relative comparison between strategies under conditions that approximate long-term equilibrium solute-transport. Capital-intensive alternatives, such as lining canals to reduce seepage, installing horizontal subsurface drains, or dredging of the river to reduce river stage, were not considered in this preliminary phase. The next modeling phase will consider these and other alternatives under more-detailed dynamic modeling. The seven modeled scenarios reported herein are:

> *Scenario 1: Baseline Conditions.* This scenario simulates flow and salt transport reflective of average conditions measured in the subregion over the irrigation season. Output was used to evaluate the comparative effects of changes to the system as described in the six other modeled scenarios.

Scenario 2: Increase Pumping Rates by 20%. This scenario investigates the impacts of increasing the average pumping rates of the currently active wells within the study area by 20% and routing all additional pumped flow into nearby drains flowing to the river.

Scenario 3: Increase Pumping Rates by 33%.

Scenario 4: Reduce Recharge Rates by 20%. This scenario considers the impacts of reducing average recharge rates from overirrigation uniformly over the entire study area by 20%.

Scenario 5: Reduce Recharge Rates by 33%.

Scenario 6: Increase Pumping Rates by 20% and Reduce Recharge Rates by 20%. An increase in the average pumping rates by 20% and a conjunctive reduction in the average recharge rates by 20% is modeled in this scenario.

Scenario 7: Increase Pumping Rates by 33% and Reduce Recharge Rates by 33%.

The preconditioned conjugate-gradient 2 method was used in MODFLOW for solving the non-linear difference equations since it is well suited for cell rewetting calculations. The following sink/source packages were used in MODFLOW (McDonald and Harbaugh 1988):

Recharge - models the areal recharge to the water table, which, in this case, results from downward flow of excess irrigation and rainfall.

Evapotranspiration - models losses due to upflux from the water table in response to evapotranspiration.

River - models groundwater flow into and out of a partially penetrating channel.

General Head - models specified hydraulic head within cells defining boundaries.

Well - models the extraction of groundwater due to pumping.

The MT3DMS model uses the groundwater flows predicted by MODFLOW along with four calculation packages to estimate contaminant transport. The packages used in the preliminary modeling were the *Advection* and the *Source/Sink Mixing* packages that calculate advective transport of solutes within the aquifer and the addition or extraction of solutes to the aquifer through pumping, recharge, or upflux. The third-order total-variation-diminishing (TVD) method was used to solve the model solute transport equations (Zheng and Wang 1999). It was assumed that variability in hydraulic conductivity, and in the rate and concentration of sinks and sources, over the study subregion will dominate over small-scale dispersivity in determining salt concentration variability (Fetter 1993, Zheng and Bennett 1995). Thus, effects of dispersion were assumed negligible in this study. Also, chemical reactions were deemed negligible in affecting the concentration of TDS.

3.4.2 System Properties and Boundary Conditions

Using the *Map* module, a variety of data were entered into the conceptual layers of GMS to describe system properties and boundary conditions over the subregion. These data were then interpolated to the finite difference grid using the *Scatter Point* module to support the numerical model. The data interpolated in this way are briefly described.

3.4.2.1 Ground Elevation

Ground elevations over the subregion were extracted from about 1200 surveyed points presented on USGS quadrangle maps of the area. These data were supplemented by global positioning system (GPS) surveys conducted in the present study at about 200 points distributed over the irrigated lands of the subregion. The GPS used a differential correction method to achieve universal transverse mercator (UTM) positions and elevations with an accuracy of about ± 0.05 m.

3.4.2.2 Aquifer Thickness

Values of aquifer thickness at 165 locations were obtained from drilling logs reported in Weist (1962) and Major et al. (1970), ranging from 1 to 30 m, with an average of about 10 m.

3.4.2.3 Hydraulic Conductivity

Slug tests (Chin 2000) were conducted in the present study in 95 of the monitoring wells to estimate horizontal saturated hydraulic conductivity in the upper 2 to 3 meters below the ground surface. Values ranged from 0.003 m/day to 10.24 m/day, and were Weibull or lognormal distributed over the subregion with a mean of 1.1 m/day and a CV_s of about 2.4.

Estimates of horizontal saturated hydraulic conductivity averaged over deeper portions of the aquifer, extending from 3 meters below ground surface to bedrock elevation, were obtained from 18 pumping tests reported by Wilson (1965). Values ranged from 12.9 m/day to 362.9 m/day, averaging about 172.2 m/day.

3.4.2.4 Crop Evapotranspiration (ET)

Crop survey data, indicating total area planted to each crop, were obtained for each main canal command area from the District 2 office of the Colorado Division of Water Resources. Based on these distributions, crop types were randomly assigned to each irrigated field in the subregion. Using crop coefficient data and meteorological data obtained from the CoAgMet on-line data center (Colorado Climate Center 1999), the soil-water balance model, *CropFlex98* (Broner and Lorenz 1998), was used to estimate average ET and irrigation requirements for each crop type.

3.4.2.5 Effective Precipitation

Rainfall data were obtained from the weather station at the Colorado Agricultural Experiment Station just east of Rocky Ford. It was estimated that about 30% of the rainfall resulted in surface runoff, leaving about 70% as effective precipitation that infiltrated into the soil or reduced evaporative demand around the crop canopy. Surface runoff from rainfall events was equivalent to about 8% of the volume applied to the land by irrigation and was assumed negligible in its effect on seasonal average water levels in watercourses in the modeled subregion.

3.4.2.6 Recharge to the Water Table

Recharge to the water table was computed as a deep-percolation (leaching) fraction of the total irrigation loss (applied irrigation depth in excess of the required depth). Average application efficiency for each canal command area was calculated as: $\bar{E}_A = \bar{E}_I / \bar{E}_C$, where $\bar{E}_I$ = the average irrigation efficiency (ratio of total water required to total water diverted by the canal and supplied from pumping wells) for the command area computed from water balance data, and $\bar{E}_C$ = the average conveyance efficiency for the canals in the command area (estimated as about 0.80). Values of application efficiency, E_A, for each field within a command area were generated from a truncated normal distribution with a mean equal to $\bar{E}_A$ and a standard deviation of 0.20, assumed to match that for field data collected for a similar region (i.e. similar irrigation practices) in Colorado's South Platte River Valley (Emond 1994, Crookston 1995, Walter 1995). Similarly, the value for the deep-percolation fraction, DP, or fraction of the total losses that percolated below the root zone (in contrast to surface runoff), was assumed to be an average value of 0.70, also estimated from the studies in the South Platte Valley (Walter 1995). Recharge was varied over the subregion by computing an average net recharge rate for each field as

$$Q_R = DP(1 - E_A)(Q_{ET} - Q_P) \tag{3-3}$$

where Q_{ET} = average evapotranspiration (m/day), and Q_P = average effective precipitation (m/day). It was recognized that in some areas part of the deep percolation was recovered to help supply Q_{ET} by return flow via upflux from the shallow water table, Q_U (m/day), leaving the net recharge to the water table computed in (3). Values of Q_U were calculated using the procedure described in the following section.

3.4.2.7 Upflux from the Water Table

The *Evapotranspiration* module in MODFLOW was used to model upward flow from the high water table to the overlying root zone. This model assumes a linear relationship between the depth to the water table below ground surface, D_{WT}. Grismer and Gates (1988) have confirmed the general applicability of a linear relationship between upflux and depth to saline water tables. The upflux, Q_U was computed as (McDonald and Harbaugh 1988):

$$\begin{aligned} Q_U &= Q_{U_{\max}} \frac{(D_{\max} - D_{WT})}{D_{\max}}, \text{ for } D_{\max} > D_{WT} \\ &= 0, \quad \text{otherwise.} \end{aligned} \tag{3-4}$$

wherein D_{max} = the "extinction depth", or depth at which upflux essentially ceases (m), estimated as 3.5 m in this study (Hoffman and Durnford 1999), and $Q_{U_{\max}}$ = maximum upflux (m/day), assumed in this study to equal *ET*.

3.4.2.8 Pumped Discharge

Data on weekly pumped volumes were obtained from the District 2 office of the Colorado Division of Water Resources for about 257 pumping wells in the subregion, of which about 165 were active during the 1999 season. Values were averaged to obtain a rate representative of the period from early April to late October. Seasonal average pumped volumes for active wells ranged from negligible to as high as about 17,000 m^3/week. The average over all active wells was about 2090 m^3/week with $CV_s = 1.26$.

3.4.2.9 Seepage from Canals and Reservoirs

Interaction between surface channels and reservoirs and the adjacent water table aquifer was modeled using the *River* module in MODFLOW. In this module, seepage to or from the channel or reservoir in a given cell is calculated as

$$Q_S = \frac{C(E_{WS} - E_{WT})}{A_C}, \text{ for } E_{WT} > E_B \qquad (3\text{-}5)$$

$$= \frac{C(E_{WS} - E_B)}{A_C}, \text{ for } E_{WT} \leq E_B$$

wherein C = conductance of the channel or reservoir bed material (m^2/day) = $\frac{K_B L W}{T}$, K_B = hydraulic conductivity of the channel or reservoir bed material (m/day), L = effective length of the channel or reservoir bed material (m), W = effective width of the channel or reservoir bed material (m), T = effective thickness of the channel or reservoir bed material (m), E_{WS} = channel or reservoir water surface elevation (m), E_{WT} = water table elevation in cell (m), E_B = channel or reservoir bottom elevation (m), and A_C = area of the computational cell (m^2). Field surveys were conducted to estimate channel bed widths. Reservoir dimensions were estimated from satellite images of the subregion. Values of K_B were estimated as one-tenth the values determined from pumping tests or from slug tests in observation wells.

3.4.2.10 Surface Water and Recharge Salinity

Salinity concentrations of water in the main canals were prescribed as averages of the values measured in the field. These values ranged from about 755 mg/l to about 1195 mg/l and were used as the concentration of irrigation water applied to fields commanded by each corresponding canal.

Salinity concentration of recharge to the water table, C_R, was calculated using the model presented in Bouwer (1969):

$$C_R = E_L C_{SW} + (1 - E_L) C_I \qquad (3\text{-}6)$$

wherein E_L = the leaching efficiency expressed as a fraction between zero and one (Boumans and van der Molen 1964), C_{SW} = salinity concentration of the soil water, expressed in the model as saturated extract salinity per unit area of the computational cell $[(kg/m^3)/m^2]$, and C_I = salinity concentration of the applied irrigation water $[(kg/m^3)/m^2]$. Equation (3-6) assumes that water draining from the root zone is a mixture of irrigation water passing unchanged through the root zone and soil water that has been displaced by the irrigation water (Hillel 1998). The value of E_L depends primarily on the size distribution of the water-filled soil pores and the extent of soil cracking. It typically varies between about 0.2 for heavy soils to about 0.6 for light soils (Boumans and van der Molen 1964, Bouwer 1969). In this study, E_L was assumed to be governed by a truncated normal distribution with mean value 0.30, CV of 0.20, minimum value of 0.15, and maximum value of 0.45. Values of C_{SW} and C_I were estimated as averages of values measured with EM38 probes in sampled fields (and interpolated over the subregion) and of values measured along main canals, respectively, as described above.

3.4.2.11 Salinity of Upflux

Salinity concentration of computed upflux from the water table was assumed to be equal to the computed depth-averaged salinity concentration of the shallow aquifer at that location.

3.4.2.12 Head and Salinity of Groundwater Boundaries

Hydraulic head and salinity concentration of the water table aquifer on the western 6-km north/south boundary (near Manzanola) and eastern 4-km north/south boundary (at the Otero-Bent County line) of the modeled subregion were estimated from interpolation of the average values measured in monitoring wells located along the boundaries. Four wells were located along the western boundary and five along the eastern boundary.

3.4.2.13 No-flow Boundaries

The interfaces between the irrigated alluvium and the desert escarpments on the north and south of the subregion were modeled as no-flow boundaries.

3.4.3 Model Calibration

The steady-state model was calibrated by systematically adjusting values of selected system parameters (e.g. hydraulic conductivity, aquifer thickness, channel conductance, recharge, etc.) to achieve an acceptable match between season-average values of measured water table elevation and salinity with corresponding values predicted by the steady-state model. Adjusted values of model parameters were constrained to lie within the range of values observed in the field. Average error (computed value minus observed value) in computed water table elevation over 63 calibration points was Weibull distributed with a mean of 0.28 m. The standard deviation in the absolute value of the error was 0.84 m. Figure 3-6 shows a plot of the model computed water table elevation versus the average observed water table elevation at each calibration point. An attempt also was made to cause model-predicted water balances to approximate water balances measured in selected watercourses over the season. Predicted canal seepage (initially estimated at 20% of diverted flow for purposes of calculating irrigation efficiencies) ranged from 10.8% for the Rocky Ford Canal up to 23.6% for the Fort Lyon Storage Canal. Predicted values of return flows from the water table aquifer to major drainages ranged from 28% of total measured streamflow for the Arkansas River upt to 84% of total measured streamflow for Timpas Creek. Reasons for discrepancies between model predictions and observations include: (1) some degree of measurement error, even in carefully-measured observations of aquifer properties, boundary conditions, and water table elevation and salinity; (2) the model predicting average values of water table elevation and salinity under cells representing areas of about 60,000 m^2, while observations are made in wells representing areas of less than 1 m^2; (3) the steady-state

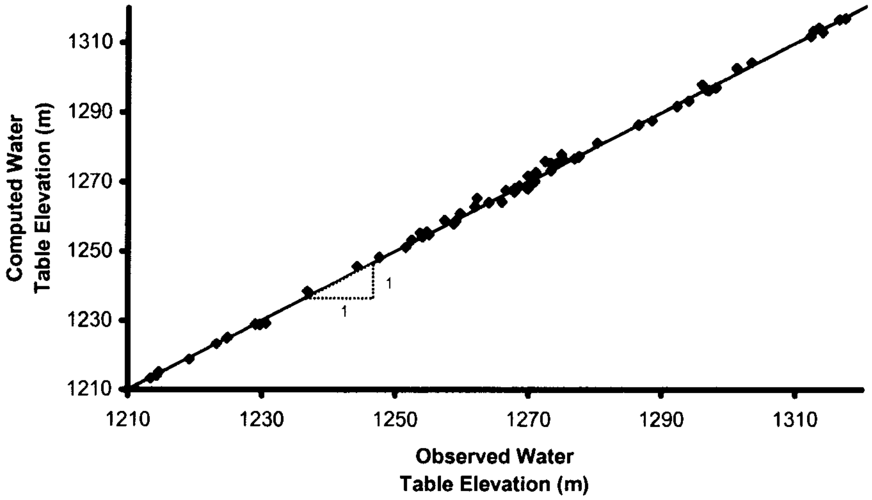

Figure 3-6. Model-computed and average observed values of water table elevation at calibration points.

model using estimates of time-averaged values of boundary conditions, sinks, and sources as inputs, resulting in predicted water table conditions that serve only as approximations of time-averaged observations of non-linear flow processes.

No parametric adjustment was made to attempt to calibrate the steady-state model for salt concentration. Instead, differences were computed between modeled concentrations for the baseline scenario and seasonal-average concentrations observed in the field. These differences suggest the presence of an average salt source of about 2.3 dS/m (2040 mg/l) over the subregion with CV_S = 0.62. It is believed that this additional salt is derived primarily from dissolution of salts in marine shale deposits (Zielinski et al. 1995); however, this hypothesis needs to be confirmed by additional investigation.

3.4.4 Increased Vertical Drainage

Scenarios 2 and 3 considered effects of increased vertical drainage caused by boosting pumping rates from existing wells by 20% and 33%, respectively. Such measures have been suggested as a relatively low-cost option for lowering the water table. Simulated results for scenarios 2 and 3 show that effects of increased pumping are limited to areas in close proximity to existing wells. Model predictions indicate that scenario 2 results in a slight decrease in average water table elevation (increase in average depth to water table) of about 0.01 m over the subregion, compared to the baseline conditions (scenario 1). Scenario 3, illustrated in the contour plot of Figure 3-7a, has a slightly greater impact than scenario 2. Reduction in water table elevation is 0.30 m or more under about 2% of the subregion. Areas that are notably affected are the vicinities near Swink and on the north side of the river, northeast of La Junta. However, the average reduction over the entire subregion is only about 0.02 m compared to baseline conditions. The model predicts a negligible change in water table salinity for both scenarios. Furthermore, the total salt load returned to the river would not be substantially altered, since increased pumping must be routed back to the river through the drainage system. However, the timing of salt loading would be affected and must be examined using an unsteady flow and mass transport model.

3.4.5 Increased Irrigation Efficiency

The model predicts that reducing recharge to the water table through increased irrigation efficiency would create widespread impacts on water table depth and salinity. Reductions in recharge of 20% (scenario 4) or 33% (scenario 5) were deemed feasible

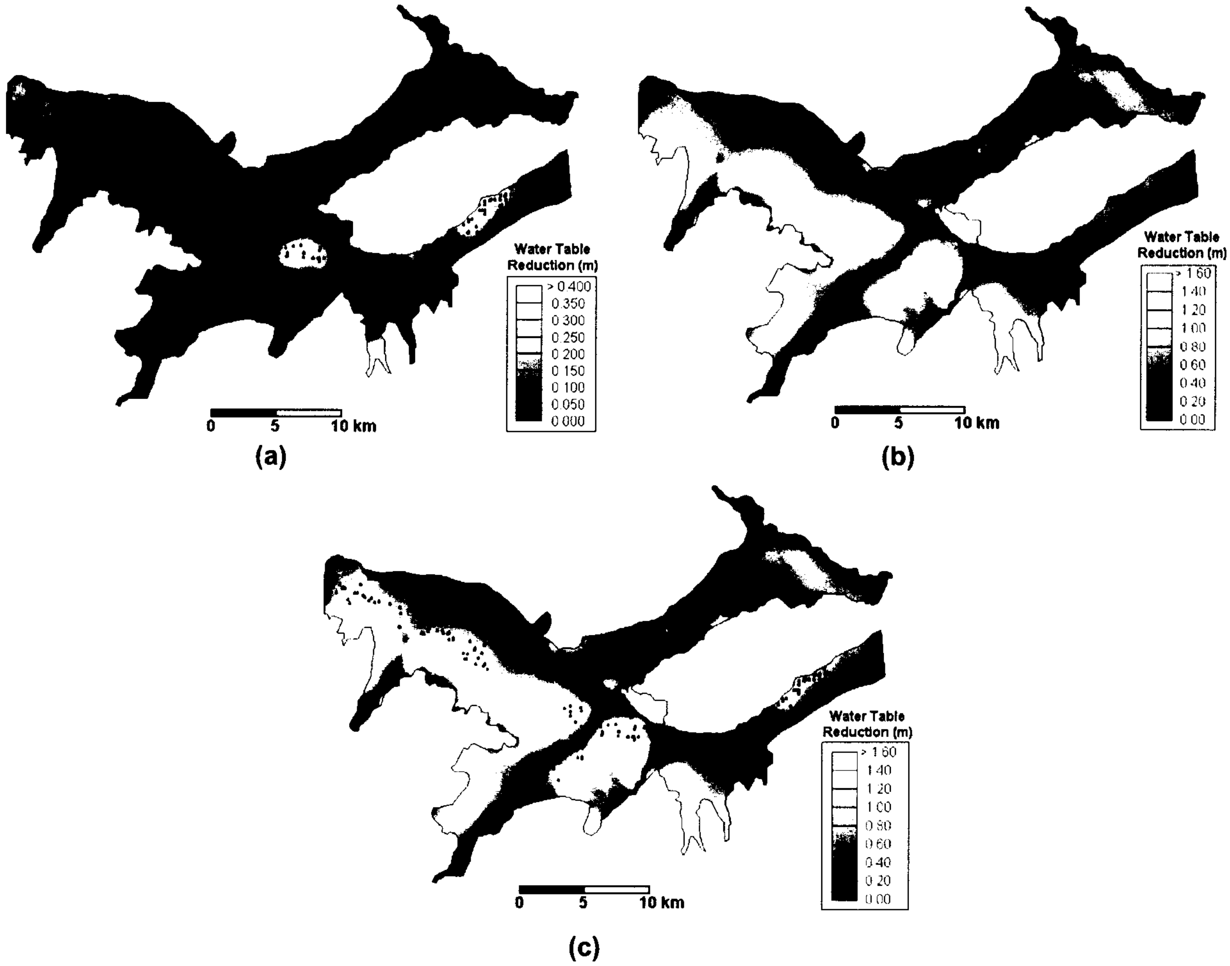

Figure 3-7. Predicted contours of reduction in water table elevation (increased water table depth) for steady-state model of (a) increased pumping by 33% (showing point locations of pumping wells), (b) decreased recharge by 33%, and (c) combination of increased pumping by 33% and decreased recharge by 33% (showing point locations of pumping wells).

through improved irrigation management such as altering timing of irrigations and flow rates applied to the field. On the other hand, these reductions in recharge would not be so great as to markedly increase soil salinity due to inadequate leaching. Scenario 4 would cause an average reduction in water table elevation of about 0.36 m but would result in a negligible change in average equilibrium groundwater salinity. As illustrated in Figure 3-7b, scenario 5 would result in an average reduction in water table elevation of about 0.62 m. Such a reduction would likely significantly reduce the salinity of overlying soils, as inferred from Figure 3-5. Scenario 5 was also predicted to slightly decrease the average water table salinity by about 0.04 dS/m (33 mg/L).

3.4.6 Combined Solution Alternatives

The combined effects of increased vertical drainage and decreased recharge were explored through scenarios 6 and 7. These scenarios result in an average decrease in water table elevation of 0.37 m and 0.63 m, respectively. Scenario 6 resulted in a negligible change in the average groundwater salinity while for scenario 7 the groundwater salinity would be reduced slightly by about 0.04 dS/m (33 mg/L). Contour plots of predicted reduction in water table elevation and change in groundwater salinity are shown in Figures 3-7c and 3-8. Under about 51% of the subregion, the predicted reduction in water table elevation is less than 0.50 m, while the reduction is less than 0.25 m under about 33% of the area.

The seasonal average rate of groundwater return flow to the river (directly and through tributary drainages) was computed as $5.5 \bullet 10^6$ m^3/week, with an accompanying diffuse salt loading rate of $16.2 \bullet 10^6$ kg/week, for the baseline scenario. Both scenarios 4 and 6 were predicted to result in a reduction in seasonal groundwater return flow to the river of about 8%. This corresponds to a predicted reduction of about 3% in seasonal diffuse salt load to the river. These effects are increased in scenarios 5 and 7, which show return

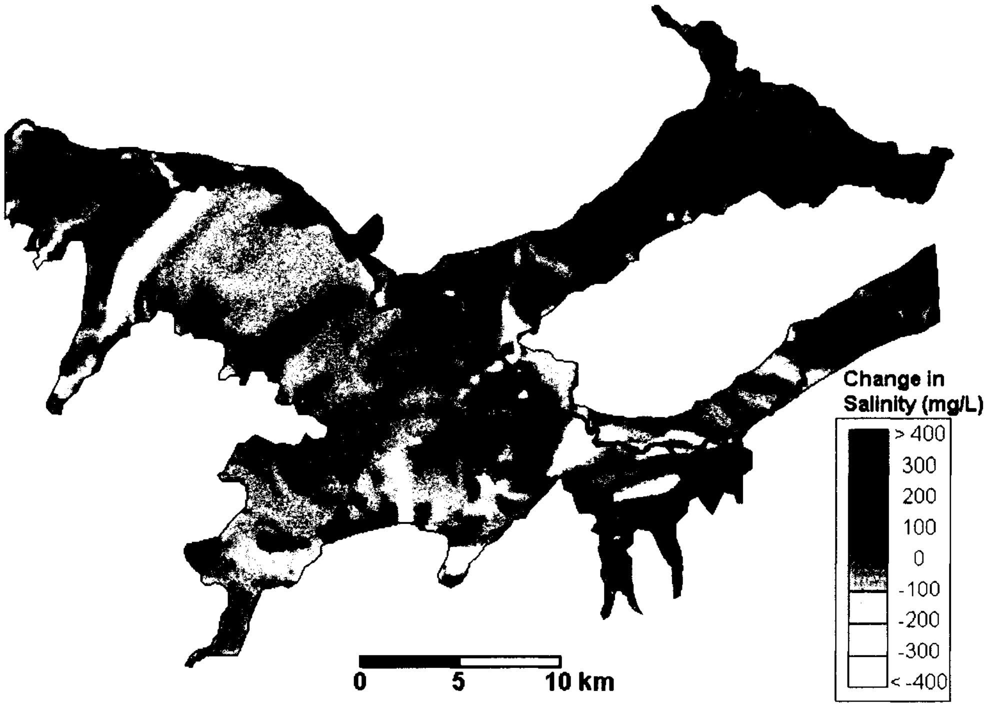

Figure 3-8. Predicted contours of change in water table salinity for steady-state model of a combination of increased pumping by 33% and decreased recharge by 33%.

flow and salt load reductions of 14% and 7%, respectively. Though reduced salt load is a perceived benefit, the timing of reductions in groundwater return flows must be carefully considered in an unsteady flow model to evaluate potential impacts on flows available to downstream users.

Model predictions indicate that increasing irrigation efficiency would significantly mitigate the saline-high-water-table problems over much of the subregion, particularly south of the river. However, substantial improvement will require consideration of other solution alternatives, especially in areas that are currently severely impacted. Specifically, it appears that areas northwest of Rocky Ford, near Cheraw in the northeast portion of the subregion, and just east of La Junta would be only marginally impacted by increased pumping and increased irrigation efficiency.

3.5 SUMMARY, CONCLUSIONS, AND FUTURE WORK

Comprehensive data, collected over a 53,100-ha subregion of the lower Arkansas River Valley, reveal a productive agricultural resource threatened by the ill effects of irrigation-induced salinization. A shallow water table with average salinity concentration of 3100 mg/l spreads out under the land at an average depth of only 2.1 m below ground surface. Moreover, the depth and salinity of the shallow water table show substantial spatial and temporal variability, affecting some areas far more than others. This variability results not only from heterogeneous soil and aquifer properties, but also from variability in irrigation water salinity, recharge from overirrigation, seepage from canals, pumping rates in wells, crop evapotranspiration rates, and channel water levels. Results also suggest significant dissolution of salts native to the soil profile. Irrigation efficiencies and salt loading among canal command areas were estimated to range 30% - 50% and 10,300 kg/ha - 17,900 kg/ha, respectively. Soil salinity measured in overlying fields varied from benign to extreme, tending to exceed threshold tolerances for crops when the depth to the saline water table was less than about 3 m. Crop yield reduction due to salinization is estimated to range between 0 and 75% on fields spread over the subregion, averaging about 10%. This indicates a total revenue loss ranging $0/ha - $750/ha, and averaging $70/ha - $100/ha over the study subregion, based on 1999 crop prices. Additional losses are likely occurring due to waterlogging.

Conditions appear serious but recoverable. Preliminary modeling indicates that increased pumping of existing well facilities would result in only limited localized improvement. Reduced recharge through increased irrigation efficiency would provide more extensive benefits, especially in much of the area south of the river. Nevertheless, lowering the saline water table in the most severely-affected areas will require more than simply increasing irrigation efficiency or increasing pumping rates. Costlier investments will need to be considered, such as canal lining, horizontal subsurface drainage, and lowering of the river level.

Plans for the next phase of the project call for efforts to refine the diagnosis of the problems as well as to accurately prescribe workable solutions. Conditions in 1999 were relatively wet; thus, properties of the saline shallow water table need to be examined under drier conditions. Analysis of data collected in the 2000 season, a year of moderate water availability, is being completed and similar data will be collected at least through the 2001 season. These data will be used to support and calibrate a more-refined unsteady flow and salt-transport model of the study subregion. Sensitivity analysis and or stochastic modeling will be used to study the influence of parametric uncertainty on model results. With guidance from Valley agencies and farmers, alternative solution strategies will be assessed by predicting how well they will control waterlogging and salinity, the impact they will have on time-varying return flows to the river, and their cost-effectiveness. Hopefully, project findings will prove a valuable resource in support of interventions that will result in sustainability of the Valley's productive agricultural base and preservation of its rural communities.

CHAPTER 4

DESCRIBING AGROECOLOGICAL IMPACTS FROM SALINIZATION AND WATERLOGGING IN AN IRRIGATED RIVER VALLEY

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4.0 ABSTRACT: Extensive field data and calibrated flow and salt transport models allow characterization of the spatial and temporal patterns of salinity and waterlogging in an intensively irrigated western river valley. Over a period encompassing three irrigation seasons, average seasonal recharge to the unconfined aquifer from irrigated fields in a 50,600 ha study area is estimated to range from 0.59 to 0.99 m, including contribution from effective precipitation. Salinity of applied irrigation water varied from 618 to 1090 mg/L. The water table is found to be shallow under much of the area, with 16 to 33% of irrigated land underlain by an average water table less than 2 m deep. Average water table salinity ranged from 2680 to 3015 mg/L, and average soil salinity from 2490 to 3860 mg/L. Crop yield reductions from salinity and waterlogging are estimated to range from 0 to 89 % on individual fields, with regional

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averages ranging from 11 to 19 %. Annual salt loading to the river from subsurface return flows, generated in large part by dissolution from irrigation recharge, averages about 533 kg/irrigated ha per km along the river. Upflux from shallow water tables under fallow ground contributes to about 65 million m^3 (52,600 ac-ft) per year of non-beneficial consumptive use. Beyond problem identification, the developed database and calibrated models provide a basis for effectively addressing these problems through a systematic and comparative assessment of alternative solutions.

4.1 INTRODUCTION

For more than a hundred years, extensive irrigation canal systems, made up of more than a thousand miles of channels, have diverted and distributed the waters of the Arkansas River to the adjacent alluvial soils of southeastern Colorado. Irrigation has made possible productive agricultural economies and scenic rural landscapes across the river valley. Over the years, while the benefits of the irrigation infrastructure have been realized, the water table has been rising and growing more saline due to irrigation inefficiencies, seepage from earthen canals, diminished groundwater pumping rates, and inadequate drainage facilities (Miles 1977, Gates et al 2002). Upward flow from the high water table has salinized and waterlogged many of the soils of the valley, limiting crop yields. Not only has land been degraded, but river water quality also diminished. Beyond the evapoconcentration of solutes in applied waters, irrigation of the alluvial soils, which are derived from marine sedimentary rocks, has resulted in dissolution and movement of resident salts and metals (e.g. selenium and iron), into the underlying alluvial aquifer that discharges to the river. Consequently, solute concentrations in river waters have risen to levels that potentially threaten not only the productivity of the land, but also the ecological health of the river. In addition, irrigation has created shallow water tables under areas of fallow land and created new wetlands from which increased transpiration and direct evaporative losses may amount to significant volumes of nonbeneficial consumptive use.

Conditions along the Arkansas River are typical of those in many other irrigated regions around the globe. Waterlogging and salinization have long challenged the sustainability of irrigated agriculture and continue to affect most irrigated areas. Saline high water tables now affect about 20 to 25% of the world's irrigated lands, including 27% of those in the United States (Ghassemi, et al., 1995, National Research Council 1996, Western Water Policy Review Advisory Commission 1998, Postel 1999, Tanji and Kielen 2002), and pose serious threats to many productive agroecological systems – the settings that provide the medium and resources to support significant crop production. An important modern challenge is to limit degradation of the world's irrigated land while protecting the broader natural resource base of watersheds that include irrigated areas.

This paper presents results from an on-going effort by Colorado State University to accurately diagnose problems in the Arkansas Valley, and to systematically develop viable solutions. The purpose of the work described herein, apart from the collection of extensive data on salinity and waterlogging problems within the selected study region, was to develop a modeling tool for use both in characterizing the current situation and in evaluating solution alternatives on a regional scale throughout the river basin. This work is a significant expansion of an earlier research reported in Gates et al. (2002). Whereas the previous phase examined steady-state groundwater flow and salt transport models of an averaged 1999 irrigation season condition, the present paper details the development of time-varied (transient) models calibrated and tested over three irrigation seasons (1999 – 2001). Also presented is the expansion of the modeling code to incorporate an unsaturated zone module for use in soil salinity estimation.

Application of these models to the Arkansas River valley provides a comprehensive space-time picture of salinization and waterlogging impacts in a typical intensely-irrigated western watershed. These impacts, if unaddressed, threaten the economic well-being of the rural communities in the valley, diminish the agricultural base of Colorado, and impair the ecological health of the river system as a whole. The developed calibrated models are an important first step of problem identification and lay the groundwork for exploring effective solutions, as will be described in forthcoming papers.

4.2 DESCRIPTION OF STUDY AREA

The Lower Arkansas River Valley of Colorado is located in the southeastern portion of the state and has a semi-arid environment. The study area extends from the city of Pueblo for approximately 298 km (185 mi) to the Colorado-Kansas border along both sides of the Arkansas River. Two regions within the valley have been designated for intensive study, including in-field data collection and detailed model construction and implementation (Figure 4-1). Investigations in the upstream region (near the town of La Junta) began in 1998 and data collection was greatly expanded in 1999 to include more intensive soil salinity monitoring, groundwater monitoring well installation and observation, surface water salinity measurements, topographic and hydrographic surveying using differential global positioning systems (GPS), measurement of soil and aquifer properties, and other related activities (Gates et al. 2002). In 2002, a data collection program of similar intensity was initiated in the downstream study region extending from the town of Lamar to the Colorado-Kansas border. Data and model results from the two regional-scale studies are being used to develop a model for assessment of improvement strategies on a basin scale, as constrained by Colorado water rights and the Arkansas River Compact.

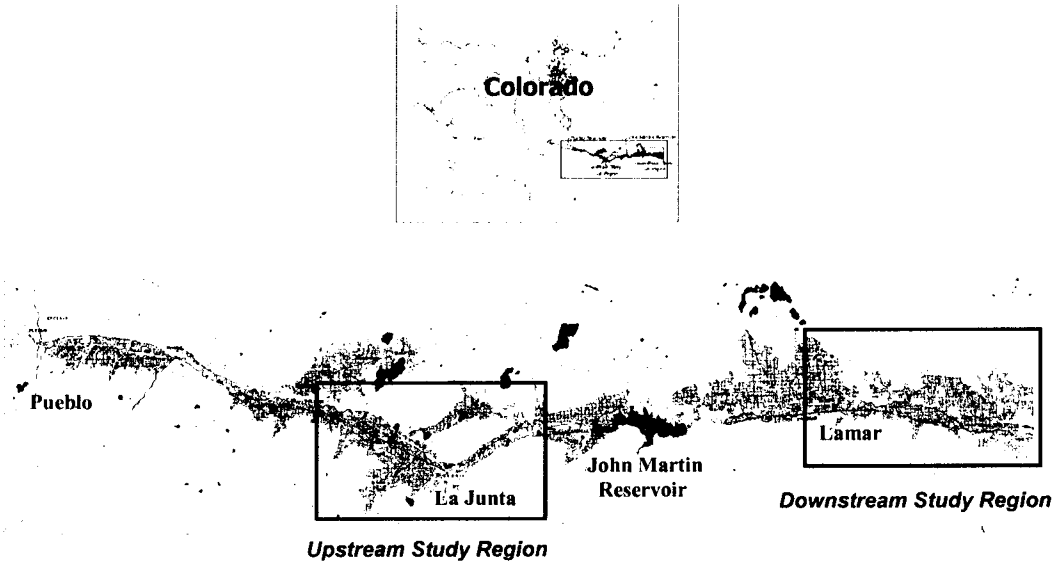

Figure 4-1. Lower Arkansas River Basin of Colorado showing upstream and downstream study regions

The work described in this paper focuses on the upstream study region, encompassing a 62 km (38.5 mi) reach along the river. This area covers about 50,600 ha (125,000 ac), of which 26,400 ha (65,300 ac) are irrigated, and was selected because the agricultural practices and geophysical features are representative of valley conditions upstream of John Martin Reservoir (Major et al. 1970, Hurr and Moore 1972, Nelson et al. 1989). The findings from this region will be useful in describing and managing other areas of the entire Arkansas River valley, as well as other river basins facing similar problems. The selected study region is also of interest because an area within the eastern portion (northeast of La Junta) has been the focus of previous studies by others (Konikow and Bredehoeft 1974, Person and Konikow 1986, Goff et al.1998). These previous studies were necessarily limited in scope, due to restricted available observations of water table elevation and salinity in pumping wells and did not consider salt concentration or salt and water transport in the unsaturated zone. Only two categories of irrigation management solution alternatives were considered, and they were based on a two-dimensional model calibrated with limited data. Although the previous studies were adequate for demonstrating system sensitivity to drastic changes in existing irrigation practices, the current study reported here covers a larger area, provides a much larger database and substantial modeling improvements, and enables a much broader range of solution alternatives to be evaluated with a greater degree of spatial and temporal resolution.

Within the upstream study region, there are six major irrigation canals, eight tributary drainages, three main reservoirs, and over 280 active pumping wells. Irrigation canals and their shareholders are allocated water based on prior-appropriation water rights. The cultivated crops include alfalfa, corn, grass, wheat, sorghum, cantaloupe, watermelon, and onions. The most common irrigation methods are furrow irrigation and border irrigation using open ditches with siphon tubes or, in some cases, gated pipe. Less than five per cent of the region is irrigated with sprinkler and drip irrigation systems.

The alluvium extends out from the river by about 1.2 to 18.4 km within the study region, consisting of porous sand/gravel materials overlain by soil with silty-clay loam to sandy loam texture (USDA 1972a, 1972b). The confining bedrock consists mainly of shale materials, and outcroppings and "lenses" of bedrock materials are evident throughout the study area. The alluvial aquifer varies in thickness from less than 1 m to as much as 30 m. Estimates of horizontal hydraulic conductivity vary from 0.001 m/day in the upper aquifer layers to 530 m/day in lower layers. The region is semi-arid with average annual rainfall of about 0.30 m (Colorado Climate Center 1999 - 2001), and average seasonal (April – October) potential evapotranspiration (ET_o) estimated at 1.02 m (based on the Kimberly-Penman method).

4.3 FIELD DATA FOR CHARACTERIZATION OF SYSTEM PROPERTIES AND IDENTIFICATION OF SALINITY AND WATERLOGGING PROBLEMS

Numerous sources of data were used for characterizing the properties of the study region, identifying the extent and severity of salinity and waterlogging problems, and to create a database for system modeling. Some data were compiled from existing sources; however, most were obtained from an extensive field data collection program, described in Burkhalter (2005). Compiled data included cultivated field layout, crop types, deep aquifer hydraulic conductivity, meteorological parameters, flow diversions to canals, river flows, irrigation application efficiency, leaching fraction, and well pumping volumes. Data collected in the field included shallow aquifer hydraulic conductivity, water table depth, water table salinity, surface water salinity, and soil salinity. Data were collected and compiled for ground surface elevation, bedrock elevation, system hydrography, soil texture and storage properties, canal seepage, and surface water levels.

More than 110 groundwater monitoring wells were installed and monitored throughout the study region (Figure 4-2). Well locations were selected using a stratified random sampling technique (Cressie 1991). The wells consisted of 6.35 cm (2.5 in) diameter perforated PVC pipe, ranging in depth from 3 to 8 m (10 to 26 ft) below the ground

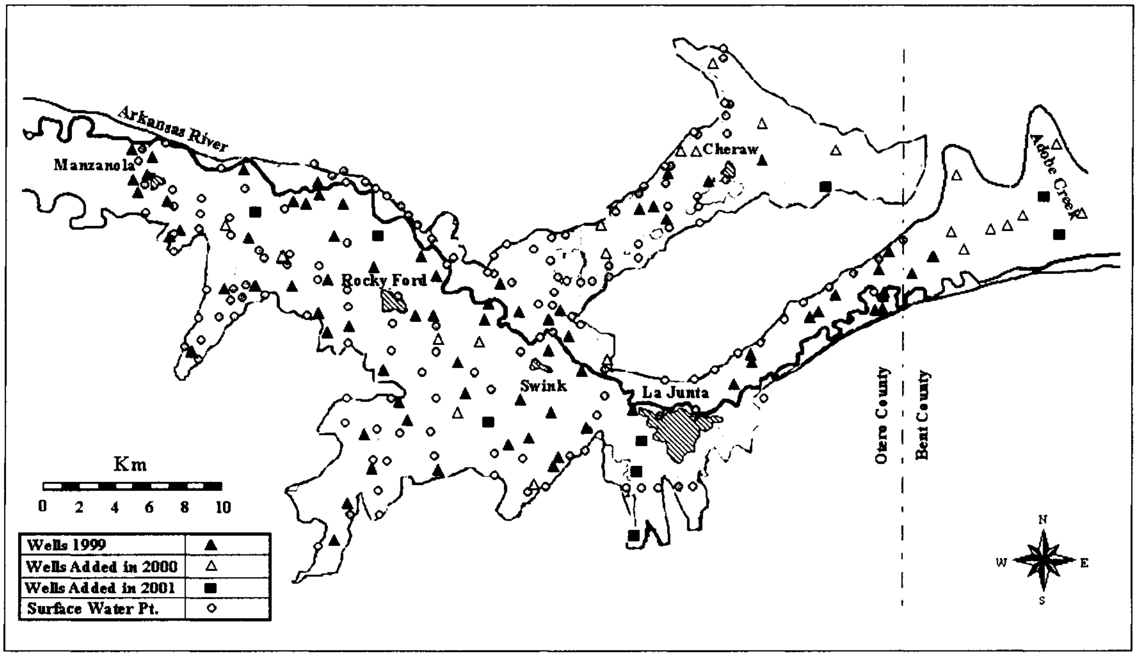

Figure 4-2. Upstream study region showing groundwater monitoring wells and surface water monitoring locations

surface. Water table depth and electrical conductivity (*EC*) (standardized at 25 °C) were measured weekly during the irrigation season and typically at bi-weekly to monthly intervals during the off-season. Surface water salinity in canals, reservoirs, and the river was also monitored (as *EC* at 25 °C) at up to 173 sites on a weekly basis (during the irrigation season). Soil salinity data were collected on a subset of fields containing or adjacent to groundwater monitoring wells.

Water table depth data are summarized in Figure 4-3. On the average, about 18 wells were found to be dry in any given week, indicating a water table elevation below the

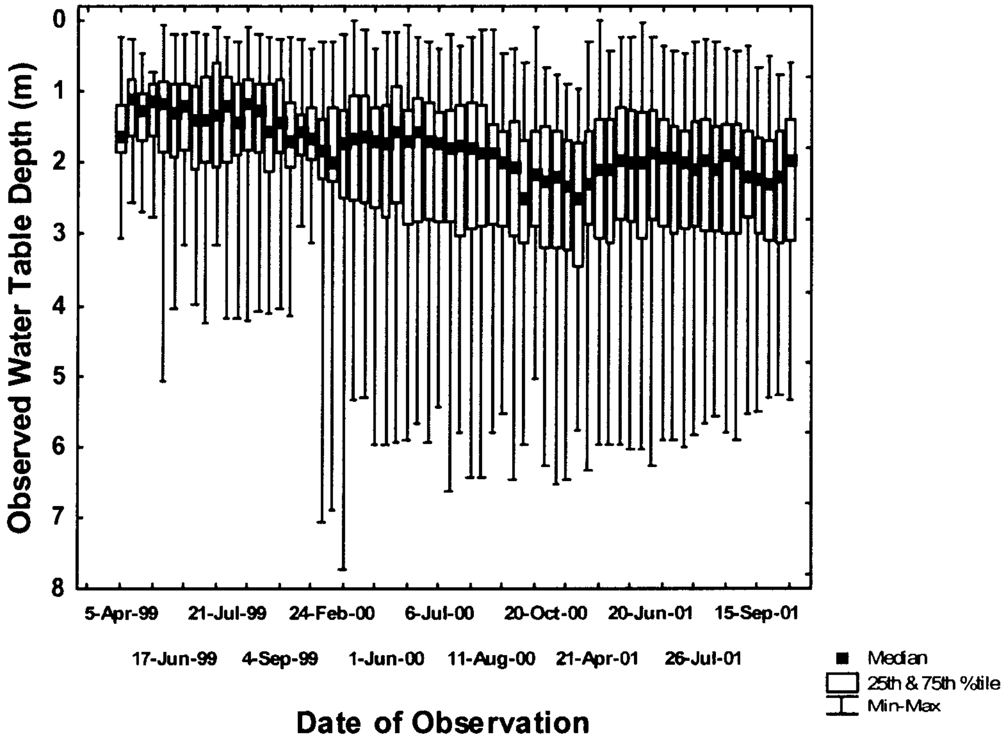

Figure 4-3. Observed water table depths and range of variation over the study period

known elevation at the bottom of the well bore. Average observed water table depth (not including dry well observations) over all sampled locations for each reading during the observation period ranged from 1.21 to 2.69 m. Period coefficients of variation (*CV*) (absolute value of ratio of standard deviation to mean) computed over the region ranged from 0.33 to 0.71. Example plots of water table depth and *EC* for four representative wells are given in Figure 4-4. Average observed depths to the water table decreased over the study period, associated with reduced flow diversions and lower irrigation applications. Data from the sampled monitoring well locations were used to calibrate the flow and salt transport model and, coupled with the model's approximation of the governing flow and transport equations, were used to estimate water table depth and salinity contours over the entire study region over the course of the study period, as described in a following section.

Average measured *EC* in the monitoring wells ranged from 2.60 to 4.62 dS/m, corresponding to *TDS* concentrations of about 2294 to 4076 mg/L. Period *CV* values ranged from 0.35 to 0.94. *EC* was translated into *TDS* using a relationship developed from lab testing of 18 groundwater samples ($r^2 = 0.97$) (Burkhalter 2005).

Analysis of State Engineering Office records revealed total diversions of surface water from the river and from storage of about 1.31 m, 1.12 m, and 0.94 m over the irrigated area, respectively, for the 1999, 2000, and 2001 irrigation seasons. Additional water for some farms was supplied from pumping wells.

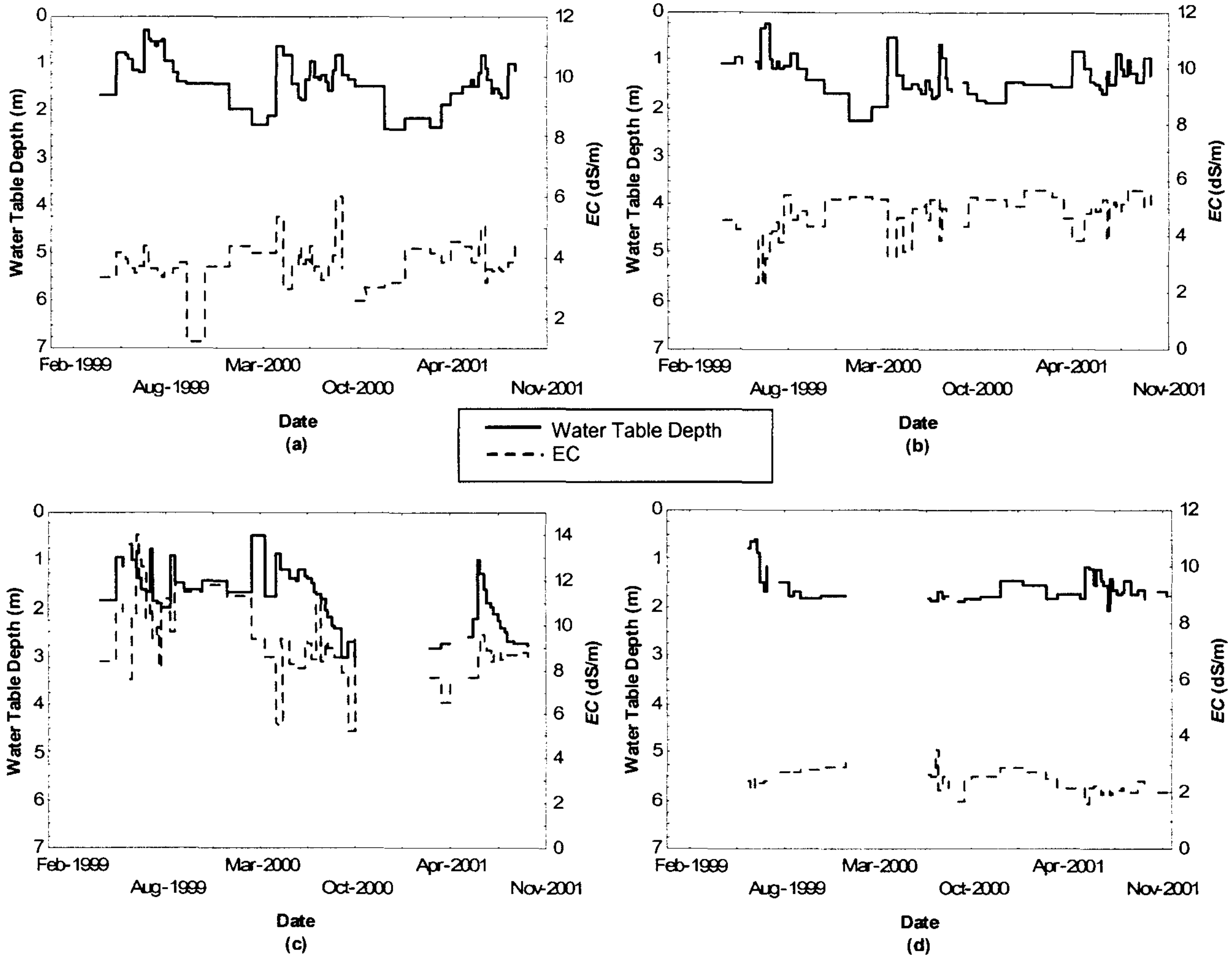

Figure 4-4. Example time series plots of observed water table depth and *EC* in (a) well 9B, (b) well 41, (c) well 61, and (d) well 70

Average measured salinity of flows delivered by the six irrigation canals into the region ranged from 0.71 dS/m (618 mg/L) to 1.05 dS/m (854 mg/L) in 1999, from 0.93 dS/m (770 mg/L) to 1.39 dS/m (1090 mg/L) in 2000, and from 0.75 dS/m (645 mg/L) to 1.19 dS/m (951 mg/L) in 2001. Average salinity measured in the Arkansas River near the upstream and downstream ends of the study region was 0.85 dS/m (715 mg/L) and 1.51 dS/m (1174 mg/L), respectively, during the 1999 irrigation season, 0.96 dS/m (791 mg/L) and 1.86 dS/m (1417 mg/L) during the 2000 irrigation season, and 0.88 dS/m (736 mg/L) and 1.63 dS/m (1257 mg/L) during the 2001 irrigation season. A separate *EC-TDS* relationship, derived from 57 samples ($r^2 = 0.97$), was used for surface water (Burkhalter 2005).

Soil salinity data were collected within selected fields (mean number of points per field was approximately 62) using Geonics™ EM-38 electromagnetic induction meters (Rhoades et al. 1999) twice per irrigation season. During the study period, a total of about 27,000 points (average of about 10 points per ha) were measured. Fifteen soil samples were extracted at depths to 1.2 m (4 ft) from three holes along the sampling axis of the EM-38 meter at about 250 selected sites within sampled fields across the region for use in calibrating the meters. A summary of soil saturated paste electrical conductivity (EC_e) data is given in Table 4-1. The final column of this table shows the percentile ranking of the value of 2.0 dS/m, significant because it roughly represents the threshold above which significant yield losses occur in corn and alfalfa, the predominant crops (Maas and Grattan 1999).

Table 4-1. Summary of Soil Salinity Data

Season	Total No. Fields	Total No. Observed Pts.	Mean EC_e (dS/m)	Min EC_e (dS/m)	Max EC_e (dS/m)	CV	90th Percentile EC_e (dS/m)	75th Percentile EC_e (dS/m)	25th Percentile EC_e (dS/m)	Percentile of 2.0 dS/m
1999 Early	67	4194	3.22	0.31	8.95	0.69	6.59	4.33	1.68	36.6%
1999 Late	67	4446	3.41	0.73	9.72	0.65	6.62	4.79	1.92	30.6%
2000 Early	73	4268	2.83	0.13	9.12	0.65	5.54	3.52	1.77	33.3%
2000 Late	76	4823	2.75	0.17	10.54	0.70	5.60	3.51	1.43	49.0%
2001 Early	78	4799	3.17	0.28	10.23	0.69	5.98	4.18	1.65	32.9%
2001 Late	75	4470	3.26	0.33	10.44	0.74	6.69	4.15	1.68	38.7%

EM-38 readings were converted to EC_e using relationships developed from lab testing of soil samples acquired from calibration sites. These relationships vary due to a number of factors (such as soil water content, soil texture, soil structure, etc.) that affect EM-38 readings. The derived relationships used, and the corresponding seasons for which the relationship was assumed to apply, were:

$$EC_e = 4.40 \cdot EM_v^{1.75},\ r^2 = 0.89 \text{ for early season 1999} \tag{4-1}$$

$$EC_e = 5.11 \cdot EM_v^{1.48},\ r^2 = 0.69 \text{ for late season 1999, early season 2000, and early season 2001} \tag{4-2}$$

$$EC_e = 5.33 \cdot EM_v^{1.37},\ r^2 = 0.83 \text{ for late season 2000, late season 2001} \tag{4-3}$$

wherein EC_e = electrical conductivity of the saturated soil water extract adjusted to 25 °C (dS/m), and EM_v = vertical-orientation EM-38 reading of bulk soil conductivity.

4.4 CONCEPTUAL MODEL OF THE IRRIGATION-STREAM-AQUIFER SYSTEM

To enable development of the finite-difference grid-based computational models, a conceptual model of the study area was first developed (Figure 4-5). Using a GIS-compatible interface known as the Groundwater Modeling System (GMS) Version 3.1 (BYU 1999), a set of arc, point and polygon coverages were created to represent important regional features. Specifically, an arc coverage was created to represent the river, tributaries, irrigation canals, and all significant drainage ditches using geo-referenced digital USGS maps and a satellite image derived from Landsat 7 Thematic Mapper data. Attributes such as water surface elevation, channel conductance, and

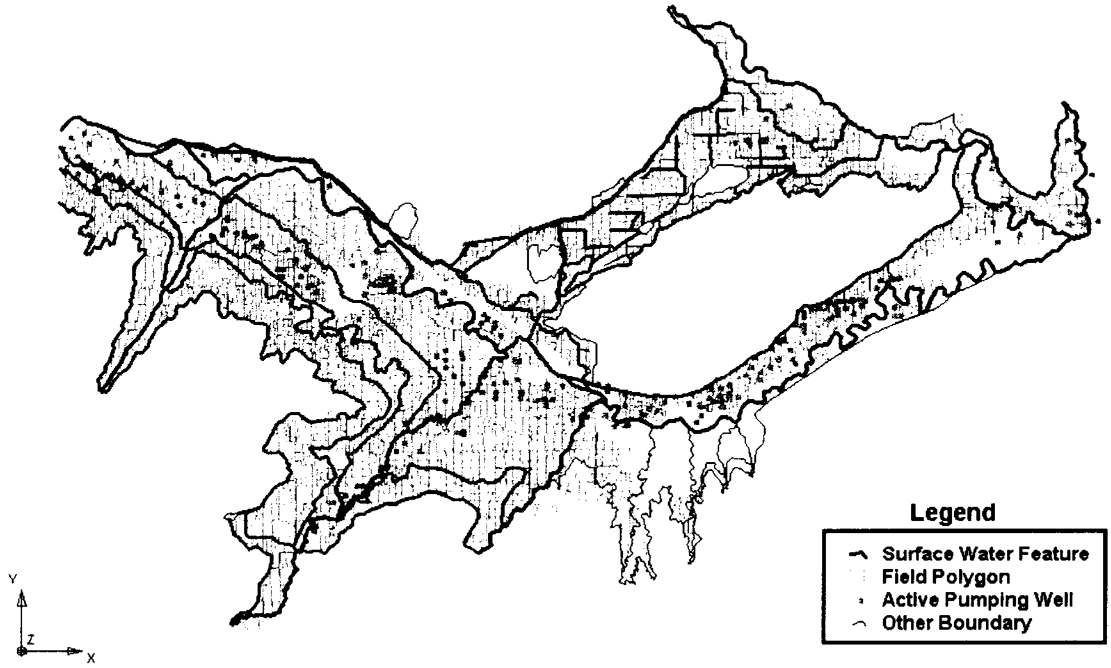

Figure 4-5. Conceptual model representation showing the surface water system, pumping wells (points), and defined field polygons

surface water salinity were associated with the links and nodes of the arc coverage for translation into the finite-difference grid format required for the groundwater flow model, MODFLOW (McDonald and Harbaugh 1988), and the salt transport model, MT3DMS (Zheng and Wang 1999), described in a following section.

Using the same methods, reservoirs were represented as polygons, and pumping wells as points. To represent approximately 2,800 cultivated and irrigated fields within the study area, aerial photographs from the Farm Service Agency (FSA) were used to manually digitize polygons within Arc/Info™ (and later ArcView™ 3.2). This field polygon coverage was used to store and manage important attributes such as field identifiers, field area, crop type, canal command, and the depth at which upflux from the high water table ceases, called *ET* extinction depth in MODFLOW. It also was used to input time-series data sets, such as infiltrated irrigation depth, recharge to the water table, irrigation water salinity, and crop evapotranspiration (*ET*). Polygons representing natural areas (uncultivated) also were generated.

A stress period is defined as a time period over which a specified set of aquifer stresses (i.e. combination of recharge sources, upflux sinks, and/or pumping sinks) are applied. For each modeled stress period, a polygon coverage could be generated from the ArcView™ database for import into GMS and subsequent translation to the finite-difference computational grid.

4.4.1 Crop Evapotranspiration

Meteorological data used to generate daily estimates of ET_o were obtained from the Colorado Climate Center's (1999-2001) on-line database CoAgMet. Data used were collected at the Rocky Ford Weather Station (Sta. No. 057167) and cover the entire modeled period. The CropFlex98 model (Broner and Lorenz 1998) was used to calculate both ET_o, using the Kimberly Penman combination method, and actual crop *ET*. In estimating *ET* it was assumed that no large soil water deficits occurred over the modeled period, i.e. estimated *ET* rates were not limited by a lack of available soil water.

4.4.2 Irrigation Depth and Recharge to the Water Table

Several steps were taken to estimate infiltrated irrigation amounts (depths) and the resulting recharge to the water table. Weekly water balance calculations were performed using records of flow diversion to canals and of pumping volumes from the Colorado Division of Water Resources (State Engineer), as well as precipitation data, estimated *ET* rates, and known crop-type distribution. Based upon seepage inflow-outflow tests conducted on the Fort Lyon Canal and upon other studies (Dash 1995, Sayer et al. 1997) it was initially assumed that canal conveyance losses (seepage) were approximately 20% of the total diverted water volume. Since pumping volume records existed only in monthly form, it was assumed that the monthly volume could be uniformly distributed to derive weekly estimates. From the water balance analysis, estimates of irrigation efficiency (E_I) (ratio of crop *ET* to total diverted flow volume) were derived for each canal command area.

To estimate likely irrigation application depths for a given field polygon, each polygon was first assigned a unique random number from a uniform distribution (values from 0 to 1). This random number remained constant throughout all modeled stress periods and was used to select a corresponding irrigation application efficiency (E_A) from a truncated normal distribution (minimum = 0.15, maximum = 0.85) with a mean value equal to the weekly value of E_I for the given canal command area divided by the conveyance efficiency of 0.20. Based on the assigned value of E_A, the estimated *ET* demand for the given crop type, and the effective precipitation, a weekly irrigation application depth was then calculated for each field polygon for each stress period. To account for actual farmer irrigation frequency patterns, crop types were assigned an appropriate irrigation frequency (weekly, bi-weekly, or monthly) and growing season length. To translate the estimated irrigation application depths into recharge amounts, a random deep percolation fraction, or the fraction of the total losses that percolated below the root zone (as opposed to surface runoff), with a mean of 0.70 was assigned to each field polygon. Details and rationale of the procedure used to estimate irrigation application and recharge depths are described in Gates et al (2002) and Burkhalter (2005).

4.4.3 Recharge Salinity

The salinity of recharge to the water table was estimated using a procedure similar to that described in Gates et al (2002) and Gates and Grismer (1989). Each field polygon was randomly assigned a leaching efficiency (E_L) value based on a truncated normal distribution with a mean value of 0.40, *CV* of 0.20, minimum value of 0.25, and maximum value of 0.55, deemed appropriate for the clay loam, loam, and sandy loam soils of the region (Boumans and van der Molen 1964, Bouwer 1969). Knowing the measured irrigation water salinity and the soil salinity (model output), the recharge salinity (C_R) was calculated from (Bouwer 1969):

$$C_R = E_L C_{SW} + (1 - E_L) C_I \tag{4-4}$$

wherein C_{SW} = soil water salinity concentration (kg/m^3) and C_I = irrigation water salinity concentration (kg/m^3). This calculation was encoded into the MT3DMS source/sink mixing package and was linked to the unsaturated zone module developed for this study as described below.

Other model parameters that had to be estimated, since direct measurements were not available, included the conductance (McDonald and Harbaugh 1988, Gates et al. 2002) of surface water features and the specific yield, porosity, and specific storage of soil and aquifer materials. Data on shallow hydraulic conductivity from slug tests conducted at 95 monitoring well sites (and interpolated over the study region), measured channel cross-section geometry, soil textures, and aquifer lithology were used to make the estimates. Values are summarized in Burkhalter (2005).

4.5 AQUIFER FLOW MODELING

4.5.1 MODFLOW Model Construction

MODFLOW is a modular three-dimensional finite-difference model that was used to approximate the governing nonlinear groundwater flow equations with a set of nonlinear difference equations applied at finite-difference cells superimposed upon the conceptual modeled region. The grid of finite-difference cells was defined using uniform cell dimensions of 250m in the horizontal plane and two vertical layers of varying thickness – the upper layer (0 – 3.5 m depth) corresponding to the low permeability zone and the lower layer (> 3.5 m depth) corresponding to the high permeability zone. The study region was represented by a total of 16,188 active cells. The period April 1999 - October 2001 was modeled with a weekly time step, each representing a unique stress period.

4.5.2 Aquifer Flow Model Calibration and Testing

Model calibration procedures complied with those specified in the ASTM guidelines for groundwater model calibration (ASTM 1996). Target values of water table elevation were established by field data at the monitoring well locations. Other targets included estimated seepage volumes and return flow volumes to the river and to the Timpas Creek tributary derived from available stream flow records. The selected calibration period encompassed the first 67 time steps of the total 133 steps modeled. Time steps 68 – 133 were reserved for model testing.

To match model targets within an acceptable error, values of selected model parameters were adjusted manually within the bounds of values considered reasonable for the study region based upon existing data (Pinder 2002). Table 4-2 lists all adjusted parameters and their corresponding ranges of final selected values.

Table 4-2. Flow Model Calibration Parameters

Model Parameter	Range of Values
Layer 1 Horizontal Hydraulic Conductivity	0.001 – 10.25 m/day
Layer 1 Vertical Hydraulic Conductivity	1/2 – 1/20th of the Horizontal Conductivity
Layer 2 Horizontal Hydraulic Conductivity	13 – 625 m/day
Layer 2 Vertical Hydraulic Conductivity	1/2 – 1/20th of the Horizontal Conductivity
Layer 1 Saturated Thickness	0.1 – 6 m
Layer 2 Saturated Thickness	2 – 30 m
Conductance	0 – 12,100 m^2/wk/m
Specific Yield	0.05 – 0.31
ET Extinction Depth	0.2 – 4.5 m

Figure 4-6 compares average simulated and average observed water table elevations for each monitoring location over the calibration period. The mean error over all observations was –0.15 m, and the mean absolute-value error was 1.00 m. Average simulated seepage loss over all the canals was 20.8%. This corresponds well with the value assumed in the water balance calculations used to derive irrigation application depth estimates and with inflow-outflow seepage measurements conducted along three segments of the Fort Lyon canal in summer 2001 (estimated seepage rates ranged from15 to 27%). Simulated return-flow volumes amounted to an average of nearly 50% of the total measured accumulated volume (surface and groundwater) between the USGS streamflow gaging stations along the river and with measured volumes at the Timpas Creek gage. Although the actual portion of measured flow accumulation that was derived from groundwater return flows was not known, a value of 50% was considered reasonable and provided additional evidence of a valid calibration.

Comparing observed water table elevations with those predicted by the calibrated model for time steps 68 - 133 provided a test of the MODFLOW model. Results were similar to

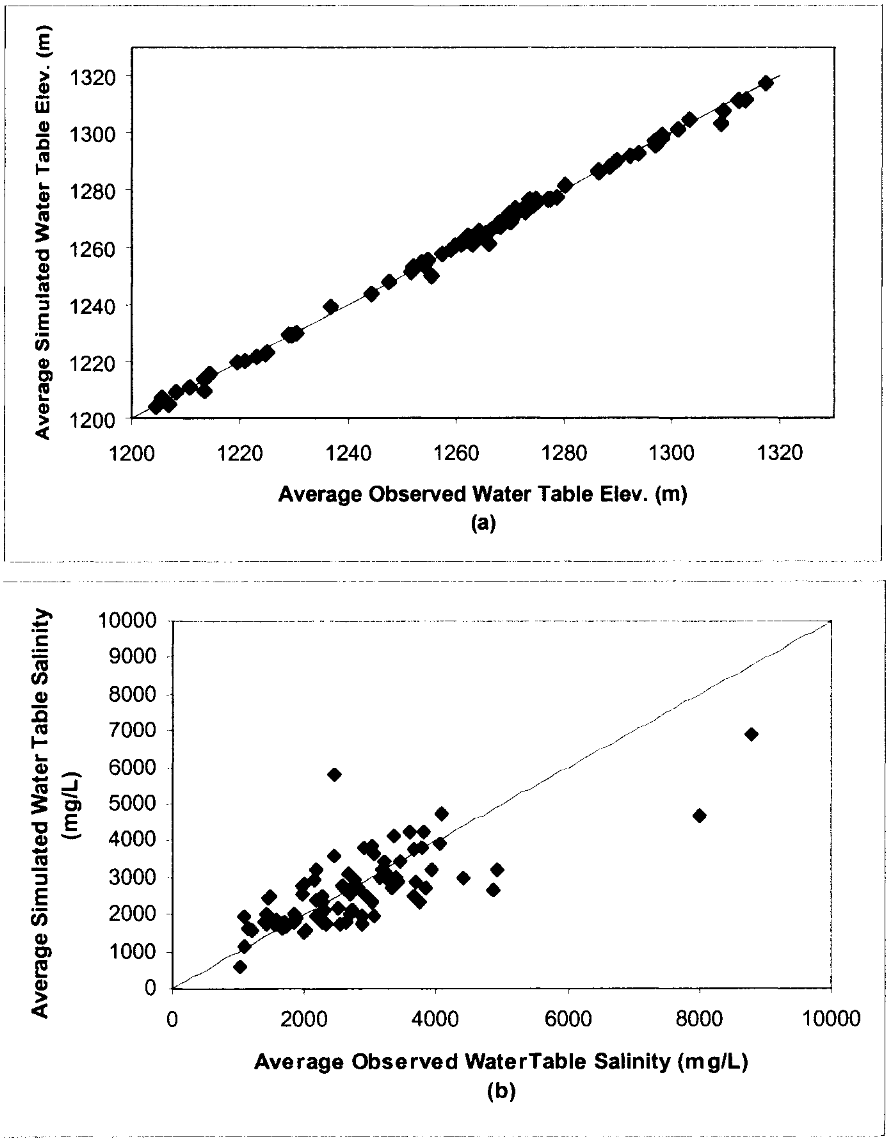

Figure 4-6. Model calibration results: (a) average simulated water table elevation versus average observed water table elevation and (b) average simulated water table salinity versus average observed water table salinity at monitoring well sites

the calibration period with a mean error of –0.21 m and a mean absolute-value error of 1.26 m. Reasons for discrepancies between model predictions and field observations include errors in field measurements and differences between observation scales and modeling scales, as discussed in Gates et al (2002).

4.6 AQUIFER SALINITY MODELING

4.6.1 MT3DMS Model Construction

Using the same finite-difference grid as in the groundwater flow (MODFLOW) model, the MT3DMS model was prepared using GMS and the established conceptual model database. MT3DMS is a three-dimensional finite-difference approximation of the governing equations for aquifer solute mass transport. Reactive and dispersive effects were assumed not to significantly impact regional scale salt transport; therefore, only the advection package of MT3DMS was used. Solution algorithms and convergence criteria are discussed in Burkhalter (2005).

The "source/sink mixing" package in MT3DMS (with input from the conceptual model) was used to simulate all associated salinity fluxes into and out of the aquifer system. Salinity of upflux from the water table (as modeled in the *ET* package of MODFLOW) was set equal to the computed groundwater salinity. Several modifications to the MT3DMS source code were made to meet project-specific needs; most importantly, an unsaturated zone module, described below, was developed to model soil salinity.

4.6.2 Aquifer Salinity Model Calibration and Testing

Target values of groundwater salinity were established from field data. Initially, the modified MT3DMS code was run assuming no contribution from salt dissolution in the aquifer. Effective porosity values were adjusted within a reasonable range by a uniformly-applied factor (maintaining a defined spatial distribution estimated from available soil texture data). Initial results indicated an average under-prediction of groundwater salinity of about 400 mg/L. Mapping these results revealed zones of varying discrepancy in simulated and observed aquifer salinity. Assuming that these deviations roughly revealed the spatial variation in degree of contributions from salt dissolution, corresponding zones of varying mass loading rates were added to the "sink-source mixing" package input. Final selected mass loading rates, resulting in the closest match to the target values, corresponded to an average weekly salt dissolution contribution of about 300 mg/L over the region.

A plot of average simulated and observed groundwater salinity at each monitoring location is shown in Figure 4-6. Outliers shown on this plot are likely indicative of monitoring locations where the observed point value is not reflective of average field conditions. Mean error over all observations during the calibration period was –48 mg/L, and mean absolute-value error was 797 mg/L. Testing of the calibrated aquifer salinity model for the reserved observations (time steps 68-133) yielded similar results: an estimated mean error of –49 mg/L and an estimated mean absolute-value error of 760 mg/L.

4.7 UNSATURATED ZONE SALT AND WATER MODELING

4.7.1 Water and Salt Balance Calculations

An unsaturated zone module was developed to estimate salt concentration in the soil water (C_{SW}) and to enable estimation of the salt concentration of the recharge via Eq. (4-4). The value of C_{SW} in a finite-difference cell at time t+1 was estimated using the mass balance approach described in Gates and Grismer (1989), a method that seemed appropriate and tractable for regional-scale estimation:

$$C_{SW}(t+1)=\frac{(C_I q_I + C_A q_U - C_W q_W + X)\Delta t + C_{SW}(t)S_{SW}(t)}{S_{SW}(t+1)} \tag{4-5}$$

wherein q_I = irrigation water application rate (m^3/week), C_A = upflux salinity concentration (kg/m^3), q_U = upflux rate (m^3/week), C_W = recharge salinity concentration (kg/m^3), q_W = recharge rate (m^3/week), X = dissolution salinity contribution (kg/week), S_{SW} = soil water storage volume (m^3), and $\Delta t = (t+1) - t$ = time step (weeks). Initially, the value of X was assumed zero; however, it was adjusted during the calibration procedure as described below. To arrive at an estimate of S_{SW}, water balance calculations were performed over each cell. The form of the water balance relationship that was used differed based on eight possible conditions described in detail in Burkhalter (2005). The particular condition assigned to a cell for a given time step was dependent upon whether irrigation had taken place, the depth of the predicted water table, and the height of the estimated capillary fringe and potential for capillary rise. It was assumed that leaching efficiency remained constant and that, if irrigation took place, the soil water volume was filled to field capacity (i.e. no significant deficit irrigation).

4.7.2 ET Adjustments for Salinity and Waterlogging Effects

Within the water balance calculations, *ET* was adjusted to account for a reduction due to soil salinity and waterlogging. Houk (2003) developed relationships from data in the literature that indicate relative crop yield (*RY* = ratio of actual yield relative to potential yield) decreases linearly with soil salinity above a threshold value and with water table depth below a threshold value. In this case, water table depth is used as a surrogate measure of the degree of detrimental waterlogging impact, where that impact increases as the depth to the shallow water table grows smaller. Since studies have shown *RY* to be linearly related to *ET* (Doorenbos et al. 1986), the ratio of *ET* under a calculated field condition to *ET* that would occur under conditions not affected by salinity and waterlogging, was assumed to decrease according to Houk's (2003) relationships for *RY*. For each modeled time step, the *ET* rate for each cell was adjusted using the calculated soil salinity and water table depth and the appropriate *ET* adjustment equation for the given crop type.

4.7.3 Unsaturated-Zone Salt and Water Model Calibration and Testing

Calibration of the unsaturated zone model involved adjustment of soil salinity initial conditions, soil water content initial conditions, and soil water content at field capacity. Model predictions of soil salinity were compared to three sets of observations (early and late seasons 1999 and early season 2000). The simulated average soil salinity mean error for early season 1999 was –173 mg/L with an absolute-value error of 659 mg/L. Results for the late season 1999 indicated a mean error of –565 mg/L and an absolute-value error of 1154 mg/L, while for early season 2000, the mean error was 360 mg/L, and the absolute-value error was 1103 mg/L. The deviation of simulated values from observed values associated with simulation over the non-irrigation period (in between late season 1999 and early season 2000) was significant; however, this result represents a calibration of the model that best maintained physically reasonable model parameter values based upon current knowledge of system properties. The tendency of the model to over-predict soil salinity, compared to field observations, during the non-irrigation season also was evident during the testing period. Predictions yielded mean errors of 568 mg/L, 916 mg/L, and 993 mg/L for the late season 2000, early season 2001, and late season 2002, respectively. Interestingly, the model appears to track the changes that occurred during the irrigation season fairly well.

Besides the possibility of unrecognized factors not accounted for in the mass-balance model formulation, there are other potential reasons for the model-to-data discrepancies, particularly during the non-irrigation season. First, estimates of soil salinity using EM-38 surveys are themselves subject to error. The standard deviation of residual errors in Eqs. (4-2), (4-3), and (4-4), for predicting EC_e from EM_V, was found to average about 1.8 dS/m (1590 mg/L), a value that easily encompasses the model-data discrepancies. Secondly, EM_V readings are affected by soil temperature, an important consideration in the early part of the season when soil temperatures may be significantly lower than 25°C. An effort to refine the analysis to better account for effects of soil temperature is currently under way. Another explanation relates to recent exploration of available NexRad precipitation data from the National Weather Service. These data indicate the possibility that measurements from the rain gage at the Rocky Ford station may have significantly under-predicted the average precipitation that occurred over the entire study region during the period of interest, particularly during the non-irrigation seasons. Further study is needed to improve the unsaturated zone model results; however, they are deemed acceptable for short-term comparative modeling applications, where predictions for proposed solutions will be compared to current baseline conditions.

4.8 MODEL CHARACTERIZATION OF SYSTEM BASELINE CONDITIONS

The calibrated flow and salt transport models were applied to simulate conditions in the region over the study period. This simulation yielded estimates of the spatial and temporal distribution of water table depth, water table salinity, and soil salinity that were constrained both by sampled space-time observations in the field and by the governing equations for flow and salt transport. Crop yield, return flow and salt load to the river, and non-beneficial consumptive use due to upflux also were predicted, yielding a baseline characterization against which future predictions of conditions under potential solution strategies can be compared.

4.8.1 Water Table Depth and Salinity Conditions

Depth to the water table was predicted at every cell for each of the 133 modeled weeks; however, only seasonal averages are presented and discussed here for the sake of brevity. These averages are valuable in identifying areas where shallow water tables are prevalent, as seen in the contour maps of Figure 4-7, and give an indication of where crop yield losses due to waterlogging may be occurring.

Over the 1999 irrigation season, the average estimated water table depth was found to be 4.07 m ($CV = 1.01$), with over 33% of the irrigated study region predicted to have water table depth of less than 2 m (i.e. beginning to intersect a typical rooting depth). In 2000, the predicted seasonal average water table depth was 5.75 m (*CV* = 0.88), with 20 % of the region shallower than 2 m; and, for the 2001 season, an average depth of 6.10 m (*CV* = 0.86) was predicted, with 16 % shallower than 2 m (Figure 4-7).

The evident increase in water table depth over each modeled season corresponds well with the observed variation in hydrologic conditions and available irrigation supply. In 1999, the Rocky Ford Experiment Station (#057167), which lies near the center of the study area, recorded 46.6 cm (18.4 in) of precipitation between April and October. In 2000, this value dropped to 17.0 cm (6.7 in), and in 2001, precipitation increased slightly

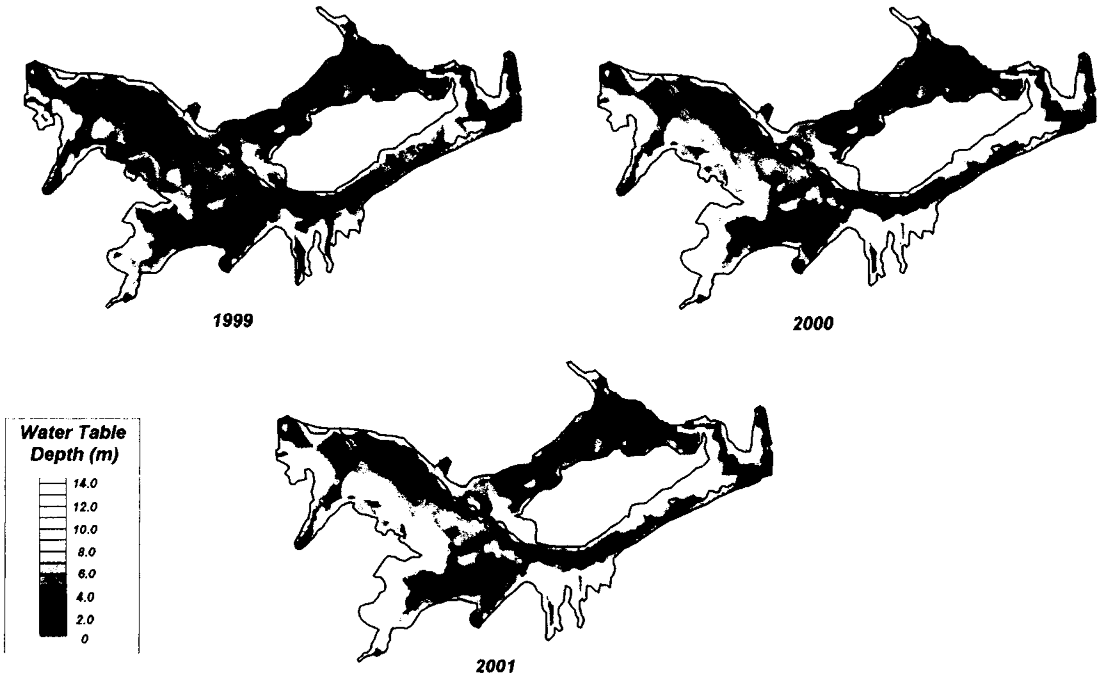

Figure 4-7. Seasonal average water table depth for each of the modeled seasons

to 24.4 cm (9.6 in). In response to precipitation amounts over each of the three study years, there also was a marked decrease in available river and reservoir water.

Salinity of the groundwater resource is important in determining the suitability of potential uses, and an accurate knowledge of groundwater salinity variability provides managers with a basis for developing conjunctive use alternatives. Over the modeled time period, the predicted average (spatial and temporal) water table salinity values for the 1999, 2000, and 2001 seasons were, respectively, 3016 mg/L ($CV = 0.50$), 2805 mg/L ($CV = 0.49$), and 2681 mg/L ($CV = 0.45$). Predicted cell-wise salinity values throughout the modeled time period ranged from 255 mg/L to 19,226 mg/L ($CV = 0.50$). This substantial level of spatial variability is likely related to high rates of natural salt dissolution occurring in some locations around marine shale deposits, as mentioned previously, while in other locations the dissolution contribution is likely negligible.

On a temporal basis, water table salinity was found not to vary greatly. Aquifer response time is likely large in comparison to the time period captured by the model, and, therefore, an extended model horizon may be required for better evaluation of long-term changes when evaluating proposed management alternatives.

4.8.2 Soil Salinity Conditions

Elevated soil salinity levels can have dramatic effects on crop yield, with reductions occurring when values exceed an empirically estimated threshold (Maas and Grattan 1999). Model results indicate an average seasonal soil salinity of 2487 mg/L ($CV = 0.48$)

for irrigated fields in 1999. In 2000, this average rose to 3108 mg/L (*CV* = 0.39), and, in 2001, it rose again to 3864 mg/L (*CV* = 0.41). Likely, this trend is due in part to significant reductions in aquifer recharge, which leaches salt from the unsaturated zone, in areas with limited available water supply during model years 2000 and 2001. Conversely, in many areas the limited supply, which resulted in smaller total irrigation application and recharge, contributed to increased water table depths, thereby reducing upflux of saline water and increasing effective leaching. Also, because of some unusually large precipitation events, it is suspected that soil salinity levels were reduced to unusually low levels during the 1999 season.

Figure 4-8 shows the spatial distribution of predicted average soil salinity over each of the modeled seasons. Comparing with Figure 4-7, an observable correlation exists between areas with shallow water tables and those with high levels of soil salinity. This relationship is common in irrigated semi-arid regions, and is documented in detail in Burkhalter (2005). Results from the baseline model of soil salinity, coupled with the results of the water table depth modeling, enable identification of target areas where lowering the water table, through effective solution strategies, could reduce soil salinity.

4.8.3 Impact on Crop Yield

The baseline model provided an estimate of relative crop yield reduction (1 - *RY*) over every upper-layer cell based on the relationships by Houk (2003) described above. Over the entire modeled period, cell-wise reductions in crop yield ranged from 0 to 89% (*CV* = 0.21). For the 1999 season, the average crop yield reduction over the irrigated areas was

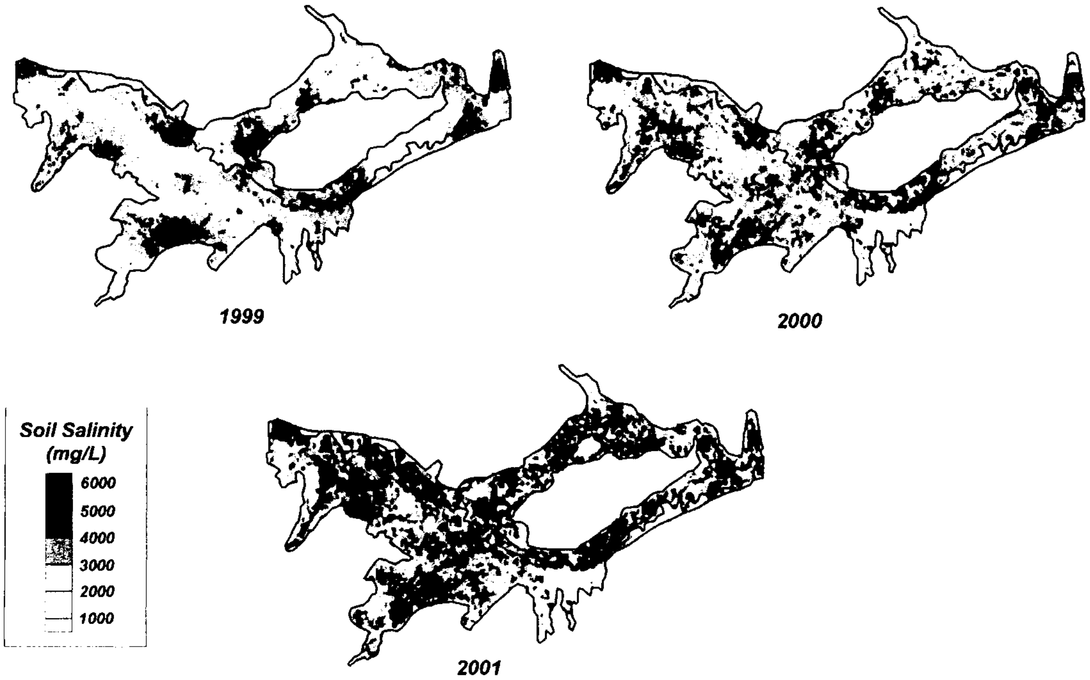

Figure 4-8. Seasonal average soil salinity for each of the modeled seasons

11% (*CV* = 0.19). For 2000 and 2001, this average rose to 13% (*CV* = 0.17) and 19% (*CV* = 0.21), respectively. On-going studies seek to improve estimates of *RY* by exploring the effect of the specific mix of soil salts on salt precipitation and dissolution and the consequent impact on crop yields. Economic impacts of these crop-yield reductions due to waterlogging and high soil salinity levels are significant (Houk 2003) and the baseline model results and the developed models themselves will support future spatial/temporal economic analyses of proposed solution alternatives.

4.8.4 Return Flows and Salt Load to River

Predictions of sub-surface return flow volume and salt load to the river, as well as the associated timing, are important in terms of basin-wide water management and assessment of ecological impacts. Baseline model results revealed that annual salt loading to the river through sub-surface return flows consisted of approximately 533 kg of salt per irrigated hectare per kilometer of river over the course of the modeled time period.

Certain reaches of the river system received substantially greater volumes of return water and salt than others (Figure 4-9). In particular, the wide portions of the modeled valley between the towns of Manzanola and Rocky Ford, including the Timpas Creek tributary, contributed the largest return flow volumes and salt loads. Identification of these reaches can aid in eco-system protection planning and can help to shape effective river quality degradation control measures. Additionally, predictions of subsurface return flow and salt loading will be critical contributions of the basin-scale model being developed.

4.8.5 Upflux Losses to Non-beneficial Consumptive Use

Upflux from shallow water tables under non-irrigated (non-cultivated) land is of particular importance because it represents water lost to non-beneficial consumptive use. Reducing its quantity would represent a real increase in water supply and could potentially have the secondary impact of improving regional water quality through higher available dilution volumes. Predicted upflux in the non-irrigated areas over the modeled

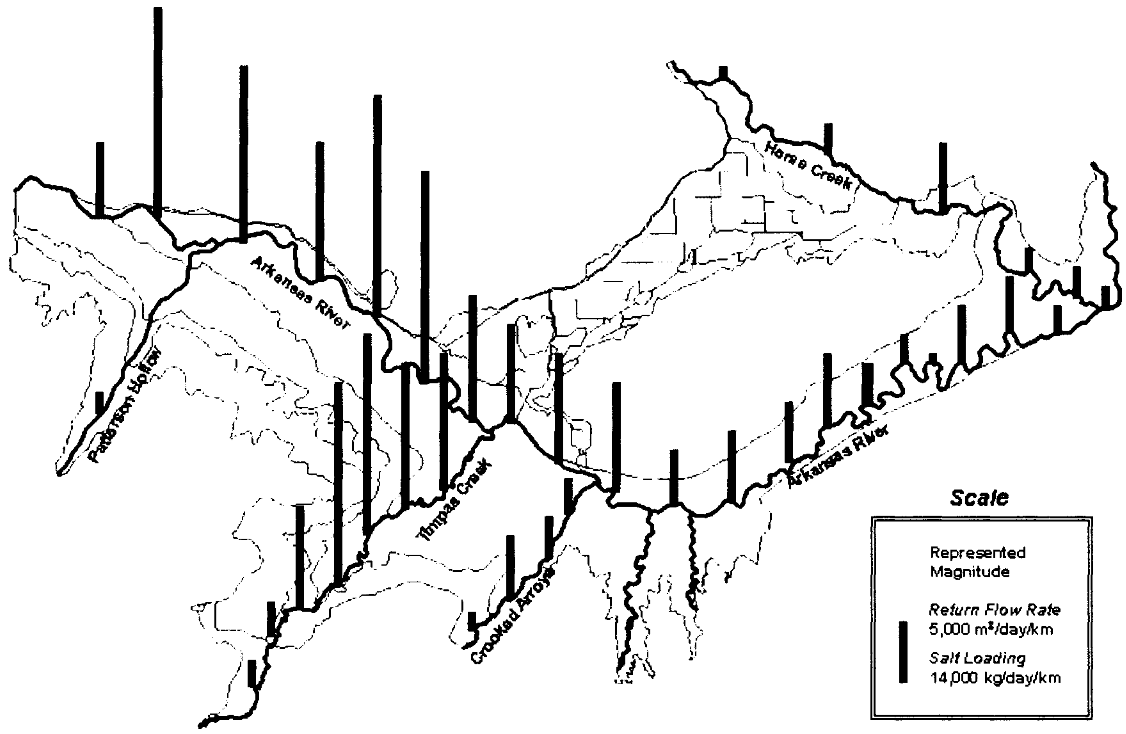

Figure 4-9. Predicted annual return flow and salt load over study region

period amounted to an overall annual volume of 65 million m^3. During non-irrigation periods, upflux over the entire region was considered as non-beneficial, and is included in this total. Converted to an equivalent depth over the non-irrigated areas only, this amounted to about 1.1 m in 1999, and 0.7 m in both 2000 and 2001.

In exploring improved management alternatives, the potential savings through reduction of upflux and the associated non-beneficial use will have to be evaluated considering the potential increases in crop *ET* due to improvements in soil salinity and waterlogging conditions. The presented model enables these tradeoffs to be predicted directly.

4.9 CONCLUSIONS AND IMPLICATIONS

Widespread field measurements and development of calibrated flow and salt transport models permitted a spatial/temporal depiction of the extent, severity, and variability of waterlogging and salinity problems within a typical western irrigated river valley. The water table is found to be shallow, at a depth of less than 2 m under 16 to 33% of the cultivated land, and to be saline, with average concentration between about 2700 and 3000 mg/L. As a result, soils are also quite saline (average 2500 to 3900 mg/L) and are often waterlogged, causing estimated average reductions in crop yield ranging from 10 to 20%. Evapo-concentration and resident salt dissolution processes associated with irrigation drive substantial subsurface salt loads to the river, contributing to a diminishing downstream water quality. Upflux from shallow groundwater under fallow fields results in substantial water loss to non-beneficial consumptive use. Computed *CV* values and spatial/temporal contours reveal a sizeable variability and a significant patterning in the conditions and impacts associated with waterlogging and salinity in the region, reflecting substantial spatial/temporal variability and trends in the major contributing factors accounted for in the model (namely, salinity of irrigation water; timing and magnitude of recharge from irrigation and precipitation; seepage from water supply canals; thickness, transport, and storage properties of the alluvial aquifer; soil properties; topography; and dissolution of salts from lithologic layers). These results imply the need to consider a broad range of alternative interventions for effective remediation and water management over the region.

The baseline model has identified agroecological problems in the area that are serious, but nevertheless, seem manageable. The developed database and modeling tool will facilitate a comparative assessment of alternatives to address these problems with the aims of sustaining the productive agricultural landscape and economy of the valley and enhancing its environmental health while minimizing river water quality degradation. Such an assessment is soon to be presented in forthcoming papers. Data collection and analysis will continue and will aid in further refinements and improvements to model calibration. Ultimately, the goal is to incorporate the present models into a basin-scale decision support system to consider not only regional-scale groundwater and soil conditions, but also total water management within the Arkansas River Valley. A more comprehensive tool that evaluates conditions from the field-scale to the basin-scale, considering water quantity, quality, and economic impacts is needed to adequately address the current problems – the presented baseline model is an important step toward this end.

CHAPTER 5

EVALUATING REGIONAL SOLUTIONS TO SALINIZATION AND WATERLOGGING IN AN IRRIGATED RIVER VALLEY

(As Accepted for Publication in the ASCE *Journal of Irrigation and Drainage Engineering*, Vol. 131; 2005. *In Press* – Copyright by ASCE, Reprinted with Permission)

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5.0 ABSTRACT: Potential solutions to high soil salinity levels and waterlogging problems are investigated on a regional scale using calibrated finite-difference flow and mass transport modeling for a portion of the Lower Arkansas River valley in Colorado. A total of 38 alternatives incorporating varying degrees of recharge reduction, canal seepage reduction, sub-surface drainage installation, and pumping volume increases are modeled over three irrigation seasons (1999 – 2001). Six performance indicators are used to evaluate the effectiveness of these alternatives in improving agroecological conditions, compared to existing conditions. Predicted average regional decrease in water table elevation (as great as 1.93 m over the irrigation season) is obtained for selected alternatives, as well as the spatial mapping of results for the different alternatives. Decrease in soil salinity concentration (with regional and seasonal average reduction as high as 950 mg/L) is also predicted and

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mapped. Estimated groundwater salinity changes, reduction in total salt loading to the river, increase in average regional crop yield, and changes in net water consumption indicate the potential for marked regional-scale enhancements to the irrigation-stream-aquifer system.

5.1 INTRODUCTION

The general methods for solving irrigation-induced salinity and waterlogging problems are well known. Sound regional water management, enhanced on-farm water application efficiency, improvements in water conveyance efficiency, and provision of sub-surface drainage facilities are all means by which remediation can be achieved (Umali 1993). Often, however, it is difficult or impossible to accurately predict the effectiveness of a particular solution strategy, particularly when applied over extensive and variable areas. The goal of this study is to apply computational models, founded upon extensive field data, to a suite of proposed salinity and waterlogging solution alternatives and to evaluate their spatial and temporal performance on a regional basis. Several indicators of agricultural and natural resource fitness are estimated in comparison to current conditions. This paper represents an extension of work presented in Gates et al. (2002), where a steady-state model was developed and applied over a limited number of proposed scenarios, and in Burkhalter et al. (2002), where an initial transient model (groundwater flow only) was built and implemented. The development and calibration of the flow and transport models used herein are described by Burkhalter and Gates (2005).

5.2 DESCRIPTION OF STUDY AREA

A 50,600 ha (125,000 ac) area containing 26,400 ha (65,300 ac) of irrigated land, centered near the town of La Junta in Colorado, was selected for analysis. This area is labeled "Upstream Study Region" on Figure 5-1. The region extends along a 62 km reach of the Arkansas River in the southeast portion of the State. The western boundary is near the town of Manzanola (Otero County), while the eastern boundary is located along a tributary known as Adobe Creek (Bent County). Predominant crops grown in the area include alfalfa, corn, grass, wheat, sorghum, cantaloupe, watermelon, and onions. Over the study period (1999 – 2001), the estimated average seasonal recharge to the aquifer ranged from 0.59 to 0.99 m, diversions to irrigation canals varied from 0.80 to 1.87 m, total actual crop evapotranspiration was estimated to range from 0.70 to 0.85 m, and total pumping volume was estimated to vary from 0.02 to 0.19 m. This area was selected because it is representative of the lower valley upstream of John Martin Reservoir, in terms of hydrogeology and farming practices. In conjunction with the work presented, a similar study currently is being conducted by Colorado State University further downstream near Lamar, Colorado (shown as "Downstream Study Area" on Figure 5-1). Gates et al. (2002) and Burkhalter and Gates (2005) describe procedures and results for the extensive field monitoring effort. Data have revealed significant problems associated with salinization and waterlogging within the study region.

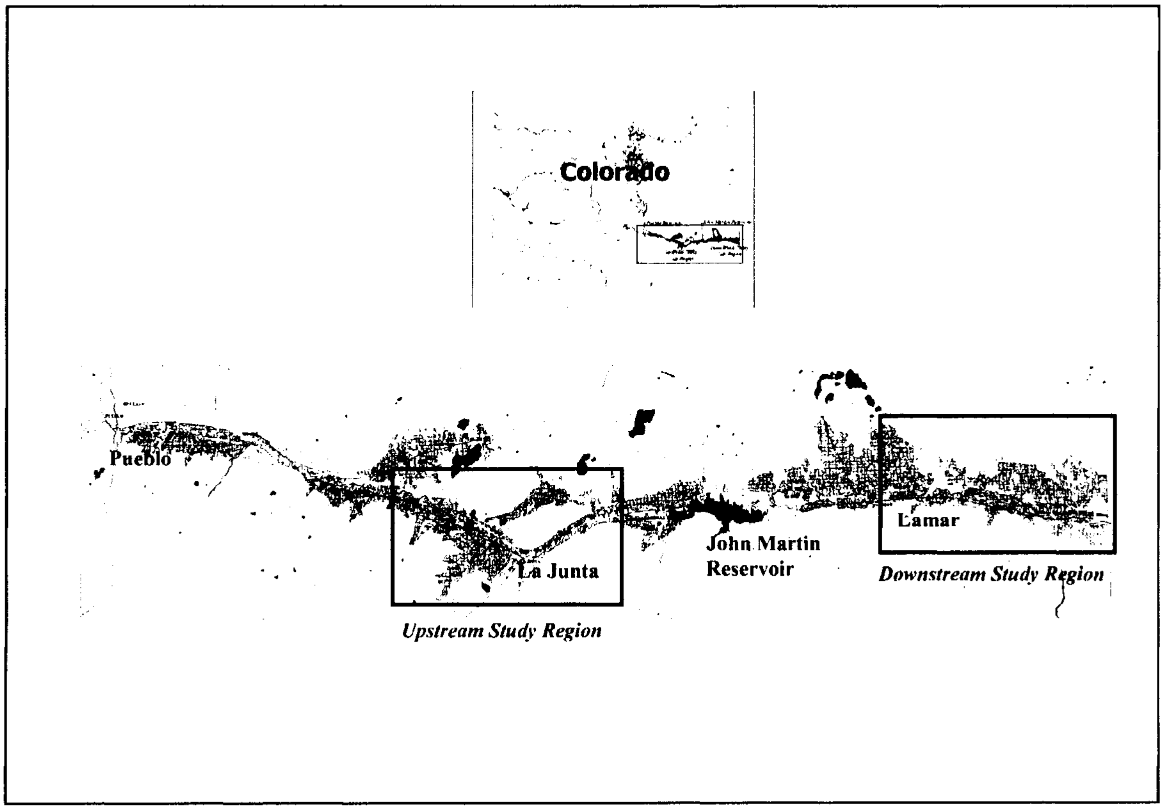

Figure 5-1. Lower Arkansas River Basin of Colorado showing upstream and downstream study regions

5.3 NATURE OF THE PROBLEMS

Over three irrigation seasons from April 1999 to October 2001, Burkhalter and Gates (2005) found the average depth to the water table to be less than 2 m under 16 to 33% of the upstream study region, with an average groundwater salinity concentration between 2700 and 3000 mg/L. Soil salinity, evaluated in terms of saturated soil paste extract salinity, averaged 2500 to 3900 mg/L over a soil depth of 2 m and caused estimated average crop yield losses ranging from 10 to 20%. Annual salt loading to the river via sub-surface return flows was substantial, averaging about 522 kg per irrigated ha per km along the river. Upflux from the shallow water table to the atmosphere under non-irrigated ground was estimated to constitute about 65 million m^3 (52,650 ac-ft) per year of nonbeneficial consumption.

A number of factors have led to the existing elevated soil salinity and waterlogged conditions within the Lower Arkansas Valley. Excessive recharge due to inefficient irrigation practices and canal seepage, coupled with low-permeability soil layers and ineffective or under-capacity drainage, has caused widespread shallow water table conditions. Groundwater, containing salts leached from irrigation events and salts dissolved from marine shales, flows upward from the shallow water table into overlying soils. Evapoconcentration further exacerbates high soil salinity levels. Also contributing to shallow water tables (and to the resultant increase in soil salinity) has been the emergence of more frequent and larger irrigation applications throughout the valley following construction of two major reservoirs (John Martin Reservoir in the 1940's and Pueblo Reservoir in the 1970's). Linked with the construction of the reservoirs is a likely reduction in sediment load in diverted canal water resulting in reduction in canal "sealing" and, thereby, an increase in canal seepage. Although a comparison with historical seepage amounts is not possible, measurements conducted by the authors along three main canals within the study area have confirmed that current seepage volumes are high, ranging between about 15% and 30% of the total diversion amounts. Other factors contributing to the high water table and salinity problems include a suspected aggradation of the river bed resulting in decreased groundwater drainage potential to the river, and a recent court-mandated reduction in allowable pumping from the shallow aquifer.

5.4 POTENTIAL SOLUTION ALTERNATIVES

Several strategies have been proposed to address salinity and waterlogging problems. Most solutions focus on lowering the water table elevation since generally there is a significant relationship between high water table conditions and high soil salinity levels. Field data from the study region have allowed this relationship to be examined. Figure 5-2 is a plot of measured soil salinity versus the average measured water table depth over the four week period prior to the corresponding soil salinity measurements. The regressed relationship shown is based on surveys between June 1999 and August 2001 of soil salinity (to a depth of 2 m) in 173 cultivated fields using calibrated electromagnetic induction probes (Burkhalter and Gates 2005). There are several other factors, such as

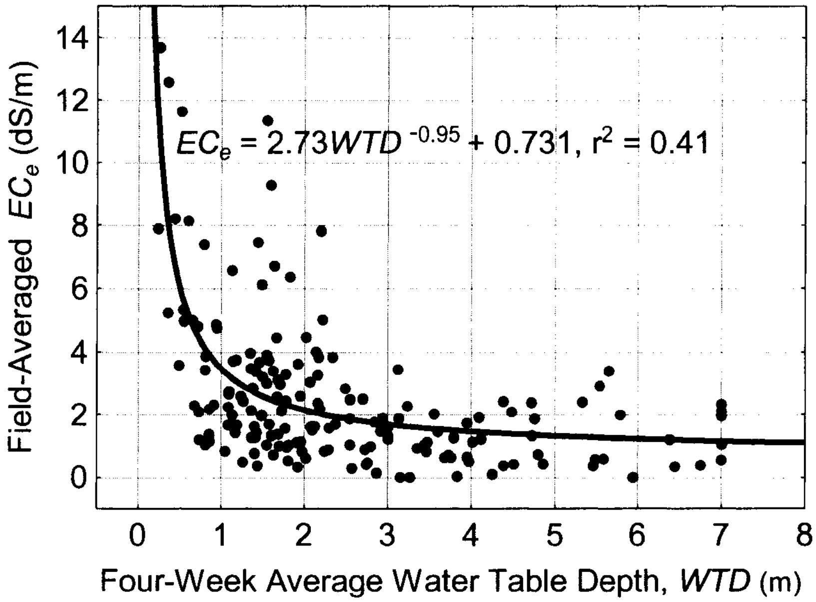

Figure 5-2. Measured soil salinity versus measured water table depth showing fitted regression relationship (Note: 1 dS/m is approximately equivalent to 880 mg/L in this region)

soil chemical and physical characteristics, salinity of the irrigation water, and on-farm management practices, as well as numerous other unknown or unidentified processes, that can have major impacts on soil salinity. However, when saline high water tables are present, the long-term ability to leach salt downward and away from crop root zones, without return via upflux, is greatly diminished.

High water tables can be lowered and soil and water salinity can be mitigated through a variety of structural and management interventions. Alternatives that would incorporate one or more such interventions were grouped under the following categories for the modeled region:

- *Recharge Reduction Alternatives.* Recharge to the high water table due to excess deep percolation can be reduced through improving irrigation application efficiency. This can be accomplished through (a) improved irrigation scheduling and monitoring of applied water volumes; (b) reduction in irrigation set sizes to increase unit flow rates; (c) land grading; (d) use of gated pipe, surge valves, trickle irrigation, and sprinkler irrigation; and (e) other structural/management measures to improve uniformity of applications and to reduce overirrigation.
- *Seepage Reduction Alternatives.* Seepage losses from irrigation canals can be diminished using (a) soil liners with permeability reduced by amendments, (b) buried plastic membranes, (c) polyacrylamide (linear-linked polymer) additives, and (d) other lining materials.

- *Pumping Volume Increase Alternatives.* Existing pumping wells can serve as vertical drains by increasing their pumped volumes.
- *Sub-surface Drainage Alternatives.* Relief drains can be installed in selected fields to draw down the water table.
- *Combination Alternatives.* The above categories can be combined to achieve varying levels of impact in reducing inflows or increasing outflows to improve water and salt balance in the irrigation-stream-aquifer system.

A total of 38 alternatives were modeled, along with the baseline conditions. Alternatives were simulated over the same historical period for which the models previously were calibrated and applied to baseline conditions (Burkhalter and Gates 2005). The approach was to consider what would have happened, in comparison to the unaltered baseline conditions, had a given alternative been implemented. The remainder of this paper will focus specifically on the formulation of the solution alternatives and the findings from the comparative modeling results. A brief description of the models is given below.

5.5 DESCRIPTION OF THE MODELS

Groundwater flow simulation was conducted via a calibrated and tested transient, three-dimensional finite-difference model using the program MODFLOW (McDonald and Harbough 1988) inside the Groundwater Modeling System (GMS) platform (BYU 1999). The finite-difference grid consisted of 16,188 active cells within two vertical layers – one representing the shallow (0 – 3.5 m) low permeability zone, and the other representing the deep (3.5 – 30 m) high permeability zone. The cell size was a uniform 250 m square in the horizontal plane, with a vertical dimension that varied depending upon aquifer geometry.

An important modification was made to the MODFLOW program's drainage package to allow a more accurate representation of the behavior of sub-surface horizontal drains. By redefining particular model input variables (specifically the conductance and drain elevation), and by adding look-up tables of empirically derived parameters, a modified form of Hooghoudt's method (Smedema et al. 2004) for predicting sub-surface drain behavior was successfully incorporated into the MODFLOW code. The revised drainage package was tested over a number of experimental runs.

Using the same finite-difference grid, and linking to the MODFLOW groundwater flow output, a groundwater salt transport model was developed using MT3DMS (Zheng and Wang 1999). It was assumed that advective transport dominates over the regional-scale (Zheng and Bennett 1995); therefore, the dispersion package was not utilized. Additionally, it was assumed that chemical reaction effects are negligible. Over the course of the calibration process, it was found that inclusion of a salinity source due to bedrock/soil material dissolution was appropriate. This was modeled using the model's mass loading feature.

To evaluate soil salinity, an unsaturated zone module for use with MT3DMS was created. This module uses soil water and salt balances to predict soil salinity (as EC_e) over the modeled stress period. It was calibrated and tested using soil salinity field data.

Burkhalter and Gates (2005) and Burkhalter (2005) describe model construction, calibration, and testing in more detail, and present the baseline conditions against which the solution alternatives described herein are compared.

5.6 FORMULATION OF SOLUTION ALTERNATIVES

Table 5-1 provides a summary of all modeled alternatives. By modifying model inputs, the solution alternatives were simulated for evaluation. The specific input adjustments required and the formulation of each investigated alternative are discussed below.

5.6.1 Recharge Reduction Alternatives

This category of alternatives represents the potential reduction in aquifer recharge (i.e. deep percolation from irrigation) that could result from regional improvements in irrigation application efficiency. For simplicity, recharge reductions were modeled within the recharge package of MODFLOW by 10% gradations (10% to 90% reductions from baseline recharge inputs). Reductions were assumed to be realized uniformly (spatially and temporally) across the study region. Additionally, the infiltrated irrigation depths entered as input into the unsaturated zone module were reduced to reflect the increase in irrigation efficiency that would be necessary to produce the specified recharge reductions.

5.6.2 Seepage Reduction Alternatives

This category addresses impacts that would occur from reduction in seepage from the major irrigation canals. To achieve these reductions, measures such as structural lining

Table 5-1. Description of Modeled Alternatives

Alternative Name	Description	Alternative Name	Description
Baseline	Simulated Actual Conditions	*Drain 50m*	Installation of Horizontal Drains over Select Fields at 50m Spacing
Rech 10%	Reduction of Recharge Rates by 10%	*Drain 75m*	Installation of Horizontal Drains over Select Fields at 75m Spacing
Rech 20%	Reduction of Recharge Rates by 20%	*Drain 100m*	Installation of Horizontal Drains over Select Fields at 100m Spacing
Rech 30%	Reduction of Recharge Rates by 30%	*Drain 150m*	Installation of Horizontal Drains over Select Fields at 150m Spacing
Rech 40%	Reduction of Recharge Rates by 40%	*Pump 25%*	Increase in Pumping Rates by 25%
Rech 50%	Reduction of Recharge Rates by 50%	*Pump 50%*	Increase in Pumping Rates by 50%
Rech 60%	Reduction of Recharge Rates by 60%	*Pump 100%*	Increase in Pumping Rates by 100%
Rech 70%	Reduction of Recharge Rates by 70%	*Pump 200%*	Increase in Pumping Rates by 200%
Rech 80%	Reduction of Recharge Rates by 80%	*Rech 30%/Seep 50%*	Combination of Alternatives
Rech 90%	Reduction of Recharge Rates by 90%	*Rech 50%/Seep 90%*	Combination of Alternatives
Seep 50%-All	Reduction of Seepage Rates by 50% over Full Length of All Canals	*Rech 80%/Seep 90%*	Combination of Alternatives
Seep 70%-All	Reduction of Seepage Rates by 70% over Full Length of All Canals	*Rech 30%/Drain 100m*	Combination of Alternatives
Seep 90%-All	Reduction of Seepage Rates by 90% over Full Length of All Canals	*Rech 50%/Drain 50m*	Combination of Alternatives
Seep 90%-20%Lined	Reduction of Seepage Rates by 90% over Targeted 20% Length of All Canals	*Rech 80%/Drain 50m*	Combination of Alternatives
Seep 90%-Holbrook	Reduction of Seepage Rates by 90% over Holbrook Canal Only	*Seep 50%/Drain 100m*	Combination of Alternatives
Seep 90%-Ft Lyon	Reduction of Seepage Rates by 90% over Ft. Lyon Canal Only	*Seep 90%/Drain 50m*	Combination of Alternatives
Seep 90%-Rocky Ford	Reduction of Seepage Rates by 90% over Rocky Ford Canal Only	*Rech 30%/Seep 50%/Drain 100m*	Combination of Alternatives
Seep 90%-Catlin	Reduction of Seepage Rates by 90% over Catlin Canal Only	*Rech 50%/Seep 90%/Drain 50m*	Combination of Alternatives
Seep 90%-Otero	Reduction of Seepage Rates by 90% over Otero Canal Only	*Rech 80%/Seep 90%/Drain 50m*	Combination of Alternatives
Seep 90%-Highline	Reduction of Seepage Rates by 90% over Highline Canal Only		

of canals, changes in sediment loading of water to promote canal sealing, or periodic application of synthetic coatings to canal beds might be employed. As with the recharge reduction scenarios, to simplify the modeling process, changes in seepage rates were considered as percent reductions from baseline conditions. In three scenarios, the reduction percentage was applied uniformly over all of the major canals within the study region. Additionally, six alternatives represented the effects of uniformly reducing seepage by 90% over a selected individual canal only, with all other canals maintaining their baseline conditions. A final scenario considered targeting 20% of the total length of each canal for a 90% level of seepage reduction, while maintaining the remaining 80% length of the canal with baseline conditions. The targeted length of each canal for this alternative was defined by examining the calibrated baseline model results and determining where the highest volumes of seepage were occurring. This scenario is an example of an alternative that might be more economically feasible than lining the entire length of each canal.

5.6.3 Pumping Increase Alternatives

This set of potential solution alternatives examines the impacts of increasing total pumping volume by a fixed percentage over the baseline levels. Increases of 25%, 50%, 100%, and 200% were modeled within the well package of MODFLOW, assuming that the additional pumped volume would be routed directly to the river (i.e. not used to supplement irrigation) within the same time step (week). This assumption was made to minimize additional consumptive use that would violate Colorado water law within the study area.

It was assumed that only existing pumping wells would be used to achieve the specified volume increase. Installing new pumping wells solely for the purpose of lowering the water table was not investigated because, on a regional scale, the number and size of wells required to achieve significant benefits would likely not prove cost-effective.

5.6.4 Sub-surface Drainage Alternatives

Regional effects of installing sub-surface horizontal relief drains over a select subset of fields were examined. All currently-cultivated fields underlain by a baseline average water table depth of less than 2.0 m (6.6 ft) were chosen for modeled drain installation (Burkhalter 2005). This translates to approximately 500 fields covering around 6,500 ha (16,000 ac) specified for application of sub-surface drainage. Drainage installations at four defined drain spacings (50 m, 75 m, 100 m, and 150 m) were modeled with the modified MODFLOW drain package assuming a uniform drain depth of 2.5 m (8.2 ft), a depth deemed great enough for effective water table control yet shallow enough to remain technically and economically feasible. For individual fields, the most effective spacing and drain depth would be variable depending upon soil conditions and other physical characteristics.

5.6.5 Combination Alternatives

These alternatives examined the impacts of implementing multiple approaches simultaneously. Because pumping increase alternatives showed only minor regional effects, they were not included in any of the examined combinations. Some combinations were established because it was anticipated that they would yield maximum benefits based upon previous model runs of individual alternatives. A second consideration was the need to consider some "reasonable" or "achievable" scenarios. Modest (i.e. likely more economical) levels of implementation of the particular individual solution alternatives were specified in these combinations.

5.7 MODELING RESULTS

To evaluate the various solution scenarios, in comparison with baseline conditions, six performance indicators were used: (1) increase in depth to water table, (2) soil salinity decrease, (3) groundwater salinity change, (4) decrease in salt load to the river, (5) relative crop yield increase, and (6) net change in consumptive use. Each indicator is discussed below along with a summary description of the modeling results across the considered alternatives.

5.7.1 Increase in Depth to Water Table

Depth to the saline water table affects the degree of soil waterlogging and salinization, the volume of water consumed by upflux to the atmosphere under fallow fields and under irrigated fields during the non-irrigation season, and the gradient driving flow to the river. Seasonal average values of water table depth for select alternatives are given in Table 5-2. This table shows the spatially-averaged values for both the total study area and for the irrigated portion only. Changes that would occur within the irrigated areas would have the greatest relative economic impact. Impacts within non-irrigated areas, although possibly beneficial, would likely yield lower direct regional economic benefit. The

Table 5-2. Predicted Average Water Table Depth Increase for Selected Solution Alternatives

Solution Alternative	*Depth Increase (m) - Irrigated Area*			*Depth Increase (m) - Total Area*		
	1999	2000	2001	1999	2000	2001
Pump 200%	0.10	0.14	0.14	0.09	0.11	0.12
Rech 30%	0.27	0.29	0.31	0.22	0.24	0.26
Rech 50%	0.43	0.55	0.55	0.35	0.44	0.43
Rech 80%	0.69	0.92	0.94	0.57	0.74	0.77
Seep 50%-All	0.23	0.50	0.55	0.21	0.44	0.49
Seep 90%-All	0.41	0.94	1.08	0.38	0.81	0.94
Seep 90%-20%Lined	0.10	0.19	0.20	0.09	0.19	0.18
Seep 90%-Holbrook	0.09	0.22	0.21	0.11	0.22	0.22
Seep 90%-Catlin	0.03	0.16	0.20	0.01	0.11	0.14
Drain 50m	0.33	0.31	0.25	0.28	0.27	0.21
Drain 150m	0.18	0.16	0.12	0.16	0.13	0.11
Rech 50%/Seep 90%	0.89	1.67	1.87	0.77	1.41	1.60
Rech 50%/Drain 50m	0.66	0.73	0.68	0.54	0.61	0.56
Seep 90%/Drain 50m	0.67	1.13	1.25	0.60	0.99	1.10
Rech 30%/Seep 50%/Drain 100m	0.65	0.99	1.01	0.56	0.82	0.86
Rech 50%/Seep 90%/Drain 50m	1.07	1.76	1.93	0.92	1.48	1.65

maximum predicted increase in average water table depth by 2001 was 1.93 m, for the *Rech 50%/Seep 90%/Drain 50 m* combined alternative.

Although the values presented in Table 5-2 provide a convenient numerical measure for comparative purposes, they do not reveal the spatial distribution of the impacts. An effective solution, besides providing significant increases in average water table depth, must result in changes where they are most needed (i.e. waterlogged areas). Figure 5-3 shows the average water table depth increase (averaged over all three modeled irrigation seasons) mapped spatially over the region for selected alternatives. Also shown is the map of the baseline average water table depth.

Inspection of Figure 5-3 reveals that both the recharge reduction and comprehensive (as opposed to targeted) seepage reduction strategies would yield widespread regional depth

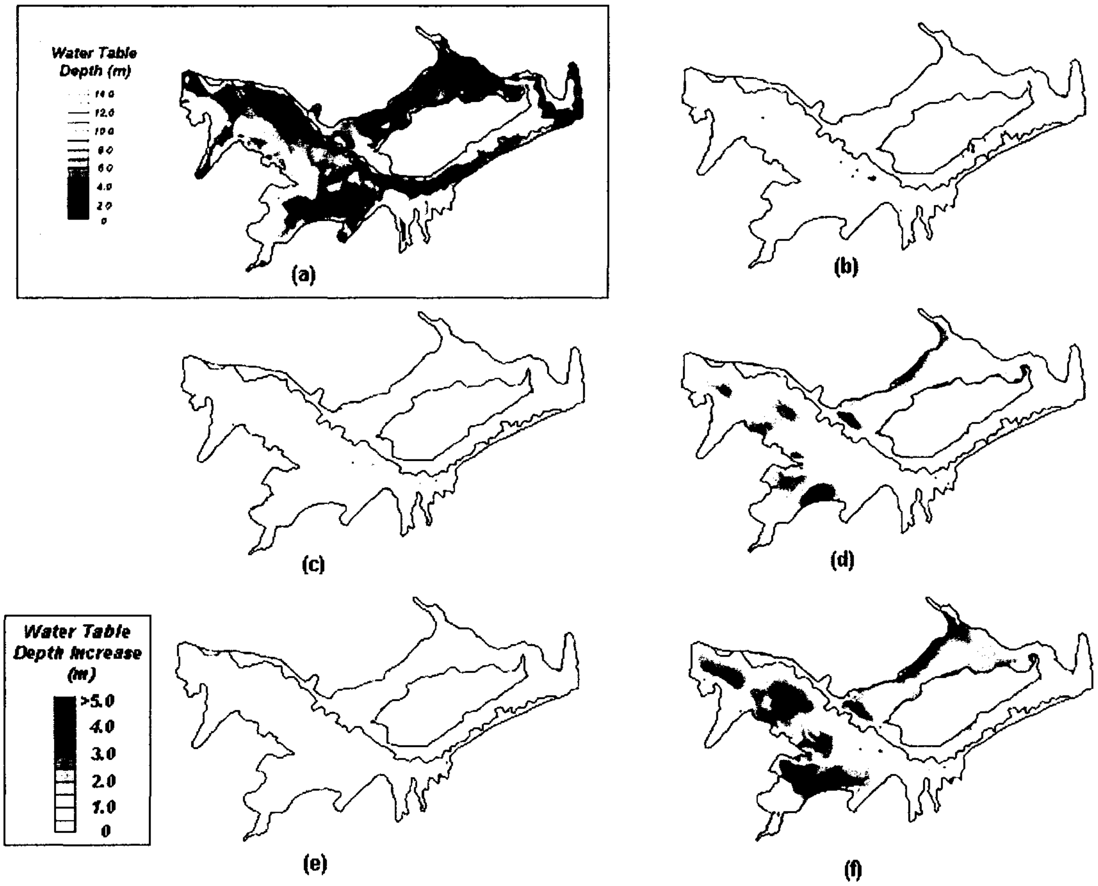

Figure 5-3. Contour maps of predicted (a) baseline average water table depth, and predicted average water table depth change for (b) *Pump 200%* solution alternative, (c) *Rech 50%* solution alternative, (d) *Seep 90%-All* solution alternative, (e) *Drain 50m* solution alternative, and (f) *Rech 50%/Seep 90%/Drain 50m* solution alternative.

increases. Spatially, however, the distributions of the effects differ significantly. Drainage scenarios indicate, as expected, that the most significant depth increases occur within fields where drains have been specified; although, significant regional impacts are also evident. Increasing volumes extracted by existing pumping wells (at the rates investigated) would likely provide only localized water table depth increases. As indicated in Figure 5-3, the combination of solution interventions results in the largest and most widespread predicted regional impacts.

5.7.2 Soil Salinity Decrease

Seasonal average values of soil salinity decrease for selected alternatives are given in Table 5-3. It is evident that combination alternatives have the greatest predicted impacts. Additionally, the predicted decreases in soil salinity grow larger over time. This corresponds with larger predicted increases in water table depth and is likely due in part to the associated increase in net leaching potential and to the soil's response time to leaching. Potentially, a longer simulated time period might reveal even larger changes before a dynamic equilibrium is achieved. Even so, the soil salinity decreases predicted within the three modeled irrigation seasons are substantial for a number of scenarios. Interestingly, among the combination alternatives, the *Rech 50%/Seep 90%* and the *Rech 50%/Drain 50m* scenarios achieved almost the same average salinity decrease (between

Table 5-3. Predicted Average Soil Salinity Decrease for Selected Solution Alternatives

Solution Alternative	*Salinity Decrease (mg/L) - Irrig. Area*			*Salinity Decrease (mg/L) - Total Area*		
	1999	2000	2001	1999	2000	2001
Pump 200%	5	-135	7	9	-127	-9
Rech 30%	141	298	486	119	227	400
Rech 50%	276	365	678	242	282	521
Rech 80%	183	228	548	164	207	448
Seep 50%-All	53	-4	30	48	-6	16
Seep 90%-All	88	16	141	78	3	92
Seep 90%-20%Lined	16	-23	-8	14	-15	-10
Seep 90%-Holbrook	22	5	17	27	2	9
Seep 90%-Catlin	-17	-17	-24	-14	-16	-29
Drain 50m	158	-39	28	132	-55	-13
Drain 150m	94	-87	-39	84	-77	-50
Rech 50%/Seep 90%	261	463	916	220	349	698
Rech 50%/Drain 50m	283	409	765	233	305	574
Seep 90%/Drain 50m	189	27	168	160	-7	98
Rech 30%/Seep 50%/Drain 100m	262	340	644	215	249	477
Rech 50%/Seep 90%/Drain 50m	306	498	950	256	361	714

750 and 950 mg/L) as the *Rech 50%/Seep 90%/Drain 50m* scenario. This suggests that recharge reduction is the main contributor to the predicted regional average soil salinity reduction. Local effects can be markedly different among alternatives, however, as suggested by the examples shown in Figure 5-4.

Figure 5-4 shows the average soil salinity reduction (over the entire modeled period) mapped for selected alternatives. The widespread effects resulting from recharge reduction measures (the *Rech 50%* scenario is given in Figure 5-4c) are evident. It is notable that, although the *Rech 90%* scenario results in the greatest increase in water table depth, it is the *Rech 50%* scenario that results in the greatest overall decrease in average soil salinity. This result reveals that there is a point at which, if recharge (i.e. deep percolation) is reduced too much, the reduction in salt leaching provided by this recharge begins to offset the benefits derived from the reduced upflux realized by water table depth increases. Predicted reductions of soil salinity resulting from pumping increases (the *Pump 200%* scenario is given in Figure 5-4b) are localized around the pumping well locations; however, there are some resulting minor regional reductions. Seepage reduction alternatives (the *Seep 90%-All* scenario is given in Figure 5-4d) would likely yield soil salinity decreases in fields adjacent to or nearby the major irrigation canal network as well as some smaller widespread regional impacts.

Results for sub-surface drainage options (the *Drain 50m* scenario is given in Figure 5-4e) revealed that soil salinity decreases are intensified and large in magnitude (2000 mg/L and greater) around the fields where drains are installed. Interestingly, the model predicts

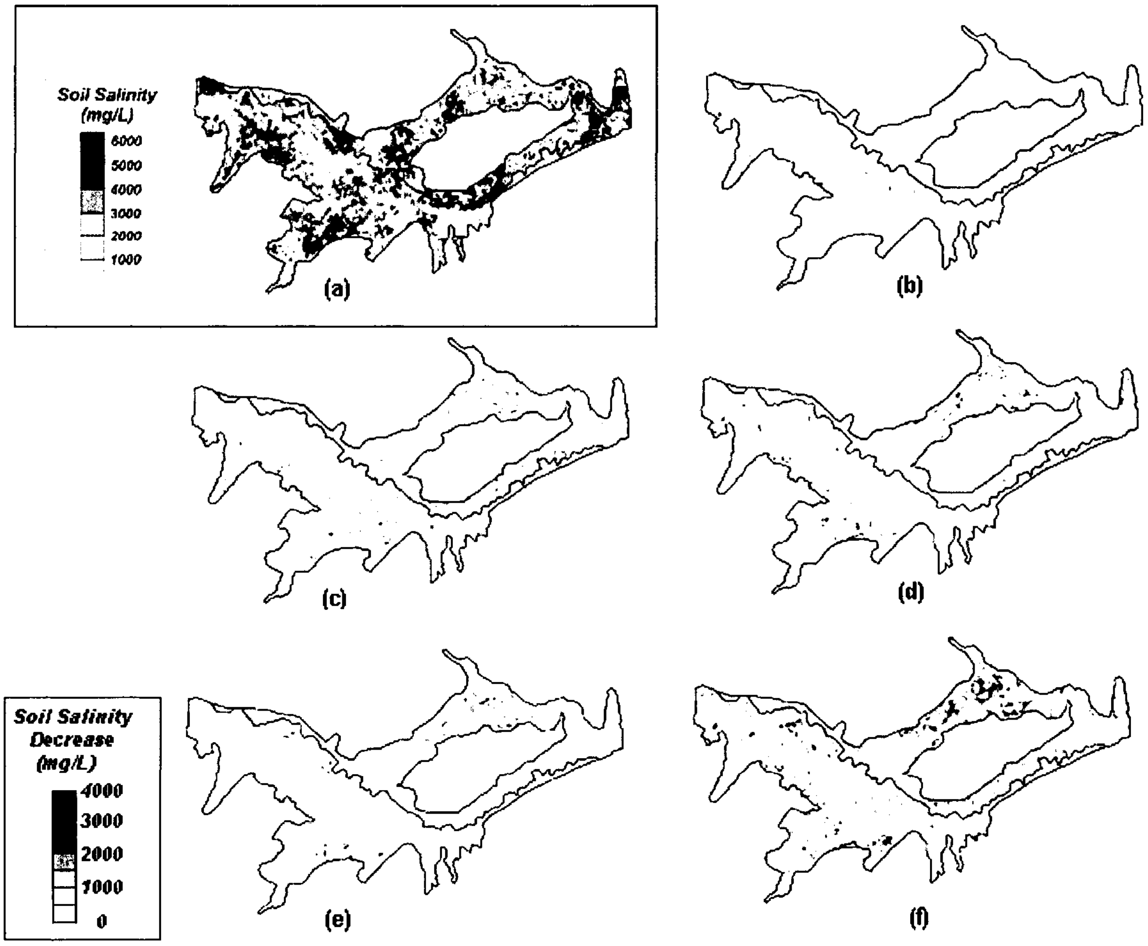

Figure 5-4. Contour maps of predicted (a) baseline average soil salinity, and predicted average soil salinity change for (b) *Pump 200%* solution alternative, (c) *Rech 50%* solution alternative, (d) *Seep 90%-All* solution alternative, (e) *Drain 50m* solution alternative, and (f) *Rech 50%/Seep 90%/Drain 50m* solution alternative

an actual average regional increase during some irrigation years for the sub-surface drainage options (see Table 5-3). This result may be somewhat misleading, however, because the average mean value is being affected by a modeling phenomenon that is reflected in the simulation of some severely waterlogged areas. The model predicts an increase in soil salinity in these areas because of the high volume of upflux water that occurs in the baseline scenario. This upflux volume has a dilution effect under baseline conditions (i.e. waterlogged) because of its large relative volume in the soil moisture balance. In reality, the installation of the sub-surface drains would allow much greater leaching of salts from the unsaturated zone to occur and, over time, soil salinity levels would decrease. Because of the limited modeling period considered, this benefit was not always captured in the regional results. As mentioned above, and as is evident from Figure 5-4f (the *Rech 50%/Seep 90%/Drain 50m* alternative), combining solution measures results in additive benefits by taking advantage of the differing spatial distributions of the impacts.

5.7.3 Groundwater Salinity Change

Groundwater salinity affects soil salinity through upflux and can significantly impact the usability of pumped water for irrigation and domestic supply (the two main uses in this region). Most alternatives were predicted to increase average groundwater salinity over the modeled time period. These short-term increases, ranging from about 20 to 600 mg/L, are likely the result of more net salts being leached to the water table from the upper soil layers and, due to the decreases in water table elevation, less groundwater being available for dilution of salts (Burkhalter 2005). Within the short modeling period (1999 – 2001), a complete examination of the impacts of the solution alternatives is not possible because the response time of the aquifer in many areas is too great for the effects to be fully captured. An expansion of the modeling horizon is required to evaluate the long-term effects of solution measures that will only be realized once the system has achieved a dynamic equilibrium. Also, other processes influencing groundwater salinity need to be further studied. One such process that might offset the predicted increase in groundwater salinity is related to dissolution of salts from the alluvial profile. Data from the region indicate a trend for groundwater salinity to decrease as the water table falls. This suggests that the principal salt-bearing strata, including shale layers, occur in the upper elevations of the profile.

5.7.4 Decrease in Salt Load to the River

The predicted total mass of salt that enters the river is an important performance indicator since salt loading significantly affects downstream users. Improvements to the quality of the water available for diversion could result in significant economic benefits. Additionally, reductions in total salt load to the river are associated with important ecological benefits, particularly since levels of pollutants like selenium in the Arkansas River are closely linked to salt concentrations. Driving the predicted decreases in total salt mass entering the river are the reductions in sub-surface return flow volumes related to lowering the water table. As discussed in the previous section, the short-term predicted salt concentration of the ground-water return flow increases under most scenarios; however, because the volume also decreases, the total mass load, in most cases, also decreases. Also, because under most alternatives there might be more water available in the river for dilution (due to possible decreased diversions associated with increased efficiencies), the average river salinity concentration should decrease significantly (although this is outside the scope of the present paper).

Figure 5-5 shows plots of percentage decreases in salt loading to the river over the modeled period for several of the more promising alternatives. Of the individual measures investigated, reducing recharge rates at the levels prescribed would reduce salt loading by the greatest amount. Seepage reduction measures also were predicted to yield

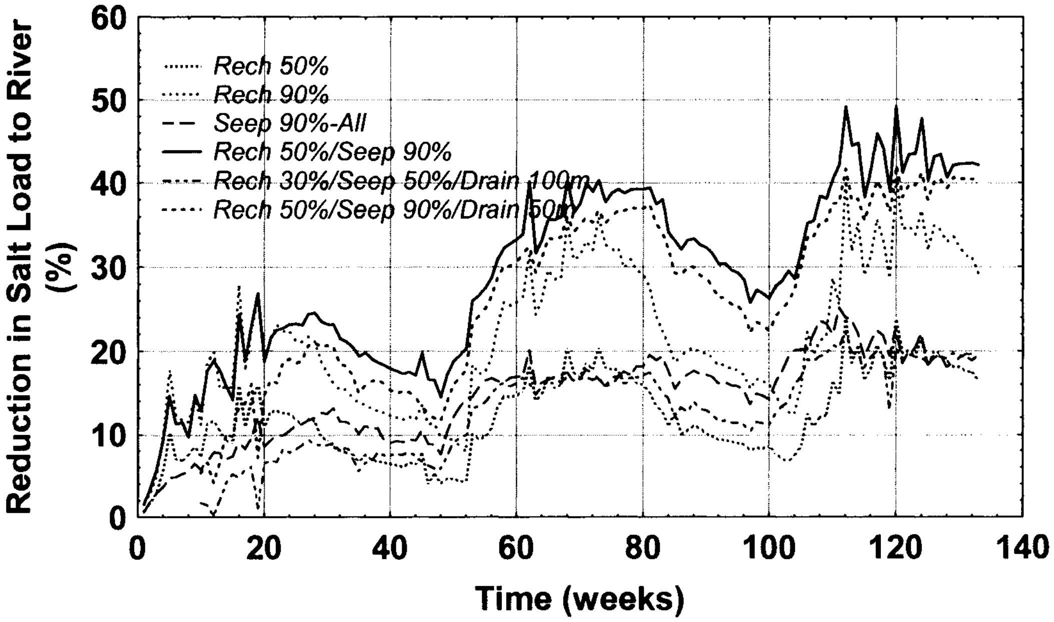

Figure 5-5. Predicted reduction in salt load to the Arkansas River for selected solution alternatives

significant reductions had they been implemented over the modeled period. For example, the temporally-averaged reductions over the study period would have been as high as 30% and 20%, respectively, for the *Rech 90%* and *Seep 90%-All* alternatives. Combination alternatives were predicted to have the greatest impact – the *Rech 50%/Seep 90%* and *Rech 50%/Seep 90%/Drain 50m* alternatives, would have caused seasonal average reductions as high as around 45% and 40%, respectively, during 2001. Average quantities of annual salt loading associated with all considered alternatives ranged from about 367 to 594 kg per irrigated ha per km along the river, corresponding to average daily ground water return flow rates of 0.11 to 0.20 m^3/s per km. Alternatives incorporating only pumping increases or sub-surface drainage installation were predicted to result in increases in the salt loading; however, these increases would likely be only short term. Once a dynamic equilibrium state would be achieved in the aquifer system, the concentration of the surface return flows associated with these alternatives would likely be much lower. Modeling a longer time period would aid in quantifying the long-term impacts.

5.7.5 Relative Crop Yield Increase

Perhaps the most important performance indicator in terms of potential overall economic benefit is the relative crop yield increase. The relationships used to relate the soil salinity and waterlogging conditions to relative crop yield were compiled from previous studies and adjusted for application to the modeled study area by Houk (2003). These relationships are crop-type dependent and were linked to the actual historical field crop types from data provided by the USDA Farm Services Agency. These relationships account only for soil salinity and waterlogging effects under general conditions and, as with most crop yield models, it should be recognized that there are a number of variables affecting actual crop production that cannot be captured mathematically or simulated with a high degree of accuracy (Rhoades et al. 1992). Nevertheless, for comparing the relative regional effects of alternative solutions, estimates of relative crop yield are useful indicators of the potential benefits.

Table 5-4 shows the predicted percentage point increase (over the baseline) in relative crop yield for selected scenarios. This value represents the overall spatial and temporal average for the indicated irrigation season. Predictions of localized increases for particular field polygons varied widely around this average value, ranging from 0 to more

Table 5-4. Predicted Relative Crop Yield Increase for Selected Solution Alternatives

Solution Alternative	*Relative Crop Yield Increase (percentage points)*		
	1999	2000	2001
Pump 200%	1.8	1.3	1.1
Rech 30%	3.5	4.1	6.1
Rech 50%	4.7	4.7	7.4
Rech 80%	4.3	3.9	6.3
Seep 50%-All	2.8	1.8	1.6
Seep 90%-All	3.4	2.0	2.5
Seep 90%-20%Lined	1.9	1.0	0.8
Seep 90%-Holbrook	2.2	1.8	1.5
Seep 90%-Catlin	1.5	1.0	0.6
Drain 50m	4.5	1.4	1.5
Drain 150m	3.7	1.0	0.9
Rech 50%/Seep 90%	5.1	5.7	9.4
Rech 50%/Drain 50m	5.4	5.3	8.3
Seep 90%/Drain 50m	4.8	2.0	2.6
Rech 30%/Seep 50%/Drain 100m	5.2	4.6	7.1
Rech 50%/Seep 90%/Drain 50m	5.5	5.8	9.6

than 80 percent. The largest crop yield increases occurred for combination solution alternatives. By 2001, the *Rech 50%/Seep 90%*, *Rech 50%/Drain 50m*, and *Rech 50%/Seep 90%/Drain 50m* alternatives indicated crop yield increases ranging from about 8 to 10 percent. The recharge reduction alternatives also indicated significant increases for all three seasons.

5.7.6 Net Consumptive Use Change

Changes in net water consumption are important not only from a water supply standpoint, but also because of the potential legal barriers that might arise if implementation of a solution alternative were to result in consumptive use increases. The net consumptive use change is derived from two key components of the system water balance. The first component is the increase in total crop *ET* derived from improving the soil conditions. To estimate this component, it was assumed that the fractional increase in *ET* was proportional to the predicted increase in relative crop yield, adjusted by an estimated yield response factor for the crops distributed over the region (Allen et al. 1998). The second component is the volume of water lost to the atmosphere via upflux in non-irrigated areas (due to high water table conditions). This volume was considered a non-beneficial use; i.e., its reduction would represent a true water savings. The net consumptive use change, therefore, was calculated as the volume of increase in crop *ET* minus the volume of decrease in non-beneficial use. Results of this analysis for select scenarios are summarized in Table 5-5.

Table 5-5. Predicted Net Change in Consumptive Use for Selected Solution Alternatives

Solution Alternative	ET Increase (m^3)	Non-Beneficial Use Decrease (m^3)	Net Consumptive Use Change (m^3)	Net Consumptive Use Change (Acre-Ft)
Pump 200%	6,074,058	1,856,157	4,217,900	3,417
Rech 30%	27,961,616	8,349,127	19,612,489	15,888
Rech 50%	34,973,341	13,816,213	21,157,128	17,139
Rech 80%	29,846,356	21,570,810	8,275,546	6,704
Seep 50%-All	10,795,698	10,708,998	86,700	70
Seep 90%-All	15,014,735	17,163,990	-2,149,255	-1,741
Seep 90%-20%Lined	4,836,072	4,773,516	62,556	51
Seep 90%-Holbrook	9,162,498	8,825,121	337,377	273
Seep 90%-Catlin	3,144,806	2,997,206	147,599	120
Drain 50m	13,814,426	25,368,883	-11,554,456	-9,360
Drain 150m	9,507,139	13,575,649	-4,068,510	-3,296
Rech 50%/Seep 90%	43,502,335	30,540,120	12,962,215	10,501
Rech 50%/Drain 50m	40,362,503	32,115,311	8,247,192	6,681
Seep 90%/Drain 50m	18,882,861	32,869,971	-13,987,110	-11,331
Rech 30%/Seep 50%/Drain 100m	36,144,982	29,655,639	6,489,343	5,257
Rech 50%/Seep 90%/Drain 50m	45,500,223	39,693,864	5,806,359	4,704

Results indicate that recharge reduction alternatives could result in significant increases in net consumptive use. However, other potential benefits of these types of interventions, such as salt load reductions to the river by up to 31% averaged over the modeled period (Figure 5-5), might justify the increases economically. Seepage reduction alternatives tended to result in relatively minor predicted increases in net consumptive use volume or, as in the case of the *Seep 90%-All* alternative, resulted in predicted net savings. Alternatives that incorporated sub-surface drainage also resulted in predicted savings. The *Seep 90%/Drain 50m* scenario resulted in the largest predicted savings at approximately 14 million m^3 (11,300 acre-ft) over the modeled period. Before making firm conclusions regarding potential consumptive use changes, other factors need to be more carefully studied. For example, it is likely that the bare soil evaporation component of *ET* might markedly decrease on fields converted to drip irrigation (Allen et al. 1998).

5.8 SUMMARY AND CONCLUSIONS

Predicted spatial and temporal responses of a variety of salinity and waterlogging solution alternatives have been examined using flow and mass transport models over three irrigation seasons for a region along the Arkansas River in southeastern Colorado. It appears that current problems can be ameliorated considerably if solution alternatives are implemented on a regional scale. Major benefits would be realized in the form of increased agricultural productivity, enhanced water quality in the river due to reduced salt loading and, in some cases, water conservation. Additionally, it is clear that combining different types of interventions can produce even greater gains. To fully analyze the long-term effectiveness of proposed solutions, model improvements aimed at extending the modeling time horizon farther into the future will be required. Also, detailed economic analysis is needed to examine solution costs and benefits.

Future work plans are to continue the data collection program, to make model refinements, and to examine improved methods of temporal model extension and spatial resolution. The modeled period currently is being extended through 2002 and 2003, some of the worst drought years on record. Also, in supplement to the work reported herein which focused on applying improvements broadly over the region, more attention will be given to targeting specific locations with varying levels of interventions so as to elicit the best cumulative results. Application of stochastic modeling techniques to address uncertainty is planned. Also, there is currently an effort underway to incorporate the presented regional-scale models, applied to both the upstream and downstream study regions, into a basin-wide decision support system.

CHAPTER 6

MODEL CALIBRATION PROCEDURES AND RESULTS

Model calibration is one of, if not the, most important steps in simulation model development. An ineffectively or inappropriately calibrated model will likely lead to erroneous results and conclusions. Alternately, an attempt to calibrate a model to produce results within unrealistic tolerances (i.e. beyond the level of model accuracy and data availability) can waste time and project resources. A proper and effective calibration is one developed with consideration to overall project goals and with an understanding of model limitations, data uncertainty, and physical system characteristics.

Calibration can be defined in the present context as "...the process of refining the model representation of the hydrogeologic framework, hydraulic properties, and boundary conditions to achieve a desired degree of correspondence between the model simulations and observations of the ground-water flow system" [ASTM D-5981 p.2]. Typically, groundwater models are calibrated using one or both of two methods: the manual (trial and error) approach or an automatic (inverse modeling) approach. For the presented research, the scope of the problem and the desired level of model accuracy and parameter variability made the use of the automatic approach impractical. Automatic approaches were initially investigated and considered for implementation, and an attempt was made to use the inverse modeling package known as MODFLOWP to refine the models locally; however, due to the high level of spatial variability of the important aquifer parameters, manual calibration techniques were found to be equally if not more efficient in arriving at comparable results. Therefore, the employed methods and results presented all relate to the manual approach. Two references in particular were useful as guides in the calibration process. The ASTM Standard D 5981-96 served as the primary guide for calibration strategy, and a text by Pinder (2002) also served to provide helpful hints and calibration guidelines.

For the presented research, calibration was performed using the general principle of parsimony [Pinder p. 121], i.e. the models were constructed and calibrated iteratively moving from the simple to the complex. An initial calibration was performed on a steady-state version of the flow model only (as presented in Gates et al. 2002 – see Chapter 3). The following iteration focused on calibration of the groundwater salinity model associated with the steady-state flow conditions. Subsequently, several calibration iterations on the groundwater flow and salinity models were performed as the transient models were being constructed (i.e. as stress periods/time steps were added). Once the transient flow and salinity models were adequately calibrated, the calibration of the unsaturated zone model was performed. The discussion below will describe the calibration procedures followed and will present results for each of the three employed models.

6.1 CALIBRATION METHODS

The general steps taken in the manual calibration approach included establishing calibration targets based on project objectives, identification of the important calibration parameters and their associated range of values, and using history matching to evaluate calibration results. As mentioned above, the calibration process was accomplished iteratively, so each of the listed steps was performed and evaluated multiple times over the course of the research.

6.1.1 Calibration Targets

The overriding goal of the presented research was to produce a set of models that represents the physical system realistically enough to enable the accurate evaluation of regional-scale solution alternatives. Because the emphasis is on capturing realistic system-wide behavior (and not on simulation/prediction at specific locations), the calibration targets established place the focus on regional average values, with secondary importance given to history matching at particular observation sites. An emphasis was also placed on temporal model response (i.e. the overall changes in important output parameter values over time periods) over the quantitative matching of the value to the observed at a specific time step.

One reason for de-emphasizing the model matching at specific observation points has to do with the inherent model scaling effects that are present. Each modeled cell represents about 6.2 ha (15.5 acres) of surface area, whereas each observation point (in the cases of water table elevation and salinity) represents only the value immediately surrounding the observation well covering an area of only tens of cm^2. Field conditions observed within the study area have demonstrated that values of water table depth, groundwater salinity, and soil salinity can vary dramatically within a single cultivated field. The comparative variation over adjacent fields is often even more severe.

Field measurements also are often prone to error or bias due to site-specific conditions or technician mistakes. For example, within the current study, an observation well was installed in a higher elevation area where the soil was typically dry and highly compacted (due to frequent farm equipment traffic). After a season of readings, it was discovered that the combination of non-standard practices that were followed during the well installation process and the prevalent soil conditions had effectively caused the screened portion of the well to become sealed. At some point during the season, a residual amount of water had been captured within the well (likely due to an irrigation event during which water entered around the annulus into the well bore) and was trapped within the well casing – the result was a season's worth of values that showed very little variability and clearly did not represent the true water table depth and groundwater salinity of the surrounding field.

Instrumentation sensitivity and errors must also be taken into account when establishing calibration targets. For the presented research, the specific conductance meters used were notably sensitive to temperature and had to be adjusted frequently (using measurements of solutions of known conductance) to maintain desired reading accuracy. The EM-38 meters used to measure soil conductivity are known to be highly sensitive to soil water conditions as well as to soil temperature [Rhoades et al. 1989]. By focusing on regional calibration targets, the overall model bias introduced by these kinds of uncertainties should be minimized.

Regional average calibration targets were established to reflect a level of model performance that would provide an acceptable degree of confidence in the important conclusions regarding solution alternative evaluation. Additionally, these targets were selected to provide baseline model results that could be used to characterize the current conditions of the study region with reasonable accuracy for regional planning purposes. Initial regional target values were varied slightly based on preliminary model sensitivity analysis that helped to frame the expected model performance.

Ultimately, the established calibration target for the prediction of water table depth averaged spatially and temporally over the region was ± 0.3 m. This value represents the target residual for the spatially and temporally averaged predicted regional values over the calibration time period (time steps 1 – 67) versus the observed values. The target average absolute value of the predicted residuals was established at 1.0 m. Additionally, the maximum allowable spatial average deviation target for a single time step was set at ± 1.0 m. The spatial and temporal frequency distribution of predicted values versus the observed also served as a secondary qualitative check of regional model performance. The established calibration target residual for the prediction of groundwater salinity was set at ± 100 mg/L, with the target average absolute value of the predicted residuals being 850 mg/L. The maximum spatial average deviation target for any particular time step was set at ± 500 mg/L. As with the water table depth, the frequency distribution of the predicted values was also used as a secondary qualitative calibration check. For the predicted soil salinity of the region, temporal averaging was not appropriate since there were a limited number of observed time steps (six in total). Because of this fact, each observed time step was evaluated independently with a calibration target of obtaining a predicted spatial average within ± 1000 mg/L of the observed regional average. Additionally, the frequency distribution of the predicted values was used as a qualitative calibration check.

Model predictions at individual observation well locations were used as a secondary check of model performance. In light of the uncertainties discussed previously, the observation wells were categorized into three groups for calibration performance evaluation purposes. The first group of wells consists of locations where there is a high level of confidence in the recorded well observations. Generally, these are wells located in areas that are frequently irrigated, are far from system boundaries or other external influences, and typically demonstrate characteristics similar to or consistent with nearby observation points. This high confidence group of wells was given a higher priority during the history matching evaluation phase. For this group of wells, the calibration targets for an individual well at a specific time step were set at ± 1.0 m and ± 1000 mg/L for water table depth and salinity, respectively. The second group of wells consists of locations where the level of confidence in the recorded well observations begins to diminish. These medium level of confidence wells are typically located in areas that are irrigated only occasionally, are relatively near system boundaries or other external influences, and typically demonstrate characteristics different from other nearby observation points. This group was given lesser priority during the history matching phase, and, therefore, calibration targets were not established or considered useful. The final group of observation wells consists of location where there is a very low level of confidence in the recorded well observations. The low level of confidence is typically associated with sporadic irrigation events (if any), highly variable readings over the course of the study, and marked dissimilarities to other nearby observation wells. Often, wells within this group are influenced heavily by location-specific factors. This group was not considered to be representative of the conditions of the immediate surrounding area, and, therefore, these data were typically not considered during the history matching phase. Table 6-1 lists all of the observation wells in their associated confidence category.

Fields used to evaluate soil water salinity modeling were also categorized based on a subjective level of confidence in the observed values. Because there were typically 60 – 120 measurements over a field sized between 4 – 20 ha (10 – 50 acres) that were used to calculate each soil salinity observed value used in calibration, there was an overall higher confidence (compared to a single observation well reading) that could be assumed. The

Table 6-1. Observation Well Confidence Categorization

Confidence Level									
High							**Medium**		**Low**
Well_1	Well_20	Well_35	Well_53	Well_73	Well_87A	Well_100	Well_6	Well_71	Well_9A
Well_2	Well_21	Well_36A	Well_59	Well_74	Well_87B	Well_200	Well_7	Well_72	Well_14
Well_5	Well_22	Well_36B	Well_60A	Well_75A	Well_90	Well_201	Well_8	Well_75C	Well_16B
Well_11	Well_23	Well_39	Well_60B	Well_76	Well_91	Well_205	Well_9B	Well_78	Well_26A
Well_12	Well_26B	Well_41	Well_61	Well_77	Well_92	Well_206	Well_24	Well_82	Well_40
Well_13	Well_27	Well_42	Well_64	Well_79	Well_93	Well_207A	Well_37	Well_86	Well_55
Well_15	Well_28	Well_45	Well_65	Well_80	Well_94	Well_208	Well_38	Well_88	Well_57
Well_16A	Well_29	Well_48	Well_66	Well_81	Well_95	Well_209	Well_43	Well_97	Well_202
Well_16C	Well_30	Well_49	Well_67	Well_83	Well_96		Well_51	Well_203	Well_204
Well_17	Well_31	Well_50	Well_68	Well_84	Well_98		Well_62	Well_207B	
Well_18	Well_33	Well_52	Well_70	Well_85	Well_99		Well_69		

uncertainty associated with the soil salinity readings relates to the particular soil conditions present on the day the observations were made. Using field notes and data collected on soil water content and temperature, the observed fields were categorized into two groups. The majority of fields were placed in the first group that represents measurements for which there is a high level of confidence. These are fields that had no unusual circumstances (such as particularly dry conditions or, as in one case, the field had been freshly plowed and soil materials were clumped) during the time when field measurements were conducted. The second group of fields represents locations at which there was some soil condition or other external factor that might have significantly affected field observations. Identified through specific field notes or soil condition measurements, these fields were not used in the history matching phase of model calibration due to their associated low level of confidence. It should be noted that conditions at a particular field could vary significantly between observation dates, and, therefore, some fields had separate readings that fell in both the high confidence and low confidence categories. Table 6-2 provides a list of all soil water salinity field observations and their associated confidence category.

Besides the identified calibration targets, three additional checks of model performance were utilized during model calibration. Average canal seepage rates were investigated in the published literature, through water balance analysis, and by limited field measurements along the Fort Lyon Canal [Gates 2001 unpublished]. Based on these sources, an average canal seepage volume of about 20% of the total diversion volume was established as a flow modeling target. An overall check of return flow volume was

Table 6-2. Soil Water Salinity Reading Confidence Categorization

Location	1999 Early	1999 Late	2000 Early	Location	1999 Early	1999 Late	2000 Early	Location	1999 Early	1999 Late	2000 Early	Location	1999 Early	1999 Late	2000 Early
Field_1	High	High	High	Field_26B	High	Low	High	Field_50	High	High	High	Field_82	N/A	N/A	N/A
Field_2	High	High	High	Field_27	High	High	High	Field_51	High	High	High	Field_84	N/A	N/A	High
Field_5	High	High	High	Field_28	High	Low	High	Field_52	High	High	High	Field_85	N/A	N/A	Low
Field_6	High	Low	High	Field_29	High	High	High	Field_53	High	Low	High	Field_87B	N/A	N/A	High
Field_7	High	Low	High	Field_30	High	High	High	Field_55	N/A	N/A	High	Field_88	N/A	N/A	High
Field_8	High	High	High	Field_31	High	Low	High	Field_57	High	Low	Low	Field_90	N/A	N/A	High
Field_9A	High	High	High	Field_33	High	High	High	Field_60A	High	High	High	Field_92	N/A	N/A	High
Field_9B	Low	Low	Low	Field_35	Low	High	High	Field_60B	High	High	High	Field_93	N/A	N/A	High
Field_11	High	Low	Low	Field_36A	High	High	Low	Field_61	High	High	High	Field_95	N/A	N/A	N/A
Field_12	High	Low	High	Field_36B	High	High	High	Field_62	High	High	High	Field_97	N/A	N/A	N/A
Field_13	High	Low	Low	Field_37	High	High	High	Field_65	High	High	Low	Field_100	N/A	N/A	N/A
Field_14	High	High	High	Field_38	High	High	High	Field_66	Low	Low	Low	Field_200	High	High	High
Field_17	High	High	High	Field_39	Low	Low	High	Field_67	High	High	High	Field_201	High	High	High
Field_18	Low	Low	High	Field_40	High	High	High	Field_68	High	High	High	Field_202	High	High	High
Field_20	Low	Low	High	Field_41	Low	Low	High	Field_69	High	High	High	Field_203	Low	Low	High
Field_21	High	High	High	Field_42	High	Low	High	Field_70	High	High	High	Field_204	High	Low	Low
Field_22	High	High	High	Field_43	Low	Low	High	Field_71	High	High	Low	Field_205	High	High	High
Field_23	Low	Low	High	Field_45	High	High	High	Field_76	Low	High	High	Field_206	High	High	High
Field_24	High	High	High	Field_48	Low	Low	Low	Field_77	High	High	High	Field_207A	Low	Low	Low
Field_26A	High	High	High	Field_49	High	High	High	Field_79X	High	High	N/A	Field_209	High	High	High

N/A : Field not observed during this reading.

used during calibration as well. Considering the hydrologic characteristics of the study region and based on review of data provided by the Colorado Division of Water Resources, it was approximated that around 50% of the annual average volume of streamflow recorded at USGS gage locations can be attributed to groundwater return flows. Using the USGS observations within the study reach, the groundwater return flow volume predicted by the flow model was evaluated based on the 50% estimate. A final calibration check used in model assessment was the relationship between predicted soil salinity and the corresponding predicted four-week average water table depth. This relationship was established from field data and is shown in Figure 6-1. As a calibration target, it was desired that the final calibrated model reproduce this relationship within a reasonable degree.

6.1.2 Calibration Parameters

Once the general calibration targets were established, the investigation focused on determining which model parameters should be varied during the history matching (trial and error) process. Two key concepts influenced the final determination of which model parameters to focus on during model calibration. The first of these concepts is the relative uncertainty of the estimated values used as model input. The second concept is the relative sensitivity of model results to variations in a particular parameter value. Additionally, subjective judgments about which model parameters most likely need adjustment were made at specific locations within the model over the course of the calibration process. These judgments typically considered the range of common parameter values and local knowledge gained from field investigations.

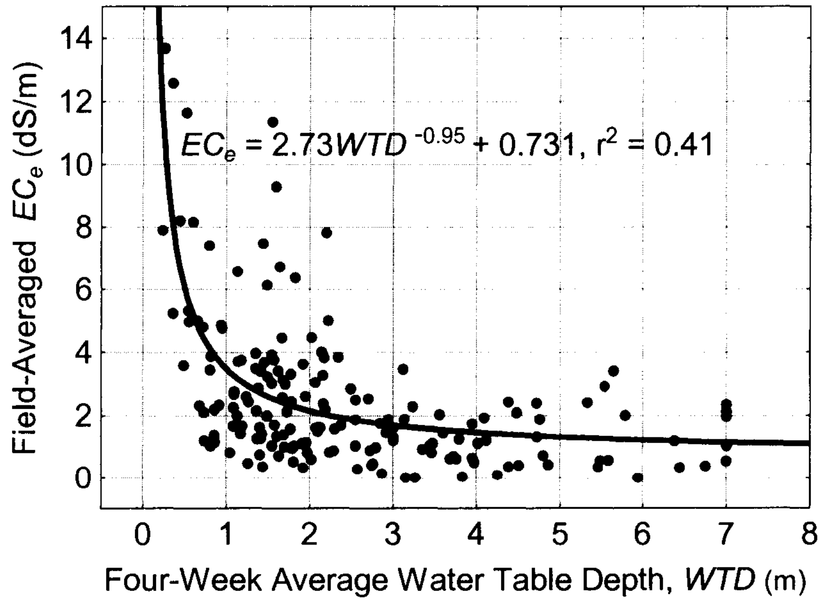

Figure 6-1. Soil water salinity (in terms of EC) versus 4-week average water table depth relationship

In regards to parameter uncertainty, a number of the required aquifer characteristic parameters are considered to be highly uncertain. In particular, the hydraulic conductivity (K), both horizontal and vertical, is known to vary spatially within the study area by several orders of magnitude. It is also known to vary not only with areal location, but also with depth in the aquifer. Because there are only a limited number of field measurements of this parameter available (15 deep K measurements and approximately 80 shallow K measurements), and because it is known to be highly variable, K was chosen to be one of the primary calibration parameters.

Related to the hydraulic conductivity is a parameter known as conductance (C) which, along with hydraulic head difference, controls the seepage flow into and out of the aquifer from the overlying surface water features. The conductance value assigned to a feature (canal, ditch, or reservoir) is dependent upon the shallow hydraulic conductivity, the feature's physical dimensions, and the assumed thickness of the interacting soil layer. Approximately 50 cross-section surveys were measured in the field to help assign the physical dimensions to particular canals; however, a number of features were not easily measurable and the physical dimensions of specific features also varied significantly over the region. The thickness of the interacting soil layer could not be easily measured and was, therefore, assumed based on suggestions from the literature and judgments based on knowledge gained through field visits. Because of these compounding factors, the prescribed C values were considered to be very uncertain, and therefore, this parameter also was used as one of the primary groundwater flow model calibration parameters.

Another uncertain parameter that was adjusted at some locations during model calibration is the aquifer thickness. Across the study area, there were a limited number of measurements of the bedrock depth. Also, although there were considerable surface elevation data available (+1000 points), the undulating terrain of the area (particularly near the boundary of the alluvium) makes the value of the surface elevation somewhat ambiguous for specific locations. Therefore, it was recognized that the aquifer thickness is a moderately uncertain parameter, and it was chosen as one of the allowable calibration parameters for the groundwater flow model.

The main model input parameters, which include the aquifer recharge, evapotranspiration (upflux) components, and the hydraulic head of the surface features/aquifer boundaries, were considered to contain a lesser degree of uncertainty than the aquifer parameters already mentioned. In the cases of recharge and evapotranspiration, their estimation was based in large part on known variables (crop type, meteorological data, canal diversions) or on variables that could be reasonably estimated (irrigation efficiency, leaching fraction, extinction depth). In the case of hydraulic head, a large number of direct field measurements using GPS surveying techniques were made and, due to the linearity of most surface features, the spatial variability could be captured with a high degree of confidence through simple interpolation. Thus, it was decided that the main model input parameters would not be included for adjustments during model calibration.

For the transient groundwater flow model, the aquifer parameters that affect the temporal variation in flow were also considered as potential calibration parameters. The specific yield (S_y) of the unconfined model layer was estimated from county-wide soil texture maps produced by the Natural Resources Conservation Service (formerly the Soil Conservation Service). Although not directly equivalent to S_y, the available water capacity (AWC) shown in this soil report was used to capture the estimated spatial variability in storage properties over the area on a cell-by-cell basis. This defined spatial variability was maintained throughout calibration; however, the assumed ratio between S_y and AWC was varied as part of the calibration process. The spatial variability of the AWC was also used to help define the storativity parameters of the confined portions (i.e. deep layer) of the aquifer. Again, a ratio was assumed and was varied during calibration.

In addition to considering the uncertainty of important modeling parameters, groundwater flow model runs were performed to evaluate the sensitivity of model results to variations in the magnitude of parameter values. A systematic set of model runs was conducted where specific parameters were incrementally varied. Results from these runs were then compared to see which parameters had the most relative impacts on model predictions. Because it had already been decided that modeling inputs (i.e. recharge estimates, evapotranspiration estimates, surface water levels, etc.) were not going to be varied for model calibration, these were excluded from the sensitivity analysis. Results from this analysis confirmed that hydraulic conductivity (K_H and K_V), conductance (C), and S_y values are significant in determining model output and would be valuable as the primary flow model calibration parameters. In a relative sense, K_H had the most impact on model output. Sample sensitivity run results are shown in Table 6-3.

As noted previously, for calibration of the groundwater salinity model, the focus of the effort was identification of salinity sources related to the dissolution of salts from the soil materials. Through field investigation and from the published literature, it was initially suspected that this natural salt source was significant. This was verified through initial

Table 6-3. Sample Sensitivity Analysis Results

	Change in Predicted Average Water Table Elevation (m)					
Time Step	Baseline	S_y (50% decrease)	S_s (50% decrease)	S_s (50% increase)	K_v layer 1 (100% increase)	K_H layer 1 (100% increase)
1	-	-0.231	0.000	0.000	0.008	-0.296
2	-	-0.329	0.000	0.000	-0.055	-0.318
3	-	-0.422	0.000	0.000	-0.095	-0.377
4	-	-0.397	0.000	0.000	-0.121	-0.430
5	-	-0.330	0.000	0.000	-0.097	-0.452
6	-	-0.438	0.000	0.000	-0.170	-0.478
7	-	-0.482	0.000	0.000	-0.177	-0.486
8	-	-0.432	0.000	0.000	-0.172	-0.469
9	-	-0.447	0.000	0.000	-0.205	-0.465
10	-	-0.482	0.000	0.000	-0.239	-0.492
11	-	-0.396	0.000	0.000	-0.209	-0.466
12	-	-0.410	0.000	0.000	-0.219	-0.482
13	-	-0.396	0.000	0.000	-0.226	-0.516
14	-	-0.399	0.000	0.000	-0.231	-0.517
15	-	-0.407	0.000	0.000	-0.235	-0.493
16	-	-0.341	0.000	0.000	-0.233	-0.526
17	-	-0.389	0.000	0.000	-0.238	-0.518
18	-	-0.424	0.000	0.000	-0.262	-0.618
19	-	-0.390	0.000	0.000	-0.249	-0.606
20	-	-0.399	0.000	0.000	-0.254	-0.630
21	-	-0.376	0.000	0.000	-0.261	-0.660
22	-	-0.351	0.000	0.000	-0.251	-0.722
23	-	-0.370	0.000	0.000	0.762	-0.739
24	-	-0.362	0.000	0.000	-0.218	-0.758
25	-	-0.383	0.000	0.000	-0.229	-0.796
26	-	-0.332	0.000	0.000	-0.162	-0.813
27	-	-0.338	0.000	0.000	-0.172	-0.855
28	-	-0.362	0.000	0.000	-0.188	-0.920
29	-	-0.422	0.000	0.000	-0.198	-0.968
Average Change =		-0.387	0.000	0.000	-0.158	-0.582

model runs which indicated that there was a large discrepancy between the observed groundwater salinity values and results of modeling that omitted the natural salt source. The main objective of the groundwater salinity calibration process was to quantify this discrepancy spatially and temporally in such a way that would produce results that would satisfy modeling goals. Besides quantifying the natural salt dissolution source, the aquifer storage parameters were considered as potential groundwater salinity model calibration parameters; however, except for a few isolated cases, their variation (within the acceptable range of values) did not significantly impact model results. Additionally, variation of the salt leaching efficiency within the unsaturated zone module had significant impact on the groundwater salinity results.

For calibration of the unsaturated zone salinity model, it was initially understood that the results are highly dependent upon the key parameters contained within the soil water and salt balances. For the soil water balance, the inputs and outputs are defined by the groundwater flow model input (recharge and associated irrigation depth) and output (upflux); however, the storage volume, as defined by the effective porosity (θ_{eff}), was uncertain and was used as one of the main unsaturated zone model calibration parameters. To facilitate the calibration effort, it was assumed that the spatial distribution of this parameter was identical to the AWC values taken from the soils report. After initial estimates (based on the published literature) were input according to this distribution, a universal soil water volume scaling factor (SW_{adj}) was incorporated into the unsaturated zone module code. This factor was then varied as one of the primary soil salinity model calibration parameters.

For the salt balance calculations, inputs and outputs were controlled by results from the groundwater salinity model and by the direct input of irrigation water salinity and initial soil salinity. The most uncertain parameter incorporated into the unsaturated zone model, however, is the salt leaching efficiency (E_L). This parameter describes the efficiency with which applied irrigation water leaches the pores in the unsaturated zone (deep percolation) and transports soil salts into the aquifer system. This parameter was assigned using the random numbers that were assigned to each field polygon during the recharge depth calculation along with an assumed distribution of values based on the published literature. Similar to the soil water volume adjustment, these values were scaled uniformly by a factor during calibration. Additionally, unsaturated zone model results were found to be sensitive to the assumed initial soil salinity conditions. Therefore, these conditions also were varied (using a uniform factor) as one of the main unsaturated zone model calibration parameters.

During the calibration process, an emphasis was placed on maintaining all calibration parameters within physically-realistic ranges of values. This helped to insure that the model performance outside of the conditions experienced during the calibration period would be realistic and, hopefully, accurate to similar degrees achieved during calibration. Based on collected field data and on values found in the published literature, the ranges of values for the primary calibration parameters presented in Table 6-4 were established. Subsequently, all calibration parameter values were maintained within their specified range. Because of the interconnected nature of the three employed models, variation of a

Table 6-4. Primary Calibration Parameters and Corresponding Range of Values

Model Parameter	*Range of Values*
Layer 1 Horizontal Hydraulic Conductivity	0.001 – 10.25 m/day
Layer 1 Vertical Hydraulic Conductivity	1:2 – 1:20 ratio of Horizontal Hyd. Cond.
Layer 2 Horizontal Hydraulic Conductivity	13 – 625 m/day
Layer 2 Vertical Hydraulic Conductivity	1:2 – 1:20 ratio of Horizontal Hyd. Cond.
Layer 1 Saturated Thickness	0.1 – 6 m
Layer 2 Saturated Thickness	2 – 30 m
Conductance (River and GHB Packages)	0 – 12,100 m^2/wk/m
Specific Yield	0.05 – 0.31
ET Extinction Depth	0.2 – 4.5 m

calibration parameter value within one model had impacts on all three models' calibrations. Therefore, as mentioned previously, the model calibration process was performed iteratively, with the final resulting models being those that produced results best fulfilling all calibration targets simultaneously.

6.1.3 History Matching

Evaluation of the effectiveness of the model calibrations depended largely on the history matching process. This process involved varying the identified calibration parameter values on a trial and error basis to achieve the established calibration targets evaluated over a defined historical period. For the presented research, this historical calibration period extended from April 1999 to mid-July 2000 (i.e. time steps 1 – 67 of the models). In addition to this calibration period, a test period was defined from mid-July 2000 to late October 2001 (i.e. time steps 68 – 133 of the models) that was used to test model performance in light of observed data.

The history matching step of the calibration process consisted of two distinct components: the quantitative and qualitative analyses. The quantitative analysis involved the testing of the current model calibration by considering the numerical deviation of the modeling results from the defined calibration targets. During this analysis, the goal of varying the calibration parameter values was to achieve the best possible numerical results. During the qualitative analysis, however, model performance was evaluated subjectively based on the researcher's experience in the field and knowledge gained from previous studies and from other available literature and/or field data. Therefore, the final model calibration may not necessarily represent the calibration that achieved the best numerical results, but, instead, is the calibration that the researcher judged to be the best overall representation of true system behavior. The final calibration results are presented mainly in terms of the quantitative results; however, there is additional discussion provided of some of the qualitative decisions that influenced the final model calibrations.

6.2 CALIBRATION RESULTS

As stated previously, the model calibration process was performed progressively, beginning with the calibration of the steady-state groundwater flow model and continuing through the calibration of the transient groundwater flow, groundwater salinity, and soil salinity models. Accordingly, the calibration results presented below will focus first on the steady-state case and then on the calibration results of the subsequent transient expansion of the models.

6.2.1 Steady-State Model Calibration Results

The final steady-state groundwater flow model achieved an average water table depth that is within 0.28 m of the observed average based on 63 observation points temporally averaged over the 1999 irrigation season. This value is within the prescribed calibration target. Figure 6-2 gives a plot of the computed water table elevation versus the observed average water table elevation for the available data locations. From this figure, the good correspondence between the predicted and observed values is evident. Figure 6-3 shows the spatial locations of the calibration points and the associated deviation of the predicted water table elevation value. As seen on this figure, which shows the relative prediction error at each observation location (larger magnitude bar = larger error), the good spatial representation of the model predictions is demonstrated.

The steady-state groundwater flow model calibration was evaluated with consideration to predicted canal seepage in addition to predicted water table elevation. Table 6-5 shows the predicted seepage losses for the major canal systems. Recalling that the calibration target is 20%, the overall predicted seepage volume, which represents 19.4% of total average diversions, was judged to be satisfactorily close to the target. Also, the range of values (10.8 – 23.6%) predicted for the individual canal systems was deemed to be acceptable. The predicted groundwater return flow volume within the modeled river reaches ranged from 28 – 84% of the measured streamflow volume. The overall total return flow volume predicted was 32.4% of the recorded streamflow. This value was considered to be acceptably close to the 50% target defined for calibration.

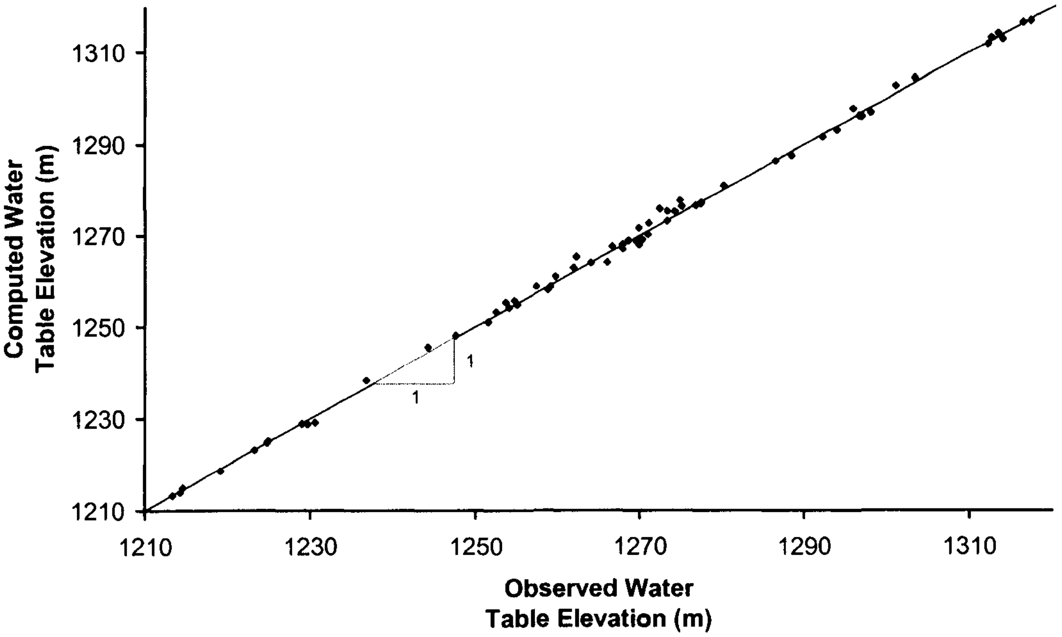

Figure 6-2. Steady-state model calibration results – Water table elevation

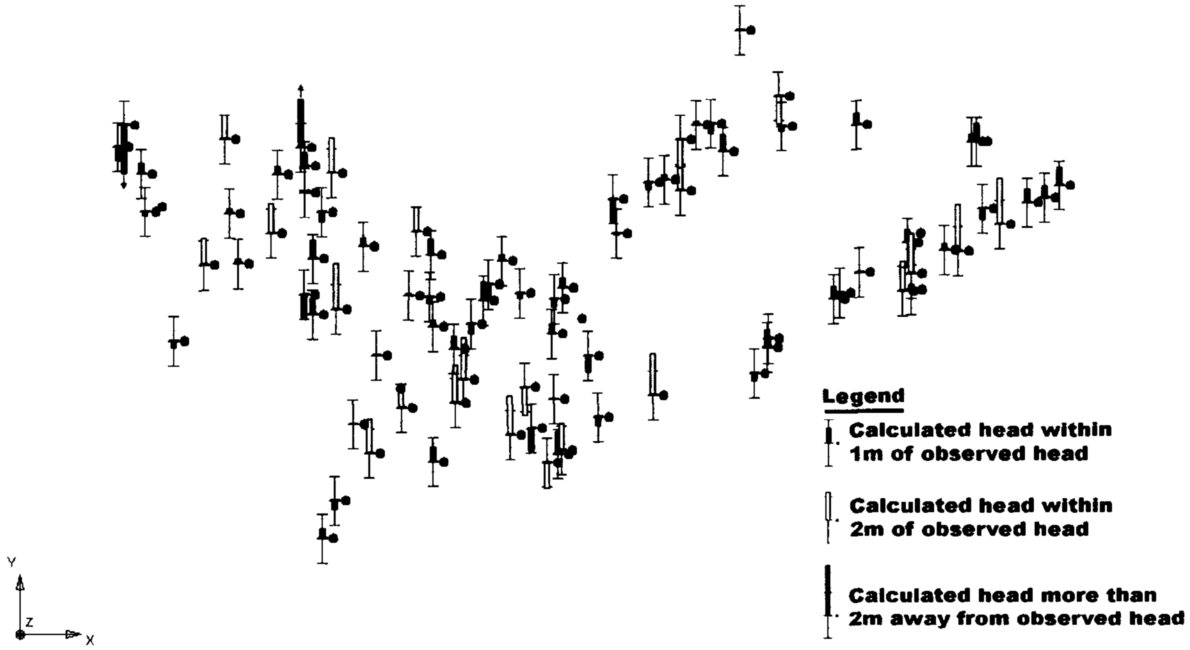

Figure 6-3. Steady-state model calibration results – Water table elevation spatial view

Table 6-5. Steady-State Model Predicted Canal Seepage

Canal System	*Seepage (% of Total Diversion Volume)*
Rocky Ford Highline	18.9
Catlin/Otero	21.9
Rocky Ford	10.8
Holbrook	16.8
Fort Lyon	23.5
Fort Lyon Storage	23.6

The steady-state groundwater salinity model was not tested in great detail since it does not approximate salt transport (as in the transient case); however, it was used to check the salinity sink/source definition. From initial results, it was apparent that there were conceptual model inadequacies. Figure 6-4 shows the initial discrepancy between the steady-state predicted groundwater salinity and the observed average values. This discrepancy suggested that the suspected source from dissolution of salts in the soil

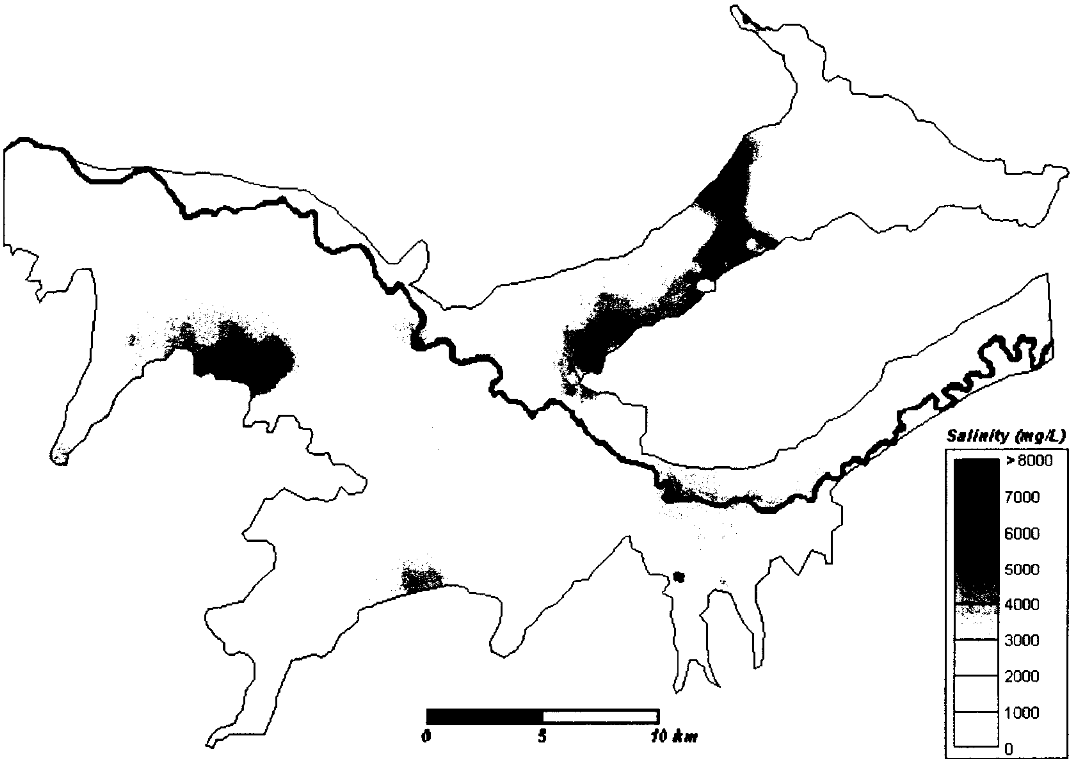

Figure 6-4. Steady-state salinity model – Initial estimated under-prediction of values

layers/bedrock was significant and needed to be included in the groundwater salinity transport model. Overall, the steady-state groundwater flow model calibration process achieved the desired calibration targets and provided valuable insight for specification of a number of calibration parameters for the transient model case. Additionally, the steady-state groundwater salinity model calibration revealed the need for conceptual model changes.

6.2.2 Transient Model Calibration Results

The results of the transient modeling calibration effort are presented below along with model results achieved over the validation period. The results of the final models' ability to achieve regional average calibration targets are presented first, followed by results of the model calibration at specific observation locations, and, lastly, the results of the additional calibration checks including canal seepage volume, groundwater return flow volume, and the soil salinity versus water table depth relationship.

In general, the final model performed well in meeting the defined regional average calibration targets. The predicted water table elevation averaged spatially and temporally over the calibration period resulted in a residual from the observed of -0.151 m. This was within the target value of ± 0.3 m. The resulting absolute value of the residuals was 0.997 m, which was just inside the target value of 1.0 m. During two time steps within the calibration period, the model did not meet the target set for the maximum allowable spatial average deviation for a single time step (± 1.0 m). Time step 47 (Feb. 17 – 23, 2000) resulted in an average residual of –1.61 m, and time step 52 (March 23-29, 2000) resulted in an average residual of –1.31 m. Because these time steps are within the less important non-irrigation season, and because their residuals could not be reduced further without violating the assumptions of the employed calibration strategy, it was decided that the predicted deviations in regional water table elevation for these two time steps were acceptable. The maximum allowable spatial average deviation target was met, however, in all other time steps (irrigation and non-irrigation seasons) within the calibration period.

Figure 6-5 gives a plot of the temporally-averaged computed water table elevation versus the observed average water table elevation for the available data locations. From this figure, which omits the lowest confidence level wells, the good correlation between simulated and observed is apparent. Figure 6-6 shows a map of the average simulated water table residual at all well locations. The magnitudes of the bars on this figure indicate the relative magnitudes of the individual calculated residuals at the wells. Green bars represent well locations where the residual value was within ± 1.0 m; yellow bars represent well locations where the residual value was within ± 2.0 m; and, red bars represent well locations where the residual value was outside of ± 2.0 m. The position of the bar as above or below the horizontal axis indicates if the predicted value of water table elevation at that location was, on average, above or below the observed value. From this figure, the generally good spatial match of the model predictions during the calibration period is demonstrated. The spatial distribution of well locations where a good match was not achieved (many of which were classified as low confidence level locations) reveals that there is not an obvious spatial bias trend. Appendix J gives

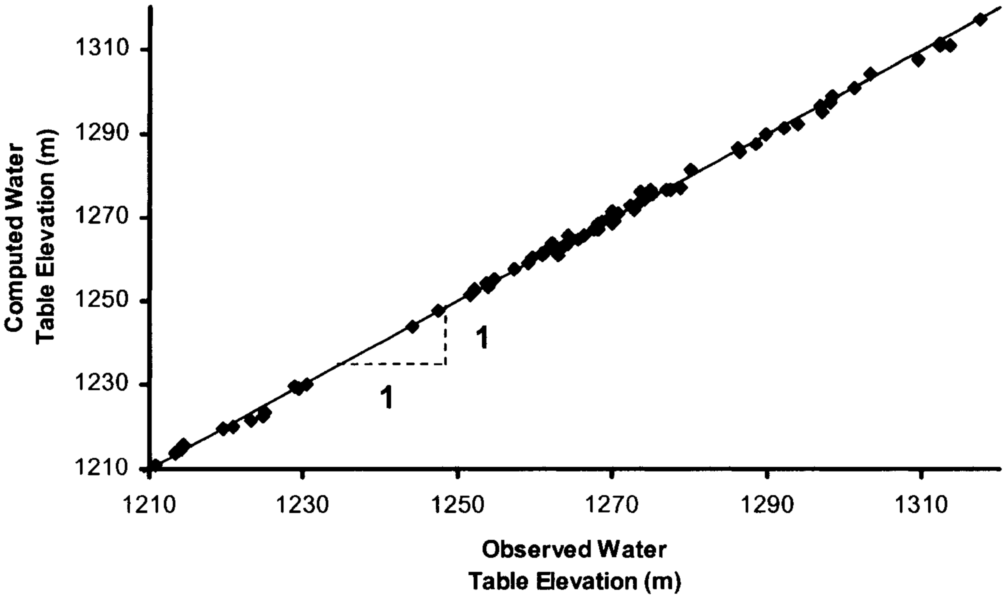

Figure 6-5. Calibration results – Water table elevation

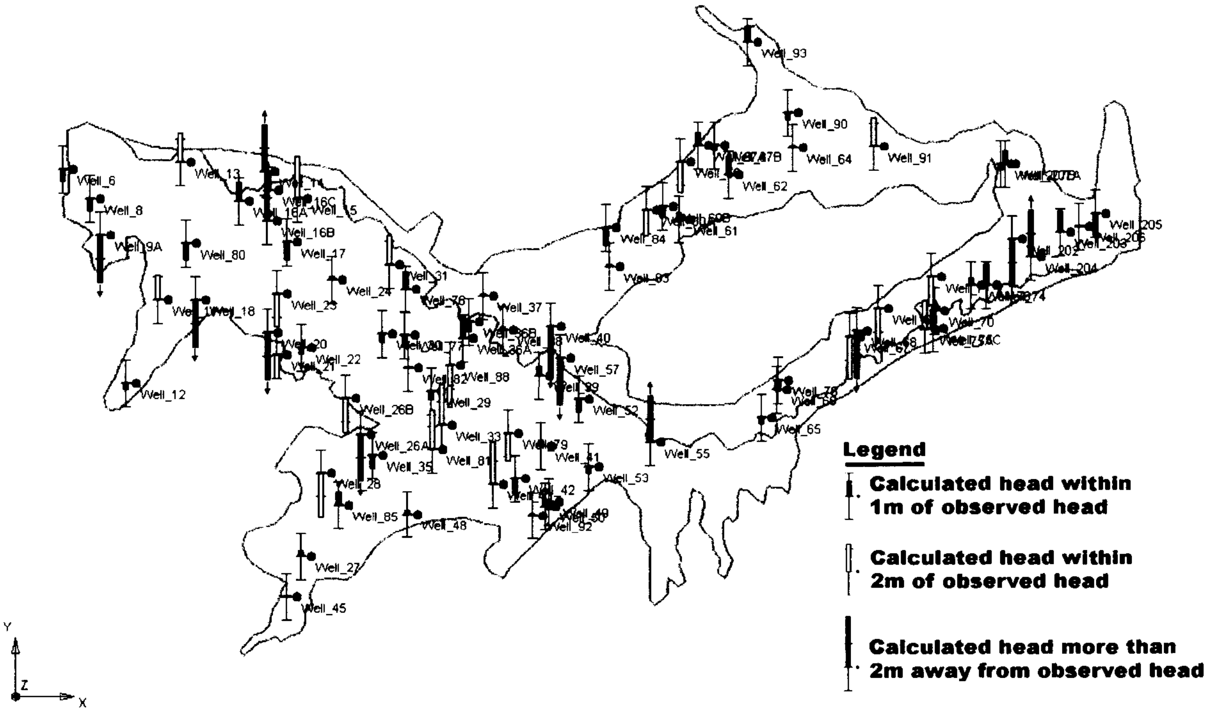

Figure 6-6. Calibration results – Water table elevation spatial view

additional spatial plots of the model calibration results for all observed time steps within the calibration period.

The groundwater salinity model calibration also produced results that generally met regional average calibration targets. The final predicted groundwater salinity, averaged spatially and temporally over the calibration period, resulted in a residual from the observed of -48.5 mg/L. This was within the target value of ± 100 mg/L. The absolute value of the residuals was 797 mg/L, which is inside the target value of 850 mg/L. During one time step within the calibration period, the model did not meet the target set for the maximum allowable spatial average deviation for a single time step (± 500 mg/L). Time step 65 (June 24 – 30, 2000) resulted in an average residual of -508 mg/L, which is very near the calibration target. Because this value is so near the target and because it could not be reduced further without violating the assumptions of the employed calibration strategy, it was decided that the predicted deviation was acceptable. The maximum allowable spatial average deviation target was met, however, in all other time steps within the calibration period.

Figure 6-7 gives a plot of the temporally-averaged computed groundwater salinity versus the observed average groundwater salinity for the available data locations. From this figure, which omits the lowest confidence level wells, the good correlation between simulated and observed is apparent. Figure 6-8 shows a map of the average simulated groundwater salinity residual at all well locations. The magnitudes of the bars on this figure indicate the relative magnitude of the individual calculated well residual. Green

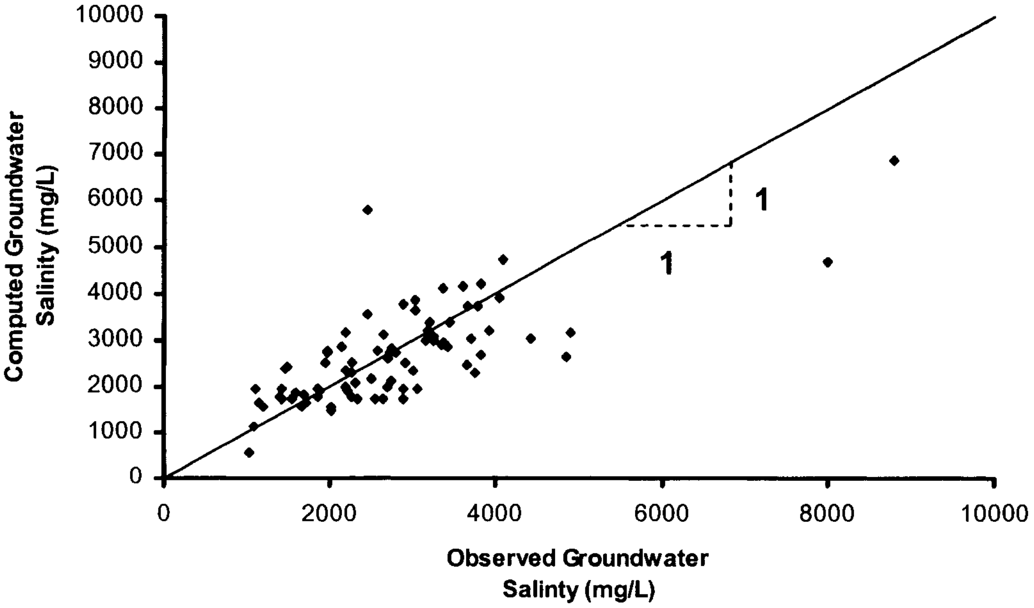

Figure 6-7. Calibration results – Groundwater salinity

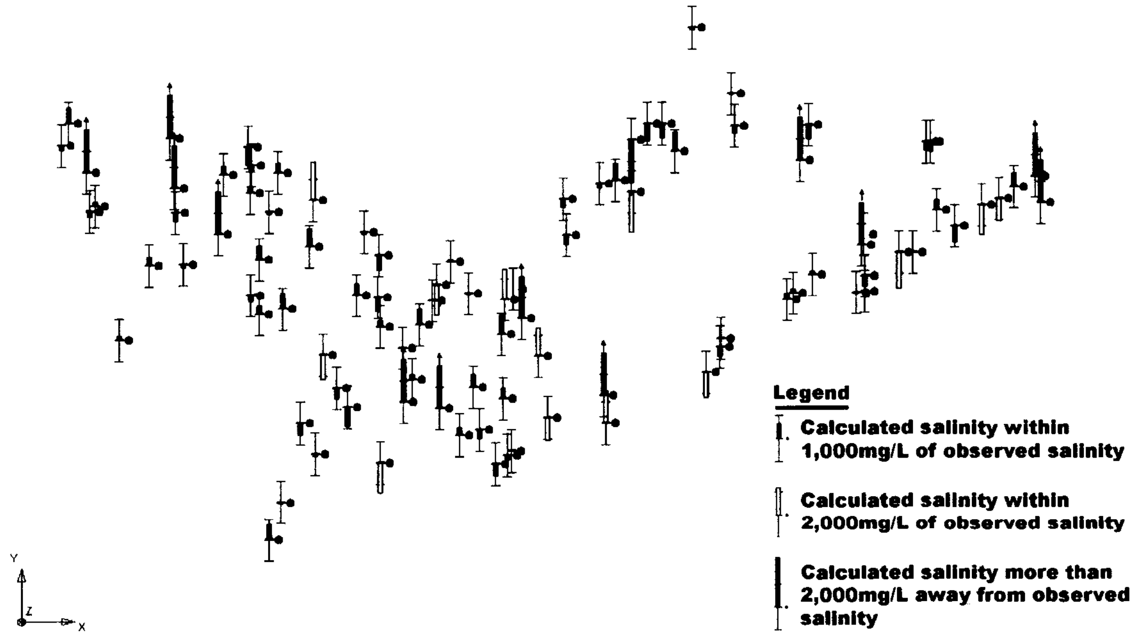

Figure 6-8. Calibration results – Groundwater salinity spatial view

bars represent well locations where the residual value was within ± 1000 mg/L; yellow bars represent well locations where the residual value was within ± 2000 mg/L; and, red bars represent well locations where the residual value was outside of ± 2000 mg/L. The position of the bar (above or below the horizontal axis) indicates if the predicted groundwater salinity at that location was, on average, above or below the observed. From this figure, the generally good spatial match of the model predictions during the calibration period is demonstrated. The spatial distribution of well locations where a good match was not achieved (many of which were classified as low confidence level locations) reveals that there is not an obvious spatial bias trend. Appendix K gives additional spatial plots of the model calibration results for all observed time steps within the calibration period.

The unsaturated zone model produced final baseline soil salinity predictions that, on the regional average scale, fulfilled the desired calibration targets. For the Early Season 1999 observation (May 31 – June 18, 1999), the average residual between the predicted and the observed values at 61 field locations (with 60 – 120 measurements per field) was –173 mg/L. This value is well within the calibration target of ± 1000 mg/L. The mean absolute value of these residuals was 660 mg/L. The standard deviation of the residuals was 1088 mg/L. A plot of the simulated values versus the observed for the Early Season 1999 reading is given in Figure 6-9. From this plot, it is apparent that the calibration of the unsaturated model could not achieve the same level of matching as the water table depth or the groundwater salinity; however, given the much higher degree of uncertainty related to this model and its associated data, as well as the simplifying assumptions made

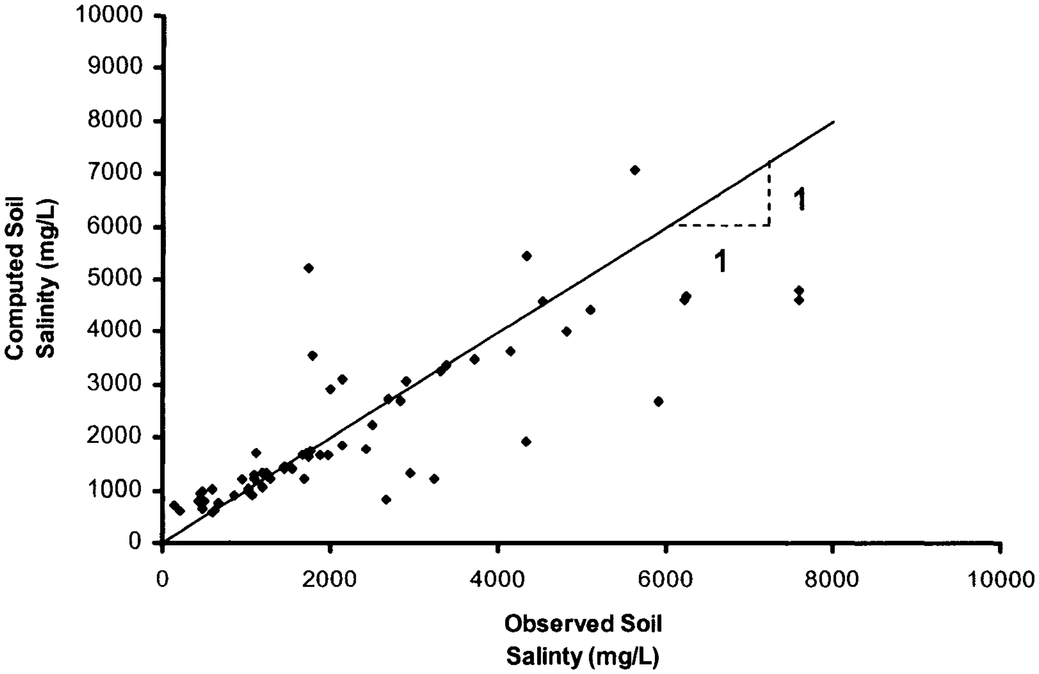

Figure 6-9. Calibration results – Soil water salinity: early season 1999

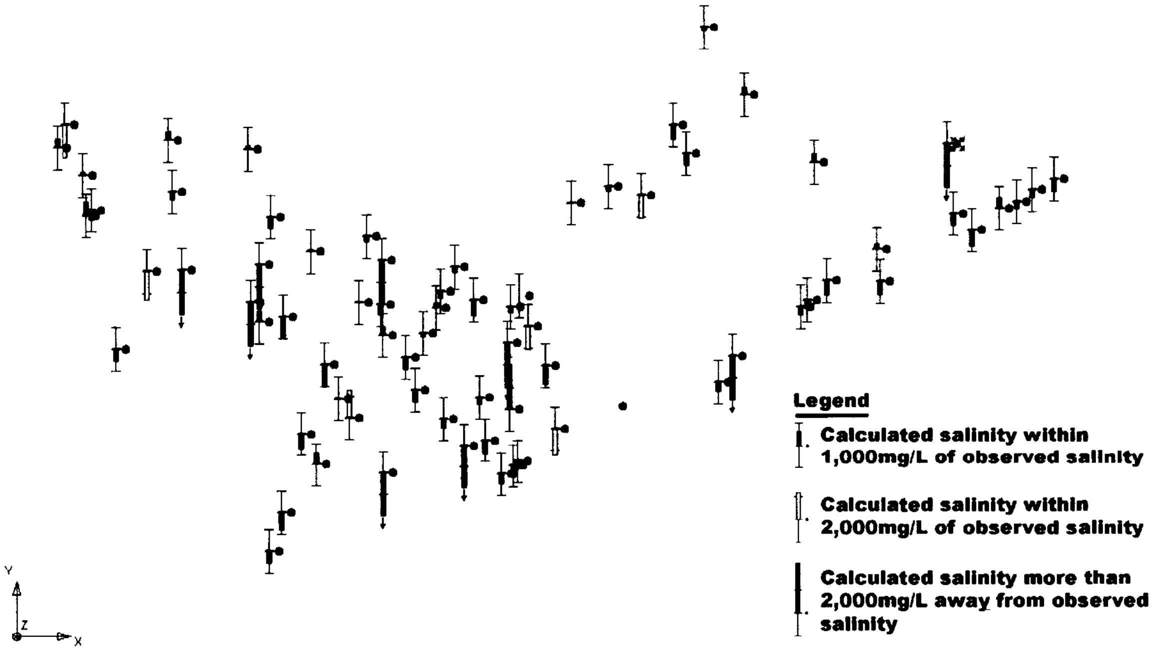

Figure 6-10. Calibration results – Soil water salinity spatial view: early season 1999

in the unsaturated zone model formulation, this is not surprising. Figure 6-10 shows a map of the residuals that gives a sense of the spatial distribution of model performance. The magnitudes of the bars on this figure indicate the relative magnitude of the individual calculated residual. Green bars represent locations where the residual value is within ± 1000 mg/L; yellow bars represent locations where the residual value is within ± 2000 mg/L; and, red bars represent locations where the residual value is outside of ± 2000 mg/L. The position of the bar (above or below the horizontal axis) indicates if the predicted soil salinity at that location was, on average, above or below the observed.

For the Late Season 1999 observation (August 10 – 18, 1999), the average residual between the predicted and the observed values at 61 field locations (with 60 – 120 measurements per field) was -565 mg/L. This value is within the calibration target of ± 1000 mg/L. The mean absolute value of these residuals was 1154 mg/L. The standard deviation of the residuals was 1676 mg/L. A plot of the simulated values versus the observed for the Late Season 1999 reading is given in Figure 6-11. From this plot, the under-prediction at higher salinity levels can be noted. Also, it is apparent that the estimated residuals of the unsaturated model tended to increase temporally. Figure 6-12 shows a map of the residuals for this observation period which gives a sense of the spatial distribution of model performance. The magnitudes of the bars on this figure represent the same relative values as is given on Figure 6-10.

For the Early Season 2000 observation (May 30 – June 8, 2000), the average residual between the predicted and the observed values at 68 field locations (with 60 – 120

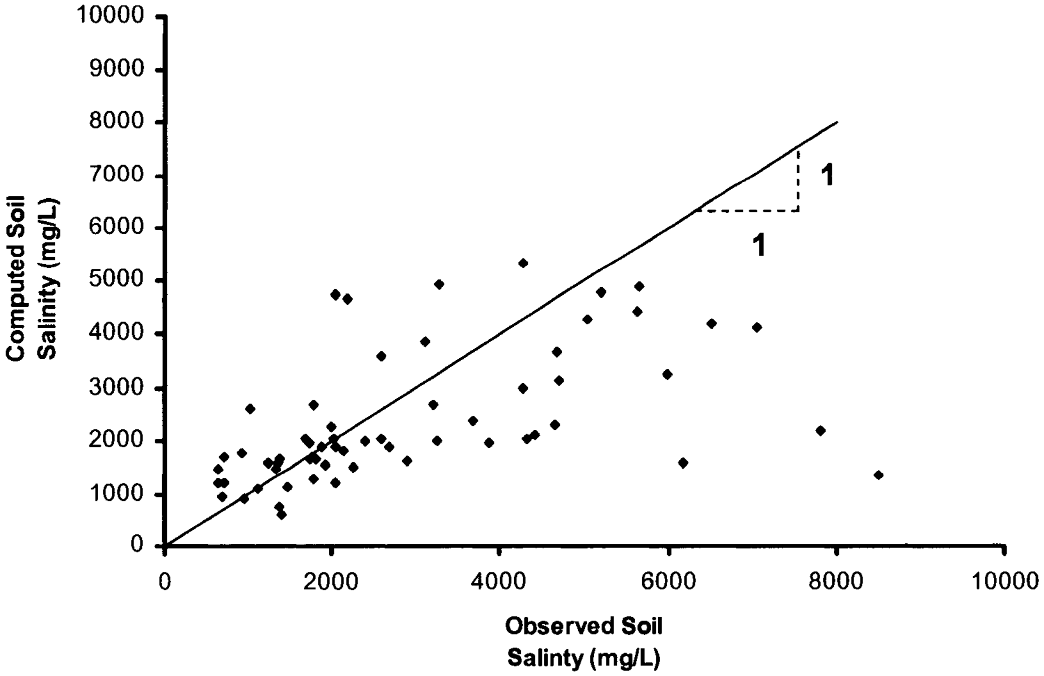

Figure 6-11. Calibration results – Soil water salinity: late season 1999

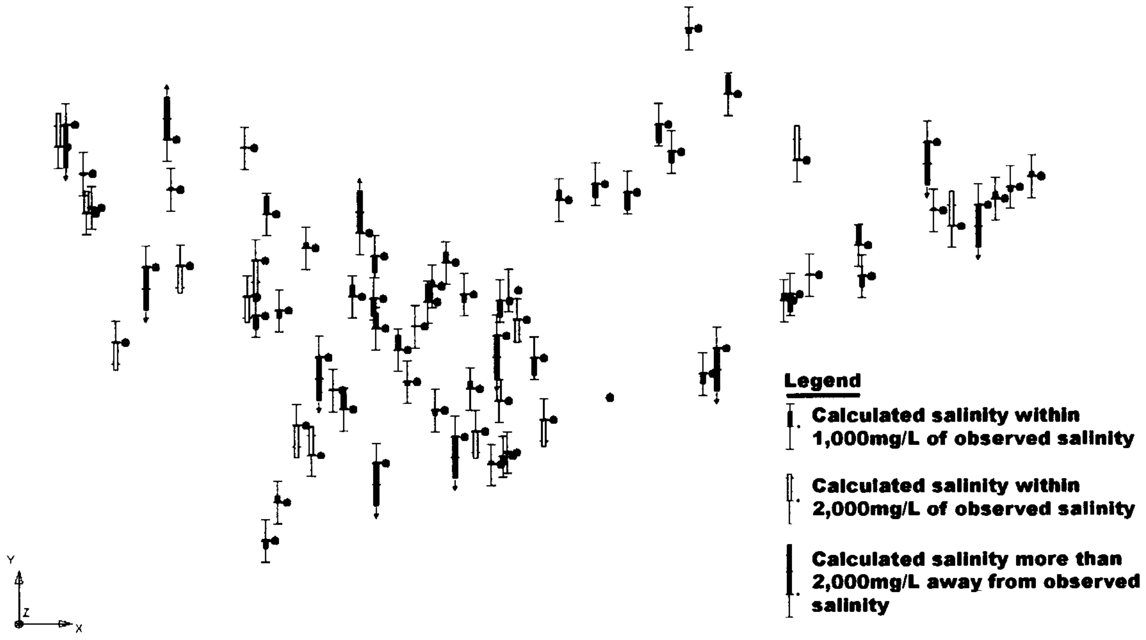

Figure 6-12. Calibration Results – Soil water salinity spatial view: late season 1999

measurements per field) was 361 mg/L. This value is within the calibration target of ± 1000 mg/L. The mean absolute value of these residuals was 1103 mg/L. The standard deviation of the residuals was 1425 mg/L. A plot of the simulated values versus the observed for the Early Season 2000 reading is given in Figure 6-13. From this plot, there is a noted under-prediction at higher salinity levels similar to what was achieved for the Late Season 1999 observation. It is also evident from this plot that the model values were over-predicted for observed locations with lower soil salinity levels. The under-prediction of higher values and the over-prediction of lower values appear to be, to some degree, a result of smoothing effects common to numerical models. Once again, it is apparent that the estimated residuals of the unsaturated model tended to increase temporally. Figure 6-14 shows a map of the residuals for this observation period which gives a sense of the spatial distribution of model performance. The magnitudes of the bars on this figure represent the same relative values as is given on Figure 6-10. As mentioned above, a comparison of the fitted frequency distribution of the observed data and the fitted distribution of the calibration output values was used as a qualitative check of the calibration performance for all models. For the groundwater flow model, the observed water table depth data over the entire calibration period yielded a best-fit distribution that was a Log-normal type. The mean of this distribution was 1.87 m, with a standard deviation of 1.07 m. The 20th percentile value is 1.00 m, and the 80th percentile has a value of 2.62 m. The simulated output from the final calibrated groundwater flow model resulted in data set which also has a Log-normal best-fit distribution. The mean of this distribution is 2.21 m, with a standard deviation of 1.73 m.

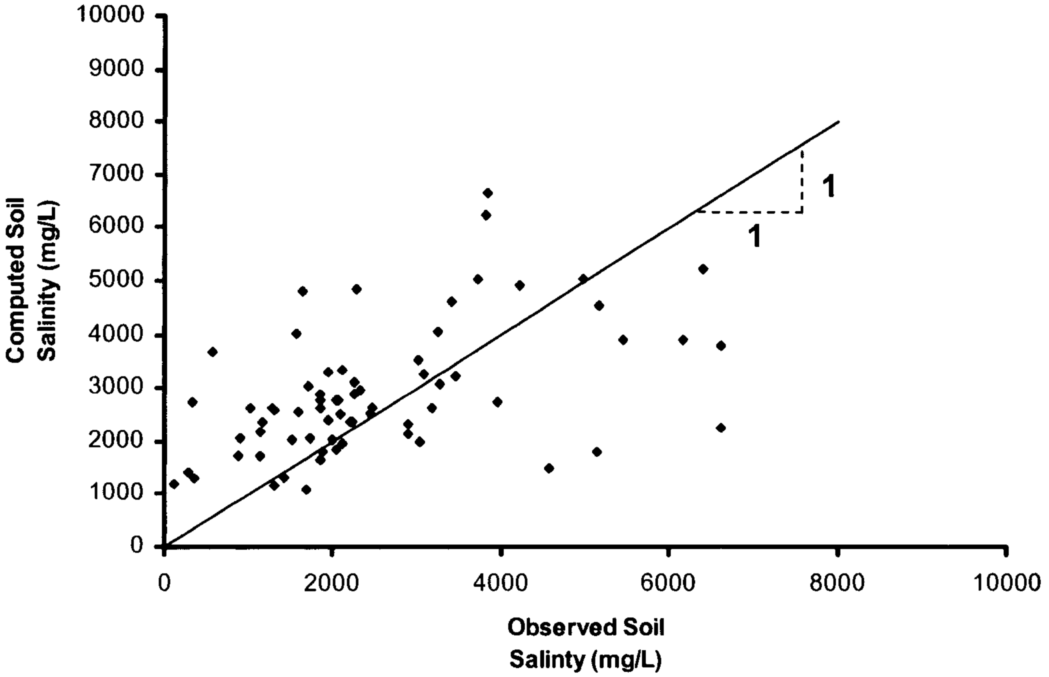

Figure 6-13. Calibration results – Soil water salinity: early season 2000

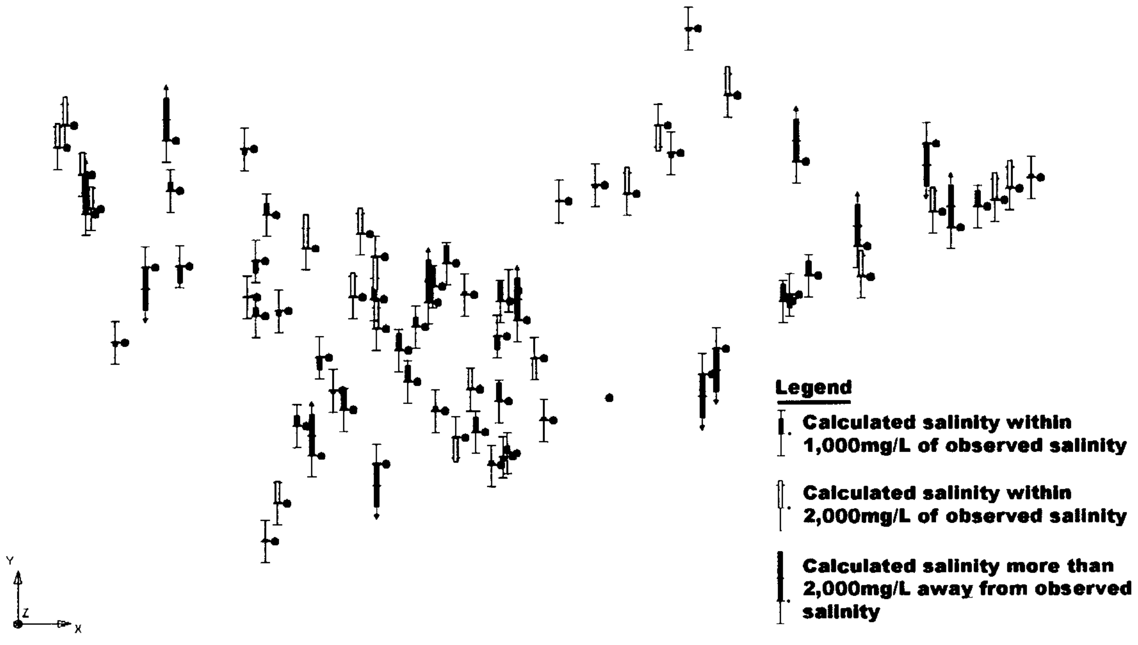

Figure 6-14. Calibration results – Soil water salinity spatial view: early season 2000

The resultant 20th percentile of this distribution is 0.90 m, and the calculated 80th percentile is 3.23 m.

Figure 6-15 shows the comparison of the two distributions. From this figure, the larger range of values predicted by the model than was observed in the field is evident. This is believed to be, in part, a result of the model predictions at some locations where there were suspected perched water table conditions. Because of these anomalous conditions, the model was intentionally allowed to predict values that were greater than the observed. Also, at some locations where deeper water table depths were observed, the observation well was often dry, thereby indicating that the water table was at some unknown depth below the bottom of the well. At these locations, the predicted depth values were intended to be greater than the depth of the bottom of the well for time steps when there was a dry reading (for some wells this was a large majority of the time); therefore, there was a tendency for the model to over-predict the depth when a non-dry reading was observed. Overall, the matching of the distributions between the observed and simulated values was considered good, and provided further evidence of a valid model calibration.

For the groundwater salinity model, the best-fit observed data distribution over the calibration period was a Log-logistic type with a mean of 2934 mg/L and a standard deviation of 2296 mg/L. The 20th percentile is 1618 mg/L and the 80th percentile is 3774 mg/L. For the simulated groundwater salinity predictions over the same period, the

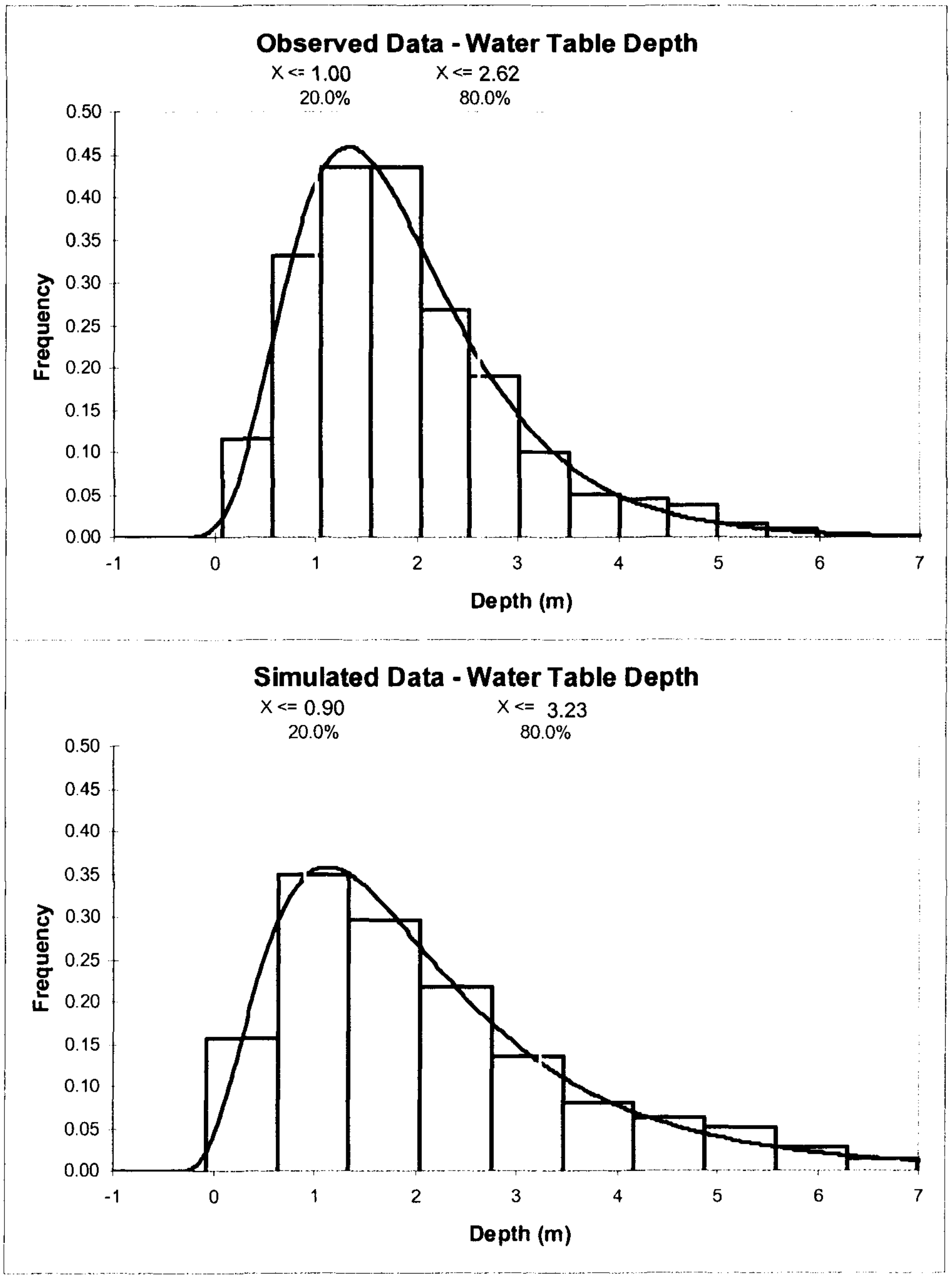

Figure 6-15. Comparison of the water table depth best-fit frequency distributions

best-fit distribution was also Log-logistic. The mean of this distribution is 2780 mg/L, and the standard deviation is 1505 mg/L. The 20th percentile is 1757 mg/L and the 80th percentile is 3531 mg/L.

Figure 6-16 shows the comparison of the two groundwater salinity distributions. In general, the two distributions look very similar, and the final conclusion was that the calibrated groundwater salinity model was performing well. One observation from the

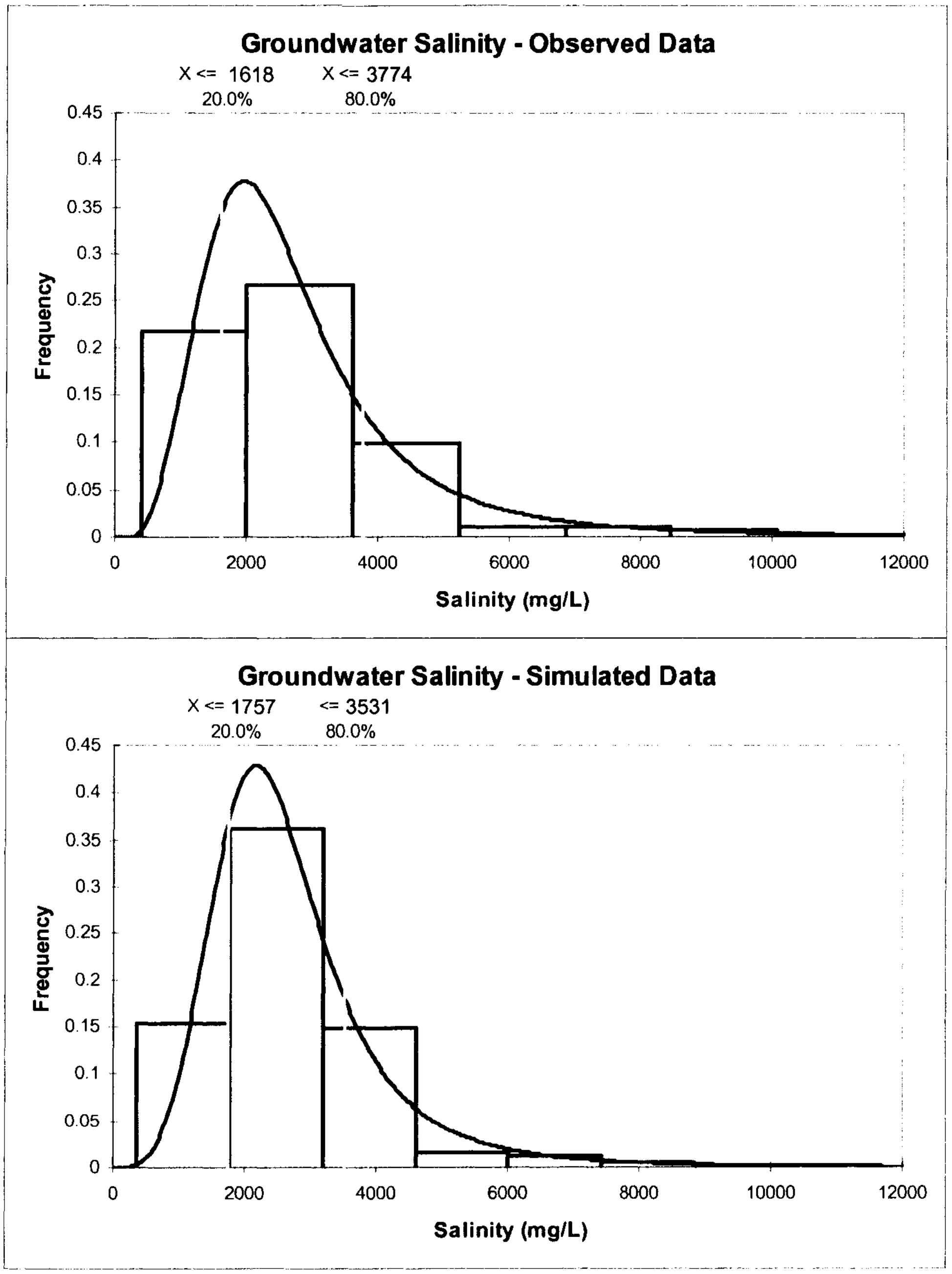

Figure 6-16. Comparison of the groundwater salinity best-fit frequency distributions

comparison of the two plots is the notable smoothing effect (resulting in a more peaked distribution) that is produced by the simulation. This is a common modeling phenomenon, and was not considered to be a problem particular to the final model calibration.

For the soil salinity model calibration, the best-fit distribution for the average observed data over the calibration period was an Inverse-Gaussian type with a mean of 2605 mg/L and a standard deviation of 1861 mg/L. The resultant 20th percentile for the observed soil salinity data is 1132 mg/L, and the 80th percentile is 3808 mg/L. For the simulated soil salinity data, the best-fit distribution was a Weibull type; however, the Inverse-Gaussian also provided a very good fit. Therefore, for comparison purposes, the Inverse-Gaussian distribution was used to represent the simulated data. This fit of the distribution results in a mean of 2497 mg/L and a standard deviation of 1433 mg/L. The estimated 20th percentile of the simulated data is 1350 mg/L, and the estimated 80th percentile is 3447 mg/L.

Figure 6-17 shows the comparison of the two distributions for the soil salinity observations and predictions. From this figure, the similarities between the two are evident; however, as seen in the groundwater salinity modeling, the smoothing effect is noted in the simulated data. From the histogram bars shown on the plots, it is noted that the simulation model could not capture the most extreme observations. Particularly, the model could not reproduce values that were below approximately 1000 mg/L and above

7000 mg/L. Overall, however, the comparison of the distributions provided confirmation that the calibrated model was performing as desired.

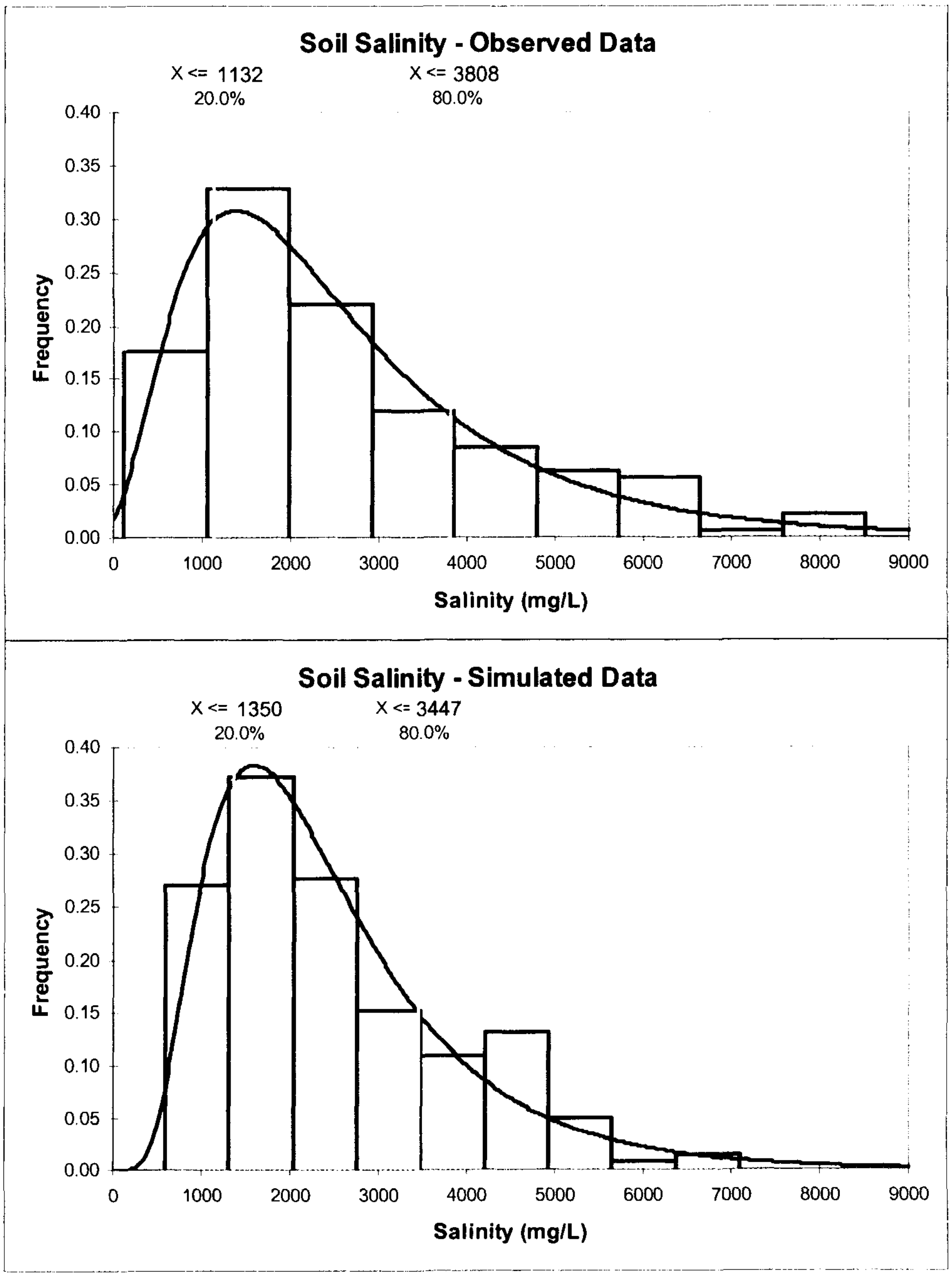

Figure 6-17. Comparison of the soil salinity best-fit frequency distributions

Besides using the frequency distributions of the observed and predicted values as a check of calibration model performance, the results at specific observation well locations were also considered. Again, since the overall goal of the modeling effort was to replicate conditions on the regional scale, more weight was given to the regional quantitative calibration targets; however, model performance at specific locations was checked to insure that there were not severe discrepancies at high-confidence locations. Criteria for model performance at specific sites were not established – instead, the evaluation was qualitative in nature.

Figure 6-18 gives example plots showing the observed and simulated values of the water table depth (shown in terms of water table absolute elevation) over the entire simulation period (calibration and validation periods). Each of the well locations shown is in the high-confidence category and were considered important for model calibration evaluation purposes. From Figure 6-18, it can be seen that model performance at these locations was good. At Well 36A, the simulated water table elevation in the cell containing the well tended to be slightly above the observed; however, the temporal variation is captured very well. Smoothing effects are notable at Well 49, but the overall average was generally replicated. Water table predictions in the cells containing Wells 50 and 90 tracked the observed well data throughout the entire simulation. Overall, the simulation results achieved in the cells containing most of the high-confidence well locations demonstrated that the model calibration was acceptable.

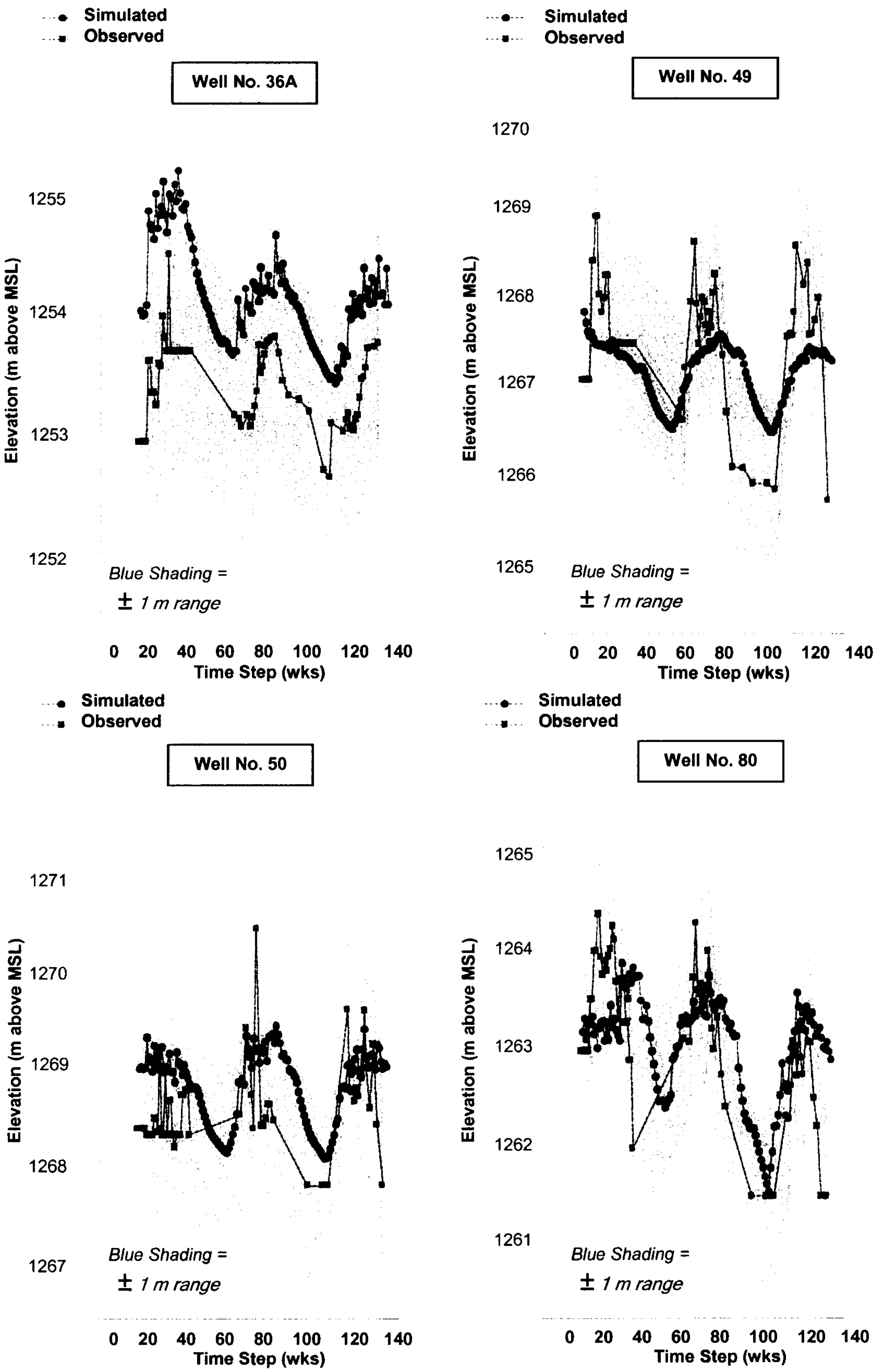

Figure 6-18. Sample plots of water table simulation at specific well locations

Figure 6-19 shows example plots of the groundwater salinity observed and predicted values for the same wells as in the previous figure. From these examples, the inherent modeling smoothing effects are evident in each case. Otherwise, the general temporal trends are captured to a degree that was considered appropriate for the modeling goals of the presented research. In the plot of the observed data for Well 90 there appears to be an anomalous point that occurs during the validation period. This point was ignored in the qualitative assessment of model performance at this location. These plots are representative of what was achieved at the other high confidence category observation points.

The final additional qualitative checks of the calibrated model performance included the check of simulated canal seepage volume, simulated return flow volume, and the output relationship between the predicted water table depth and soil water salinity. The final analysis of the predicted seepage rates of the modeled canal systems revealed that the simulated percentage of the total diversion volume lost to seepage ranged from 11.4 – 42.6%. The overall volumetric seepage rate over the calibration period was estimated as 20.8% of the total diversions. This value was very close to the seepage rate of 20% that was assumed during model formulation and was considered as a further qualitative indicator that the model calibration is appropriate. The predicted total return flow volume was evaluated for two main reaches along the Arkansas within the study area. For the reach between the Catlin canal diversion (near Manzanola) and Rocky Ford, the model-predicted groundwater return flow volume translates to 48.8% of the total recorded streamflow gain (which includes groundwater and surface water return flows).

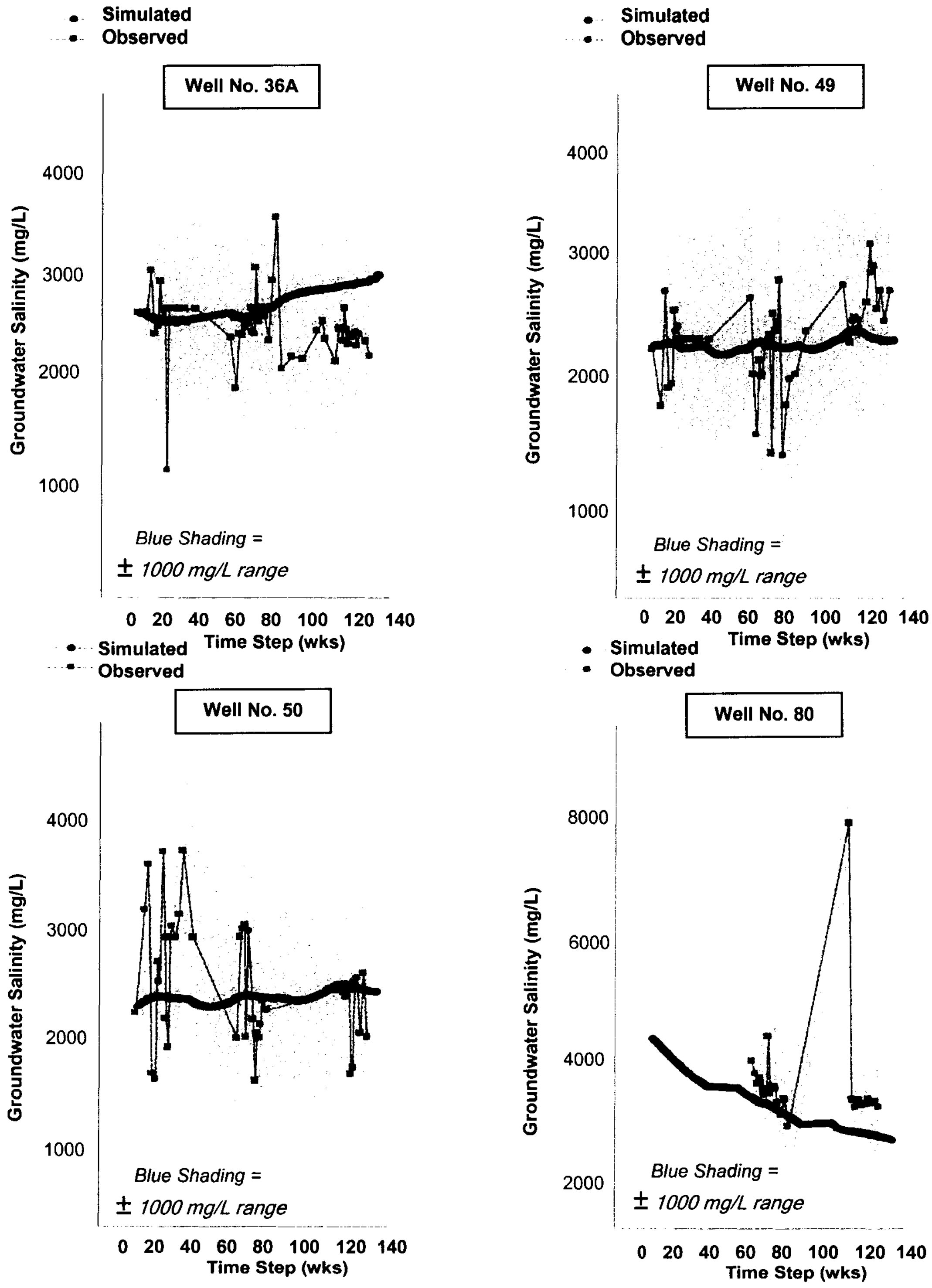

Figure 6-19. Sample plots of groundwater salinity simulation at specific well locations

For the reach between Rocky Ford and La Junta, this value was also estimated as 48.8%. The reach downstream of La Junta could not be analyzed due to large diversions upstream of the Las Animas streamflow gage. For the two reaches analyzed, however, the predicted return flow volumes were near the value of 50% that was considered a reasonable target; therefore, the predicted return flow volumes were considered to be further validation that the model calibration performs well.

The predicted water table depth-soil water salinity relationship was compared to the observed relationship as a final confirmation of an appropriate model calibration. Figure 6-20 shows the predicted soil water salinity versus the four-week average water table depth at the observed field locations for the entire calibration period. Also shown on this figure is the trendline developed from the observed data. From this figure, the general

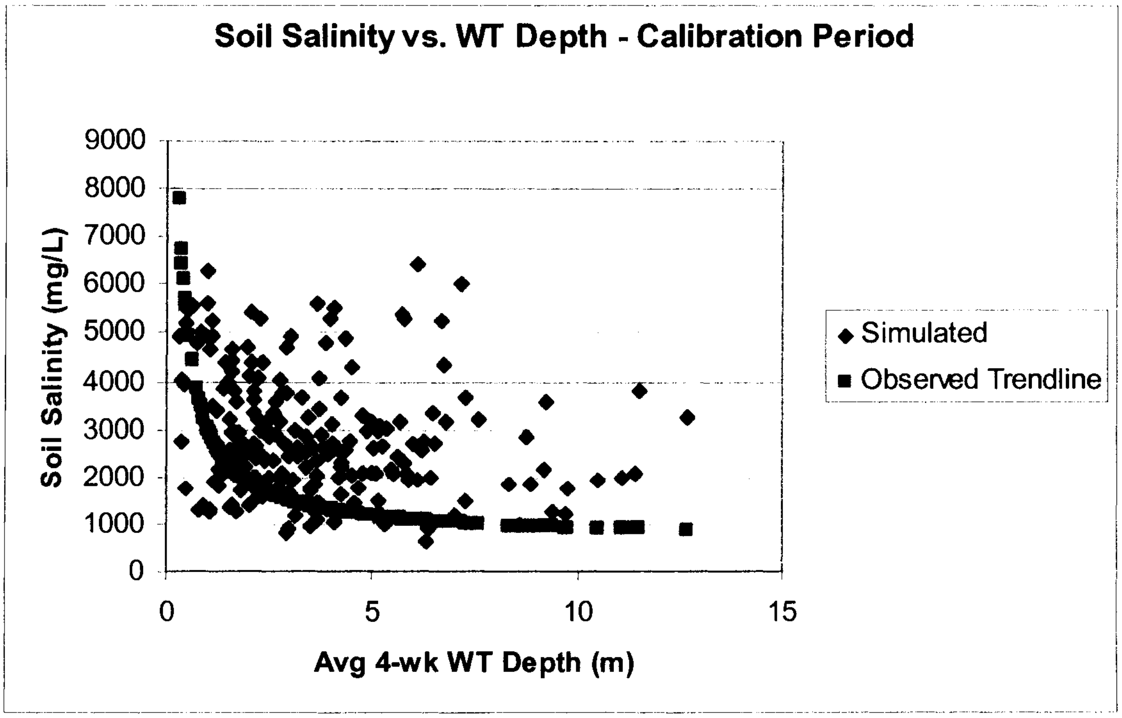

Figure 6-20. Simulated water table depth-soil salinity values at observed points

trend appears to be captured to a reasonable degree by the simulated results. When viewing a plot of all simulated points as shown in Figure 6-21, this trend in the simulated output becomes more apparent. Knowing that the points shown from the observed trendline represent a correlation coefficient (r^2 value) of only 0.32, it was not expected that the simulated relationship would be a strong one; however, it was expected that a similar nonlinear trend of decreasing soil water salinity with increasing water table depth would be evident. Note from Figure 6-21 that the model predicts several values of 9000 mg/L, which is the ceiling value that was specified in the unsaturated model formulation to prevent extreme model divergence at individual cells. Generally, cells where the simulated average seasonal value was 9000 mg/L were ones that received very small irrigation depths, and, therefore, the soil water volume remained very small (and thus the

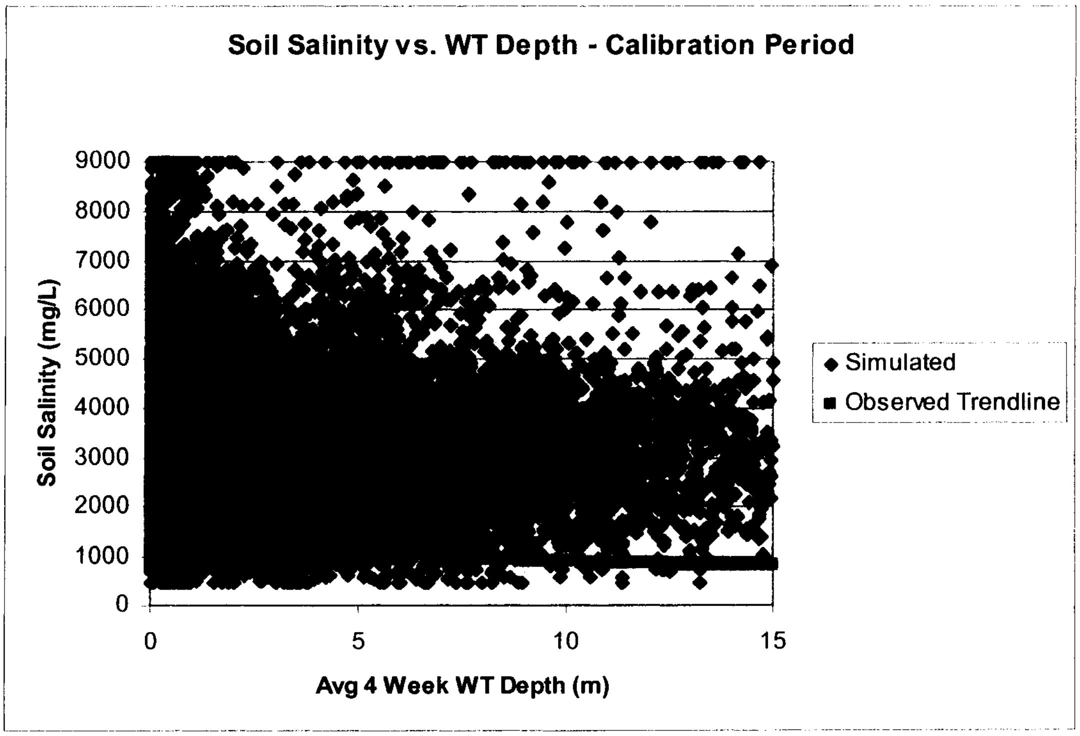

Figure 6-21. Simulated water table depth-soil salinity values at all simulated points (irrigated areas only)

salt concentration remained high). Ultimately, the water table depth-soil salinity relationship was considered to be further qualitative confirmation that the calibrated simulation models were operating as intended.

6.3 TEST PERIOD RESULTS

To insure that model performance was not affected by over-specification of model parameters to the unique conditions that existed over the calibration period, a test period was specified over which model results could be analyzed. A properly calibrated model should produce results over the test period that are similar to those achieved over the calibration period. Large differences in results may indicate that the model calibration should be rejected or that there are significant conceptual problems in model formulation. Table 6-6 gives a summary of the test results compared to the results achieved over the calibration period for the important calibration target categories. From this table, the similarity of the results achieved over the validation period can be seen. For the soil water salinity, there was a notable increase in the resultant residuals; the likely reasons for this positive drift are discussed in detail in Chapter 4 (the second journal article) and in the final chapter (Conclusions and Recommendations) of this document. Besides comparing test results of the major calibration target categories, the qualitative calibration targets also were checked over the test period. All results evaluated yielded model performance that was considered similar to that achieved during calibration; therefore, the test period provided confirmation of an appropriately calibrated set of models.

Table 6-6. Summary of Test Period Results

Calibration Target	Calibration Period	Test Period
WT Depth Average Residual (m)	-0.151	-0.207
Abs Value of Residuals (m)	0.997	1.260
GW Salinity Average Residual (mg/L)	-48	-49
Abs Value of Residuals (mg/L)	797	760
Soil Salinity Average Residual (mg/L)	-126	826
Abs Value of Residuals (mg/L)	972	1638

6.4 SUMMARY

The manual calibration approach employed during the presented research resulted in a final set of models that met all defined calibration targets. Through the assessment of likely parameter and observation uncertainty and by conducting limited sensitivity analyses, the important model calibration parameters were identified. By adjusting these parameters on a trial and error basis, the models were refined to the point where project goals could be satisfied. Besides the evaluation of quantitative calibration targets, which included analysis of both temporal and spatial regional average output, more-qualitative judgments were made about model performance in several areas (site-specific output, canal seepage and return flow volume, and output frequency distributions). Subsequent to final model calibration, a test period of a length similar to the calibration period was evaluated. Test period results confirmed that the model performed well; however, there was a noticeable positive drift in soil water salinity output that could not be reconciled. Overall, the final calibrations of all models, which were derived using the presented calibration methods, should provide a high degree of accuracy in the comparative analyses of baseline conditions and solution alternatives, and should insure that all modeling output will be of great value in future water planning and management decisions within the Lower Arkansas River Valley.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

The major conclusions derived from the presented study are described in the journal papers given in Chapters 3 through 5. Other conclusions and recommendations not explicitly stated in these papers are presented here.

The research described herein demonstrates the full progression of the modeling process. Included within this progression are the following activities:

- Initial definition of project objectives
- Collection of required data
- Development of an initial conceptual model
- Transfer of data into a mathematical model(s)
- Sensitivity analysis and calibration of the preliminary mathematical model(s) to fit observations
- Redefinition of particular conceptual model components to more accurately define the system
- Improvement of model calibration and testing of the mathematical model
- Definition of a set of system baseline conditions
- Application of the developed model(s) to predict system response to changes in input

- Evaluation of investigated scenarios
- Recommendations on a future course of action

This progression, of course, often involves feedback, with each listed element being repeated to better achieve project objectives or to achieve redefined or new objectives. For the present project, this feedback process underwent several iterations, and continues through the time of this writing with on-going data collection and plans for future model improvements and additional model applications. The hope is that, even if all project objectives are fully achieved, the procedures, modeling approach, and developed models will find future, if as of yet unidentified, applications.

7.1 CONCLUSIONS REGARDING THE CURRENT CRISIS

Within the Lower Arkansas River Valley, it is evident that the salinity and waterlogging problems are serious. The current situation is not sustainable and conditions likely will continue to worsen if not adequately addressed. Developing and implementing solution alternatives should be considered an urgent priority for preserving the economic stability of the project area. From the developed baseline models, it was estimated that the irrigated region had overall average soil salinity values ranging from 2487 mg/L to 3864 mg/L during the modeled period. Additionally, results indicate that 16% to 33% of the irrigated fields within the study region had average water table depths that were shallower than 2.0 m (6.56 ft). The high rates of dissolution of natural salts from the soils and aquifer materials are being exacerbated by high water table conditions and resulting in exceptionally high salt loads to the river through the subsurface return flows. Overall, besides the observable ecological consequences which the Valley is enduring, it is highly likely that these conditions are causing significant reductions in crop yield, and directly costing farmers sizeable amounts of income. The widespread impact on the communities along the Arkansas River should not be underestimated.

7.2 CONCLUSIONS REGARDING GENERAL METHODS

The regional problem solving approach presented enables the identification of effective solution alternatives through providing information on the spatial and temporal relationships between adjacent and nearby areas. This information can help to improve the overall efficiency of designed solution alternatives and can facilitate more accurate economic analyses. Ultimately, the modeling approach presented should provide basin planners and water managers with a greatly increased level of confidence in final solution design and anticipated impacts.

The steady-state model of the system revealed that significant, basin-wide effects could, in fact, be achieved through spatially-distributed means such as a reduction in recharge to the water table. This modeling also revealed that, likely, only limited, localized impacts would occur through an increase in pumping volume from existing wells. The steady-state modeling results hinted that effects from multiple solution strategies were, in fact, approximately additive, and that implementing a combined solution alternative could enable the Valley to recover from the current crisis. Also, calibration of the steady-state model provided valuable insight into the spatial distribution of various aquifer parameters (e.g. hydraulic conductivity) and set the stage for the development of the set of three-dimensional, transient models.

Development of the transient models proved difficult at times. Input data management and preparation was challenging considering the spatial and temporal nature of the data. To be able to successfully construct and apply the transient models, effective and efficient methods using GIS technologies (namely GMS and ArcView™) had to be formulated. Even with these methods in place, the data entry process was undoubtedly the most time-consuming component of model construction (apart from the actual collection of the field data). Similar methods were employed in the post-processing of model output. Without the GIS tools used, the project described could not have produced results at a level of detail even remotely similar to those achieved.

7.3 CONCLUSIONS REGARDING DATA COLLECTION

The data collection program initiated in support of the present research demonstrates that large-scale data collection with the spatial and temporal density required for regional salinity and waterlogging modeling is possible under reasonable budgetary and human resource constraints. Critical to the success of this program was the cooperation of numerous farmers and local agencies. Also, the availability of the latest field instruments, including Geonics EM-38 induction meters, EC/salinity meters, and GPS surveying equipment, proved essential in making the data collection process efficient and, therefore, workable in terms of personnel management. Database management and data quality control, in particular, were two of the more challenging and time-consuming aspects of the current project. Several times, problems could be traced back to errors that occurred during the original data entry process.

Often engineers and scientists are tempted to treat observed data as almost infallible; however, as was demonstrated several times during the course of this project, there is uncertainty even in the observed data, and, occasionally, there are human errors or unanticipated circumstances that render observations unusable for calibration purposes. Of particular importance is the proper calibration and maintenance of all field measurement instruments. Additionally, calibration soil samples and accurate lab analysis are crucial to verifying the EM-38 reading conversion equations (and providing a sense of the related uncertainty), and accurate calibration solutions are necessary for ensuring the quality of all EC measurements. Unfortunately, on a project of the magnitude presented, gaps (at the temporal and spatial density scale) are inevitable. Undoubtedly, unforeseen events such as weather conditions, instrumentation malfunctions, temporary loss of access to data collection sites, vehicle breakdowns, etc., will occur to some degree over the course of a project. The hope is that these instances are minimal and that the data collection program design is such that missing data will not significantly affect project outputs.

Additionally, an element of the data collection process that is vital to success is the proper interpretation and understanding of the data itself. Knowledge of the physical setting (e.g. geologic features, geochemistry, etc.) can influence how particular data may be interpreted. For example, within the study area, the presence of lenses of shale is common, particularly near the higher elevation boundaries of the alluvial aquifer. A shallow water table reading in an area such as this might be indicative of a "perched" water table condition, i.e. the groundwater depth data at this location may not represent the true water table and may not be suitable for saturated flow model calibration purposes. Fortunately, during this project, instances of data errors were very limited and were generally discovered during reviews of data quality. The large majority of observed data points provided a strong foundation for the modeling process.

7.4 CONCLUSIONS REGARDING MODELING APPROACH

The general modeling approach utilized in the current study proved successful in achieving results at an accuracy level that will allow incorporation of the models into the proposed basin-wide DSS. Throughout the implementation of this approach, numerous conclusions were surmised about various elements of the process. Specific conclusions concerning the modeling approach that were not necessarily enumerated in the presented journal papers are as follows:

1. ***Models should be as simple as possible.*** Complexity should be increased only when necessary to achieve project goals. In the current study, the initial step was to develop a steady-state model of groundwater flow for a portion of the total project area. This model was based on published aquifer parameter data and simple water balance calculations and was calibrated to average conditions

estimated from published historical data. Following this initial step, a steady-state groundwater salinity model was linked to the flow model. The modeled study area was then expanded to include areas north and east of the initially modeled region. Calibration to average conditions (based on collected data) was then performed. The groundwater flow and salinity models were then expanded into transient form for the year 1999 only. Following the successful transient modeling of this year, the models were expanded further to include years 2000 and 2001. After calibration of these models, the final layer of additional complexity was to develop the unsaturated zone salinity model. This model was then calibrated to collected field data. Successful development of the final models, due to the high level of complexity, would not have been successful had this complexity not been increased progressively in several stages.

2. ***Computing limitations still exist and should be considered a constraint upon project objectives.*** Although tremendous computer hardware and software improvements occurred over the life of this study, there were limitations that arose in terms of usable file sizes, software functionality, and model interface capabilities. Future improvements in all of these areas will undoubtedly occur; however, project size and scope are currently limited by the commonly available technical resources.

3. ***Water balance calculations should be performed as a part of the standard modeling approach, and the results must be reflected in model inputs and***

> ***outputs***. This process can be difficult because canal flow records are typically only available at diversion points and because the true crop ET is only estimated. However, this step is critical in verifying the reasonability and consistency of the model components, and it can aid in identifying modeling errors or faulty assumptions. In the current study, the water balance over the modeled time period verified the assumption that deficit irrigation practices were not widely occurring. It may be found, through water balance calculations of future periods, that this assumption breaks down under drought conditions. Also, water balance calculations incorporated internally within the unsaturated zone module ensured consistency between the unsaturated and saturated models. Again, this was critical for establishing and maintaining model validity.

Other less significant conclusions drawn from the modeling approach were not necessarily explicitly stated within any of the presented papers. One of these related to the direct linking of the unsaturated and saturated models. This linking proved to be very useful in terms of establishing the unsaturated zone model input/output framework, and it should be considered as a desirable element of any regional-scale soil water salinity modeling effort. The importance of recharge and irrigation application depth estimation cannot be understated. The utmost care should be given to this step of the modeling process. Also, as demonstrated in this study, a modeling time step of one week works well for regional-scale modeling. This interval appears to capture system changes well while maintaining a reasonable modeling burden in terms of specifying required model inputs.

7.5 CONCLUSIONS REGARDING MODEL CALIBRATION

The model calibration effort performed as a part of this study demonstrated several aspects of the calibration process that should be emphasized. Because of the extensive data collection effort, there was ample information to establish calibration targets for the models. In fact, one interesting dynamic of this study was that feedback from the model output during the calibration process occasionally pointed to potential problems with the data itself. On more than one instance, at points where there was difficulty in matching the predicted model output with observed or expected values, it was found that the data contained bias due to database input errors or was severely affected due to some ulterior influence. In some of these cases, data collection locations were moved or added, or model parameters were confirmed through field investigation.

The development and calibration of the unsaturated zone module of MT3DMS enhanced the salinity modeling component of the project tremendously. Through the process of creating and calibrating this model, it became evident that a critical component of model definition (and potentially the most significant driving force behind the model results) was the imbedded representation of the soil water system (i.e. the accurate modeling of the soil water balance). Model results were very sensitive to parameters that affected the estimated soil water volume. Adjustment of the parameters that define the maximum water holding capacity (i.e. field capacity) of the soil layers and the unsaturated zone/saturated zone interaction (in terms of defining the capillary fringe, capillary rise height, etc.) became a key component of the model calibration process. Future improvements to this model should focus on this aspect.

Additionally, noting the significant drift (over-prediction) that occurred over time in results of this model, attention should be placed on better identifying and quantifying all soil leaching processes – particularly those that may occur during the non-irrigation (November – March) season. It is likely that the model calibration presented could not be improved because there was not enough knowledge captured during the winter (non-irrigation) months. However, the predicted unsaturated zone module results, in terms of the changes in soil water salinity accrued due to implemented solution alternatives, were likely not significantly affected by the calibration deficiencies.

Interpretation of model calibration results must consider the averaging effects inherent in finite-difference modeling techniques. The specified modeling cell size for this study represented an area of 6.25 ha (15.5 acres). Compared with the point measurements used to specify calibration targets, measured at a scale substantially smaller than the model cell (i.e. at sub-cell scale), it would be surprising and perhaps erroneous if exact matches were achieved. As field measurements have revealed, the filed variability of salinity and water table depth within the model cell size can be very significant. Therefore, interpretation of each calibration point must consider scaling/averaging effects. The magnitude of each calibration residual must be evaluated in light of expected sub-cell variability at the specific calibration point location and a subjective conclusion concerning model performance must be made.

An appropriate calibration should include multiple types of calibration targets that demonstrate that the replication of the physical system is realistic. Related to this, model parameter values specified to achieve the calibration results should fall within a physically-realistic range of values. As in the presented research, field measurements may be required to determine these ranges. An initial sensitivity analysis of model parameters can aid in focusing on which parameters should be varied during calibration and which parameters may require further investigation to verify the appropriate range of likely values.

7.6 CONCLUSIONS REGARDING MODELING RESULTS

As observed in the field and as predicted through modeling, there is an undeniable direct relationship between saline high water tables and high soil water salinity. In general, solution scenarios that effectively lowered the water table, also lowered soil water salinity levels. When recharge is reduced due to more efficient irrigation techniques, however, as demonstrated in the presented modeling, caution must be taken to maintain enough deep percolation to provide for adequate leaching.

Modeling clearly indicated that the effects of implementing multiple solution scenarios simultaneously can be dramatic. Because scenarios such as reducing recharge, reducing canal seepage, and installing sub-surface drainage affect different system components and are often spatially distributed in different areas, their effects are compound in nature. Out of the scenarios modeled, the combined alternatives were the most successful in lowering soil water salinity levels and reducing high water tables. Specifically, the alternative that combined a 50% reduction in recharge, a 90% reduction in total canal seepage, and incorporated installation of sub-surface drains at a 50-m spacing over selected fields, achieved predicted average reductions in soil salinity of 241 mg/L, 426 mg/L, and 985 mg/L across all irrigated fields for the three modeled seasons. This scenario also resulted in average reductions in the water table elevation of 1.02 m, 1.93 m, and 2.12 over the three seasons. In terms of soil water salinity reduction, this was the most effective scenario. Undoubtedly, efforts to control soil water salinity levels and high water tables can be more effective on a regional level if multiple approaches are adopted and are well distributed within the basin. Modeling showed that even modest levels of implementation of various means, when done in conjunction with one another, can have tremendous impacts.

Modeling also showed that potentially large volumes of water could be prevented from being consumed through upflux in non-irrigated areas by increasing water table depths. However, improving soil salinity conditions would increase overall crop ET. The net effect of these impacts on basin-wide consumptive use could prove to be an important decision making factor. Results indicate that scenarios incorporating subsurface drains could yield a net decrease in consumptive use, thereby making them attractive from the water manager's perspective. Seepage reduction scenarios are predicted to have a near net-zero impact on consumptive use, and recharge reduction scenarios are predicted to result in potential increases to overall water consumption. Also, significant reductions in salt loading to the river that are predicted under numerous scenarios could greatly enhance the overall environment of the Valley and improve the usability of water for downstream consumers. It is critical to note that these predicted impacts apply only over the modeled time frame – under other conditions the predicted results might be much different. Also, the uncertainty inherent in these results should be recognized. Future stochastic modeling efforts could help to quantify the magnitude of this uncertainty.

7.7 RECOMMENDATIONS

Over the course of the presented research, a number of potential modeling improvements were identified that fell outside of the scope of the existing project or that were not pursued due to time and/or budgetary constraints. Also, there are some specific components of the modeling tools that need to be improved to enable future applications in other river basins. Several recommended improvements are as follows:

1. ***Automate the iterative modeling procedure utilized to adjust the MODFLOW ET package input based on the unsaturated zone model output.*** This will likely require extensive additional coding, but will result in significant reduction in model run-time.

2. ***Incorporate additional relative crop yield functions into the unsaturated zone module.*** The current functions represent only the crop types found within the study area. For model applications outside of this area, additional crop types will need to be specified. This should require limited coding changes and additions.

3. ***Create a graphical user interface (GUI) that enables data input/output to and from the unsaturated zone model.*** This interface could be expanded to include all utilized data preparation tools (GMS, ArcView™, spreadsheet analysis, text editing); however, this would likely prove to be very technically challenging. It would require a highly-skilled programming expert and would be costly, but would maximize the portability of the models to applications in other basins.

4. ***Expand the time horizon of current models to include recent drought years (2002-2004).*** This will likely reveal areas where modeling improvements are necessary. Specifically, the assumptions concerning deficit irrigation and associated recharge estimation will require improvements.

5. ***Develop methods for extending the model time horizon to incorporate long-term (multi-decade) future prediction scenarios.***

6. ***Incorporate stochastic techniques into model predictions.*** Methods such as presented in Appendix M should be pursued and should yield results upon which more confidence can be placed.

7. ***Continue the current data collection program and utilize data for improved model calibration and continued model testing and enhancement.***

Implementation of some or all of these recommendations should increase the usability and, therefore, the attractiveness of adopting the modeling approach and tools in regions facing problems similar to those in the Lower Arkansas River Valley.

7.8 FINAL THOUGHTS

Ultimately, it is likely that economic analyses (which also consider legal, institutional, and social impacts) of proposed solution alternatives and their potential benefits will determine what means, if any, are adopted in the Lower Arkansas River Valley. Hopefully, the tools developed and applied through this research effort (and future modeling improvements and basin DSS development) will provide the economists and decision-makers with the evidence they need to adequately analyze the current crisis that has slowly emerged. In reporting for the World Bank on salinity issues, Dina Umali has captured the urgency of this crisis well in the following warning:

> It is widely recognized that irrigation has been a powerful force in fostering development in many countries. But when it is pursued injudiciously, it can become the progenitor of agricultural devastation, embodied in the form of irrigation-induced salinity. Irrigation-induced salinity has begun to cause drastic reductions in agricultural productivity in many parts of the world and the time has come for farmers, governments and donors to take it seriously (1993).

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APPENDICES

APPENDIX A: DATA COLLECTION METHODS AND COLLECTED DATA SUMMARY

Data collection began in 1998 in a limited fashion, with soil water salinity being the only property investigated with intensity. By April, 1999, however, a rigorous data collection program had been developed and initiated. Included in this program is the monitoring of water table depth and salinity, surface water salinity, soil texture, soil water content, and soil water salinity. Also, hydraulic conductivity was estimated using slug tests, topographic surveys of land and water features were conducted using GPS technology, and several deep boreholes were drilled to better describe aquifer lithology and depth to bedrock. This program is on-going; however, only data collected through 2001 was used in the presented research.

Monitoring Wells

Initially, a total of 74 monitoring wells were utilized for collection of water table depth and salinity data (see Figure A-1, "Wells 1999"). Of these 74 wells, 69 were installed as part of the program, and 5 were adopted from previous studies. Sites were selected using a stratified random sampling technique (Cressie 1991) to minimize any bias in well placement; although, a few wells were specifically placed near the eastern and western boundaries, and a few randomly-selected sites were moved slightly to accommodate farmer preferences. Wells were installed using a truck-mounted Giddings rig as shown in Figure A-2. Wells were cased using screened PVC pipe with an inside diameter of 6.4

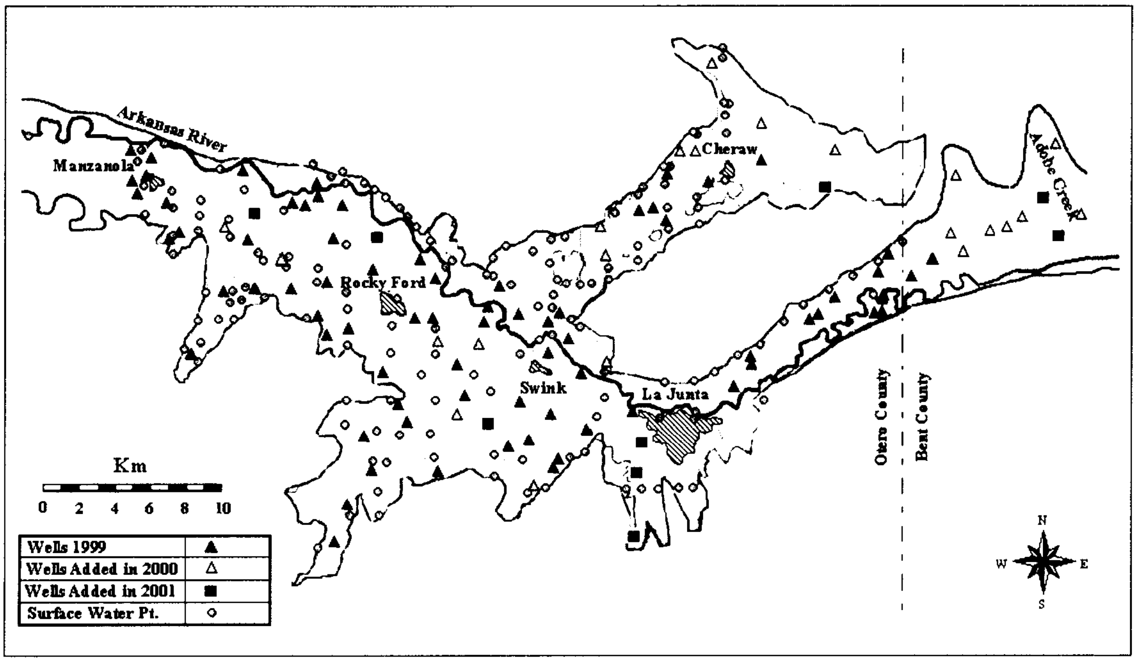

Figure A-1. Study Area Map Showing Monitoring Well and Surface Water Sites

cm (2.5 in), and, initially, were drilled to a depth of 3.05 m (10.0 ft). A picture of one of the monitoring well sites is shown in Figure A-3. In 2000, 21 of the wells were deepened to a depth of about 7.0 m (23.0 ft), and 23 additional wells ranging in depth from 3.05 to 7.0 m (10.0 to 23.0 ft) were installed (see Figure A-1, "Wells added in 2000"). In 2001, nine more wells were added in locations specifically targeted to increase data density where needed (see Figure A-1, "Wells added in 2001").

Measurements of water table depth and salinity were taken at each monitoring site weekly during the peak irrigation season (May through September) and biweekly to monthly during the remainder of the year. Depths were measured manually using a standard measuring tape with an attached float (as shown in Figure A-4), and salinity was

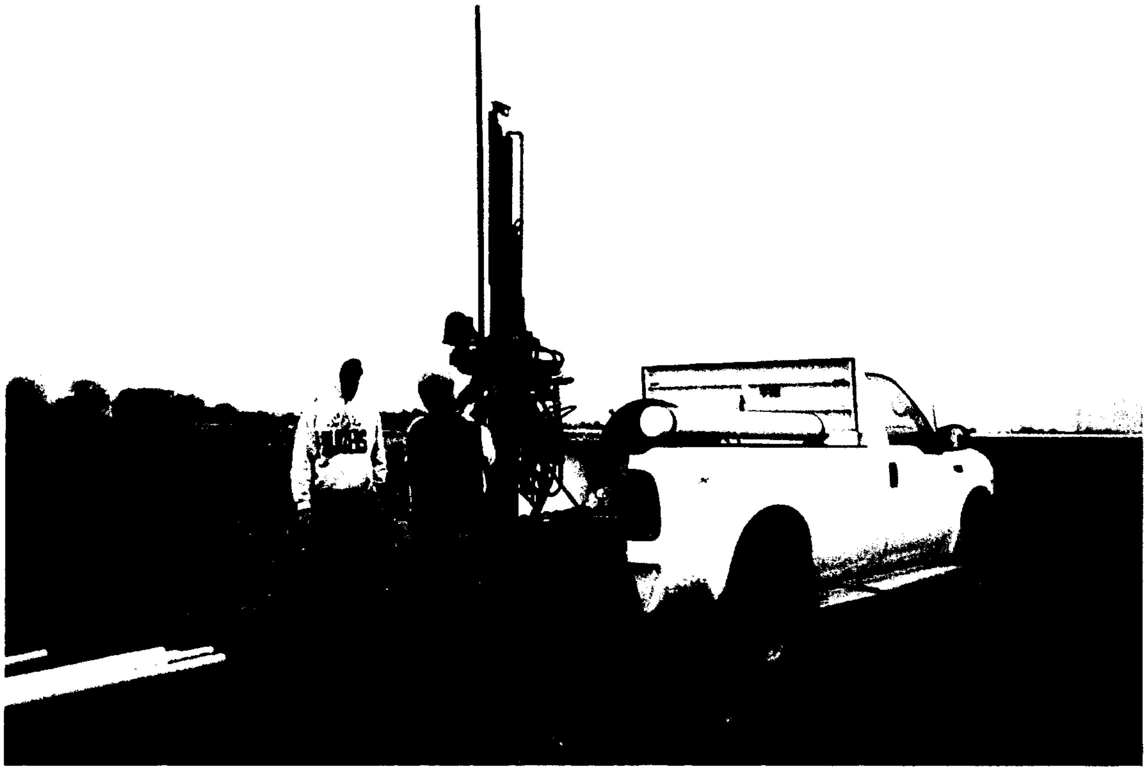

Figure A-2. Monitoring Well Installation Using Truck-Mounted Giddings Rig.

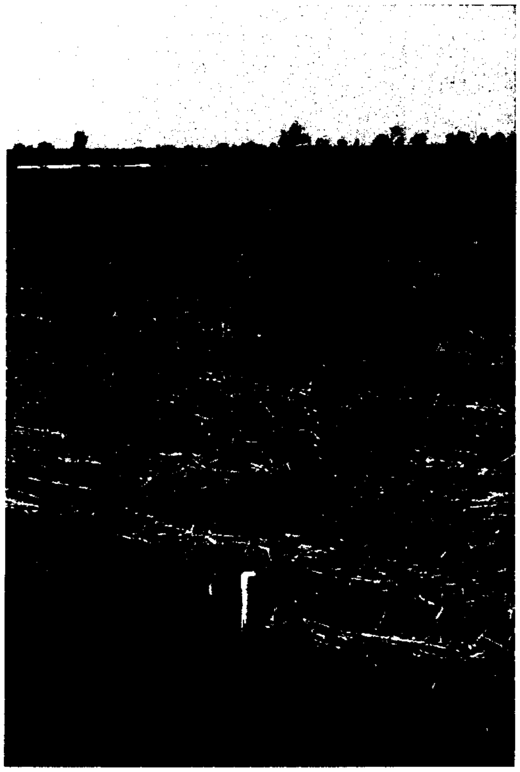

Figure A-3. Monitoring Well Site in the Lower Arkansas Valley Study Area.

Figure A-4. Measuring Water Table Depth Using a Standard Measuring Tape and Float

Figure A-5. Specific Conductance Meter Used to Measure EC measured indirectly as electrical conductivity (EC) using a calibrated, temperature-compensating specific conductance meter (as shown in Figure A-5). At each monitoring site, three EC measurements (one just below the water table level, one at an intermediate depth, and one near the bottom of the well) were recorded and averaged to obtain a representative value. Measurements were converted to total dissolved solids (TDS), i.e. salinity, using the relationship: $TDS = 882.2EC$. This relationship was derived from analysis of groundwater samples collected at 17 of the monitoring wells in 1999 and reflects an r^2 value of 0.98.

Field Soil Water Salinity Surveys

A key component of the data collection program was the surveying of soil water salinity within approximately 80 fields twice per year. Soil salinity to a depth of near 1.0 m (3.28 ft) was estimated at the selected fields (corresponding to a subset of the groundwater monitoring sites) utilizing electromagnetic induction techniques (Rhoades et al. 1989, 1999). Geonics™ EM-38 instruments (as shown in Figure A-6) were used to measure about 30 to 90 locations per monitoring site, depending on field size. Readings were taken once near the beginning of the irrigation season (late May to early June) and once near the end of the irrigation season (mid to late August). The approximate data density within a field was about one point (including both vertical and horizontal instrument readings, EM_V and EM_H, respectively) per 0.10 ha (0.25 ac). Measured values were converted to electrical conductivity of the soil saturated paste (EC_e) for modeling and analysis purposes using relationships developed from comparison with collected soil samples whose salinity values were obtained through lab analysis (Cardon 2003).

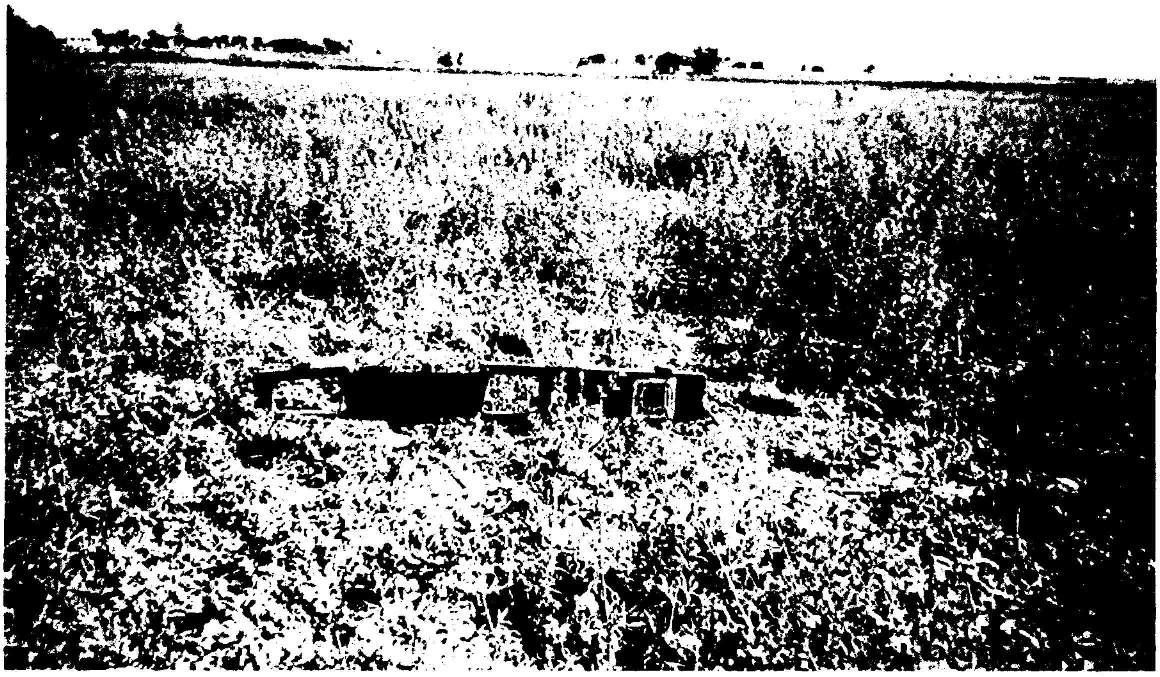

Figure A-6. Geonics™ EM-38 Meter Used for Soil Salinity Surveys

Over the course of the study, it was found that these relationships were different depending upon field conditions under which the EM-38 readings were obtained. These influencing conditions include soil water content and soil temperature. It was assumed that for a given survey period (e.g. Early Season 1999) fields were surveyed under the same general conditions. This was likely not always the case, but this assumption allowed for only one regression relationship to be required for each survey period. More detailed study on the EM-38/soil salinity relationship using the samples collected as part of the presented research is currently being conducted by others. The derived relationships relating EM_V readings to EC_e are given in Table A-1.

Table A-1. EM-38 to Soil Salinity Calibration Equations

Survey Period	derived relationship	r^2 value
Early Season 1999	$EC_e = 4.40 \cdot EM_v^{1.75}$	0.89
Late Season 1999	$EC_e = 5.11 \cdot EM_v^{1.48}$	0.69
Early Season 2000	$EC_e = 5.11 \cdot EM_v^{1.48}$	0.69
Late Season 2000	$EC_e = 5.33 \cdot EM_v^{1.37}$	0.83
Early Season 2001	$EC_e = 5.11 \cdot EM_v^{1.48}$	0.69
Late Season 2001	$EC_e = 5.33 \cdot EM_v^{1.37}$	0.83
Note: EC_e = electrical conductivity of the saturated soil water extract adjusted to 25 °C (dS/m) EM_v = vertical-orientation EM-38 reading of bulk soil conductivity.		

Collection of the soil samples used to develop the calibration equations was performed with a hand-operated sampling tool with an attached bucket auger as shown in Figure A-7. Typically, one site within each surveyed field was selected for collecting soil samples for calibration. At this site, three vertical soil profiles were extracted which coincided with the left end, right end, and middle positions along the longitudinal axis of the EM-38 meter. Each vertical profile was separated into five samples (surface, 30-cm depth, 60-cm depth, 90-cm depth, and 120-cm depth), resulting in a total of 15 samples collected at each calibration site. Corresponding EM-38 measurements (taken in both the vertical and horizontal orientations) were made prior to removing the samples and served as the basis for comparison.

Surface Water Monitoring

Another component of the data collection program was the monitoring of surface water salinity. Like the groundwater measurements, salinity was measured indirectly by the measurement of EC using a conductance meter at 163 monitoring points in the river tributaries, canals, drains, and reservoirs (see Figure A-1, "Surface Water Pt."). A relationship between EC and TDS with an r^2 value of 0.97 was derived from the analysis of 28 surface water samples: $TDS = 1479.2EC^{0.67} - 617.8$.

At most monitoring locations, measurements were taken from a bridge crossing or from the bank near the most convenient access point. The picture shown in Figure A-8 shows a typical situation. For small canals and ditches, it was assumed that sufficient mixing occurs to avoid any bias that might result from the selection of the particular measurement orientation. For larger surface water features, however, to avoid potential bias, three measurements were taken at different points across the width of the channel. Typically, these points correspond to points near the left bank, near the center, and near the right bank of the channel. Over the course of the study, there were times when some surface water features were dry, and, therefore, no EC reading could be taken. In a limited number of cases, readings could not be obtained because the measurement site was inaccessible.

Additional Data Collection Activities

Additional data collection program activities included performing slug tests (Chin 2000) at each monitoring well to estimate hydraulic conductivity, as well as the surveying of land and water surface elevations using multiple GPS receivers (Trimble 4600LS and Ashtech Locus systems) and differential correction techniques accurate up to ±0.03 m (0.1 ft). Also, numerous river, tributary, and canal cross-sections were surveyed from bridges using a measuring tape and depth probe. In September 2001, exploratory boreholes were drilled in a cooperative effort with the U. S. Bureau of Reclamation at sixteen different sites in the study region to obtain additional data on aquifer lithology and depth to bedrock. A separately-funded study to estimate seepage from the Fort Lyon Canal using inflow-outflow tests was performed in 2001.

Figure A-7. Soil Sampling Using a Hand-Operated Sampling Tool and Bucket Auger

Figure A-8. Surface Water Salinity Measurement Using a Specific Conductance Meter

COLLECTED DATA SUMMARY

Data obtained through the data collection program, as well as data gathered from outside sources, were used to describe and assess the current conditions within the study region. The following is a brief summary of the findings over the reported study period.

Water Table Depth and Salinity: A few important statistics that have been compiled from the collected water table depth and salinity data are shown in Table A-2. These statistics indicate the general condition of the shallow aquifer within the study region. Detailed tables showing all measured values of water table depth and salinity are given in Appendix B. In total, 4,318 individual readings were taken at monitoring well sites over the period from April 1999 to December 2001. Of these 1,139 (or 26.4%) were recorded as dry.

Table A-2. Summary of Collected Water Table (WT) Depth and Salinity Data

Year	*Avg. # of Wells per Reading*	*Seasonal Avg. WT Depth (m)*	*Est. % of Area with WT Depth < 1.5 m*	*Seasonal Avg. WT Salinity (mg/L)*	*Est. % of Area with WT Salinity > 2000 mg/L*
1999	69	2.14	25	3117	27
2000	90	2.48	19	2850	33
2001	96	2.69	18	2706	48

The values presented in Table A-2 represent both spatial and temporal averaging. Spatial averaging was achieved by interpolating across the study region between data points using the inverse distance weighted (IDW) method (Shepard 1968). The values shown reflect "seasonal" conditions, i.e. the conditions that occurred during the main growing season (April through October). Data collected between November and March were not included in the calculation of the statistics shown since this time period is less critical from an agricultural standpoint. These off-season months, however, are included in the numerical modeling analysis. It should also be noted that the salinity data presented represents only the upper layer of the aquifer which is penetrated by the monitoring wells – the deep aquifer characteristics are likely significantly different.

The data conclusively reveal that large portions of the study region are subjected to waterlogged conditions, with some areas exposed to very high groundwater salinity. Figure A-9 shows example contours of water table depth for three readings in 1999, along with a sample contouring of groundwater salinity for July 14 –17, 1999. Specific areas identified from the data collection as having particularly acute waterlogging problems are the Patterson Hollow area west of Rocky Ford, an area directly south of the town of Swink, the area surrounding the town of Cheraw, and an area just east of North La Junta along the Fort Lyon canal. High levels of groundwater salinity were found in an area directly west of Rocky Ford, the Holbrook Reservoir area, the Cheraw Lake area, and the La Junta area.

Interestingly, the seasonal average water table depth has increased (i.e. the water table has lowered) in each of the study years reported herein. This trend is likely a result of water table response to reduced aquifer recharge stemming from decreased irrigation

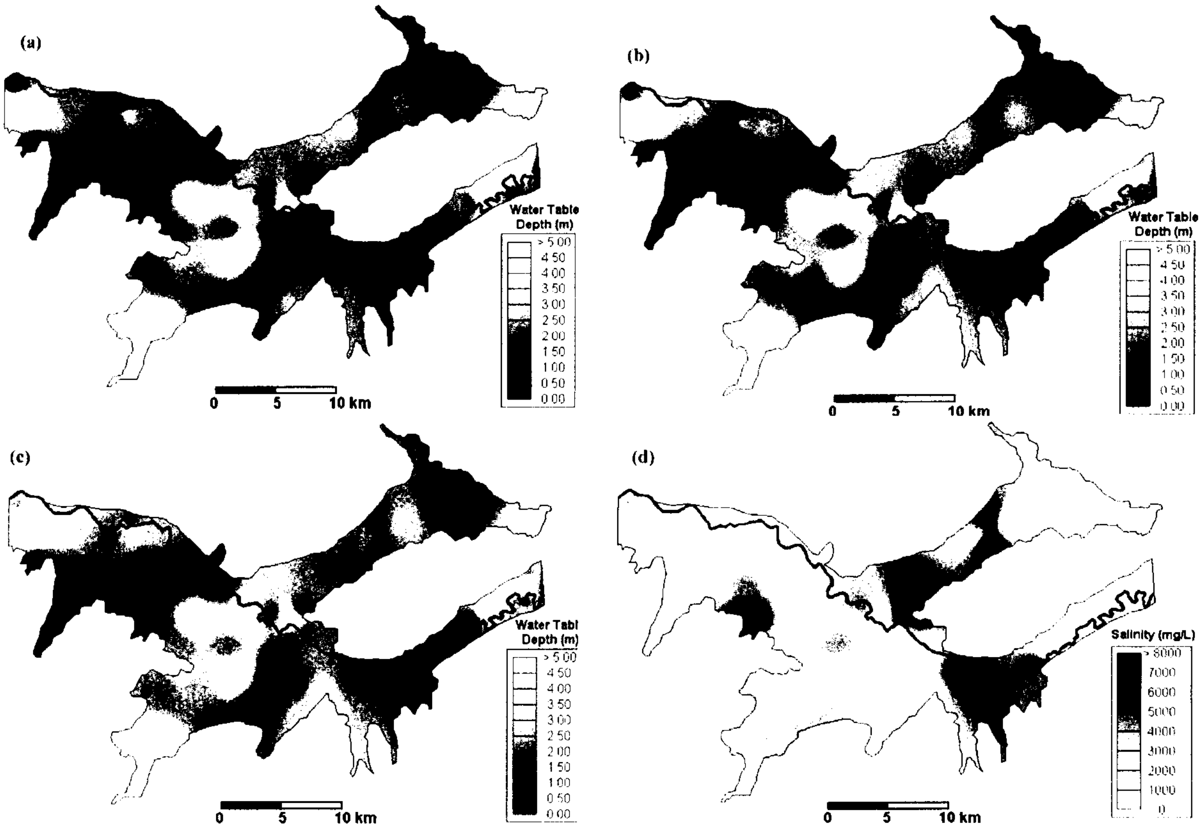

Figure A-9. Contours derived from IDW Interpolation: WT Depth for (a) May 11-12, 1999, (b) July 14-17, 1999, (c) Sept. 16-17, 1999; and (d) WT Salinity for July14-17, 1999 water supply and diversions. Over the course of the study, the Rocky Ford Weather Station (#057167) has reported seasonal (April – Oct.) total precipitation amounts of 30.38 cm (11.96 in) in 1998, 46.63 cm (18.36 in) in 1999, 17.04 cm (6.71 in) in 2000, and 24.41 cm (9.61 in) in 2001 (NCDC 2002). Diversion records from the Colorado Division of Water Resources support this theory. Seasonal average water table salinity also decreased over the study period. A possible explanation of this observation is a decrease in dissolution of native salts from salt-bearing marine shales and shale-derived soil layers that may exist higher in the profile (Zielinski et al. 1995).

Soil Water Salinity: Summary results of the soil water salinity monitoring are given in Table A-3. Values are shown in terms of soil saturation extract electrical conductivity (EC_e) derived using the relationships shown in Table A-1 and represent spatial averages using IDW interpolation. In total, 27,000 points were measured using the EM-38 meter over the reported study period. This translates to 436 field surveys, with an average of 73 fields surveyed per season. The average number of points within a field measured with the EM-38 was 62.

Table A-3. Summary of Soil Salinity Monitoring Data

Year	*# of Fields Monitored*	*Early Season Avg. EC_e (dS/m)*	*Late Season Avg. EC_e (dS/m)*
1998	30	2.3	3.1
1999	68	2.6	2.9
2000	77	2.4	2.0
2001	80	2.8	2.5

The data show a seasonal increase in average soil salinity during the wetter study years (1998 and 1999); conversely, a decrease occurs in the drier years (2000 and 2001). Likely, this pattern is due to a greater upflux of salts from high water tables and less potential for leaching during 1998 and 1999, with less salt upflux and greater leaching occurring in 2000 and 2001. Detailed data tables of measured soil water salinity values are given in Appendix B.

Surface Water Salinity: Table A-4 summarizes the average salinity (shown in terms of EC) for the Arkansas River and the six main canals for each study year. The values are reflective of the dilution that takes place in higher water supply years (such as 1999). Although only overall averages (spatial and temporal) are shown, it should be noted that the spatial variability in each watercourse was significant, with salinity levels increasing downstream in all cases. Major surface drains and tributaries also were monitored and yielded an overall seasonal average EC of 2.61 dS/m in 1999, 3.19 dS/m in 2000, and 3.10 dS/m in 2001.

Additionally, three major storage facilities were monitored. The Fort Lyon Storage Canal had a seasonal average EC of 1.89 dS/m in 1999, 2.03 dS/m in 2000, and 1.91 dS/m in 2001. Holbrook Reservoir was found to have a season average EC of 1.31 dS/m in 1999, 1.66 dS/m in 2000, and 1.32 dS/m in 2001, and Cheraw Lake, which receives drainage from the northern portion of the study region, had a seasonal average EC of 13.87 dS/m in 1999, 13.27 dS/m in 2000, and 15.06 dS/m in 2001.

Table A-4. Summary of Surface Water Salinity Data as EC (dS/m)

Year	*Arkansas River*	*Rocky Ford Canal*	*Catlin Canal*	*Otero Canal*	*Rocky Ford Highline Canal*	*Holbrook Canal*	*Fort Lyon Canal*
1999	0.97	1.05	0.88	1.35	0.70	0.80	1.00
2000	1.33	1.06	0.93	1.48	0.84	1.04	1.35
2001	1.19	1.00	0.91	1.35	0.77	0.97	1.18

Additional Data: Analysis of collected data, as well as diversion records obtained from the Colorado Division of Water Resources and data from the Colorado Climate Center, has indicated that existing irrigation efficiencies range from 30 to 50% over the study region. Analysis of slug tests performed at 95 of the monitoring well sites yielded estimates of hydraulic conductivity ranging from 0.003 m/day (0.01 ft/day) to 10.24 m/day (33.60 ft/day) in the upper aquifer layer. Seepage tests conducted in the Fort Lyon Canal indicated that conveyance losses are approximately 0.25 % per km (0.40 % per mi) to 0.33 % per km (0.53 % per mi).

APPENDIX A REFERENCES

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APPENDIX B: COLLECTED DATA SETS

B.1 OBSERVATION WELL DATA

Date	Well 1		Well 2		Well 5		Well 6		Well 7		Date
	WTD (m)	EC (dS/m)	WTD (m)	EC (dS/m)	WTD (m)	EC (dS/m)	WTD (m)	EC (dS/m)	WTD (m)	EC (dS/m)	
04/05/99	1.75	2.27	DRY	DRY	DRY	DRY	DRY	DRY	1.02	4.85	04/05/99
05/11/99	1.24	5.04	DRY	DRY	DRY	DRY	DRY	DRY	0.51	4.24	05/11/99
05/27/99	1.27	4.45	DRY	DRY			DRY	DRY	0.76	4.95	05/27/99
06/01/99	1.27	4.09			DRY	DRY	DRY	DRY	0.76	4.91	06/01/99
06/11/99	1.52	2.84	DRY	DRY	DRY	DRY	DRY	DRY	0.94	4.80	06/11/99
06/17/99	1.19	2.34	DRY	DRY	DRY	DRY	DRY	DRY	0.74	4.28	06/17/99
06/24/99	1.21	2.48	DRY	DRY	DRY	DRY	DRY	DRY	1.63	4.20	06/24/99
06/30/99	1.19	2.45			DRY	DRY	DRY	DRY	2.08	4.39	06/30/99
07/07/99	1.59	2.47	DRY	DRY	DRY	DRY	DRY	DRY	1.61	4.47	07/07/99
07/14/99	1.75	2.73	DRY	DRY	DRY	DRY	DRY	DRY	1.13	4.56	07/14/99
07/21/99	1.49	2.33	DRY	DRY	DRY	DRY	DRY	DRY	0.85	2.26	07/21/99
07/28/99	1.78	2.40	DRY	DRY	DRY	DRY	DRY	DRY	1.55	2.60	07/28/99
08/04/99	1.37	2.25	DRY	DRY	DRY	DRY	DRY	DRY	0.99	3.96	08/04/99
08/12/99	1.30	2.37	DRY	DRY	DRY	DRY	DRY	DRY	0.72	4.19	08/12/99
08/18/99	2.29	2.48	DRY	DRY	DRY	DRY	DRY	DRY	2.11	4.59	08/18/99
09/04/99	1.80	2.48	DRY	DRY	DRY	DRY	DRY	DRY	1.73	4.20	09/04/99
09/16/99	1.93	2.45	DRY	DRY	DRY	DRY	DRY	DRY	2.06	3.75	09/16/99
10/01/99	2.01	2.49	DRY	DRY	DRY	DRY	DRY	DRY	1.47	3.50	10/01/99
11/13/99	1.91	2.32	DRY	DRY	DRY	DRY	DRY	DRY	0.74	3.88	11/13/99
01/04/00	1.83	2.59			DRY	DRY	DRY	DRY	0.99	4.13	01/04/00
02/24/00	1.93	2.83	DRY	DRY	DRY	DRY	DRY	DRY	1.12	4.08	02/24/00
03/25/00	1.73	2.75	DRY	DRY	DRY	DRY	DRY	DRY	0.99	3.50	03/25/00
04/15/00	1.47	3.12	DRY	DRY	DRY	DRY	DRY	DRY	1.68	4.03	04/15/00
04/28/00	1.98	2.76	DRY	DRY	DRY	DRY	4.94	1.09	1.42	3.81	04/28/00
05/17/00	1.80	2.92	DRY	DRY	DRY	DRY	5.96	1.41	1.36	3.33	05/17/00
06/01/00	1.58	2.83	DRY	DRY	DRY	DRY	5.98	1.42	1.83	3.06	06/01/00
06/06/00	1.65	2.97	DRY	DRY	DRY	DRY	5.94	1.47	0.85	2.52	06/06/00
06/15/00	1.85	2.65	DRY	DRY	DRY	DRY	5.90	1.55	2.17	2.88	06/15/00
06/23/00	1.90	2.78	DRY	DRY	DRY	DRY	5.68	1.37	1.39	2.39	06/23/00
06/29/00	1.80	2.67	DRY	DRY	DRY	DRY	5.40	1.57	1.59	2.85	06/29/00
07/06/00	2.00	2.69	DRY	DRY	DRY	DRY	5.44	1.62	1.69	2.77	07/06/00
07/14/00	1.97	3.46	DRY	DRY	DRY	DRY		1.64	1.38	2.99	07/14/00
07/20/00	1.69	2.57	DRY	DRY	DRY	DRY	5.80	1.68	1.21	2.22	07/20/00

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 1		Well 2		Well 5		Well 6		Well 7		Date
	WTD (m)	EC (dS/m)	WTD (m)	EC (dS/m)	WTD (m)	EC (dS/m)	WTD (m)	EC (dS/m)	WTD (m)	EC (dS/m)	
07/27/00	1.95	3.16	6.45	1.36	DRY	DRY	6.05	1.95	2.25	2.95	07/27/00
08/02/00	2.03	3.12	6.44	1.40	DRY	DRY	4.91	1.71	1.33	2.65	08/02/00
08/11/00	2.00	2.65	DRY	DRY	DRY	DRY	3.94	0.98	1.44	2.72	08/11/00
08/19/00	1.95	2.50	DRY	DRY	DRY	DRY	5.53	1.21	1.61	2.52	08/19/00
09/01/00			6.48	1.35	DRY	DRY	5.91	1.21	1.24	2.36	09/01/00
09/16/00			DRY	DRY	DRY	DRY	DRY	DRY	1.62	2.49	09/16/00
09/29/00	2.11	2.11	DRY	DRY	DRY	DRY	DRY	DRY	1.45	3.41	09/29/00
10/20/00	2.16	2.75	DRY	DRY	DRY	DRY	DRY	DRY	1.42	3.58	10/20/00
12/01/00	1.83	2.81	6.54	1.18	DRY	DRY	DRY	DRY	1.46	3.76	12/01/00
01/19/01	2.01	3.01	6.46	1.38	DRY	DRY	DRY	DRY	1.49	3.23	01/19/01
03/05/01	2.01	2.35	DRY	DRY	DRY	DRY	DRY	DRY	0.94	2.35	03/05/01
03/30/01	2.13	2.10	DRY	DRY	DRY	DRY	DRY	DRY	0.88	1.99	03/30/01
04/21/01	1.87	2.36	DRY	DRY	DRY	DRY	4.14	1.33	1.93	3.42	04/21/01
05/14/01	2.00	2.37	DRY	DRY	DRY	DRY	4.06	1.10	2.06	3.22	05/14/01
05/29/01	1.60	2.59	DRY	DRY	DRY	DRY	5.42	0.52	1.12	5.81	05/29/01
06/07/01	1.71	2.55	DRY	DRY	DRY	DRY	5.66	0.75	1.04	6.40	06/07/01
06/14/01	1.83	2.75	DRY	DRY	DRY	DRY	5.61	1.05	1.24	5.90	06/14/01
06/20/01	1.93	3.02	DRY	DRY	DRY	DRY			2.00	5.98	06/20/01
06/29/01	1.80	2.74	DRY	DRY	DRY	DRY			1.94	3.57	06/29/01
07/06/01	1.91	2.70	DRY	DRY	DRY	DRY			1.60	3.58	07/06/01
07/12/01	2.04	2.46	DRY	DRY	DRY	DRY			1.88	3.52	07/12/01
07/18/01	1.87	2.55	DRY	DRY	DRY	DRY	5.44	0.83	2.13	3.37	07/18/01
07/26/01	1.96	2.67	DRY	DRY	DRY	DRY			2.21	3.36	07/26/01
08/02/01	2.02	2.42	DRY	DRY	DRY	DRY	5.48	1.48	2.27	1.65	08/02/01
08/10/01	1.94	2.36	DRY	DRY	DRY	DRY	5.06	0.82	1.64	3.14	08/10/01
08/17/01	1.94	0.75	DRY	DRY	DRY	DRY	5.04	0.78	1.56	2.98	08/17/01
09/01/01	2.12	2.22	DRY	DRY	DRY	DRY	5.07	1.15	DRY	DRY	09/01/01
09/15/01	2.15	2.35	DRY	DRY	DRY	DRY					09/15/01
09/29/01	1.95	2.20	DRY	DRY	DRY	DRY			DRY	DRY	09/29/01
10/12/01											10/12/01
10/27/01	1.08	1.72	DRY	DRY	DRY	DRY	DRY	DRY	0.88	2.16	10/27/01
11/17/01	1.99	2.21							1.34	3.34	11/17/01
12/18/01	1.93	1.73	DRY	DRY	DRY	DRY	DRY	DRY	1.19	2.88	12/18/01

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 8		Well 9A		Well 9B		Well 11		Well 12		Date
	WTD (m)	EC (dS/m)	WTD (m)	EC (dS/m)	WTD (m)	EC (dS/m)	WTD (m)	EC (dS/m)	WTD (m)	EC (dS/m)	
04/05/99	DRY	DRY	1.63	3.02	1.68	3.33	1.47	5.04			04/05/99
05/11/99	DRY	DRY	1.14	3.00	0.74	4.15	1.60	5.90			05/11/99
05/27/99	DRY	DRY	1.24	3.03	0.79	3.95	1.42	6.30			05/27/99
06/01/99	DRY	DRY	0.93	3.07	0.91	3.72	1.14	5.57			06/01/99
06/11/99	DRY	DRY	0.66	2.07	1.14	3.60	0.94	4.48	1.85	4.10	06/11/99
06/17/99	DRY	DRY	0.97	2.89	1.12	3.44	1.33	4.26	1.93	3.62	06/17/99
06/24/99			0.99	3.02	1.17	3.69	0.89	5.22			06/24/99
06/30/99	DRY	DRY	1.07	3.09	1.17	3.67	1.32	4.70	1.50	2.62	06/30/99
07/07/99	DRY	DRY	1.17	3.14	0.28	4.36	1.23	3.73	1.77	3.37	07/07/99
07/14/99	DRY	DRY	1.14	3.09	0.48	3.79	0.41	2.39	0.64	0.84	07/14/99
07/21/99	DRY	DRY	0.86	2.58	0.53	3.61	0.89	3.42	1.35	2.96	07/21/99
07/28/99	DRY	DRY	0.94	2.75	0.61	3.62	1.00	4.19	1.50	3.30	07/28/99
08/04/99	DRY	DRY	0.48	1.58	0.54	3.38	0.86	4.44	1.65	3.64	08/04/99
08/12/99	DRY	DRY	0.88	2.70	0.47	3.33	1.04	4.19	2.17	3.35	08/12/99
08/18/99	DRY	DRY	1.18	2.93	0.94	3.50	1.60	4.79	2.95	4.63	08/18/99
09/04/99	DRY	DRY	0.99	3.10	1.17	3.61	1.42	4.09	1.91	3.67	09/04/99
09/16/99	DRY	DRY	1.22	3.02	1.40	3.86	1.52	4.65	0.66	1.36	09/16/99
10/01/99	DRY	DRY	1.32	3.18	1.41	1.23	1.45	4.76	1.60	2.04	10/01/99
11/13/99	DRY	DRY	1.22	3.27	1.42	3.69	1.42	5.18	1.91	4.39	11/13/99
01/04/00			2.51	3.49	1.93	4.36	1.27	5.20			01/04/00
02/24/00			2.64	3.18	2.29	4.16	1.35	5.45	2.06	4.57	02/24/00
03/25/00	DRY	DRY	1.73	3.18	2.11	4.13	1.27	5.59	1.60	3.47	03/25/00
04/15/00	DRY	DRY	1.60	3.12	0.61	5.31	0.86	3.66	1.04	4.15	04/15/00
04/28/00	DRY	DRY	1.77	2.06	0.81	2.95	1.01	2.34	1.20	3.38	04/28/00
05/17/00	DRY	DRY	1.73	3.11	1.45	3.80	1.24	3.99	1.73	4.58	05/17/00
06/01/00	DRY	DRY	1.80	2.99	1.72	4.27	1.43	4.47	2.04	4.82	06/01/00
06/06/00	DRY	DRY	1.45	2.90	1.74	3.80	1.25	5.06	0.66	2.09	06/06/00
06/15/00	DRY	DRY	1.40	2.90	1.32	3.88	1.40	2.96	1.70	4.46	06/15/00
06/23/00	DRY	DRY	1.50	2.81	0.94	4.40	1.55	4.24	1.94	4.62	06/23/00
06/29/00	DRY	DRY	1.32	3.09	0.94	3.52	1.77	3.78	2.00	4.76	06/29/00
07/06/00	DRY	DRY	1.52	3.13	1.28	3.66	2.04	3.97	2.19	4.84	07/06/00
07/14/00	DRY	DRY	1.68	3.03	1.31	3.56	2.25	4.16	2.45	4.61	07/14/00
07/20/00	DRY	DRY	1.40	3.13	1.25	3.26	1.89	3.63	2.44	4.76	07/20/00

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 8		Well 9A		Well 9B		Well 11		Well 12		Date
	WTD (m)	EC (dS/m)	WTD (m)	EC (dS/m)	WTD (m)	EC (dS/m)	WTD (m)	EC (dS/m)	WTD (m)	EC (dS/m)	
07/27/00	DRY	DRY	1.33	3.37	1.38	3.38	2.14	3.80	0.22	0.86	07/27/00
08/02/00	DRY	DRY	1.52	3.31	1.58	3.71	2.14	4.18	1.58	4.71	08/02/00
08/11/00	DRY	DRY	1.54	2.60	1.13	4.10	2.43	3.95	1.62	4.86	08/11/00
08/19/00	DRY	DRY	1.64	3.16	0.80	6.04	2.32	4.46			08/19/00
09/01/00	DRY	DRY	1.62	3.16	1.22	3.59	2.50	4.54	2.26	5.50	09/01/00
09/16/00	DRY	DRY	1.69	2.95	1.32		2.58	4.63	2.54	5.37	09/16/00
09/29/00	DRY	DRY	1.64	2.03	1.47	2.56	2.48	3.61	2.75	3.09	09/29/00
10/20/00	DRY	DRY	1.73	2.42	1.45	3.04	2.14	4.61	2.81	5.40	10/20/00
12/01/00	DRY	DRY	1.42	2.71	2.40	3.15	1.82	4.27	1.98	3.17	12/01/00
01/19/01	DRY	DRY	1.59	2.82	2.12	4.32	1.73	4.92	2.08	3.94	01/19/01
03/05/01	DRY	DRY	1.72	3.17	2.31	4.15	1.81	5.26	2.80	3.87	03/05/01
03/30/01	DRY	DRY	1.84	3.09	1.86	3.86	1.84	5.09	2.24	4.22	03/30/01
04/21/01	DRY	DRY	1.83	3.52	1.64	4.53	1.86	5.98	0.34	2.02	04/21/01
05/14/01	DRY	DRY	1.58	3.20	1.48	4.35	1.74	5.42	1.21	2.81	05/14/01
05/29/01	DRY	DRY	0.24	3.90	1.34	3.82	0.81	5.15	1.73	4.17	05/29/01
06/07/01	DRY	DRY	1.13	4.85	1.48	3.81	1.25	4.01	1.88	3.89	06/07/01
06/14/01	5.80	0.83	1.30	5.12	1.17	4.48	0.29	4.44	0.04	1.04	06/14/01
06/20/01	5.87	2.22	1.03	4.43	0.79	5.03	1.02	4.92	0.91	2.22	06/20/01
06/29/01	5.84	1.98	1.26	3.37	1.10	3.16	1.25	4.13	1.33	2.78	06/29/01
07/06/01	5.89	2.69	1.47	4.32	1.32	3.62	0.71	5.56	1.65	4.06	07/06/01
07/12/01	6.00	1.35	1.54	3.93	1.61	3.57	1.54	5.62	1.96	4.43	07/12/01
07/18/01	DRY	DRY	1.43	4.32	1.50	3.69	1.51	5.95	1.86	4.35	07/18/01
07/26/01	DRY	DRY	1.19	3.51	1.60	3.66	1.60	5.52	1.14	3.25	07/26/01
08/02/01	DRY	DRY	1.39	3.64	1.70	3.56	1.71	5.53	1.51	3.54	08/02/01
08/10/01	DRY	DRY	1.45	3.93	1.73	3.62	1.80	5.40	1.53	4.28	08/10/01
08/17/01	DRY	DRY	1.39	3.77	1.01	3.88	1.87	5.35	1.66	4.44	08/17/01
09/01/01	DRY	DRY	1.36	3.67	1.13	4.51	1.99	5.35	1.16	3.12	09/01/01
09/15/01	DRY	DRY	1.44	3.64			2.22	4.98	1.69	4.36	09/15/01
09/29/01	DRY	DRY					2.33	4.97	1.92	4.37	09/29/01
10/12/01											10/12/01
10/27/01	DRY	DRY	1.32	4.24	1.80	3.84	2.06	4.95			10/27/01
11/17/01											11/17/01
12/18/01	DRY	DRY	1.26	3.43	1.93	3.28	1.80	4.94	2.08	4.11	12/18/01

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 13		Well 14		Well 15		Well 16A		Well 16B		Date
	WTD (m)	EC (dS/m)	WTD (m)	EC (dS/m)	WTD (m)	EC (dS/m)	WTD (m)	EC (dS/m)	WTD (m)	EC (dS/m)	
04/05/99	DRY	DRY	1.45	2.17	2.29	1.58	1.85	1.80	DRY	DRY	04/05/99
05/11/99	2.16	7.32	0.89	2.07	2.06	2.09	1.40	1.92	DRY	DRY	05/11/99
05/27/99	2.34	5.92	1.04	2.27	2.67	1.80	1.60	1.89	2.03	2.93	05/27/99
06/01/99			1.06	2.24							06/01/99
06/11/99	2.49	4.10	1.32	1.80	2.36	1.63	1.65	1.66	5.08	1.95	06/11/99
06/17/99	2.36	3.30	1.42	0.77	2.22	1.52	1.59	1.52	4.04	1.34	06/17/99
06/24/99	2.20	3.18	0.48	0.70	DRY	DRY			DRY	DRY	06/24/99
06/30/99	2.29	3.04	0.94	1.54	2.29	1.59	1.57	1.51	3.99	1.55	06/30/99
07/07/99	2.46	3.29	1.28	1.91	DRY	DRY	1.69	1.55	3.89	1.45	07/07/99
07/14/99	2.59	2.28	1.24	2.23	DRY	DRY	1.73	1.56	2.76	1.53	07/14/99
07/21/99	2.50	1.97	1.13	1.49			1.52	1.15	3.86	1.62	07/21/99
07/28/99	2.68	2.20	1.45	1.62	DRY	DRY	1.40	2.20	1.50	1.60	07/28/99
08/04/99	2.49	1.92	1.14	0.46	2.25	0.70	1.47	1.43	4.22	1.66	08/04/99
08/12/99	2.30	1.64	1.04	2.34	DRY	DRY	1.60	1.27	DRY	DRY	08/12/99
08/18/99	2.41	2.40	1.24	2.33	2.49	1.10	1.59	1.25	4.11	1.59	08/18/99
09/04/99	2.69	1.80	0.91	1.43	DRY	DRY	1.65	1.51	4.04	1.61	09/04/99
09/16/99	2.90	2.76	1.45	2.17	DRY	DRY	1.68	1.57	4.14	1.34	09/16/99
10/01/99	2.87	2.79	1.70	2.52	DRY	DRY	1.75	1.55			10/01/99
11/13/99	2.84	2.82	1.65	2.49	DRY	DRY					11/13/99
01/04/00	2.97	2.77	1.70	2.38	DRY	DRY					01/04/00
02/24/00	DRY	DRY			DRY	DRY	2.08	1.67	4.50	2.21	02/24/00
03/25/00	DRY	DRY			DRY	DRY	1.98	1.63	4.17	1.92	03/25/00
04/15/00	2.74	2.23			DRY	DRY	1.91	1.60	3.99	1.71	04/15/00
04/28/00	DRY	DRY	1.45	7.54	2.57	1.21	1.91	1.60	4.01	1.57	04/28/00
05/17/00	2.82	1.83	1.40	7.22	2.62	1.49	1.73	1.47	4.09	1.42	05/17/00
06/01/00	2.74	2.27	1.23	6.16	2.69	1.04	2.05	1.53	4.13	1.42	06/01/00
06/06/00	2.59	2.29	1.08	4.26	2.68	0.75	1.73	1.58	4.17	1.53	06/06/00
06/15/00	2.56	2.38	1.58	3.88	2.72	0.96	1.75	1.54	4.00	1.45	06/15/00
06/23/00	2.82	2.04	1.30	2.80	2.77	1.00	1.68	1.54	4.00	1.55	06/23/00
06/29/00	DRY	DRY	1.51	2.99	2.79	1.13	1.69	1.52	3.93	1.47	06/29/00
07/06/00	2.86	1.93	1.59	3.04	2.80	1.12	1.65	1.56	4.01	1.48	07/06/00
07/14/00	2.86	2.20	1.52	4.05	2.77	1.61	1.49	1.72	4.01	1.86	07/14/00
07/20/00	2.79	1.63	1.03	3.44	2.80	1.40	1.40	1.55	4.05	1.44	07/20/00

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 13		Well 14		Well 15		Well 16A		Well 16B		Date
	WTD	EC	WTD	EC	WTD	EC	WTD	EC	WTD	EC	
07/27/00	2.87	2.33	1.53	3.17	2.76	1.78	1.36	1.60	4.02	1.52	07/27/00
08/02/00	2.95	2.18	1.91	3.30	2.81	1.95	1.27	1.78	4.00	1.65	08/02/00
08/11/00	2.91	1.92	1.62	3.18	2.84	1.77	1.42	1.47	4.18	1.39	08/11/00
08/19/00	2.91	2.07	1.57	3.42	2.83	1.83	1.34	1.56	4.00	1.60	08/19/00
09/01/00	3.20	1.85	1.93	3.72	2.90	1.77	1.42	1.37	4.22	1.25	09/01/00
09/16/00	2.97	2.32			DRY	DRY	1.60	2.55	4.88	1.96	09/16/00
09/29/00			1.86	2.79	2.88	1.85	1.47	1.61	4.27	1.53	09/29/00
10/20/00			1.52	2.71	2.83	1.40	1.35	1.60	4.25	1.59	10/20/00
12/01/00			1.80	2.65	2.80	1.92	1.55	2.42	4.36	1.87	12/01/00
01/19/01			1.89	3.10	2.82	2.03	1.68	2.51	4.24	1.92	01/19/01
03/05/01			1.95	2.60	2.87	1.85	1.89	2.31	4.51	2.06	03/05/01
03/30/01			1.95	2.57	DRY	DRY	1.95	2.35	4.57	2.10	03/30/01
04/21/01			1.92	2.88	2.65	1.89	1.63	1.53	3.84	1.64	04/21/01
05/14/01	2.95	1.76	1.26	2.62	2.71	1.90	1.37	1.53	3.91	1.41	05/14/01
05/29/01	2.37	1.86	1.31	2.75	2.71	1.89					05/29/01
06/07/01	2.58	1.91	1.26		2.69	1.91	1.40	1.58	3.99	1.50	06/07/01
06/14/01	2.79	1.85	0.94	2.87	2.81	1.87	1.51	1.61	4.03	1.44	06/14/01
06/20/01	2.93	2.19	1.20	3.15	2.80	2.05	1.58	1.82	4.13	1.76	06/20/01
06/29/01	2.88	1.64	1.40	2.65	2.81	1.92	1.59	1.72	4.12	1.39	06/29/01
07/06/01	2.90	1.61	1.48	2.58	2.86	1.96	1.95	1.71	4.07	1.40	07/06/01
07/12/01			1.58	2.53	2.92	1.96	1.76	1.89	3.84	1.34	07/12/01
07/18/01	2.87	1.64	1.24	2.65	2.83	1.93	1.71	2.23	4.16	1.30	07/18/01
07/26/01	2.96	2.11	1.35	2.54	2.89	1.87	1.69	2.11	4.18	1.29	07/26/01
08/02/01	2.98	0.89			2.94	1.94	2.67	3.57	4.21	1.32	08/02/01
08/10/01	2.85	1.85	1.48	2.65	2.93	1.94	1.68	2.33	4.32	1.30	08/10/01
08/17/01			1.51	2.76	2.88	1.92	1.68	2.24	4.35	1.48	08/17/01
09/01/01	2.97	1.98	1.74	2.62	2.92	1.89	1.67	2.29	4.21	1.31	09/01/01
09/15/01			1.87	2.63	2.94	1.86	1.69	2.26	4.22	1.49	09/15/01
09/29/01			1.88	2.58	DRY	DRY	1.67	2.16	4.25	1.45	09/29/01
10/12/01											10/12/01
10/27/01			1.84	2.60	DRY	DRY	1.66	1.62	4.32	1.62	10/27/01
11/17/01			1.71	2.65	DRY	DRY	1.99	2.69	4.21	1.69	11/17/01
12/18/01					DRY	DRY	1.75	1.58			12/18/01

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 16C		Well 17		Well 18		Well 20		Well 21		Date
	WTD (m)	EC (dS/m)	WTD (m)	EC (dS/m)	WTD (m)	EC (dS/m)	WTD (m)	EC (dS/m)	WTD (m)	EC (dS/m)	
04/05/99	2.59	2.39	1.02	3.13	1.27	4.20	0.23	21.70	2.57	3.34	04/05/99
05/11/99	1.75	2.83	0.84	4.77	0.91	4.88	0.28	21.50	1.88	3.14	05/11/99
05/27/99				2.93	1.07	4.69	0.46	20.13	1.83	2.61	05/27/99
06/01/99			0.89	4.37	1.02	4.41	0.84	19.37	1.98	2.55	06/01/99
06/11/99	2.21	2.34	0.94	3.73	1.14	4.29	0.76	17.27	0.91	2.29	06/11/99
06/17/99	2.24	2.39			0.97	4.35	0.53		1.24	1.94	06/17/99
06/24/99			0.86	3.39	0.64	4.64	0.71	15.26	1.55	2.14	06/24/99
06/30/99			0.91	3.74	0.86	4.45	0.69	14.07	1.80	2.37	06/30/99
07/07/99					0.99	4.57	0.86	14.79	1.52	2.83	07/07/99
07/14/99	1.36	2.41	0.89	3.42	0.10	3.39	0.33	9.53	0.36	0.56	07/14/99
07/21/99	1.93	2.31	0.81	4.48	0.64	4.70	0.41	17.86	1.09	2.32	07/21/99
07/28/99	2.29	2.40	0.89	4.24	0.61	4.56	0.47	14.66	1.37	2.43	07/28/99
08/04/99	2.46	2.47	0.86	2.84	0.61	4.64	0.19	19.71		2.58	08/04/99
08/12/99	1.91	2.69	0.36	2.89	0.84	4.56	0.36	15.98	1.54	2.71	08/12/99
08/18/99	2.31	2.42	0.97	3.11	0.46	4.85	0.88	13.89	2.11	2.45	08/18/99
09/04/99	2.34	2.45	0.61	2.83	0.48	4.65	1.17	15.16	1.56	2.79	09/04/99
09/16/99	2.49	2.44	0.99	2.70	0.43	4.26	1.09	15.16	0.97	1.93	09/16/99
10/01/99			0.99	2.70	0.97	4.58	0.86	15.30	1.12	2.64	10/01/99
11/13/99	2.51	2.45	0.97	2.85	1.02	4.59	0.69	16.61	2.08	2.17	11/13/99
01/04/00			1.07	2.77	0.28	4.72	0.43	21.50	1.84	3.26	01/04/00
02/24/00	1.93	2.52	1.01	2.65	1.22	4.69	0.28	24.17	2.11	3.33	02/24/00
03/25/00	2.13	2.52	1.01	2.60	1.09	4.64	0.20	24.40	2.21	3.44	03/25/00
04/15/00	2.34	2.49	0.89	2.74	0.97	4.69	0.23	19.97	2.16		04/15/00
04/28/00	2.41	2.49	0.66	2.94	1.13	3.19	0.36	11.94	0.97	2.17	04/28/00
05/17/00		1.61	0.41	2.11	1.21	4.74	0.46	16.87	1.55	2.86	05/17/00
06/01/00	2.47	2.48	0.83	2.74	0.91	4.59	0.40	15.84	1.90	3.17	06/01/00
06/06/00	2.36	2.60	0.84	2.75	1.07	4.71	0.77	16.35	1.59	2.82	06/06/00
06/15/00	2.48	2.50	0.95	2.65	0.61	4.76	0.90	15.55	1.95	2.35	06/15/00
06/23/00	2.53	2.61	0.70	2.90	1.08	4.81					06/23/00
06/29/00	2.57	2.51	0.85	2.88	1.17	4.81	0.93	16.34	2.44	3.17	06/29/00
07/06/00	2.68	2.54	0.92	2.75	1.07	5.05	1.13	15.43	2.54	3.28	07/06/00
07/14/00	2.51	3.38	0.82	3.58	0.80	4.94	1.26	15.14	2.60	2.98	07/14/00
07/20/00	2.53	2.49			1.19	4.92	1.28	15.27	2.68	2.92	07/20/00

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 16C		Well 17		Well 18		Well 20		Well 21		Date
	WTD	EC	WTD	EC	WTD	EC	WTD	EC	WTD	EC	
07/27/00	2.58	2.67	0.98	2.53	1.24	5.28	1.41	15.90	1.17	2.63	07/27/00
08/02/00	2.59	2.90	0.94	2.68	1.16	5.16	1.47	16.61	1.83	2.30	08/02/00
08/11/00	2.59	2.64			1.16	4.53	1.63	15.45	2.21	1.99	08/11/00
08/19/00	2.62	2.94	0.99	2.65	1.14	4.60	1.65	14.85	2.05	2.21	08/19/00
09/01/00	2.62	2.32	1.40	3.22	1.27	4.90	1.81	15.62	2.42	2.53	09/01/00
09/16/00	3.05	2.61	1.60	3.43	1.47	4.78	1.98	16.88	2.69	2.96	09/16/00
09/29/00	2.72	2.78	1.03	2.76	1.57	3.51	2.07	13.02	2.88	2.59	09/29/00
10/20/00	2.75	2.87	0.94	3.03	1.48	4.39	2.15	16.36	2.67	1.99	10/20/00
12/01/00	2.90	3.05	1.10	2.65	1.30	3.74	2.03	16.37	2.22	2.10	12/01/00
01/19/01	2.79	3.12	1.05	2.87	1.31	5.13	1.88	7.30	2.59	2.61	01/19/01
03/05/01			1.22	2.44	1.36	4.38	1.69	15.41	2.79	2.45	03/05/01
03/30/01			1.28	2.62	1.41	4.34	1.57	9.03	2.87	2.61	03/30/01
04/21/01	2.52	2.78	0.93	2.49	1.41	4.99	1.39	16.90	2.72	2.36	04/21/01
05/14/01	2.60	2.75	0.93		1.13	4.16	1.09	16.46	2.92	1.85	05/14/01
05/29/01			1.23	2.46	1.15	4.24	1.06	15.63	1.20	1.79	05/29/01
06/07/01	2.37	2.73	0.94	2.51	1.20	4.22	1.13	15.59	1.81	4.48	06/07/01
06/14/01	2.50	2.73	0.77	2.44	0.55	4.83	1.23	15.26	2.12	3.52	06/14/01
06/20/01	2.52	3.21	0.85	3.04	0.62	4.46	1.31	15.24	2.16	3.19	06/20/01
06/29/01	2.53	2.87	0.75	2.74	0.96	3.48	1.40	12.47	2.48	2.61	06/29/01
07/06/01	2.55	2.75	0.91	2.66	1.11	4.31	1.55	15.39	2.67	2.79	07/06/01
07/12/01	2.65	2.71	0.86	2.52	1.09	4.26	1.68	15.55	2.71	2.27	07/12/01
07/18/01	2.53	2.72	0.89	2.52	0.96	4.54	1.53	16.21	2.79	2.53	07/18/01
07/26/01	2.61	2.74	0.67	2.54	1.05	4.26	1.44	15.79	DRY	DRY	07/26/01
08/02/01		2.07	0.95	2.50	1.22	4.21	1.64	15.66	DRY	DRY	08/02/01
08/10/01	2.63	2.68	0.87	2.52	1.19	4.17	1.47	15.82	DRY	DRY	08/10/01
08/17/01	2.57	2.72	1.31	2.50	1.19	4.14	1.51	16.48	2.67	1.23	08/17/01
09/01/01	2.68	2.69	0.92	2.57	1.34	4.11	1.56	16.07	DRY	DRY	09/01/01
09/15/01	2.72	2.75	0.97	2.51	1.55	3.99	1.66	16.32	DRY	DRY	09/15/01
09/29/01	2.76	2.72	1.01	2.51	1.66	3.89	1.79	16.02	DRY	DRY	09/29/01
10/12/01											10/12/01
10/27/01	2.70	2.72	0.92	2.57	1.45	3.65	1.98	15.93	DRY	DRY	10/27/01
11/17/01	2.59	2.70	0.92	2.58							11/17/01
12/18/01	2.65	2.24			1.37	3.39	1.95	15.90	1.93	2.83	12/18/01

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 22		Well 23		Well 24		Well 26A		Well 26B		Date
	WTD (m)	EC (dS/m)	WTD (m)	EC (dS/m)	WTD (m)	EC (dS/m)	WTD (m)	EC (dS/m)	WTD (m)	EC (dS/m)	
04/05/99	1.19	4.37	DRY	DRY	1.27	2.47	DRY	DRY	1.75	3.59	04/05/99
05/11/99	0.81	4.99	0.81	3.92	1.17	2.77	DRY	DRY	1.57	3.44	05/11/99
05/27/99	1.42	5.06	1.68	4.44	1.65	2.66	DRY	DRY	1.42	3.41	05/27/99
06/01/99	1.37	4.88	1.75	4.19	1.63	2.83	DRY	DRY	1.78	0.71	06/01/99
06/11/99	1.42	4.14	0.08	4.57	1.50	2.25	DRY	DRY	2.16	3.27	06/11/99
06/17/99	1.50	4.43	0.50	4.20	1.22	2.25	DRY	DRY	2.16	3.11	06/17/99
06/24/99	1.57	4.48	1.12	4.49	0.95	2.43	DRY	DRY	2.26	3.18	06/24/99
06/30/99	1.65	4.38	1.37	4.63	0.94	2.53	DRY	DRY	2.36	3.19	06/30/99
07/07/99	1.80	4.37	1.32	4.75	1.36	2.54	DRY	DRY	DRY	DRY	07/07/99
07/14/99	1.55	0.45	1.32	4.75	1.50	2.45	DRY	DRY	2.46	3.17	07/14/99
07/21/99	1.60	1.79	0.91	4.00	1.19	2.72	DRY	DRY	2.29	3.12	07/21/99
07/28/99	1.73	1.21	1.07	4.83	1.16	2.60	DRY	DRY	2.22	3.13	07/28/99
08/04/99	1.63	3.28	0.84	4.88	1.18	2.64	DRY	DRY	2.06	3.32	08/04/99
08/12/99	1.69	1.74	0.90	3.59	1.42	1.89	DRY	DRY	1.98	2.49	08/12/99
08/18/99	2.07	2.77	0.90	5.02	1.52	2.63	DRY	DRY	2.59	2.96	08/18/99
09/04/99	1.75	2.05	1.19	4.95	0.94	2.48	DRY	DRY	2.06	3.17	09/04/99
09/16/99	1.73	3.31	1.19	5.27	1.19	2.59	DRY	DRY	2.13	3.21	09/16/99
10/01/99	1.68	3.44	1.02	5.19	1.55	2.52	DRY	DRY	2.08	3.22	10/01/99
11/13/99	1.68	4.61	1.80	5.00	1.32	2.10	DRY	DRY	2.01	3.20	11/13/99
01/04/00	1.85	4.72	DRY	DRY	1.83	2.57	DRY	DRY	2.08	3.43	01/04/00
02/24/00	1.98	4.55	2.49	5.11	1.98	2.50	DRY	DRY	2.26	3.24	02/24/00
03/25/00	1.83	4.51	1.73	4.32	1.52	2.56	3.81		1.37	3.74	03/25/00
04/15/00	1.50	4.56	0.00	2.93			DRY	DRY	1.60	3.68	04/15/00
04/28/00	1.93	3.04	0.93	3.10	1.28	1.93	3.42	0.86	1.78	2.45	04/28/00
05/17/00	1.57	4.51	1.84	4.94	1.40	1.54	3.54	1.15	1.97	3.47	05/17/00
06/01/00	1.55	4.25	2.07	4.96	1.53	1.67	3.20	1.06	1.95	3.35	06/01/00
06/06/00	1.50	4.31	0.48	4.10	1.60	1.84	3.30	1.07	1.55	3.43	06/06/00
06/15/00	1.50	4.10	1.35	4.25	1.66	1.90	3.27	1.07	1.94	3.29	06/15/00
06/23/00	1.32	4.40	0.89	5.11	1.65	1.81	3.01	1.04	1.57	3.42	06/23/00
06/29/00	1.45	4.39	0.75	5.17	1.62	1.74	3.38	1.06	1.72	3.44	06/29/00
07/06/00	1.38	4.50	1.33	5.06	1.61	1.72	3.30	1.17	2.00	3.58	07/06/00
07/14/00	1.51	4.44	2.22	5.25			3.27	1.14	1.91	3.45	07/14/00
07/20/00	1.35	4.42	2.03	5.18	0.93	1.50	3.29	1.12	2.15	3.53	07/20/00

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 22		Well 23		Well 24		Well 26A		Well 26B		Date
	WTD	EC	WTD	EC	WTD	EC	WTD	EC	WTD	EC	
07/27/00	1.58	4.61	2.15	5.44	1.65	1.67	3.32	1.02	2.05	3.22	07/27/00
08/02/00	1.74	4.44	2.23	5.54	1.74	1.84	3.06	1.19	2.26	3.67	08/02/00
08/11/00	1.69	3.99	2.45	4.93	1.77	1.46	2.84	1.04	2.43	3.26	08/11/00
08/19/00	1.85	4.24	2.86	5.06	1.96	1.30	2.90	1.11	2.40	3.43	08/19/00
09/01/00	1.75	4.44	1.91	3.63	2.06	1.11	3.01	1.10	2.28	3.49	09/01/00
09/16/00	2.00	4.40	2.51	5.01	2.16	1.24	2.68	1.14	2.52	3.41	09/16/00
09/29/00	2.16	3.35	2.83	3.81	2.03	1.07	2.90	1.02	2.43	3.51	09/29/00
10/20/00	2.20	4.23	2.88	5.15	1.98	1.01	3.17	1.07	2.52	3.35	10/20/00
12/01/00	2.29	4.18	3.04	4.24	2.10	1.67	3.24	1.09	2.30	3.07	12/01/00
01/19/01	2.31	5.33	2.94	7.71	2.13	2.33	3.58	1.71	2.33	4.37	01/19/01
03/05/01	2.42	4.83	DRY	DRY	2.26	1.93	4.50	1.14	2.51	3.42	03/05/01
03/30/01	2.37	4.40	1.86	3.01	2.10	2.03	4.95	1.02	2.57	3.16	03/30/01
04/21/01	2.27	5.30	1.39	3.30	1.38	2.30	5.02	1.10	1.89	3.91	04/21/01
05/14/01	2.30	4.41	0.44	2.14	1.40	2.12	3.94	1.21	2.05	3.37	05/14/01
05/29/01	2.33	4.46	1.97	3.72	1.57	2.43	4.00	1.00	2.00	3.03	05/29/01
06/07/01	2.37	4.45	2.00	3.59	1.63	2.22			2.06	3.03	06/07/01
06/14/01	2.29	4.41	2.01	3.53			3.65	1.28	2.04	3.28	06/14/01
06/20/01	2.14	4.39	0.74	3.68	1.46	2.69	3.59	1.16	1.87	3.15	06/20/01
06/29/01	2.37	4.07	1.36	2.93	1.61	2.61	3.53	0.90	1.89	2.55	06/29/01
07/06/01	1.91	4.31	0.67	3.60	1.71	2.41	3.47	1.08	1.91	3.11	07/06/01
07/12/01	1.95	4.21	0.72	3.54	1.82	2.40	3.48	1.08	1.54	3.13	07/12/01
07/18/01	2.07	4.22	0.70	3.48	1.83	2.35	3.52	1.17	1.60	3.09	07/18/01
07/26/01	1.49	4.26	1.40	2.90	1.82	2.48	3.14	1.17	2.02	3.17	07/26/01
08/02/01	1.59	4.23	0.55	4.27	1.88	2.47	3.12	1.13	2.09	3.15	08/02/01
08/10/01	1.73	4.28			1.66	2.47	3.01	1.05	1.81	3.17	08/10/01
08/17/01	1.66	5.23			1.73	2.50	2.94	1.07	2.00	3.15	08/17/01
09/01/01	1.94	4.33			1.80	2.37	2.82	1.20	1.79	3.18	09/01/01
09/15/01	2.10	4.22			1.94	2.07	3.01	1.13	2.18	3.19	09/15/01
09/29/01	2.18	4.38			1.68	1.93	3.10	1.20	2.31	3.19	09/29/01
10/12/01											10/12/01
10/27/01	1.85	4.37			1.96	2.36	3.19	1.20	2.22	3.08	10/27/01
11/17/01					1.65	1.65					11/17/01
12/18/01	2.24	4.16			1.28	1.32	2.99	0.98	2.22	3.08	12/18/01

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 27		Well 28		Well 29		Well 30		Well 31		Date
	WTD (m)	EC (dS/m)	WTD (m)	EC (dS/m)	WTD (m)	EC (dS/m)	WTD (m)	EC (dS/m)	WTD (m)	EC (dS/m)	
04/05/99	DRY	DRY	2.36	3.34	1.65	4.47	DRY	DRY	1.65	3.24	04/05/99
05/11/99	DRY	DRY	1.63	3.48	1.75	4.55	DRY	DRY	0.79	1.84	05/11/99
05/27/99	DRY	DRY	1.70	3.73	1.91	4.63	DRY	DRY	1.07	2.36	05/27/99
06/01/99					1.82	4.47	DRY	DRY	0.87	3.11	06/01/99
06/11/99	DRY	DRY	1.57	3.72	2.01	4.38	DRY	DRY	1.07	2.97	06/11/99
06/17/99	DRY	DRY	1.47	3.66	1.98	4.31	DRY	DRY	0.86	3.19	06/17/99
06/24/99	DRY	DRY	1.98	3.87	2.01	4.59	DRY	DRY	0.97	3.23	06/24/99
06/30/99	DRY	DRY	1.93	3.87	1.85	4.46	DRY	DRY	1.02	3.29	06/30/99
07/07/99	DRY	DRY	2.06	3.81	2.01	4.51	DRY	DRY	1.19	3.30	07/07/99
07/14/99	DRY	DRY	1.85	3.92	1.66	4.56	DRY	DRY	1.22	2.78	07/14/99
07/21/99	DRY	DRY	1.83	3.79	1.37	3.96	DRY	DRY	0.56	2.32	07/21/99
07/28/99	DRY	DRY	1.65	3.43	1.77	4.52	DRY	DRY	1.14	2.36	07/28/99
08/04/99	DRY	DRY	1.63	4.08	1.73	3.66			0.91	3.03	08/04/99
08/12/99	DRY	DRY	1.63	3.29	1.83	3.58	DRY	DRY	1.23	2.69	08/12/99
08/18/99	DRY	DRY	2.11	4.06	1.98	1.15	DRY	DRY	1.04	3.03	08/18/99
09/04/99	DRY	DRY	1.59	4.18	1.91	4.61	DRY	DRY	1.22	3.16	09/04/99
09/16/99	DRY	DRY	1.93	4.10	2.03	4.66	DRY	DRY	1.32	3.22	09/16/99
10/01/99	DRY	DRY	2.11	4.62	2.11	4.64	DRY	DRY	1.35	3.25	10/01/99
11/13/99	DRY	DRY	1.55	4.44	1.96	4.60	DRY	DRY	1.22	3.52	11/13/99
01/04/00	DRY	DRY	1.98	4.40	1.70	4.62	DRY	DRY	1.32	3.18	01/04/00
02/24/00	DRY	DRY	2.16	3.90	1.27	4.57	DRY	DRY	1.27	3.11	02/24/00
03/25/00	DRY	DRY	1.60	3.78	1.91	4.56	DRY	DRY	1.24	3.20	03/25/00
04/15/00	DRY	DRY	1.12	3.72	1.68	4.56	DRY	DRY	1.22	3.50	04/15/00
04/28/00	DRY	DRY	1.49	2.77	1.78	3.23	5.06	1.36	1.22	3.24	04/28/00
05/17/00	DRY	DRY	1.89	3.96	1.76	4.65	4.22	1.68	1.24	3.19	05/17/00
06/01/00	DRY	DRY	2.06	3.87	1.67	4.47	4.33	1.62	1.28	3.60	06/01/00
06/06/00	DRY	DRY	2.23	3.96	1.60	2.76	4.24	1.48	1.24	3.96	06/06/00
06/15/00	DRY	DRY	2.15	3.68	1.61	4.30	3.84	1.46	1.34	3.47	06/15/00
06/23/00	4.96	3.79	1.55	3.77	1.32	2.77	3.78	1.51	1.47	3.31	06/23/00
06/29/00	DRY	DRY	1.96	3.88	1.77	4.64	3.87	1.47	1.13	2.99	06/29/00
07/06/00	DRY	DRY	2.15	4.10	1.52	4.85	3.96	1.53	1.55	2.88	07/06/00
07/14/00	5.32	3.61	2.22	4.09	1.68	1.24	3.54	1.53	1.82	3.67	07/14/00
07/20/00	DRY	DRY	2.01	3.97	1.82	4.73	3.58	1.43	1.21	2.67	07/20/00

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 27		Well 28		Well 29		Well 30		Well 31		Date
	WTD	EC	WTD	EC	WTD	EC	WTD	EC	WTD	EC	
07/27/00	DRY	DRY	2.17	3.78	1.85	4.51	3.88	1.36	2.12	2.89	07/27/00
08/02/00	DRY	DRY	2.27	4.25	2.02	4.99	3.91	1.49	1.50	2.97	08/02/00
08/11/00	DRY	DRY	2.39	3.71	2.09	4.45	3.64	1.56	1.55	2.92	08/11/00
08/19/00	DRY	DRY	2.06	3.98	2.26	4.65	3.38	1.44	1.57	2.57	08/19/00
09/01/00	5.32	1.76	2.10	3.89	2.55	4.58	3.80	1.50	1.50	2.51	09/01/00
09/16/00	DRY	DRY	2.32	3.94	2.75	4.65	3.81	1.59	1.65	2.54	09/16/00
09/29/00	DRY	DRY	1.83	3.91	2.66	4.37	4.39	1.55	1.52	2.59	09/29/00
10/20/00	DRY	DRY	2.28	3.81	1.83	4.33	4.54	1.94	1.40	1.76	10/20/00
12/01/00	5.32	1.68	2.31	3.55	1.94	4.45	4.76	1.79	1.52	2.18	12/01/00
01/19/01	DRY	DRY	2.42	4.84	1.81	5.65	5.20	2.95	1.60	2.53	01/19/01
03/05/01	DRY	DRY	2.52	3.97	1.96	4.72	5.78	2.47	1.52	2.37	03/05/01
03/30/01	DRY	DRY	2.45	3.58	1.32	1.87	6.34	1.73	1.52	1.95	03/30/01
04/21/01	DRY	DRY	2.33	4.43	1.67	4.30	5.59	2.29	1.25	2.43	04/21/01
05/14/01	DRY	DRY	2.35	3.45	1.52	4.53	5.16	2.22	1.40	2.44	05/14/01
05/29/01	DRY	DRY	2.32	3.55	1.61	4.31	4.73	1.90	1.07	2.46	05/29/01
06/07/01	DRY	DRY	2.37	3.55	1.82	4.10	4.79	1.99	1.01	3.03	06/07/01
06/14/01	DRY	DRY	2.35	3.55	1.90	4.70	4.84	2.07	1.17	4.18	06/14/01
06/20/01	DRY	DRY	2.18	3.52	1.88	4.35	4.92	2.01	1.27	4.56	06/20/01
06/29/01	DRY	DRY	2.05	2.86	1.98	3.50	4.73	1.57	1.40	3.68	06/29/01
07/06/01	DRY	DRY	2.15	3.60	1.99	4.31	4.67	2.01	1.47	3.14	07/06/01
07/12/01	DRY	DRY	2.16	3.76	1.86	4.39	4.54	2.02	1.56	2.88	07/12/01
07/18/01	DRY	DRY	2.12	4.04	1.55	4.70	4.62	2.05	1.36	2.66	07/18/01
07/26/01	DRY	DRY	2.30	3.82	1.69	4.36	4.17	1.93	1.25	2.60	07/26/01
08/02/01	DRY	DRY	2.37	3.84	1.73	4.40	4.54	1.62	1.47	2.64	08/02/01
08/10/01	DRY	DRY	2.31	3.88	1.87	4.37	4.33	2.02	1.44	2.66	08/10/01
08/17/01	DRY	DRY	2.37	3.89	1.87	4.42	4.27	1.83	1.32	2.55	08/17/01
09/01/01	DRY	DRY	2.54	3.93	1.98	4.38	3.91	1.64	1.53	2.48	09/01/01
09/15/01	DRY	DRY	2.49	3.98	2.11	4.42	4.08	1.59	1.52	2.48	09/15/01
09/29/01	DRY	DRY	2.57	3.86	2.18	4.44	4.18	1.88	1.50	2.43	09/29/01
10/12/01											10/12/01
10/27/01	DRY	DRY	2.70	3.75	2.05	4.39	4.42	1.69	1.39	2.21	10/27/01
11/17/01									1.30	2.02	11/17/01
12/18/01	DRY	DRY	2.61	3.66	1.98	4.08	4.66	1.68	1.27	1.68	12/18/01

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 33		Well 35		36A		36B		Well 37		Date
	WTD (m)	EC (dS/m)	WTD (m)	EC (dS/m)	WTD (m)	EC (dS/m)	WTD	EC	WTD	EC	
04/05/99	DRY	DRY	2.36	3.04	DRY	DRY	3.05	2.51	DRY	DRY	04/05/99
05/11/99	DRY	DRY	2.24	3.00	DRY	DRY	2.57	7.70			05/11/99
05/27/99	DRY	DRY	1.58	3.12	DRY	DRY	2.69	5.57			05/27/99
06/01/99	DRY	DRY	1.54	3.10	DRY	DRY	2.74	5.17			06/01/99
06/11/99	DRY	DRY	1.65	3.00	DRY	DRY	2.82	4.98			06/11/99
06/17/99	DRY	DRY	1.35	2.91	DRY	DRY	2.59	4.26			06/17/99
06/24/99	DRY	DRY	0.86	3.03	DRY	DRY	2.59	4.49	DRY	DRY	06/24/99
06/30/99	DRY	DRY	1.19	3.03	DRY	DRY	2.59	4.71	2.59	1.97	06/30/99
07/07/99	DRY	DRY	1.12	2.97	DRY	DRY	2.90	5.04	3.01	1.93	07/07/99
07/14/99	DRY	DRY	1.19	2.67	DRY	DRY	3.10	4.92			07/14/99
07/21/99	DRY	DRY	1.24	3.04	3.07	0.71	2.69	4.49	2.86	3.76	07/21/99
07/28/99	DRY	DRY	1.52	3.06	DRY	DRY	2.97	4.87	DRY	DRY	07/28/99
08/04/99	DRY	DRY	1.56	3.01	DRY	DRY	2.67	4.59	DRY	DRY	08/04/99
08/12/99	DRY	DRY	1.65	2.47	DRY	DRY	2.59	4.41	DRY	DRY	08/12/99
08/18/99	DRY	DRY	2.10	3.45	DRY	DRY	2.87	4.05	2.90	3.43	08/18/99
09/04/99	DRY	DRY	1.93	3.15					DRY	DRY	09/04/99
09/16/99	DRY	DRY	2.29	3.15	DRY	DRY	3.20	4.82			09/16/99
10/01/99	DRY	DRY	2.31	3.15	DRY	DRY					10/01/99
11/13/99	DRY	DRY	1.73	3.05	DRY	DRY	3.10	4.57			11/13/99
01/04/00	DRY	DRY	2.31	3.16	DRY	DRY			DRY	DRY	01/04/00
02/24/00	DRY	DRY	2.72	2.83	DRY	DRY	DRY	DRY	DRY	DRY	02/24/00
03/25/00	5.21		DRY	DRY	4.40	2.37			4.14	1.87	03/25/00
04/15/00	DRY	DRY	1.88	3.03	4.42	1.73	3.02	2.55	DRY	DRY	04/15/00
04/28/00	4.89	2.14	1.90	2.07	4.48	2.42	3.00	3.45	3.29	1.82	04/28/00
05/17/00	5.03	2.23	1.50	3.03	4.40	2.40	2.92	3.46	3.33	1.73	05/17/00
06/01/00	5.00	1.95	1.65	2.95	4.49	2.51	2.95	3.82	2.97	1.50	06/01/00
06/06/00	4.95	1.88	1.17	2.98	4.41	2.53	2.88	3.44	2.48	1.72	06/06/00
06/15/00	4.65	2.68	1.67	2.96	4.32	2.61	3.07	3.49	2.93	1.78	06/15/00
06/23/00	4.78	2.42	1.86	3.03	4.20	2.74	3.11	3.59			06/23/00
06/29/00	4.52	3.04	1.85	3.04	3.83	2.45	3.10	3.31	3.23	1.53	06/29/00
07/06/00	4.41	3.02	1.95	3.09	4.05	2.41	3.25	3.42	3.32	1.37	07/06/00
07/14/00	4.34	2.13	2.10	3.21	4.00	3.25	3.10	3.55	DRY	DRY	07/14/00
07/20/00	4.32	2.45	1.75	3.09	3.90	2.58	3.00	3.53	3.45	1.32	07/20/00

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 33		Well 35		36A		36B		Well 37		Date
	WTD	EC	WTD	EC	WTD	EC	WTD	EC	WTD	EC	
07/27/00	4.13	2.62	1.79	2.89	3.83	2.58	3.19	3.18	3.46	1.48	07/27/00
08/02/00	4.00	2.96	1.99	3.27	3.80	2.67	3.15	3.40	3.33	1.73	08/02/00
08/11/00	4.00	2.32	2.15	2.93	3.79	2.75	3.72	3.43	3.65	1.67	08/11/00
08/19/00	3.93	2.01	2.62	3.21	3.77	2.64			3.44	1.74	08/19/00
09/01/00	4.34	3.02	2.08	3.16	3.76	2.34	3.07	3.09	3.45	1.49	09/01/00
09/16/00	4.58	3.35	1.58	3.12	3.89	3.09	3.33	3.32	3.89	2.08	09/16/00
09/29/00	4.79	2.82	2.20	3.11	4.11	3.89	3.35	4.37	4.14	1.69	09/29/00
10/20/00	4.83	2.76	2.29	3.07	4.24	1.97	3.57	3.77	4.36	1.46	10/20/00
12/01/00	5.18	3.07	2.15	2.90	4.27	2.13	3.38	3.81	DRY	DRY	12/01/00
01/19/01	5.68	3.61	3.81	2.52	4.36	2.11	3.60	2.95	DRY	DRY	01/19/01
03/05/01	DRY	DRY	3.13	2.88	4.85	2.45	3.84	3.13	DRY	DRY	03/05/01
03/30/01	DRY	DRY	2.58	2.81	4.91	2.58	4.08	2.86	DRY	DRY	03/30/01
04/21/01	5.40	2.78	3.06	2.44	4.46	2.36	3.11	3.32	4.12	2.01	04/21/01
05/14/01	4.99	2.82	3.12	2.21	4.52	2.07	3.18	3.10	4.10	1.64	05/14/01
05/29/01	5.07	2.80	2.61	2.37	4.43	2.48			3.76	1.47	05/29/01
06/07/01	4.90	2.74	2.83	2.44	4.37	2.49	2.95	3.00	2.83	1.96	06/07/01
06/14/01	4.93	2.83	3.10	1.73	4.50	2.33	3.11	3.04	2.54	1.61	06/14/01
06/20/01	4.71	2.81	2.97	1.80	4.49	2.74	3.14	3.60	2.73	2.12	06/20/01
06/29/01	4.67	1.82	2.35	1.95	4.51	2.47	3.07	2.85	3.14	1.76	06/29/01
07/06/01	4.68	2.56	3.00	2.21	4.42	2.29	3.19	2.77	3.30	1.64	07/06/01
07/12/01	4.65	2.41	3.02	2.33	4.39	2.40	3.27	2.76	3.46	1.58	07/12/01
07/18/01	4.69	2.63	3.36	2.40	4.25	2.39	3.10	2.63	3.50	1.57	07/18/01
07/26/01	4.78	2.45	3.00	2.51	4.10	2.42	3.22	2.70	3.53	1.72	07/26/01
08/02/01	4.80	2.60	2.99	2.03	4.08	2.44	2.96	2.78			08/02/01
08/10/01	4.86	2.73	2.89	2.10	4.01	2.27	3.22	2.62	3.23	1.91	08/10/01
08/17/01	4.82	2.73	3.01	2.09	3.85	2.42	3.16	2.73	3.55	1.70	08/17/01
09/01/01	4.87	2.74	3.01	2.43					3.94	1.65	09/01/01
09/15/01	5.00	2.76	3.03	2.65	3.84	2.32	3.37	2.77	4.16	1.63	09/15/01
09/29/01	5.14	2.77	3.04	2.28	3.81	2.14	3.28	2.82	4.33	1.77	09/29/01
10/12/01											10/12/01
10/27/01	5.34	1.53	3.02	2.52					4.54	1.47	10/27/01
11/17/01									4.62	1.67	11/17/01
12/18/01	5.63	2.37	2.82	2.39	3.69	1.66	3.19	2.18			12/18/01

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 38		Well 39		Well 40		Well 41		Well 42		Date
	WTD	EC	WTD	EC	WTD	EC	WTD	EC	WTD	EC	
04/05/99	DRY	DRY	1.68	4.44	0.97	6.49	1.09	4.61	DRY	DRY	04/05/99
05/11/99	1.14	1.91	0.41	1.56	0.48	8.25	0.94	4.24	0.91	2.56	05/11/99
05/27/99	1.27	0.85	0.84	3.13	0.61	8.05	1.09	4.13	0.74	3.74	05/27/99
06/01/99	1.31	1.07	1.08	3.30	0.74	7.71					06/01/99
06/11/99	DRY	DRY	1.14	3.31	0.69	7.61	0.86	0.53	0.71	0.22	06/11/99
06/17/99	1.73	2.34	1.14	2.29	0.53	5.81			1.04	3.47	06/17/99
06/24/99	1.82	2.80	1.17	3.29	1.19	1.99	1.04	2.34	1.12	4.34	06/24/99
06/30/99	1.73	0.68	1.17	1.92	0.71	5.36	1.17	4.00			06/30/99
07/07/99	1.47	1.66	1.13	1.18	0.64	6.36	0.30	2.24	0.71	4.30	07/07/99
07/14/99	1.32	1.95	1.60	1.78	0.13	11.96	0.25	3.26	0.33	2.29	07/14/99
07/21/99	1.04	0.96	1.05	1.95	0.28	9.69	0.99	4.12	0.71	2.79	07/21/99
07/28/99	1.30	1.19	1.30	2.54	0.38	5.15	1.19	4.20	0.89	4.35	07/28/99
08/04/99	1.04	0.98	1.10	2.94	0.11	9.65	1.02	4.54	0.81	4.33	08/04/99
08/12/99	1.17	2.50	1.12	4.00	0.25	8.59	1.17	3.78	0.95	3.27	08/12/99
08/18/99	1.32	2.19	1.24	3.90	0.23	6.47	1.12	5.45	0.56	3.83	08/18/99
09/04/99	1.27	1.06	0.33	3.72			0.84	4.58	1.40	4.04	09/04/99
09/16/99	1.65	1.88	1.78	3.71	0.51	4.75	1.17	4.88	1.12	4.19	09/16/99
10/01/99	1.52	2.08	1.50	3.62			1.42	4.32	1.55	4.41	10/01/99
11/13/99	1.65		1.37	3.68	0.74	4.68	1.70	5.33	1.73	4.63	11/13/99
01/04/00	2.11	2.42	1.75	4.18	0.69	4.76	2.26	5.37	DRY	DRY	01/04/00
02/24/00	2.11	2.51	1.65	3.79	0.81	4.99	1.96	5.32	DRY	DRY	02/24/00
03/25/00	2.03	2.59	1.37	3.62	0.30	4.84	0.53	3.35	DRY	DRY	03/25/00
04/15/00	1.78	1.71	1.22	2.83			1.32	4.69	DRY	DRY	04/15/00
04/28/00	2.31	2.52	1.24	3.51	0.32	10.11	1.61	3.49	1.09	2.33	04/28/00
05/17/00	2.21	2.76	1.25	3.56	0.38	7.99	1.51	5.03	1.49	3.81	05/17/00
06/01/00	2.28	2.75	1.45	3.78	0.41	9.48	1.59	5.06			06/01/00
06/06/00	2.24	2.77	1.64	3.98	0.15	11.39	1.70	5.12	1.55	4.50	06/06/00
06/15/00	2.46	1.10	1.39	3.62	0.07	9.83	1.41	4.63	0.79	4.35	06/15/00
06/23/00	DRY	DRY	1.51	3.92			1.60	5.28	1.07	4.36	06/23/00
06/29/00	DRY	DRY	1.52	3.89			1.77	5.31	1.18	4.54	06/29/00
07/06/00	DRY	DRY	1.32	3.95			1.75	5.42	1.05	4.68	07/06/00
07/14/00	DRY	DRY	1.55	5.45	0.53	11.72	0.65	3.85	0.99	5.04	07/14/00
07/20/00	DRY	DRY	1.72	4.00	0.73	7.52	0.94	4.99	1.15	4.71	07/20/00

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 38		Well 39		Well 40		Well 41		Well 42		Date
	WTD	EC	WTD	EC	WTD	EC	WTD	EC	WTD	EC	
07/27/00	DRY	DRY	1.72	3.79	0.45	7.57	1.38	4.89	0.98	4.34	07/27/00
08/02/00	DRY	DRY	1.53	3.65	0.31	6.14	1.59	5.01	1.20	4.37	08/02/00
08/11/00	DRY	DRY	1.68	4.23	0.59	5.18	1.62	4.97	1.45	4.45	08/11/00
08/19/00	DRY	DRY	1.72	3.95	0.58	6.48			1.62	4.94	08/19/00
09/01/00	DRY	DRY	1.42	3.78	0.38	5.74	1.48	4.36	1.39	4.04	09/01/00
09/16/00	DRY	DRY	1.67	4.02	0.91	5.97	1.69	5.39	1.75	4.62	09/16/00
09/29/00	DRY	DRY	1.63	4.04	0.81	6.29	1.85	5.30	1.83	4.67	09/29/00
10/20/00	DRY	DRY	1.77	4.51	0.91	4.36	1.90	5.28	1.92	4.84	10/20/00
12/01/00	DRY	DRY	2.06	4.25	0.76	4.10	1.47	5.11	2.14	4.78	12/01/00
01/19/01	DRY	DRY	1.97	3.66	0.91	4.43	1.52	5.68	2.45	5.41	01/19/01
03/05/01	DRY	DRY	2.32	4.03	1.52	6.52	1.53	5.38	DRY	DRY	03/05/01
03/30/01	DRY	DRY	2.29	3.92	1.43	5.02	1.54	4.64	DRY	DRY	03/30/01
04/21/01	DRY	DRY	1.57	3.77	1.33	5.08	0.78	3.88	2.33	4.14	04/21/01
05/14/01	DRY	DRY	1.49	3.69	0.91	4.10	1.17	4.84	1.04	4.05	05/14/01
05/29/01	2.42	2.04	1.42	3.67	0.43	6.11	1.44	5.04	1.15	4.15	05/29/01
06/07/01	2.09	2.09	1.41	3.67	0.32	5.78	1.48	4.91	1.25	4.25	06/07/01
06/14/01	2.13	1.58	1.52	3.64	0.22	4.95	1.61	5.25			06/14/01
06/20/01			1.76	3.72	0.23	6.17	1.68	5.31	0.69	4.02	06/20/01
06/29/01	DRY	DRY	1.92	3.48	0.37	4.77	1.23	3.89	1.12	4.44	06/29/01
07/06/01	DRY	DRY	2.01	3.59	0.43	4.57	1.49	5.14	0.48	4.28	07/06/01
07/12/01	DRY	DRY	1.99	3.73	0.46	4.42	1.52	5.22	0.50	5.03	07/12/01
07/18/01	DRY	DRY			0.31	4.71	0.83	4.94	0.89	5.02	07/18/01
07/26/01	DRY	DRY	1.50	3.89	0.27	4.35	1.18	5.19	0.83	4.69	07/26/01
08/02/01	DRY	DRY	1.49	3.96	0.30	4.57	1.30	5.25	0.97	4.71	08/02/01
08/10/01	DRY	DRY	1.62	3.95	0.41	4.46	1.00	5.74	1.28	4.73	08/10/01
08/17/01	DRY	DRY			0.48	4.49	1.24	5.64	1.55	4.95	08/17/01
09/01/01	DRY	DRY	1.93	4.50	0.80	4.38	1.46	5.65	1.72	4.95	09/01/01
09/15/01	DRY	DRY	2.04	3.93	1.25	4.12	0.94	5.11	1.09	4.78	09/15/01
09/29/01	DRY	DRY	1.70	3.89	1.23	4.03	1.32	5.55	1.10	4.87	09/29/01
10/12/01											10/12/01
10/27/01	DRY	DRY	1.68	3.78	1.41	4.17	0.98	5.11	1.71	4.75	10/27/01
11/17/01	DRY	DRY	1.62	3.61							11/17/01
12/18/01	DRY	DRY	1.76	2.73	0.69	3.07	1.41	5.16	1.78	4.58	12/18/01

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 43		Well 45		Well 48		Well 49		Well 50		Date
	WTD	EC	WTD	EC	WTD	EC	WTD	EC	WTD	EC	
04/05/99	0.43	1.52			1.63	5.77	DRY	DRY	DRY	DRY	04/05/99
05/11/99	0.86	0.52	DRY	DRY	1.09	5.86	DRY	DRY	DRY	DRY	05/11/99
05/27/99	0.81	1.01	DRY	DRY	1.14	5.87	DRY	DRY	DRY	DRY	05/27/99
06/01/99											06/01/99
06/11/99			DRY	DRY	1.07	5.52	DRY	DRY	2.84	1.42	06/11/99
06/17/99	0.53	1.24	DRY	DRY	0.60	5.21	DRY	DRY	2.97	1.36	06/17/99
06/24/99	0.20	1.51	1.98	3.87	0.99	5.15	DRY	DRY	2.16	2.63	06/24/99
06/30/99	0.61	1.48	DRY	DRY	1.27	5.08	DRY	DRY	2.95	2.42	06/30/99
07/07/99	0.43	1.50	DRY	DRY	1.07	4.98	DRY	DRY	DRY	DRY	07/07/99
07/14/99	0.20	0.94	DRY	DRY	1.24	4.21	DRY	DRY	2.40	3.82	07/14/99
07/21/99	0.71	0.83	DRY	DRY	1.35	3.30	DRY	DRY	DRY	DRY	07/21/99
07/28/99	0.57	1.28	DRY	DRY	1.49	5.21	DRY	DRY	2.68	2.02	07/28/99
08/04/99	0.33	1.04					DRY	DRY	2.67	1.70	08/04/99
08/12/99	0.99	1.07	DRY	DRY	1.45	4.15	DRY	DRY	DRY	DRY	08/12/99
08/18/99	0.41	1.50	DRY	DRY	1.93	4.82	DRY	DRY	3.12	3.02	08/18/99
09/04/99	1.07	1.66	DRY	DRY	0.81	6.74	DRY	DRY	DRY	DRY	09/04/99
09/16/99	0.33	1.66	DRY	DRY	1.83	5.59	DRY	DRY	2.62	3.15	09/16/99
10/01/99	1.45	1.66	DRY	DRY	1.93	5.70	DRY	DRY	2.57	3.83	10/01/99
11/13/99	1.37	1.62	DRY	DRY	1.65	5.23	DRY	DRY	DRY	DRY	11/13/99
01/04/00	1.70	1.67	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	01/04/00
02/24/00	0.99	1.57	DRY	DRY	2.46	4.50	DRY	DRY	DRY	DRY	02/24/00
03/25/00	1.12	1.55	DRY	DRY	2.16	4.91	DRY	DRY	DRY	DRY	03/25/00
04/15/00			DRY	DRY	1.60	6.63	3.81	2.66			04/15/00
04/28/00	1.06	1.07	DRY	DRY	1.76	3.47	3.25	1.86	2.81	1.81	04/28/00
05/17/00	1.32	1.52	DRY	DRY	2.00	5.54	2.55	1.24	1.96	2.91	05/17/00
06/01/00	1.22	1.51	DRY	DRY	2.14	5.27	1.90	2.01	2.25	2.98	06/01/00
06/06/00	0.79	1.52	DRY	DRY	1.27	5.67	2.56	1.84	2.62	3.04	06/06/00
06/15/00	1.40	1.47	DRY	DRY	1.38	4.86	3.00	1.86	2.94	1.82	06/15/00
06/23/00	1.21	1.50	5.64	2.19	1.34	5.06	2.71	2.18	1.00	2.96	06/23/00
06/29/00	1.48	1.62	5.93	1.92	1.87	5.01	2.50	2.15			06/29/00
07/06/00	0.92	1.65	DRY	DRY	2.05	4.94	2.55	2.22			07/06/00
07/14/00	0.52	1.63	5.69	1.57	2.28	4.56	2.80	2.28	2.92	2.01	07/14/00
07/20/00	0.46	1.64	4.15	1.33	2.37	4.34	2.89	1.05	2.91	1.34	07/20/00

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 43		Well 45		Well 48		Well 49		Well 50		Date
	WTD	EC	WTD	EC	WTD	EC	WTD	EC	WTD	EC	
07/27/00	0.60	1.45	5.29	1.47	2.25	4.44	2.66	2.50	2.91	1.85	07/27/00
08/02/00	0.68	1.61	6.19	1.56	2.27	4.35	2.82	2.32	2.85	1.81	08/02/00
08/11/00	0.42	1.47	5.81	1.31	2.46	3.52	2.45	2.41	2.71	1.95	08/11/00
08/19/00	0.49	1.61	DRY	DRY	2.51	3.41	2.25	2.84	2.70	2.21	08/19/00
09/01/00	1.36	1.23	5.98	1.42	2.69	3.52	2.90	1.03	2.87	2.10	09/01/00
09/16/00	0.96	1.48	DRY	DRY	2.79	3.76	3.12	1.54			09/16/00
09/29/00	1.44	1.35	DRY	DRY	2.85	2.33	3.73	1.81	DRY	DRY	09/29/00
10/20/00	1.31	1.36	DRY	DRY	2.91	2.20	4.32	1.86	DRY	DRY	10/20/00
12/01/00	1.55	1.38	DRY	DRY	2.84	3.41	4.34	2.31	DRY	DRY	12/01/00
01/19/01	1.51	1.85	DRY	DRY	2.87	4.97	DRY	DRY	DRY	DRY	01/19/01
03/05/01			DRY	DRY	2.92	4.49	DRY	DRY	DRY	DRY	03/05/01
03/30/01	1.14	1.35	DRY	DRY	DRY	DRY			DRY	DRY	03/30/01
04/21/01	1.13	1.45	5.97	1.84	DRY	DRY	4.57	2.80			04/21/01
05/14/01	1.42	1.62	5.98	1.67	DRY	DRY	2.93	2.20			05/14/01
05/29/01	1.34	1.49	DRY	DRY	2.78	4.71	2.88	2.43			05/29/01
06/07/01	2.42	1.51	5.67	1.30	2.87	5.08	2.91	2.45	1.78	2.32	06/07/01
06/14/01	1.45	1.45	5.47	1.46	DRY	DRY	2.66	2.44	2.55	2.37	06/14/01
06/20/01	1.06	1.45	6.27	1.44	1.68	4.60	1.94	2.33	2.56	2.32	06/20/01
06/29/01	0.92	1.17	5.56	1.00	1.84	3.63			2.59	2.30	06/29/01
07/06/01	1.37	1.40	5.74	1.33	1.64	4.37			2.68	2.25	07/06/01
07/12/01	1.31	1.38	DRY	DRY	1.86	4.38			2.55	2.30	07/12/01
07/18/01	1.36	1.39	5.86	1.21	1.93	4.64	2.36	2.61	2.63	2.32	07/18/01
07/26/01			DRY	DRY	2.06	4.42			2.43	1.41	07/26/01
08/02/01			5.35	1.19	2.11	4.40	2.12	3.22	2.45	1.49	08/02/01
08/10/01	1.20	1.48	5.82	1.38	1.85	4.43	2.90	2.92	1.79	2.41	08/10/01
08/17/01	1.37	1.39	5.90	1.13	1.95	4.43	2.88	2.99	2.35	2.46	08/17/01
09/01/01	0.80	1.35			2.12	4.46	2.75	2.54	2.74	1.86	09/01/01
09/15/01	1.38	1.36			2.25	4.47	2.50	2.73	2.12	2.51	09/15/01
09/29/01	1.49	1.35			2.36	4.46	3.09	2.42	2.90	1.81	09/29/01
10/12/01									0.92	1.75	10/12/01
10/27/01	1.37	1.30	DRY	DRY	2.36	4.39	4.69	2.73	DRY	DRY	10/27/01
11/17/01							2.85	1.21	3.38	2.10	11/17/01
12/18/01	1.56	1.25	DRY	DRY	2.12	3.83			DRY	DRY	12/18/01

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 51		Well 52		Well 53		Well 55		Well 57		Date
	WTD	EC	WTD	EC	WTD	EC	WTD	EC	WTD	EC	
04/05/99	DRY	DRY	2.06	2.95					DRY	DRY	04/05/99
05/11/99	DRY	DRY	1.63	1.39					0.76	7.49	05/11/99
05/27/99	1.65	3.39	2.01	1.68					0.94	6.41	05/27/99
06/01/99											06/01/99
06/11/99	DRY	DRY	1.96	1.97	DRY	DRY			1.09	1.65	06/11/99
06/17/99	DRY	DRY	1.88	1.71	DRY	DRY	0.94	6.26	2.26	7.82	06/17/99
06/24/99	1.47	3.26	1.84	2.15	DRY	DRY			DRY	DRY	06/24/99
06/30/99	DRY	DRY	1.85	2.38	2.95	1.44	1.40	7.03	2.06	11.46	06/30/99
07/07/99	DRY	DRY	2.13	2.54			1.40	7.36	1.97	11.88	07/07/99
07/14/99	DRY	DRY	2.22	2.57	DRY	DRY	1.60	7.64	1.85	12.04	07/14/99
07/21/99	DRY	DRY	1.96	1.07	DRY	DRY	1.14	5.14	2.01	12.34	07/21/99
07/28/99	DRY	DRY	2.21	0.83	DRY	DRY	1.44	5.96	1.93	12.58	07/28/99
08/04/99	DRY	DRY	1.88	0.51	DRY	DRY	1.03	7.58	1.84	12.70	08/04/99
08/12/99	DRY	DRY	1.87	1.07	DRY	DRY	0.99	6.56	DRY	DRY	08/12/99
08/18/99	DRY	DRY			DRY	DRY			1.98	13.43	08/18/99
09/04/99	DRY	DRY	DRY	DRY	DRY	DRY	1.42	7.53	DRY	DRY	09/04/99
09/16/99	DRY	DRY	2.36	1.24	DRY	DRY	1.78	7.62	1.85	14.55	09/16/99
10/01/99	DRY	DRY	2.41	1.49	DRY	DRY	1.55	7.27	1.85	14.83	10/01/99
11/13/99	DRY	DRY	2.46	2.41	DRY	DRY	1.55	6.27	2.13	14.80	11/13/99
01/04/00	DRY	DRY	DRY	DRY	DRY	DRY	7.06	1.62	2.11	15.13	01/04/00
02/24/00	DRY	DRY	2.34	2.83	DRY	DRY	6.89	1.42	DRY	DRY	02/24/00
03/25/00	DRY	DRY	2.29	2.87	2.95		7.72	1.52			03/25/00
04/15/00	DRY	DRY	1.88	1.15			4.38	1.55			04/15/00
04/28/00	DRY	DRY	2.29	1.48			5.29	1.59			04/28/00
05/17/00	DRY	DRY	2.30	1.53	3.25	1.42	5.26	1.61			05/17/00
06/01/00	DRY	DRY	2.02	0.66	3.07	1.64	5.20	1.56			06/01/00
06/06/00	DRY	DRY	1.88	1.51	3.25	2.32	4.96	1.47			06/06/00
06/15/00	DRY	DRY	2.01	1.93	3.51	2.06	4.81	1.73			06/15/00
06/23/00	DRY	DRY			3.60	2.15	5.29	1.81			06/23/00
06/29/00	DRY	DRY	2.15	2.19	3.32	1.87	5.02	1.84			06/29/00
07/06/00	DRY	DRY	2.20	2.24	3.44	2.06	4.81	1.74			07/06/00
07/14/00	DRY	DRY	2.19	2.92	3.36	1.23	6.64	1.42			07/14/00
07/20/00	DRY	DRY	2.13	1.08	3.26	1.20	5.29	1.54			07/20/00

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 51		Well 52		Well 53		Well 55		Well 57		Date
	WTD	EC	WTD	EC	WTD	EC	WTD	EC	WTD	EC	
07/27/00	DRY	DRY	2.03	2.36	3.48	1.99	5.26	1.63	0.84	2.41	07/27/00
08/02/00	DRY	DRY	2.23	2.62	3.44	2.08	5.60	1.65			08/02/00
08/11/00	DRY	DRY	2.21	2.64	3.49	3.35	5.71	1.67			08/11/00
08/19/00	DRY	DRY	2.25	2.49	3.82	3.34	5.22	1.84			08/19/00
09/01/00	DRY	DRY	2.23	1.16	3.62	3.00	5.81	1.77			09/01/00
09/16/00	DRY	DRY	2.28	1.41	3.85	3.63	5.96	1.71			09/16/00
09/29/00	DRY	DRY	2.39	1.59	3.95	3.44					09/29/00
10/20/00	DRY	DRY	2.62	2.10	3.98	3.44	6.27	1.58			10/20/00
12/01/00	DRY	DRY	2.67	1.87	4.04	1.53	6.55	1.62			12/01/00
01/19/01	DRY	DRY	2.67	1.87	4.29	2.88	1.62	6.55			01/19/01
03/05/01	DRY	DRY			4.19	2.55					03/05/01
03/30/01	DRY	DRY	2.53	1.22	3.77	2.37					03/30/01
04/21/01	DRY	DRY	2.12	1.28	3.31	1.88	1.48	5.60			04/21/01
05/14/01	DRY	DRY	2.07	1.59	3.44	1.57	1.51	5.04			05/14/01
05/29/01	DRY	DRY	1.97	1.06	3.09	1.44	1.23	5.41			05/29/01
06/07/01	DRY	DRY	1.99	1.16	2.75	1.51	1.26	5.45			06/07/01
06/14/01	DRY	DRY	1.98	1.24	3.44	1.53	1.47	5.49			06/14/01
06/20/01	DRY	DRY			3.54	1.84					06/20/01
06/29/01	DRY	DRY	2.08	1.30	3.66	2.06	1.45	6.87			06/29/01
07/06/01	DRY	DRY	1.99	1.46	3.61	2.73	1.53	5.90			07/06/01
07/12/01	DRY	DRY	2.09	1.58	3.71	2.87	1.75	5.39			07/12/01
07/18/01	DRY	DRY	2.02	1.40	3.82	2.82	1.55	5.37			07/18/01
07/26/01	DRY	DRY	2.12	1.01	3.45	1.74					07/26/01
08/02/01	DRY	DRY	2.23	0.82	3.40	1.67	1.46	7.30			08/02/01
08/10/01	DRY	DRY			2.98	2.06	1.43	5.65			08/10/01
08/17/01	DRY	DRY	2.04	1.11	3.11	1.82	1.26	8.58			08/17/01
09/01/01	DRY	DRY	2.19	1.24	2.59	1.84	1.51	5.91			09/01/01
09/15/01	DRY	DRY	2.25	1.40	3.67	2.26	1.62	5.59			09/15/01
09/29/01	DRY	DRY	2.26	1.49	3.82	3.02	1.59	5.43			09/29/01
10/12/01			2.26	1.88	4.02	3.25	1.56	4.93			10/12/01
10/27/01	DRY	DRY	2.17	1.94	3.76	3.07	1.47	4.96			10/27/01
11/17/01	DRY	DRY	2.12	1.93			1.50	4.70			11/17/01
12/18/01	DRY	DRY			4.06	2.21	1.38	3.55			12/18/01

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 59		Well 60A		Well 60B		Well 61		Well 62		Date
	WTD	EC	WTD	EC	WTD	EC	WTD	EC	WTD	EC	
04/05/99							1.83	8.37			04/05/99
05/11/99	1.50	10.40	DRY	DRY	1.93	4.98	0.91	10.50	DRY	DRY	05/11/99
05/27/99	1.17	10.24	DRY	DRY	2.08	4.44	1.12	10.84	1.96	1.01	05/27/99
06/01/99											06/01/99
06/11/99	1.35	10.32	DRY	DRY			0.66	7.54	DRY	DRY	06/11/99
06/17/99	1.50	8.54	DRY	DRY			0.97	10.39	2.57	0.95	06/17/99
06/24/99	1.68	10.05	1.07	3.19	1.78	3.61	1.17	14.03	DRY	DRY	06/24/99
06/30/99	1.42	10.30	2.01	2.94	1.85	3.09	1.37	13.01	2.13	0.84	06/30/99
07/07/99	1.24	10.13	2.46	2.97	1.88	2.39	1.60	12.56	DRY	DRY	07/07/99
07/14/99	1.02	8.38	2.72	3.03	2.06	1.71	1.65	10.25	2.69	0.90	07/14/99
07/21/99	1.22	9.38	DRY	DRY	2.16	1.78	0.76	10.87	DRY	DRY	07/21/99
07/28/99	1.40	8.28	DRY	DRY	2.26	2.07	1.82	9.35	DRY	DRY	07/28/99
08/04/99	1.52	9.48	DRY	DRY	2.41	2.94	1.85	9.91	DRY	DRY	08/04/99
08/12/99	1.63	9.41	DRY	DRY	2.51	3.59	1.85	8.05	2.84	1.02	08/12/99
08/18/99	1.83	9.75	DRY	DRY	2.62	4.05	1.96	11.19	2.92	0.99	08/18/99
09/04/99	1.07	9.47	DRY	DRY	2.16	1.45	0.89	9.71	DRY	DRY	09/04/99
09/16/99	1.50	9.79	1.85	3.16	2.29	1.52	1.47	11.93	2.87	1.08	09/16/99
10/01/99	1.88	9.64	1.88	3.55	1.42	1.30	1.57	11.45			10/01/99
11/13/99	1.93	9.36	2.41	3.97	1.78	1.43	1.40	11.74	DRY	DRY	11/13/99
01/04/00	2.44	8.95	2.77	4.18	2.26	6.38	1.62	11.26	DRY	DRY	01/04/00
02/24/00	1.14	9.66	DRY	DRY	DRY	DRY	0.46	9.38	1.98	1.55	02/24/00
03/25/00	1.27	9.38	1.17	2.19	1.58	6.71	1.73	8.59	2.49	2.33	03/25/00
04/15/00	1.04	6.41	1.78	2.34	1.70	3.93	0.86	5.60	2.64	1.46	04/15/00
04/28/00	1.52	9.16	2.08	3.71	1.65	3.38	1.17	9.35	2.59	2.20	04/28/00
05/17/00	1.57	7.89	2.26	4.22	1.99	5.65	1.34	8.23	2.62	1.10	05/17/00
06/01/00	1.27	8.73	1.66	4.39	1.19	3.91	1.39	8.17	2.19	0.90	06/01/00
06/06/00	1.50	8.78	1.83	3.92	1.35	2.67	1.16	8.07	2.55	1.01	06/06/00
06/15/00	1.83	7.88	1.95	4.64	1.68	2.43	1.31	9.26	2.80	1.00	06/15/00
06/23/00	2.03	7.33	1.46	1.56	1.31	2.91	1.34	9.13	2.80	1.12	06/23/00
06/29/00	1.59	8.13					1.46	8.47	3.07	1.04	06/29/00
07/06/00	1.89	8.07	2.05	3.91	1.68	2.97	1.66	8.45	3.14	1.08	07/06/00
07/14/00	1.79	10.98	2.23	5.88	1.53	4.80	1.69	11.04	DRY	DRY	07/14/00
07/20/00	1.79	7.80	1.71	3.87	1.36	3.41	1.79	8.35	3.27	1.66	07/20/00

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 59		Well 60A		Well 60B		Well 61		Well 62		Date
	WTD	EC	WTD	EC	WTD	EC	WTD	EC	WTD	EC	
07/27/00	1.84	6.90	1.78	3.32	1.13	3.19	2.00	9.23	3.42	1.89	07/27/00
08/02/00	2.02	8.62	1.83	4.92	1.10	4.49	2.17	8.93	3.49	1.77	08/02/00
08/11/00		8.46	0.14	5.01	1.74	3.59	2.33	8.84	3.59	1.71	08/11/00
08/19/00	2.44	7.85	2.45	4.70	1.93	6.21	2.40	8.53	3.60	1.69	08/19/00
09/01/00	2.03	5.65	2.84	4.66	2.26	4.32	3.00	7.90	3.05		09/01/00
09/16/00	2.58	3.97	2.96	3.16	2.65	7.39	2.65	5.22	3.79	1.02	09/16/00
09/29/00	2.90	8.26	DRY	DRY	DRY	DRY	3.00	9.61	2.90		09/29/00
10/20/00	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	10/20/00
12/01/00	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	12/01/00
01/19/01	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	01/19/01
03/05/01	DRY	DRY	4.02	5.14	2.68	6.10	2.80	7.62	DRY	DRY	03/05/01
03/30/01			4.05	4.32	2.68	6.65	2.71	6.56	DRY	DRY	03/30/01
04/21/01	2.58	5.72	DRY	DRY	0.71	10.58	2.70	7.38	3.51	1.59	04/21/01
05/14/01	2.69	5.38	2.30	3.80	2.04	6.19			3.62	1.59	05/14/01
05/29/01	2.59	3.87	1.95	3.70	1.69	3.95	2.57	7.70	3.66	1.26	05/29/01
06/07/01	2.54	3.27	2.13	4.30	1.43	2.00	2.18	7.62	3.71	1.34	06/07/01
06/14/01	1.88	5.19	2.41	4.79	1.58	1.85	1.00	8.88	3.36	1.86	06/14/01
06/20/01	2.29	5.75	2.40	4.38	1.70	1.85	1.26	9.52	3.23	1.83	06/20/01
06/29/01	2.66	5.14	2.72	4.61	2.10	2.02	1.61	9.07	3.54	1.62	06/29/01
07/06/01	2.32	3.99	2.67	4.67	1.60	1.83	1.89	8.82	3.58	1.50	07/06/01
07/12/01	2.35	3.59	1.98	3.86	1.83	1.74	1.99	8.35	3.76	1.50	07/12/01
07/18/01	2.44	3.53	2.08	2.66	1.74	1.62	2.10	8.82	3.68	1.52	07/18/01
07/26/01	0.94	5.18	2.37	4.60	1.87	1.81	2.24	8.80	3.62	1.48	07/26/01
08/02/01	1.82	8.02	2.33	4.77	2.28	1.47	2.39	8.50	3.75	1.65	08/02/01
08/10/01	1.99	7.58	2.05	4.15	2.31	1.56	2.47	8.66	3.81	1.45	08/10/01
08/17/01	2.19	6.67	2.15	4.60	2.31	1.47	2.65	8.67	3.83	1.63	08/17/01
09/01/01	2.62	6.26	2.57	4.68	2.76	1.64	2.71	8.71	DRY	DRY	09/01/01
09/15/01	2.98	6.01	2.91	4.53	2.96	0.91	2.74	8.72	DRY	DRY	09/15/01
09/29/01	DRY	DRY	3.06	4.52	DRY	DRY	2.77	8.60	DRY	DRY	09/29/01
10/12/01											10/12/01
10/27/01	DRY	DRY	3.43	4.34	DRY	DRY	2.86	9.69	DRY	DRY	10/27/01
11/17/01	DRY	DRY	3.56	4.29	DRY	DRY	2.87	9.44	DRY	DRY	11/17/01
12/18/01	DRY	DRY	3.76	3.54	DRY	DRY	2.74	5.72	DRY	DRY	12/18/01

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 64		Well 65		Well 66		Well 67		Well 68		Date
	WTD	EC	WTD	EC	WTD	EC	WTD	EC	WTD	EC	
04/05/99			1.45	2.78	0.81	2.20	1.52	2.15			04/05/99
05/11/99	0.97	2.44	0.89	3.32	0.48	2.08	1.37	0.42	DRY	DRY	05/11/99
05/27/99	1.17	3.48		1.27	0.62		1.27	1.27	DRY	DRY	05/27/99
06/01/99											06/01/99
06/11/99	0.84	4.48	1.37	4.58	0.30	2.12	0.79	1.32	DRY	DRY	06/11/99
06/17/99	0.74	3.38	1.07	5.17	0.20	1.77	1.12	1.60	DRY	DRY	06/17/99
06/24/99	0.76	4.39	1.17	5.25	0.25	2.14	1.19	2.06	DRY	DRY	06/24/99
06/30/99	0.86	4.49	1.09	5.85	0.25	2.15	0.97	1.01	DRY	DRY	06/30/99
07/07/99	0.53	3.26	1.40	6.43	0.33	1.89	0.99	1.03	DRY	DRY	07/07/99
07/14/99	0.77	2.33	2.06	6.18	0.32	2.13	0.90	1.31	DRY	DRY	07/14/99
07/21/99	0.77	2.07	1.22	5.53	0.23	1.87	0.86	1.28	DRY	DRY	07/21/99
07/28/99	0.91	2.02	1.55	5.06	0.30	1.81	0.85	1.20	DRY	DRY	07/28/99
08/04/99	0.94	2.09	1.12	4.48	0.20	2.11	0.79	1.07	DRY	DRY	08/04/99
08/12/99	1.17	2.10	1.12	5.28	0.20	2.13	0.76	2.18	DRY	DRY	08/12/99
08/18/99	1.22	2.41	1.30	5.42	0.25	2.11	0.74	1.41	DRY	DRY	08/18/99
09/04/99	0.64	1.28	1.57	5.01	0.27	2.25	0.67	1.68	DRY	DRY	09/04/99
09/16/99	1.17	1.58	1.52	4.95	0.23	2.26	0.61	2.12	DRY	DRY	09/16/99
10/01/99	1.12	1.16	1.55	4.74	0.28	2.27	0.66	2.29	DRY	DRY	10/01/99
11/13/99	1.22	1.08	1.65	3.98	0.41	2.13	0.76	2.50	DRY	DRY	11/13/99
01/04/00	1.47	1.05	1.65	3.61	0.61	2.15	0.97	2.28	DRY	DRY	01/04/00
02/24/00	1.30	1.09	1.50	3.22	0.69	2.14	1.05	2.34	DRY	DRY	02/24/00
03/25/00	1.07	1.25	1.73	3.25	0.81	2.13	1.24	2.49	4.47	1.60	03/25/00
04/15/00	1.07	1.12	1.65	2.12	0.71	1.45	1.22	1.70	5.00	1.24	04/15/00
04/28/00	1.35	2.33	1.71	3.11	0.52	2.03	1.05	2.35	4.29	1.37	04/28/00
05/17/00	1.22	2.98	1.65	3.11	0.41	1.96	0.86	1.67	4.18	1.62	05/17/00
06/01/00	1.14	3.51	1.79	2.90	0.35	2.04	0.82	1.91	4.35	1.55	06/01/00
06/06/00	1.28	3.55	1.62	3.10	0.33	2.11	0.86	2.13	3.96	1.62	06/06/00
06/15/00	1.39	4.07	1.91	3.03	0.39	2.06	0.88	2.17	4.11	1.74	06/15/00
06/23/00	1.45	3.73	1.89	2.89	0.37	2.03	0.87	2.02	3.86	1.60	06/23/00
06/29/00	1.04	3.89	1.90	2.91	0.36	2.06	0.80	1.94	3.79	1.60	06/29/00
07/06/00	1.33	3.86	1.95	2.91	0.49	2.06	0.87	1.88	4.12	1.57	07/06/00
07/14/00	1.46	5.16	1.80	3.51	0.44	2.79	0.57	2.63	3.89	2.17	07/14/00
07/20/00	1.56	3.97	1.74	3.34	0.35	2.16	0.80	2.02	3.80	1.61	07/20/00

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 64		Well 65		Well 66		Well 67		Well 68		Date
	WTD	EC	WTD	EC	WTD	EC	WTD	EC	WTD	EC	
07/27/00	1.84	4.33	1.78	3.77	0.36	2.29			4.15	1.99	07/27/00
08/02/00	1.75	4.40	1.67	3.38	0.39	2.37	0.82	3.46	3.76	1.75	08/02/00
08/11/00	1.72	4.47	1.73	3.30	0.53	2.26	0.91	2.90	4.18	1.87	08/11/00
08/19/00	1.73	4.20	1.64	3.28	0.48	2.29	0.85	2.63	3.97	1.55	08/19/00
09/01/00	1.47	3.94	1.93	2.03	0.66	1.51	0.89	2.20	3.86	0.95	09/01/00
09/16/00	1.78	2.71	1.93	3.23	0.60	2.08	0.91	2.81	3.93	1.84	09/16/00
09/29/00	2.08	3.86	1.92	2.84	0.61	2.12	0.97	2.49	4.09	1.95	09/29/00
10/20/00	2.35	4.03	1.78	3.16	0.67	2.11	1.04	2.35	4.08	1.48	10/20/00
12/01/00	2.19	4.30	1.80	3.10	0.91	2.15	1.25	2.33	4.25	1.71	12/01/00
01/19/01	2.21	4.50	1.92	3.34	0.99	2.52	1.34	2.52	4.15	1.73	01/19/01
03/05/01	2.26	1.01	1.92	1.56	1.31	0.24	1.71	2.36	3.90	2.35	03/05/01
03/30/01	2.29	1.26	1.83	1.40	1.46	1.11	1.65	2.30	3.51	2.14	03/30/01
04/21/01	2.22	3.87	1.76	2.78	0.99	2.08	1.78	2.28	5.30	1.66	04/21/01
05/14/01	1.92	3.94	1.79	2.92	0.97	3.01	1.94	2.35	5.29	1.67	05/14/01
05/29/01	1.99	3.93	1.06	3.18	0.65	3.10	1.85	1.79	5.13	1.29	05/29/01
06/07/01	1.75	3.97	1.63	4.57	0.60	3.00	1.72	2.06	4.84	1.21	06/07/01
06/14/01	1.82	3.92	1.77	4.51	0.61	2.93	1.66	2.10	4.99	1.81	06/14/01
06/20/01	1.62	4.11	1.79	4.40	0.55	2.79	1.51	2.37	4.72	1.98	06/20/01
06/29/01	1.88	4.05	1.66	4.12	0.66	2.69	1.59	2.36	4.73	1.85	06/29/01
07/06/01	2.01	3.88	1.66	3.95	0.65	2.55	1.53	2.47	4.80	2.08	07/06/01
07/12/01	2.14	4.04	1.73	3.92	0.66	2.50	1.49	2.49	4.64	2.23	07/12/01
07/18/01	2.12	3.88	1.56	3.71	0.60	2.45	1.46	2.54	4.79	1.83	07/18/01
07/26/01	2.02	4.12	1.27	3.38	0.52	2.34	1.42	2.51	4.65	1.60	07/26/01
08/02/01	2.14	4.10	1.53	2.78	0.59	2.16	1.39	2.46	4.91	1.76	08/02/01
08/10/01	1.99	4.16	1.85	3.45	0.57	2.29	1.44	2.87	4.54	2.28	08/10/01
08/17/01	1.96	4.14	1.69	3.33	0.51	2.25	1.30	2.91	4.45	2.25	08/17/01
09/01/01	2.20	3.43	1.94	3.00	0.68	2.10	1.37	2.50	4.68	1.52	09/01/01
09/15/01	2.40	4.02	1.98	3.36	0.73	2.42	1.31	2.79	4.65	1.81	09/15/01
09/29/01	2.40	4.20	1.87	2.74	0.80	2.02	1.26	2.28	4.41	1.72	09/29/01
10/12/01			1.92	2.88	0.75	2.14	1.24	2.47	4.43	1.76	10/12/01
10/27/01	2.88	3.62	1.75	2.66	0.59	1.95	1.21	2.27	4.40	1.71	10/27/01
11/17/01	2.89	4.22	2.00	2.72	0.58	2.12	1.15	2.48	4.39	1.56	11/17/01
12/18/01	2.69	3.39	1.85	2.04	0.94	1.60	1.32	1.91	4.59	1.31	12/18/01

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 69		Well 70		Well 71		Well 72		Well 73		Date
	WTD	EC	WTD	EC	WTD	EC	WTD	EC	WTD	EC	
04/05/99	DRY	DRY							2.13	3.51	04/05/99
05/11/99	DRY	DRY			DRY	DRY	2.26	2.91	0.71	2.91	05/11/99
05/27/99	DRY	DRY	0.89	2.68	DRY	DRY	1.14	2.96	1.14	4.08	05/27/99
06/01/99											06/01/99
06/11/99	DRY	DRY	0.79	2.41	DRY	DRY	1.60	1.13	1.91	4.77	06/11/99
06/17/99	DRY	DRY	0.64	2.09	DRY	DRY	1.93	1.22	1.60	3.25	06/17/99
06/24/99	DRY	DRY	0.61	2.46	DRY	DRY	2.16	1.79	1.50	3.96	06/24/99
06/30/99	DRY	DRY	0.86	2.45	DRY	DRY	2.08	2.45	1.52	4.06	06/30/99
07/07/99	DRY	DRY	1.47	2.34	DRY	DRY	2.31	2.41	1.63	4.13	07/07/99
07/14/99	DRY	DRY	1.69	2.42	DRY	DRY	2.13	1.70	1.27	3.06	07/14/99
07/21/99	DRY	DRY	1.14	2.39	DRY	DRY	2.36	1.07	1.17	3.86	07/21/99
07/28/99	DRY	DRY	DRY	DRY	DRY	DRY	2.26	1.22	1.44	3.22	07/28/99
08/04/99	DRY	DRY	1.47	1.96	DRY	DRY	2.36	1.53	1.22	3.86	08/04/99
08/12/99	DRY	DRY	DRY	DRY	DRY	DRY	2.39	2.22	1.04	6.80	08/12/99
08/18/99	DRY	DRY	1.50	2.74	DRY	DRY	1.91	3.10	1.14	7.38	08/18/99
09/04/99	DRY	DRY	1.75	2.82	DRY	DRY	1.59	1.74	1.52	7.59	09/04/99
09/16/99	DRY	DRY	1.70	2.73	DRY	DRY	1.78	2.28	1.75	7.46	09/16/99
10/01/99	DRY	DRY	1.80	2.79	DRY	DRY	0.89	2.15	1.91	7.30	10/01/99
11/13/99	DRY	DRY	1.75	2.86	DRY	DRY	1.50	2.20	2.41	6.50	11/13/99
01/04/00	DRY	DRY	1.78	3.07	DRY	DRY	1.83	4.71	2.19	6.16	01/04/00
02/24/00	DRY	DRY			DRY	DRY			2.03	5.75	02/24/00
03/25/00	5.36	2.13			DRY	DRY					03/25/00
04/15/00	5.33	1.53	1.78	1.88	DRY	DRY			DRY	DRY	04/15/00
04/28/00	5.31	2.35			DRY	DRY			2.11	10.98	04/28/00
05/17/00	5.02	2.36			DRY	DRY			2.19	9.88	05/17/00
06/01/00	4.50	2.08	1.78	2.38	DRY	DRY			DRY	DRY	06/01/00
06/06/00	4.44	1.91			DRY	DRY			2.03	5.61	06/06/00
06/15/00	4.49	1.68	1.79	2.45	DRY	DRY			1.87	5.30	06/15/00
06/23/00	5.27	1.52							2.01	5.17	06/23/00
06/29/00	4.53	1.94	1.80	2.66	DRY	DRY			2.17	5.35	06/29/00
07/06/00	4.53	2.59	1.85	2.59	DRY	DRY			2.22	5.22	07/06/00
07/14/00	DRY	DRY	1.86	3.55	DRY	DRY	DRY	DRY	2.22		07/14/00
07/20/00	4.45	1.94	1.67	2.05	DRY	DRY	2.16	0.84	1.85	4.38	07/20/00

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 69		Well 70		Well 71		Well 72		Well 73		Date
	WTD	EC	WTD	EC	WTD	EC	WTD	EC	WTD	EC	
07/27/00	4.35	1.99	1.82	2.57	DRY	DRY	DRY	DRY	1.99	5.01	07/27/00
08/02/00	4.33	2.16	1.78	2.50	DRY	DRY	DRY	DRY	2.16	5.37	08/02/00
08/11/00	4.53	1.95	1.77	2.19	DRY	DRY			1.95	4.95	08/11/00
08/19/00	4.33	1.96			DRY	DRY	DRY	DRY	1.88	5.03	08/19/00
09/01/00	4.43	1.17	1.89	1.71	DRY	DRY	DRY	DRY	2.19	3.24	09/01/00
09/16/00	4.55	1.92	1.84	2.48			DRY	DRY	DRY	DRY	09/16/00
09/29/00	4.60	1.54	1.80	2.58	DRY	DRY	DRY	DRY	DRY	DRY	09/29/00
10/20/00	4.71	1.78	1.78	2.54	DRY	DRY	DRY	DRY	DRY	DRY	10/20/00
12/01/00	DRY	DRY	1.46	2.85	DRY	DRY	DRY	DRY			12/01/00
01/19/01	DRY	DRY	1.55	2.72	DRY	DRY	DRY	DRY			01/19/01
03/05/01	DRY	DRY	1.83	2.50			DRY	DRY			03/05/01
03/30/01	DRY	DRY	1.74	2.19			DRY	DRY			03/30/01
04/21/01	DRY	DRY	1.75	2.18	DRY	DRY	DRY	DRY			04/21/01
05/14/01	2.65	7.89	1.81	2.13	DRY	DRY	DRY	DRY	2.19	1.69	05/14/01
05/29/01	DRY	DRY	1.16	1.63	DRY	DRY			2.06	1.75	05/29/01
06/07/01	6.04	2.18	1.21	2.16	DRY	DRY			2.01	2.38	06/07/01
06/14/01	6.04	2.21	1.54	2.21	DRY	DRY			1.56	4.47	06/14/01
06/20/01	5.88	2.16	1.19	2.16	DRY	DRY	DRY	DRY	1.53	6.34	06/20/01
06/29/01	5.91	2.05	1.46	1.96	DRY	DRY			1.91	5.99	06/29/01
07/06/01	5.91	2.07	1.55	2.02	DRY	DRY			2.01	6.13	07/06/01
07/12/01	5.91	2.22	2.06	2.10	DRY	DRY			2.04	6.12	07/12/01
07/18/01	5.85	2.13	1.41	1.95	DRY	DRY			2.17	6.05	07/18/01
07/26/01	5.68	1.99	1.62	2.12	DRY	DRY			2.07	5.65	07/26/01
08/02/01	5.57	1.92	1.74	2.04	DRY	DRY			2.04	4.84	08/02/01
08/10/01	5.55	2.03	1.69	2.20	DRY	DRY			1.82	5.30	08/10/01
08/17/01	5.42	2.00	1.44	1.99	DRY	DRY	DRY	DRY	2.01	5.27	08/17/01
09/01/01	5.56	1.83	1.71	2.00	DRY	DRY	DRY	DRY	2.22	4.95	09/01/01
09/15/01	5.51	2.08	1.64	2.39	DRY	DRY	DRY	DRY			09/15/01
09/29/01	5.32	1.79	1.83	2.03	DRY	DRY	DRY	DRY			09/29/01
10/12/01	5.29	2.00			DRY	DRY	DRY	DRY			10/12/01
10/27/01	5.31	1.97	1.67	2.00	DRY	DRY	DRY	DRY			10/27/01
11/17/01	3.84	1.95	1.75	2.19	DRY	DRY	DRY	DRY			11/17/01
12/18/01	5.72	1.31			DRY	DRY					12/18/01

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 74		Well 75A		Well 75C		Well 76		Well 77		Date
	WTD	EC	WTD	EC	WTD	EC	WTD	EC	WTD	EC	
04/05/99							0.84	5.03	DRY	DRY	04/05/99
05/11/99			1.50	2.16			0.48	7.15	DRY	DRY	05/11/99
05/27/99			1.45	2.64	2.06		0.69	7.40	DRY	DRY	05/27/99
06/01/99							0.89	6.70	DRY	DRY	06/01/99
06/11/99			2.44	2.08			1.12	5.55	DRY	DRY	06/11/99
06/17/99			2.31	1.87	1.68	1.44	0.69	4.89	DRY	DRY	06/17/99
06/24/99	1.35	3.31	2.13	2.35			0.78	3.89	DRY	DRY	06/24/99
06/30/99			2.74	2.05	2.29	2.21	0.84	3.67			06/30/99
07/07/99	DRY	DRY	2.44	2.23	DRY	DRY	1.04	4.33			07/07/99
07/14/99	2.11	3.38	2.51	2.17	2.36	2.17	0.99	3.21	DRY	DRY	07/14/99
07/21/99			2.59	2.10	2.01	2.10	0.51	7.93	DRY	DRY	07/21/99
07/28/99	DRY	DRY	2.69	1.90	2.21	1.90	0.70	7.37	DRY	DRY	07/28/99
08/04/99	DRY	DRY	3.89	2.00					DRY	DRY	08/04/99
08/12/99			1.80	2.16	2.77	2.09	0.61	4.10	DRY	DRY	08/12/99
08/18/99			1.91	2.09	2.54	1.92	0.74	4.07	DRY	DRY	08/18/99
09/04/99	2.50	3.07	2.87	1.88	2.24	1.98	0.84	4.21	DRY	DRY	09/04/99
09/16/99			2.36	2.25	2.90	1.82	0.86	3.98	DRY	DRY	09/16/99
10/01/99							0.76	5.66	DRY	DRY	10/01/99
11/13/99			3.12	1.67	2.64	2.14	0.76	4.31	DRY	DRY	11/13/99
01/04/00			2.59	2.09	3.25	1.65	0.84	3.95	DRY	DRY	01/04/00
02/24/00			3.07	1.66	2.49	2.05	0.76	3.96	DRY	DRY	02/24/00
03/25/00			3.18	1.69	2.51	2.07	0.76	4.30	4.27	2.61	03/25/00
04/15/00	2.51	1.70	3.22	1.62	2.51	1.94			4.19	2.70	04/15/00
04/28/00	1.42	6.13	2.58	1.55	3.24	1.36	0.55	6.85	4.09	1.97	04/28/00
05/17/00	1.44	5.82	3.05	1.57	2.64	2.00	0.61	4.25	3.86	2.79	05/17/00
06/01/00	1.44	4.57	3.11	1.67	2.69	2.07	0.66	3.05	3.64	2.91	06/01/00
06/06/00	1.22	4.29	3.10	1.71			0.61	3.67	3.61	3.05	06/06/00
06/15/00	1.47	3.84	3.11	1.61	2.61	2.04	0.65	3.34	3.47	2.86	06/15/00
06/23/00	1.83	3.62			3.12	1.52	0.95	3.16	3.08	3.13	06/23/00
06/29/00	1.58	3.93	3.15	1.73	2.59	2.04	1.09	1.74	3.27	3.15	06/29/00
07/06/00	1.63	3.66	3.23	1.69	2.62	2.05	0.69	2.44	3.19	3.16	07/06/00
07/14/00	1.38	4.76	3.29	2.09			0.82	2.82	3.06	3.02	07/14/00
07/20/00	1.56	3.89	3.32	1.61	4.54	1.93	1.03	2.16	3.05	2.91	07/20/00

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 74		Well 75A		Well 75C		Well 76		Well 77		Date
	WTD	EC	WTD	EC	WTD	EC	WTD	EC	WTD	EC	
07/27/00	1.63	4.04	3.25	1.84		2.22	0.83	2.02	2.94	2.62	07/27/00
08/02/00	1.66	4.28	3.27	1.81	2.59	2.28	0.94	2.48	2.86	2.95	08/02/00
08/11/00	1.63	3.90	3.30	1.74	2.70	1.97	1.31	3.47	2.90	2.49	08/11/00
08/19/00	1.66	3.94	3.29	1.72	2.64	2.10	1.11	3.42	2.89	2.61	08/19/00
09/01/00	1.73	2.44			2.64	2.06	0.76	3.41	2.93	2.51	09/01/00
09/16/00	1.69	3.67	3.30	1.80	2.74	2.37	1.40	4.25	3.20	2.44	09/16/00
09/29/00	1.69	3.59	3.27	1.51	2.65	2.09	1.52	4.56	3.30	2.41	09/29/00
10/20/00	1.63	3.50	3.22	1.53	2.30	2.15	0.82	4.05	3.69	2.56	10/20/00
12/01/00	1.77	3.68	3.19	1.50	2.64	2.12	0.91	4.12	3.67	2.42	12/01/00
01/19/01	1.68	3.62	3.23	2.44		2.39	0.88	4.20	3.88	3.37	01/19/01
03/05/01			3.19	1.70	2.50	2.19	0.98	4.35	4.21	2.53	03/05/01
03/30/01			3.22	1.68	2.49	2.06	1.01	3.63	4.17	2.58	03/30/01
04/21/01	1.36	3.46	3.06	1.67	2.38	1.99	0.37	4.18	3.93	2.63	04/21/01
05/14/01	1.42	3.48	3.16	1.67	2.51	2.03	0.66	4.45	3.76	2.65	05/14/01
05/29/01	1.10	3.47	3.06	1.69	2.34	2.04	0.67	4.03	3.71	2.70	05/29/01
06/07/01	1.13	3.48	2.92	1.67	2.25	2.03	0.61	3.51	3.64	2.79	06/07/01
06/14/01	1.23	3.49	3.05	1.68			0.85	3.82	3.70	2.83	06/14/01
06/20/01	1.33	3.59	2.78	1.75	2.33	2.12	0.93	3.32	3.66	2.87	06/20/01
06/29/01	1.38	3.21	2.95	1.92	2.03	2.23	1.10	2.14	3.61	2.21	06/29/01
07/06/01	1.46	3.29	3.03	1.69	2.42	1.93	0.87	2.22	3.62	2.84	07/06/01
07/12/01	1.58	3.35	3.05	1.65	2.36	2.05	0.94	2.55	3.69	2.69	07/12/01
07/18/01	1.34	3.46	3.01	1.65	2.38	2.05	0.55	3.79	3.55	3.00	07/18/01
07/26/01	1.39	3.30					0.80	2.78	3.59	2.85	07/26/01
08/02/01			2.97	1.57	2.43	1.89	0.69	3.71	3.63	2.84	08/02/01
08/10/01	1.51	3.30	3.01	1.67	2.43	1.93	0.94	3.77	3.69	2.74	08/10/01
08/17/01	1.44	3.43	3.01	1.61	2.35	1.99	0.98	3.94	3.70	2.68	08/17/01
09/01/01	1.61	3.20			2.49	1.88	0.91	3.78	3.77	2.51	09/01/01
09/15/01	1.68	3.79	3.08	1.73	2.51	2.13	0.77	2.37	3.86	2.47	09/15/01
09/29/01	1.70	3.23	3.10	1.68	2.54	2.14	0.97	3.93	3.93	2.43	09/29/01
10/12/01			3.13	1.55	2.50	1.98					10/12/01
10/27/01	1.55	3.20	3.09	1.50	2.49	1.98	0.66	2.08			10/27/01
11/17/01	1.55	3.31	3.10	1.52	2.48	1.97	0.67	3.39			11/17/01
12/18/01			3.12	1.50	2.50	1.94	0.80	3.11	4.13	2.50	12/18/01

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 78		Well 79A1		Well 79A2		Well 79A3		Well 79B1		Date
	WTD	EC	WTD	EC	WTD	EC	WTD	EC	WTD	EC	
04/05/99											04/05/99
05/11/99											05/11/99
05/27/99	1.35	1.40									05/27/99
06/01/99											06/01/99
06/11/99	0.65	1.01									06/11/99
06/17/99	0.64	0.93									06/17/99
06/24/99	0.79	1.10	1.92	1.97	3.17	3.41	2.00	1.57	1.39	1.39	06/24/99
06/30/99	0.61	1.08	2.17	1.99	3.42	3.34	2.21	1.44	0.58	1.30	06/30/99
07/07/99	0.64	1.09	2.75	2.07	4.25	3.41	2.92	1.61	0.54	1.30	07/07/99
07/14/99	0.61	1.00	2.88	2.04	DRY	DRY	3.17	1.57	DRY		07/14/99
07/21/99	0.51	1.04	2.33	1.92	3.92	3.22	2.75	1.63	1.25	1.28	07/21/99
07/28/99	0.53	0.95	1.88	2.00	3.92	3.19	2.08	1.59	1.21	1.22	07/28/99
08/04/99	0.48	1.03	1.33	1.80	3.00	2.99	1.50	1.62	0.92	1.08	08/04/99
08/12/99	0.58	1.22	1.83	1.76	3.08	2.32	2.25	1.49	1.46	1.10	08/12/99
08/18/99	0.53	1.15	1.92	2.15	0.58	1.18	2.13	1.86	0.58	1.38	08/18/99
09/04/99	0.52	1.19	2.25	2.17	DRY	DRY	2.67	1.79	1.50	1.46	09/04/99
09/16/99	0.64	1.06	2.17	1.92			2.83	1.65	1.75	1.41	09/16/99
10/01/99											10/01/99
11/13/99	1.22	1.09	2.33	1.65	DRY	DRY	2.50	1.41	1.50	1.89	11/13/99
01/04/00	1.65	1.19	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	01/04/00
02/24/00	2.16	1.32	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	02/24/00
03/25/00	2.31	1.37									03/25/00
04/15/00											04/15/00
04/28/00	1.70	1.42	0.39	1.16	DRY	DRY	0.45	1.01	0.15	1.17	04/28/00
05/17/00	1.20	1.50	0.46	1.61	1.04	3.10	0.59	1.58	0.43	1.51	05/17/00
06/01/00	1.26	1.47	0.38	1.58	1.03	3.00	0.45	1.45	0.18	1.54	06/01/00
06/06/00	1.04	1.52	0.41	1.48	1.14	3.02	0.56	1.39	0.16	1.49	06/06/00
06/15/00	0.97	1.48	0.60	1.53	0.95	3.10	0.72	1.40	0.47	1.54	06/15/00
06/23/00	0.94	1.43	0.49	1.56	1.25	3.13	0.74	1.45	0.29	1.39	06/23/00
06/29/00	0.89	1.31	0.56	1.48	1.30	3.15	0.74	1.48	0.30	1.39	06/29/00
07/06/00	1.05	1.42	0.70	1.52	1.31	3.07	0.88	1.59	0.47	1.49	07/06/00
07/14/00	DRY	DRY	0.72	1.47	1.30	3.03	0.97	1.60	0.39	1.34	07/14/00
07/20/00		1.49	0.58	1.52	DRY	DRY	0.83	1.53	0.40	1.35	07/20/00

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 78		Well 79A1		Well 79A2		Well 79A3		Well 79B1		Date
	WTD	EC	WTD	EC	WTD	EC	WTD	EC	WTD	EC	
07/27/00	0.94	1.63	0.78	1.36	1.63		1.01	1.44	0.45	1.24	07/27/00
08/02/00	0.84	1.55	0.79	1.45	DRY	DRY	1.11	1.54	0.13	1.27	08/02/00
08/11/00	1.16	1.65	0.66	1.38	DRY	DRY	1.01	1.41	0.66	1.24	08/11/00
08/19/00	1.31	0.88									08/19/00
09/01/00	1.49	1.43	0.70	1.27	1.32	2.84	0.89	1.42	0.62	1.22	09/01/00
09/16/00	1.62	1.24			DRY	DRY					09/16/00
09/29/00	1.62	1.24	1.30	1.41	DRY	DRY	1.27	1.47	1.02	1.43	09/29/00
10/20/00	1.83	1.30	DRY	DRY	DRY	DRY	1.15	1.51	0.80	1.35	10/20/00
12/01/00	1.89	1.35	DRY	DRY	DRY	DRY	DRY	DRY	1.12	1.45	12/01/00
01/19/01	1.92	1.61	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	01/19/01
03/05/01	3.44	1.28	DRY	DRY	DRY	DRY	DRY	DRY	1.28	1.94	03/05/01
03/30/01	3.44	1.25	DRY	DRY			DRY	DRY	0.65	1.43	03/30/01
04/21/01	2.88	1.40									04/21/01
05/14/01	2.60	1.47									05/14/01
05/29/01	1.94	1.46									05/29/01
06/07/01	1.65	1.46									06/07/01
06/14/01	1.78	1.46									06/14/01
06/20/01	1.65	1.53									06/20/01
06/29/01	1.68	1.46									06/29/01
07/06/01	1.58	1.11									07/06/01
07/12/01	1.56	1.13									07/12/01
07/18/01	1.11	1.14									07/18/01
07/26/01	1.38	1.13									07/26/01
08/02/01	1.34	1.27									08/02/01
08/10/01	1.40	1.29									08/10/01
08/17/01	1.65	1.30									08/17/01
09/01/01	1.52	1.29									09/01/01
09/15/01	1.77	1.40									09/15/01
09/29/01	1.89	1.23									09/29/01
10/12/01	1.92	1.20									10/12/01
10/27/01	1.85	1.25									10/27/01
11/17/01	1.79	1.34									11/17/01
12/18/01											12/18/01

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 79B2		Well 79B3		Well 79C1		Well 79C2		Well 79C3		Date
	WTD	EC	WTD	EC	WTD	EC	WTD	EC	WTD	EC	
04/05/99											04/05/99
05/11/99											05/11/99
05/27/99											05/27/99
06/01/99											06/01/99
06/11/99											06/11/99
06/17/99											06/17/99
06/24/99	3.00	4.56	1.33	1.25	0.51	1.61	1.12	6.16	0.48	1.53	06/24/99
06/30/99	3.25	4.95	0.42	1.28	0.18	1.61	0.99	6.11	0.25	1.53	06/30/99
07/07/99	4.25	4.99	0.46	1.29	0.20	1.59	0.70	6.03	0.20	1.51	07/07/99
07/14/99	DRY	DRY	0.33	1.19	0.30	1.57	0.58	5.60	0.38	1.36	07/14/99
07/21/99	4.17	4.58	1.33	1.22	0.66	1.58	0.89	4.86	0.66	1.39	07/21/99
07/28/99	4.17	4.50	1.17	1.23	0.34	1.57	0.86	6.03	0.36	1.36	07/28/99
08/04/99	DRY	DRY	1.00	1.10	0.46	1.73	0.76	4.76	0.36	1.33	08/04/99
08/12/99	4.08	3.77	1.63	1.09	0.64	1.46	1.18	4.74	0.43	1.24	08/12/99
08/18/99	4.13		0.42	1.39	0.48	1.82	1.22		0.32	1.54	08/18/99
09/04/99	DRY	DRY	0.75	1.36	0.72	1.80	DRY	DRY	0.41	1.45	09/04/99
09/16/99			1.75	1.28	0.61	1.64			0.38	1.34	09/16/99
10/01/99											10/01/99
11/13/99	DRY	DRY	1.50	1.90	0.58	1.69	DRY	DRY	0.41	1.35	11/13/99
01/04/00	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	01/04/00
02/24/00	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	02/24/00
03/25/00											03/25/00
04/15/00											04/15/00
04/28/00	DRY	DRY	0.17	1.07	0.23	1.39	0.62	2.72	0.44	1.02	04/28/00
05/17/00	DRY	DRY	0.48	1.35	0.46	1.69	1.12	5.05	0.51	1.37	05/17/00
06/01/00	DRY	DRY	0.18	1.37	0.37	1.69	0.73	5.04	0.34	1.38	06/01/00
06/06/00	DRY	DRY	0.18	1.26	0.34	1.61	0.94	5.31	0.30	1.41	06/06/00
06/15/00	1.21	5.26	0.49	1.25	0.57	1.57	0.92	5.20	0.55	1.39	06/15/00
06/23/00	1.23	5.41	0.25	1.28	0.34	1.57	0.62	4.37	0.30	1.35	06/23/00
06/29/00	1.24	5.41	0.29	1.29	0.41	1.57	0.90	5.03	0.30	1.36	06/29/00
07/06/00	1.25	4.74	0.39	1.36	0.51	1.67	0.79	4.71	0.55	1.49	07/06/00
07/14/00	1.26	4.28	0.20	1.38	0.43	1.61	0.88	4.70	0.34	1.40	07/14/00
07/20/00	DRY	DRY	0.36	1.34	0.48	1.58	0.98	0.52	0.36	1.44	07/20/00

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 79B2		Well 79B3		Well 79C1		Well 79C2		Well 79C3		Date
	WTD	EC	WTD	EC	WTD	EC	WTD	EC	WTD	EC	
07/27/00	1.24		0.27	1.25	0.42	1.46	1.08	4.85	0.41	1.35	07/27/00
08/02/00	1.23	4.22	0.35	1.35	0.59	1.55	DRY	DRY	0.53	1.35	08/02/00
08/11/00	DRY	DRY	0.62	1.26	0.78	1.46	DRY	DRY	0.83	1.20	08/11/00
08/19/00					0.51	1.40			0.48	1.22	08/19/00
09/01/00	1.25	3.90	0.68	1.16	0.89	1.38	DRY	DRY	0.82	1.12	09/01/00
09/16/00	DRY	DRY					DRY	DRY			09/16/00
09/29/00	DRY	DRY	1.02	1.44	1.09	1.48	DRY	DRY	0.99	1.23	09/29/00
10/20/00	DRY	DRY	0.78	1.34	0.83	1.45	DRY	DRY	0.70	1.24	10/20/00
12/01/00	DRY	DRY	1.24	1.47	1.18	1.47	DRY	DRY	1.16	1.32	12/01/00
01/19/01	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	01/19/01
03/05/01	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	03/05/01
03/30/01	DRY	DRY	0.47	1.31	0.29	1.47			0.33	1.31	03/30/01
04/21/01	1.14	4.11									04/21/01
05/14/01	1.22	3.14									05/14/01
05/29/01											05/29/01
06/07/01											06/07/01
06/14/01											06/14/01
06/20/01											06/20/01
06/29/01											06/29/01
07/06/01											07/06/01
07/12/01											07/12/01
07/18/01											07/18/01
07/26/01											07/26/01
08/02/01											08/02/01
08/10/01											08/10/01
08/17/01											08/17/01
09/01/01											09/01/01
09/15/01											09/15/01
09/29/01											09/29/01
10/12/01											10/12/01
10/27/01											10/27/01
11/17/01											11/17/01
12/18/01											12/18/01

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 79X		Well 80		Well 81		Well 82		Well 83		Date
	WTD	EC	WTD	EC	WTD	EC	WTD	EC	WTD	EC	
04/05/99											04/05/99
05/11/99											05/11/99
05/27/99											05/27/99
06/01/99											06/01/99
06/11/99											06/11/99
06/17/99											06/17/99
06/24/99											06/24/99
06/30/99											06/30/99
07/07/99			0.71	10.24							07/07/99
07/14/99			0.36	10.24							07/14/99
07/21/99			0.74	8.38							07/21/99
07/28/99			0.80	9.27							07/28/99
08/04/99			0.48	7.95							08/04/99
08/12/99			0.51	6.77							08/12/99
08/18/99			0.72	9.47							08/18/99
09/04/99			0.56	9.39							09/04/99
09/16/99											09/16/99
10/01/99											10/01/99
11/13/99			1.24	10.28							11/13/99
01/04/00			DRY	DRY							01/04/00
02/24/00			DRY	DRY							02/24/00
03/25/00			2.06	1.49							03/25/00
04/15/00			0.76	1.20	4.34	3.00	DRY	DRY		2.33	04/15/00
04/28/00			0.81	0.87	4.08	2.95			0.97	4.09	04/28/00
05/17/00			0.81	1.24	3.86	4.34			1.04	4.76	05/17/00
06/01/00			1.22		3.80	3.97	DRY	DRY	1.05	5.03	06/01/00
06/06/00			1.04				DRY	DRY	0.85	3.75	06/06/00
06/15/00			0.65		4.01	4.02	DRY	DRY	1.22	4.22	06/15/00
06/23/00			0.76		3.66	4.33	DRY	DRY	1.20	4.50	06/23/00
06/29/00			0.47		4.06	3.64	2.46	2.50	1.27	4.45	06/29/00
07/06/00			0.83		4.09	4.22	2.81	2.88	1.40	4.69	07/06/00
07/14/00			0.70		4.00	4.21	DRY	DRY	1.49	6.34	07/14/00
07/20/00			0.63		3.86	4.20	DRY	DRY	0.88	4.93	07/20/00

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 79X		Well 80		Well 81		Well 82		Well 83		Date
	WTD	EC	WTD	EC	WTD	EC	WTD	EC	WTD	EC	
07/27/00			0.84		3.92	3.68	2.34	2.00	1.40	4.99	07/27/00
08/02/00			0.71		3.90	4.19	2.80	2.93	0.80	5.86	08/02/00
08/11/00			0.95		1.86	1.58	DRY	DRY	1.54	5.71	08/11/00
08/19/00			0.48				DRY	DRY	0.65	5.55	08/19/00
09/01/00			0.67		3.91	1.65	DRY	DRY	1.65	5.11	09/01/00
09/16/00					4.08	1.79	2.74	2.93	1.91	6.24	09/16/00
09/29/00					4.25	1.87	DRY	DRY	2.16	6.29	09/29/00
10/20/00					4.19	2.03	DRY	DRY	2.32	5.33	10/20/00
12/01/00					4.49	1.82	DRY	DRY	2.59	6.15	12/01/00
01/19/01					4.53	3.05	DRY	DRY	2.62	6.20	01/19/01
03/05/01					4.70	2.94	DRY	DRY	1.28	4.25	03/05/01
03/30/01					4.49	2.78	2.79	2.76	1.28	4.82	03/30/01
04/21/01			1.73	1.53	4.40	3.27	DRY	DRY	1.12	4.07	04/21/01
05/14/01			0.88	1.95	4.12	3.52	2.41	2.01	1.16	4.44	05/14/01
05/29/01	DRY	DRY	0.93	1.12	4.15	3.21	DRY	DRY	0.89	4.18	05/29/01
06/07/01	DRY	DRY	0.62	1.13	4.15	3.32	DRY	DRY	1.05	4.25	06/07/01
06/14/01	2.85	4.13					2.28	1.93	1.20	4.43	06/14/01
06/20/01	2.76	4.30	0.61	1.79	3.95	3.49	2.54	2.87	1.32	4.74	06/20/01
06/29/01	2.73	3.49	0.70	1.71	4.04	3.49	DRY	DRY	1.37	4.30	06/29/01
07/06/01	DRY	DRY	0.78	1.77	3.94	3.47	DRY	DRY	1.49	4.31	07/06/01
07/12/01	2.78	4.05	0.55	1.35	3.97	3.51	1.72	0.81	1.38	4.35	07/12/01
07/18/01	2.87	3.96	0.60	1.75	3.92	3.85	2.52	3.27	0.49	3.85	07/18/01
07/26/01	2.81	3.10	0.50	1.63	3.99	3.48	DRY	DRY	0.97	4.74	07/26/01
08/02/01	2.80	1.79	0.82	1.43	3.97	3.49	DRY	DRY	1.21	4.65	08/02/01
08/10/01	2.55	3.97	0.54	1.56	3.77	3.72	DRY	DRY	1.35	4.59	08/10/01
08/17/01	2.62	3.98	0.79	1.57	3.82	3.50	DRY	DRY	1.46	4.80	08/17/01
09/01/01	2.70	4.02	0.69	1.29	3.82	3.55	2.38	2.32	1.68	4.62	09/01/01
09/15/01	2.72	4.11	1.00	1.25	4.06	3.56	2.72	1.39	1.80	4.52	09/15/01
09/29/01	2.71	2.00	1.44	1.24	4.13	3.54	2.72	1.47	1.80	4.38	09/29/01
10/12/01											10/12/01
10/27/01	DRY	DRY	1.27	1.18	4.16	3.45	DRY	DRY	1.70	3.90	10/27/01
11/17/01									1.53	3.98	11/17/01
12/18/01	DRY	DRY	DRY	DRY	4.48	3.32	DRY	DRY	1.47	3.26	12/18/01

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 84		Well 85		Well 86		Well 87A		Well 87B		Date
	WTD	EC	WTD	EC	WTD	EC	WTD	EC	WTD	EC	
04/05/99											04/05/99
05/11/99											05/11/99
05/27/99											05/27/99
06/01/99											06/01/99
06/11/99											06/11/99
06/17/99											06/17/99
06/24/99											06/24/99
06/30/99											06/30/99
07/07/99											07/07/99
07/14/99											07/14/99
07/21/99											07/21/99
07/28/99											07/28/99
08/04/99											08/04/99
08/12/99											08/12/99
08/18/99											08/18/99
09/04/99											09/04/99
09/16/99											09/16/99
10/01/99											10/01/99
11/13/99											11/13/99
01/04/00											01/04/00
02/24/00											02/24/00
03/25/00											03/25/00
04/15/00	0.94	2.30					1.88	2.47	1.14	2.51	04/15/00
04/28/00	1.42	3.01	4.69	2.45	DRY	DRY	2.03	3.37	1.37	3.61	04/28/00
05/17/00	1.37	3.16	4.59	3.43	DRY	DRY	2.08	3.40	1.17	3.59	05/17/00
06/01/00			4.42	3.25	DRY	DRY	1.61	4.76	0.76	3.99	06/01/00
06/06/00	1.28	3.03	4.55	2.86	DRY	DRY	2.01	4.30	0.79	3.56	06/06/00
06/15/00	1.56	2.85	4.63	3.29	DRY	DRY	2.29	4.50	0.99	3.82	06/15/00
06/23/00	1.53	2.87	4.74	3.12	DRY	DRY	1.95	4.23	0.59	3.63	06/23/00
06/29/00	1.52	2.62	4.67	3.45	DRY	DRY	2.08	4.16	0.49	3.76	06/29/00
07/06/00	1.41	2.39	4.69	3.58	DRY	DRY	2.31	4.31	1.08	4.04	07/06/00
07/14/00	1.25	3.13	4.75	3.62	DRY	DRY	2.49	5.84	0.87	5.24	07/14/00
07/20/00	1.30	2.42	4.82	3.55	DRY	DRY	1.67	5.51	0.93	4.77	07/20/00

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 84		Well 85		Well 86		Well 87A		Well 87B		Date
	WTD	EC	WTD	EC	WTD	EC	WTD	EC	WTD	EC	
07/27/00	1.49	2.10	4.82	3.30	DRY	DRY	1.53	5.78	0.81	4.43	07/27/00
08/02/00	1.17	2.35	4.87	3.78	DRY	DRY	1.87	6.24	1.15	4.58	08/02/00
08/11/00	1.69	2.27	4.93	2.98	DRY	DRY	2.11	5.98	1.36	3.17	08/11/00
08/19/00	1.90	2.24	4.94	3.69	DRY	DRY			1.41	3.36	08/19/00
09/01/00	2.18	1.85	4.95	3.77			1.73	5.50	1.52	3.46	09/01/00
09/16/00	2.44	3.28	4.95	3.77	DRY	DRY	2.13		1.84	2.52	09/16/00
09/29/00	2.36	2.37	5.03	3.58	DRY	DRY	1.83	7.32	1.70	3.09	09/29/00
10/20/00	2.50	1.51	5.07	3.72	DRY	DRY	1.98	5.99	1.89	3.14	10/20/00
12/01/00	2.29	1.75	5.00	3.39	DRY	DRY	2.36	5.81	1.80	3.03	12/01/00
01/19/01	2.38	2.10	5.01	4.64	DRY	DRY	2.36	5.55	1.97	3.25	01/19/01
03/05/01			5.09	3.75	DRY	DRY	2.53	4.42	1.77	3.61	03/05/01
03/30/01			5.06	3.48	DRY	DRY	2.51	4.51	1.77	3.55	03/30/01
04/21/01			4.98	4.25	DRY	DRY	DRY	DRY	2.34	3.43	04/21/01
05/14/01	1.88	1.52	4.79	3.60	DRY	DRY	2.10	1.78	1.25	4.26	05/14/01
05/29/01	1.82	2.09	4.74	3.11	DRY	DRY	1.96	2.48	0.47	4.24	05/29/01
06/07/01	0.24	1.96	4.70	3.04			1.49	2.83	0.58	4.31	06/07/01
06/14/01	1.04	2.50	4.55	3.49	DRY	DRY	1.81	2.76	0.88	4.68	06/14/01
06/20/01	1.01	2.86	4.57	3.34	DRY	DRY	1.70	2.51	0.57	4.86	06/20/01
06/29/01	1.51	2.55	4.58	2.60	DRY	DRY			1.29	4.01	06/29/01
07/06/01	1.25	2.05	4.62	3.36	DRY	DRY			1.05	3.70	07/06/01
07/12/01	1.65	2.15	4.57	3.34	DRY	DRY			1.53	3.56	07/12/01
07/18/01	1.52	1.90	4.62	3.63	DRY	DRY			1.26	3.03	07/18/01
07/26/01	1.84	2.00	4.67	3.34	DRY	DRY			1.31	2.83	07/26/01
08/02/01	2.01	2.00	4.65	3.33	DRY	DRY	1.80	1.85	1.40	2.89	08/02/01
08/10/01	2.13	1.93	4.72	3.32	DRY	DRY			1.30	2.41	08/10/01
08/17/01	1.72	2.10	4.65	3.28	DRY	DRY	1.65	1.97	1.43	2.56	08/17/01
09/01/01	2.22	2.01	4.73	3.29	DRY	DRY			1.86	2.45	09/01/01
09/15/01	2.50	2.04	4.81	3.42	DRY	DRY			2.13	2.48	09/15/01
09/29/01			4.89	3.59	DRY	DRY			2.30	2.39	09/29/01
10/12/01											10/12/01
10/27/01			5.04	3.51	DRY	DRY			2.67	2.38	10/27/01
11/17/01									2.61	2.30	11/17/01
12/18/01			5.02	3.26	DRY	DRY			2.58	2.02	12/18/01

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 88		Well 90		Well 91		Well 92		Well 93		Date
	WTD	EC	WTD	EC	WTD	EC	WTD	EC	WTD	EC	
04/05/99											04/05/99
05/11/99											05/11/99
05/27/99											05/27/99
06/01/99											06/01/99
06/11/99											06/11/99
06/17/99											06/17/99
06/24/99											06/24/99
06/30/99											06/30/99
07/07/99											07/07/99
07/14/99											07/14/99
07/21/99											07/21/99
07/28/99											07/28/99
08/04/99											08/04/99
08/12/99											08/12/99
08/18/99											08/18/99
09/04/99											09/04/99
09/16/99											09/16/99
10/01/99											10/01/99
11/13/99											11/13/99
01/04/00											01/04/00
02/24/00											02/24/00
03/25/00											03/25/00
04/15/00	DRY	DRY			0.69	1.14					04/15/00
04/28/00	DRY	DRY	1.85	3.57	1.04	1.98	1.47	2.34	1.27	2.36	04/28/00
05/17/00	DRY	DRY	1.88	3.34	1.27	2.59	1.51	3.41	1.35	2.22	05/17/00
06/01/00	DRY	DRY	1.21	3.16			1.18	3.09	1.48	2.53	06/01/00
06/06/00	DRY	DRY	0.65	3.26			1.30	3.42	1.50	4.31	06/06/00
06/15/00	DRY	DRY	1.34	3.16	1.74	1.18	1.34	3.19			06/15/00
06/23/00	2.77	2.48	1.39	3.08	1.55	1.14	1.02	3.40	1.69	3.76	06/23/00
06/29/00	DRY	DRY	1.28	2.95	1.39	2.64	1.19	3.40	1.65	3.94	06/29/00
07/06/00	DRY	DRY	1.43	3.06	1.59	2.97	1.12	3.45	1.73	3.26	07/06/00
07/14/00	DRY	DRY	1.35	4.01	1.60	4.03	0.88	3.48	1.80	3.39	07/14/00
07/20/00	DRY	DRY	1.30	2.98	1.52	3.34	0.60	3.57	1.58	3.18	07/20/00

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 88		Well 90		Well 91		Well 92		Well 93		Date
	WTD	EC	WTD	EC	WTD	EC	WTD	EC	WTD	EC	
07/27/00	DRY	DRY	0.94	3.11	1.51	3.79	0.48	3.68	1.49	3.50	07/27/00
08/02/00	DRY	DRY	1.20	3.12	1.46	3.64	0.55	3.27	1.34	3.73	08/02/00
08/11/00	DRY	DRY	1.74	3.08	1.65	3.75	0.42	3.46	1.75	3.66	08/11/00
08/19/00	DRY	DRY	1.96	2.82	1.70	3.56	0.50	3.41	1.82	3.16	08/19/00
09/01/00	DRY	DRY	1.62	2.61	1.65	3.34	0.62	2.93	1.70	3.18	09/01/00
09/16/00	DRY	DRY	2.23	2.89	1.80	3.65	0.82	3.56	1.79	3.21	09/16/00
09/29/00	DRY	DRY	2.57	2.40	1.83	3.32	0.99	3.31	DRY	DRY	09/29/00
10/20/00	DRY	DRY	DRY	DRY	DRY	DRY	1.00	3.37	DRY	DRY	10/20/00
12/01/00			DRY	DRY	DRY	DRY	0.97	3.49	DRY	DRY	12/01/00
01/19/01	DRY	DRY	DRY	DRY	DRY	DRY		3.87	DRY	DRY	01/19/01
03/05/01	DRY	DRY	DRY	DRY					DRY	DRY	03/05/01
03/30/01	DRY	DRY	DRY	DRY			2.31	3.52	DRY	DRY	03/30/01
04/21/01	3.75	2.28	DRY	DRY	2.66	3.19			DRY	DRY	04/21/01
05/14/01	DRY	DRY	2.66		2.17	2.16			1.73	3.08	05/14/01
05/29/01	DRY	DRY	2.69	2.90			0.56	2.48	1.49	3.46	05/29/01
06/07/01	DRY	DRY	2.34	2.87			0.58	3.34	1.55	3.35	06/07/01
06/14/01	DRY	DRY	1.87	2.74	2.28	2.76		0.89	1.54	3.31	06/14/01
06/20/01	DRY	DRY	1.79	2.87	2.20	3.18	0.40		1.58	3.46	06/20/01
06/29/01	DRY	DRY	2.23	2.87	2.51	3.04	0.73	1.73	1.70	3.34	06/29/01
07/06/01	DRY	DRY	1.72	2.78	2.16	1.22	0.49	1.43	1.80	3.30	07/06/01
07/12/01	DRY	DRY	2.05	2.78	2.60	1.46	0.53	1.60	DRY	DRY	07/12/01
07/18/01	DRY	DRY	2.23	2.80	2.35	1.74	0.65	2.11	DRY	DRY	07/18/01
07/26/01	DRY	DRY	DRY	DRY	2.23	2.42			1.79	1.64	07/26/01
08/02/01	DRY	DRY	1.77	2.89			0.29	1.69	1.81	2.04	08/02/01
08/10/01	DRY	DRY	1.88	2.82	2.14	2.86	0.41	2.42	1.85	2.36	08/10/01
08/17/01	DRY	DRY	1.90	2.81	2.16	3.02	0.44	2.61	1.85	2.49	08/17/01
09/01/01	DRY	DRY	2.47	2.83	2.24	3.12	0.37	2.98	DRY	DRY	09/01/01
09/15/01	DRY	DRY	2.77	2.75	2.42	3.17	0.65	3.32	DRY	DRY	09/15/01
09/29/01	DRY	DRY	DRY	DRY	2.58	3.14	0.50	1.24	DRY	DRY	09/29/01
10/12/01							0.92	1.75			10/12/01
10/27/01	DRY	DRY	DRY	DRY	2.70	3.10	1.00	1.95	DRY	DRY	10/27/01
11/17/01			DRY	DRY	2.72	2.90	1.02	2.10	DRY	DRY	11/17/01
12/18/01	DRY	DRY	DRY	DRY	2.70	2.41	1.37	2.86	DRY	DRY	12/18/01

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 94		Well 95		Well 96		Well 97		Well 98		Date
	WTD	EC	WTD	EC	WTD	EC	WTD	EC	WTD	EC	
04/05/99											04/05/99
05/11/99											05/11/99
05/27/99											05/27/99
06/01/99											06/01/99
06/11/99											06/11/99
06/17/99											06/17/99
06/24/99											06/24/99
06/30/99											06/30/99
07/07/99											07/07/99
07/14/99											07/14/99
07/21/99											07/21/99
07/28/99											07/28/99
08/04/99											08/04/99
08/12/99											08/12/99
08/18/99											08/18/99
09/04/99											09/04/99
09/16/99											09/16/99
10/01/99											10/01/99
11/13/99											11/13/99
01/04/00											01/04/00
02/24/00											02/24/00
03/25/00											03/25/00
04/15/00											04/15/00
04/28/00											04/28/00
05/17/00											05/17/00
06/01/00											06/01/00
06/06/00											06/06/00
06/15/00											06/15/00
06/23/00											06/23/00
06/29/00											06/29/00
07/06/00											07/06/00
07/14/00											07/14/00
07/20/00											07/20/00

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 94		Well 95		Well 96		Well 97		Well 98		Date
	WTD	EC	WTD	EC	WTD	EC	WTD	EC	WTD	EC	
07/27/00											07/27/00
08/02/00											08/02/00
08/11/00											08/11/00
08/19/00											08/19/00
09/01/00											09/01/00
09/16/00											09/16/00
09/29/00											09/29/00
10/20/00											10/20/00
12/01/00											12/01/00
01/19/01											01/19/01
03/05/01											03/05/01
03/30/01											03/30/01
04/21/01	2.15	1.44	2.03	3.26							04/21/01
05/14/01	2.25	1.31	1.37	2.90	DRY	DRY	4.64	3.21	4.27	3.40	05/14/01
05/29/01	2.09	1.42	1.53	2.96	DRY	DRY	4.42	2.77	3.89	3.30	05/29/01
06/07/01	0.62	0.99	1.31	2.82	DRY	DRY	4.40	2.65	3.69	3.38	06/07/01
06/14/01	2.41	1.42	1.64	3.06	DRY	DRY			3.69	3.61	06/14/01
06/20/01	2.14	1.57	1.22	3.06	DRY	DRY	3.30	3.04	3.67	3.63	06/20/01
06/29/01	2.15	1.51	1.39	2.81	DRY	DRY			3.27	4.08	06/29/01
07/06/01	2.15	1.31	1.50	2.84	DRY	DRY			3.36	3.55	07/06/01
07/12/01	2.22	1.28	1.47	2.87							07/12/01
07/18/01	2.13	1.30	1.53	2.87	DRY	DRY	4.10	3.02	2.87	3.75	07/18/01
07/26/01	2.17	1.28	1.55	2.88					2.49	3.91	07/26/01
08/02/01	2.23	1.39	1.26	2.89	DRY	DRY	3.57	3.00	2.81	3.95	08/02/01
08/10/01	2.18	1.25	1.31	2.75	DRY	DRY	4.33	2.87	2.96	3.96	08/10/01
08/17/01	2.21	1.39	1.36	3.06	DRY	DRY	4.44	2.86	2.97	3.72	08/17/01
09/01/01	2.19	1.24	1.47	2.86	DRY	DRY	4.40	3.00	2.91	4.28	09/01/01
09/15/01	2.25	1.28	1.52	2.80	DRY	DRY	3.83	3.03		3.68	09/15/01
09/29/01	2.21	1.23	1.18	2.72	DRY	DRY	3.99	3.04	3.19	3.84	09/29/01
10/12/01					DRY	DRY			3.29	3.49	10/12/01
10/27/01	DRY	DRY	1.37	2.84	DRY	DRY	4.35	3.01	3.51	3.72	10/27/01
11/17/01	2.13	1.33	1.17	2.75	DRY	DRY					11/17/01
12/18/01	DRY	DRY	1.55	2.05	DRY	DRY	4.63	2.84	3.50	3.46	12/18/01

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 99		Well 100		Well 200		Well 201		Well 202		Date
	WTD	EC	WTD	EC	WTD	EC	WTD	EC	WTD	EC	
04/05/99											04/05/99
05/11/99											05/11/99
05/27/99											05/27/99
06/01/99											06/01/99
06/11/99											06/11/99
06/17/99											06/17/99
06/24/99											06/24/99
06/30/99											06/30/99
07/07/99											07/07/99
07/14/99											07/14/99
07/21/99											07/21/99
07/28/99											07/28/99
08/04/99											08/04/99
08/12/99											08/12/99
08/18/99											08/18/99
09/04/99											09/04/99
09/16/99											09/16/99
10/01/99											10/01/99
11/13/99											11/13/99
01/04/00											01/04/00
02/24/00											02/24/00
03/25/00											03/25/00
04/15/00											04/15/00
04/28/00											04/28/00
05/17/00					4.54	2.70	1.69	3.74	DRY	DRY	05/17/00
06/01/00					5.19	2.38	1.97	3.25	DRY	DRY	06/01/00
06/06/00					4.39	1.35	1.58	3.31	5.51	2.25	06/06/00
06/15/00					4.55	1.59	1.45	3.18	DRY	DRY	06/15/00
06/23/00					4.57	1.88	1.94	3.03	DRY	DRY	06/23/00
06/29/00					4.58	2.20	1.48	2.86	DRY	DRY	06/29/00
07/06/00					4.64	2.29	1.62	3.16	DRY	DRY	07/06/00
07/14/00					4.81	3.71	1.75	4.58	DRY	DRY	07/14/00
07/20/00					4.92	1.54	1.50	2.49	DRY	DRY	07/20/00

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 99		Well 100		Well 200		Well 201		Well 202		Date
	WTD	EC	WTD	EC	WTD	EC	WTD	EC	WTD	EC	
07/27/00					4.74	2.58	1.72	3.50	DRY	DRY	07/27/00
08/02/00					4.81	2.99	1.69	3.43	DRY	DRY	08/02/00
08/11/00					4.80	2.79	1.64	2.99	DRY	DRY	08/11/00
08/19/00					4.85	2.92	1.84	3.55	DRY	DRY	08/19/00
09/01/00					4.82	2.58	2.14	3.41	DRY	DRY	09/01/00
09/16/00					4.77	2.09	2.19	3.11	DRY	DRY	09/16/00
09/29/00					4.84	2.45	0.09	2.10	DRY	DRY	09/29/00
10/20/00					4.84	2.51	2.32	2.80	DRY	DRY	10/20/00
12/01/00					5.06	2.62	2.50	3.79	DRY	DRY	12/01/00
01/19/01					4.60	2.31	2.44	3.11	DRY	DRY	01/19/01
03/05/01					5.55	2.55	2.56	1.07	DRY	DRY	03/05/01
03/30/01					5.36	2.62	2.59	1.15	DRY	DRY	03/30/01
04/21/01					5.44	2.21	1.72	1.84	DRY	DRY	04/21/01
05/14/01	5.63	1.15	DRY	DRY	5.57	1.80	2.29	1.58	DRY	DRY	05/14/01
05/29/01	DRY	DRY	2.83	4.34	5.33	2.65	1.72	2.02	5.98	0.91	05/29/01
06/07/01	DRY	DRY	2.94	4.37	5.47	1.02	1.30	1.49	DRY	DRY	06/07/01
06/14/01	DRY	DRY	3.05	4.31	DRY	DRY	1.51	2.08	5.99	0.95	06/14/01
06/20/01	DRY	DRY	2.69	4.56	DRY	DRY	1.55	2.39	DRY	DRY	06/20/01
06/29/01	5.60	1.20	2.87	4.36	DRY	DRY	1.80	2.48	DRY	DRY	06/29/01
07/06/01	5.65	1.19	3.06	4.33	DRY	DRY	1.78	2.37	2.61	5.69	07/06/01
07/12/01	DRY	DRY	3.14	4.31					DRY	DRY	07/12/01
07/18/01	DRY	DRY	3.12	4.33	DRY	DRY	1.86	2.35	DRY	DRY	07/18/01
07/26/01			3.06	4.24							07/26/01
08/02/01	DRY	DRY	3.15	4.17			1.99	1.88	DRY	DRY	08/02/01
08/10/01	DRY	DRY	2.99	4.16							08/10/01
08/17/01	DRY	DRY	3.00	4.06	DRY	DRY	1.96	1.72	DRY	DRY	08/17/01
09/01/01	DRY	DRY	3.23	3.85	DRY	DRY	2.30	1.80	DRY	DRY	09/01/01
09/15/01	DRY	DRY	3.43	4.13	DRY	DRY	2.09	2.40	DRY	DRY	09/15/01
09/29/01	DRY	DRY	3.55	4.03	DRY	DRY	2.31	1.94	DRY	DRY	09/29/01
10/12/01	DRY	DRY			DRY	DRY	2.47	2.03			10/12/01
10/27/01	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	10/27/01
11/17/01	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	11/17/01
12/18/01	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	12/18/01

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 203		Well 204		Well 205		Well 206		Well 207A		Date
	WTD	EC	WTD	EC	WTD	EC	WTD	EC	WTD	EC	
4/5/99											4/5/99
5/11/99											5/11/99
5/27/99											5/27/99
6/1/99											6/1/99
6/11/99											6/11/99
6/17/99											6/17/99
6/24/99											6/24/99
6/30/99											6/30/99
7/7/99											7/7/99
7/14/99											7/14/99
7/21/99											7/21/99
7/28/99											7/28/99
8/4/99											8/4/99
8/12/99											8/12/99
8/18/99											8/18/99
9/4/99											9/4/99
9/16/99											9/16/99
10/1/99											10/1/99
11/13/99											11/13/99
1/4/00											1/4/00
2/24/00											2/24/00
3/25/00											3/25/00
4/15/00											4/15/00
4/28/00											4/28/00
5/17/00	2.56	5.79	2.97	4.70	DRY	DRY	4.38	3.02	0.67	3.95	5/17/00
6/1/00	2.81	5.18	3.29	4.41	DRY	DRY	4.51	3.35	0.87	4.20	6/1/00
6/6/00	2.49	5.80	DRY	DRY	DRY	DRY	4.01	3.35	0.61	4.01	6/6/00
6/15/00	2.57	5.55	2.97	4.15	4.65	1.70	3.90	3.84	0.31	3.66	6/15/00
6/23/00	2.57	4.84	DRY	DRY	DRY	DRY	3.87	3.29	0.58	1.62	6/23/00
6/29/00	2.58	5.41	2.72	3.88	3.92	1.48	3.87	3.53	0.45	2.15	6/29/00
7/6/00	2.28	5.10	2.57	4.22	4.01	1.35	3.69	3.46	0.60	2.71	7/6/00
7/14/00	DRY	DRY	DRY	DRY	3.68	1.96	3.97	4.51	0.51	4.44	7/14/00
7/20/00	2.37	5.51	2.85	3.51	4.30	1.47	3.71	3.18	0.78	3.09	7/20/00

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 203		Well 204		Well 205		Well 206		Well 207A		Date
	WTD	EC	WTD	EC	WTD	EC	WTD	EC	WTD	EC	
7/27/00	2.51	6.01	2.87	5.24	3.78	1.83	3.80	3.75	0.92	3.91	7/27/00
8/2/00	2.54	6.13	2.89	4.49	4.01	1.83	3.93	3.84	0.50	3.91	8/2/00
8/11/00	2.58	5.69	2.94	4.66	3.94	1.51	4.01	3.39	0.57	3.79	8/11/00
8/19/00	2.56	5.59	2.94	4.48	4.05	3.40	4.05	3.40	0.64	3.56	8/19/00
9/1/00	2.61	5.58	DRY	DRY	4.28	1.71	4.13	3.03	0.84	2.50	9/1/00
9/16/00	2.63	5.27	2.92	4.81	4.44	1.61	4.19	2.83	0.94	3.57	9/16/00
9/29/00	2.64	5.12	2.95	4.48	4.29	1.45	4.24	2.76	1.01	3.38	9/29/00
10/20/00	2.64	5.22	2.82	4.22	4.58	1.58	4.36	2.85	0.99	3.47	10/20/00
12/1/00	2.38	6.12	DRY	DRY	DRY	DRY	3.63	3.22	1.10	3.50	12/1/00
1/19/01	2.68	4.84	DRY	DRY	DRY	DRY	3.93	2.65	1.22	3.63	1/19/01
3/5/01	2.77	10.60	DRY	DRY	DRY	DRY	4.91	2.03	1.04	2.98	3/5/01
3/30/01	2.65	1.21	DRY	DRY	DRY	DRY	4.72	1.89	1.37	2.50	3/30/01
4/21/01	2.60	4.61			DRY	DRY	DRY	DRY	0.01	1.79	4/21/01
5/14/01	2.64	4.33	2.75	4.07	DRY	DRY	4.74	2.68	0.60	1.59	5/14/01
5/29/01	2.64	4.59	2.61	3.73	DRY	DRY	4.64	2.88	0.81	2.09	5/29/01
6/7/01	2.56	4.53	2.54	3.76	DRY	DRY	4.57	2.96			6/7/01
6/14/01	2.50	4.76	2.40	2.55	DRY	DRY	4.43	2.95	0.17	3.03	6/14/01
6/20/01			2.19	2.97	DRY	DRY	4.21	3.61	0.41	3.04	6/20/01
6/29/01	2.49	4.82	2.11	3.01	DRY	DRY	4.32	3.32	0.95	2.89	6/29/01
7/6/01	2.61	5.69	2.75	3.44	DRY	DRY	4.40	3.59	0.68	1.78	7/6/01
7/12/01											7/12/01
7/18/01	2.62	1.26	2.76	1.94	DRY	DRY	4.89	3.21	0.75	1.72	7/18/01
7/26/01											7/26/01
8/2/01	2.48	11.50	2.55	2.29	4.68	1.34	4.25	3.49	0.59	1.62	8/2/01
8/10/01											8/10/01
8/17/01	2.62	1.84	2.59	2.50	4.52	1.42	4.26	3.38	0.48	1.41	8/17/01
9/1/01	2.67	2.48	2.55	2.59	4.58	1.39	4.44	3.07	0.88	1.65	9/1/01
9/15/01	DRY	DRY	2.88	3.29	DRY	DRY	4.56	3.58	1.02	2.34	9/15/01
9/29/01	DRY	DRY	DRY	DRY	DRY	DRY	4.59	3.11	1.06	2.38	9/29/01
10/12/01			2.88	2.95	DRY	DRY	4.60	3.22	0.98	2.95	10/12/01
10/27/01	DRY	DRY	DRY	DRY	DRY	DRY	4.68	2.99	0.74	2.30	10/27/01
11/17/01			DRY	DRY	DRY	DRY	2.95	3.10			11/17/01
12/18/01	DRY	DRY			DRY	DRY	DRY	DRY			12/18/01

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 207B		Well 208		Well 209		Date
	WTD	EC	WTD	EC	WTD	EC	
4/5/99							4/5/99
5/11/99							5/11/99
5/27/99							5/27/99
6/1/99							6/1/99
6/11/99							6/11/99
6/17/99							6/17/99
6/24/99							6/24/99
6/30/99							6/30/99
7/7/99							7/7/99
7/14/99							7/14/99
7/21/99							7/21/99
7/28/99							7/28/99
8/4/99							8/4/99
8/12/99							8/12/99
8/18/99							8/18/99
9/4/99							9/4/99
9/16/99							9/16/99
10/1/99							10/1/99
11/13/99							11/13/99
1/4/00							1/4/00
2/24/00							2/24/00
3/25/00							3/25/00
4/15/00							4/15/00
4/28/00							4/28/00
5/17/00							5/17/00
6/1/00							6/1/00
6/6/00							6/6/00
6/15/00							6/15/00
6/23/00	1.58	3.15					6/23/00
6/29/00	1.09	3.20					6/29/00
7/6/00	1.32	3.35					7/6/00
7/14/00							7/14/00
7/20/00	1.77	3.44					7/20/00

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

Date	Well 207B		Well 208		Well 209		Date
	WTD	EC	WTD	EC	WTD	EC	
7/27/00							7/27/00
8/2/00	1.87	3.97					8/2/00
8/11/00	1.87	3.72					8/11/00
8/19/00	1.56	3.79					8/19/00
9/1/00	1.62	3.35					9/1/00
9/16/00	1.71	3.77					9/16/00
9/29/00	1.84	3.67					9/29/00
10/20/00	1.90	3.66					10/20/00
12/1/00	1.86	3.48					12/1/00
1/19/01	1.98	4.07					1/19/01
3/5/01							3/5/01
3/30/01							3/30/01
4/21/01	0.11	3.54	1.28	2.36	2.10	4.81	4/21/01
5/14/01	1.35	3.78	1.31	2.59	2.08	3.76	5/14/01
5/29/01	1.71	3.86	0.97	2.58	2.24	4.00	5/29/01
6/7/01	0.74	3.64	1.26	2.61	2.53	3.92	6/7/01
6/14/01	1.20	3.80	1.29	2.45	2.08	3.05	6/14/01
6/20/01	1.40	4.71	1.08	2.46	1.99	3.24	6/20/01
6/29/01	1.32	3.79	1.25	2.40	1.56	3.50	6/29/01
7/6/01	1.39	3.81	1.68	2.79	1.59	6.16	7/6/01
7/12/01							7/12/01
7/18/01	1.44	3.91	1.40	2.52	1.64	4.32	7/18/01
7/26/01							7/26/01
8/2/01	1.70	3.73	1.26	2.90	1.87	3.99	8/2/01
8/10/01							8/10/01
8/17/01	0.95	3.70	1.34	2.75	1.99	4.02	8/17/01
9/1/01	1.68	3.71	1.47	2.69			9/1/01
9/15/01	1.89	4.24	1.55	3.21	2.14	3.98	9/15/01
9/29/01	2.06	3.58	0.66	2.85	2.17	3.37	9/29/01
10/12/01	2.05	3.58	1.61	3.24	2.19	3.52	10/12/01
10/27/01	1.19	3.46	1.54	3.16	2.13	3.24	10/27/01
11/17/01			1.40	3.21	2.12	3.3895	11/17/01
12/18/01			1.40	3.01	2.21	3.0005	12/18/01

WTD = Measured Water Table Depth; EC = Measured Electrical Conductivity

B.2 SOIL WATER SALINITY (EC_e) DATA

	Field #	1	2	5	6	7	8	9A	9B
1999	**Mean EC_e**	2.28	1.21	0.42	0.31	6.14	0.45	2.18	5.52
Early	**CV**	2.52	1.32	3.84	1.95	2.96	4.22	2.11	2.51
	# Points	58	84	73	64	67	40	64	61
1999	**Mean EC_e**	1.99	1.09	3.11	1.17	7.46	1.11	4.78	6.46
Late	**CV**	2.41	2.11	1.95	2.83	2.79	2.95	2.36	1.96
	# Points	76	87	74	68	72	41	65	64
2000	**Mean EC_e**	2.39	0.16	1.11	0.30	4.25	0.13	1.28	2.40
Early	**CV**	2.96	1.95	1.24	1.59	1.51	2.28	2.30	1.43
	# Points	97	73	81	63	99	47	56	68
2000	**Mean EC_e**	2.03	0.48	1.13	0.64	4.01	0.17	1.43	4.33
Late	**CV**	2.59	1.56	1.13	1.99	1.25	2.62	1.96	1.68
	# Points	97	71	81	45	117	73	70	44
2001	**Mean EC_e**	3.11	0.28	2.13	0.51	4.37	0.52	1.92	3.62
Early	**CV**	2.28	1.82	1.24	3.34	1.22	0.88	1.47	2.03
	# Points	44	40	123	50	81	48	121	61
2001	**Mean EC_e**	1.70	0.33	1.54	0.58	5.83	0.46	1.67	4.49
Late	**CV**	2.58	3.73	1.38	3.45	2.05	4.58	2.31	1.12
	# Points	52	80	80	40	60	45	62	97
UTM	**x (m)**	597,987	598,033	598,401	598,743	599,088	599,990	600,470	600,179
Coord.	**y (m)**	4,219,947	4,218,169	4,217,695	4,218,390	4,219,549	4,217,023	4,215,331	4,215,069

EC_e = Electrical Conductivity in dS/m of the Soil Paste Extract, derived from EM-38 measurements; CV = Coefficient of Variation of Data Points; UTM Zone = 13.

	Field #	11	12	13	14	17	18	20	21
1999	**Mean EC$_e$**	5.24	3.62	2.89	1.73	1.69	3.69	7.04	2.92
Early	**CV**	3.54	1.45	3.77	1.24	3.85	4.08	1.60	1.00
	# Points	57	66	86	57	55	40	63	67
1999	**Mean EC$_e$**	7.01	4.87	2.49	2.08	1.03	3.28	6.35	2.96
Late	**CV**	4.01	1.41	2.60	1.70	1.68	4.23	1.48	1.21
	# Points	66	75	82	60	89	72	81	76
2000	**Mean EC$_e$**	6.10	3.51	1.77	3.72	1.69	3.21	5.65	2.41
Early	**CV**	3.30	1.15	3.06	1.42	3.49	3.07	1.64	1.23
	# Points	61	74	84	50	96	33	45	44
2000	**Mean EC$_e$**	3.37	5.34	0.76	5.62	1.87	3.96	5.62	1.84
Late	**CV**	2.74	1.69	3.55	1.46	2.97	3.07	1.63	1.92
	# Points	67	79	63	38	77	69	77	68
2001	**Mean EC$_e$**	6.23	4.19	2.00	4.48	1.00	3.26	5.75	2.36
Early	**CV**	3.43	1.46	2.93	3.59	3.10	4.17	1.54	1.68
	# Points	81	69	42	48	121	61	77	27
2001	**Mean EC$_e$**	5.71	5.52	2.16	2.82	1.79	2.94		2.14
Late	**CV**	2.40	1.67	2.85	0.97	4.20	3.05		1.36
	# Points	54	60	50	52	62	47		65
UTM	**x (m)**	603,166	601,672	604,215	608,133	608,785	604,917	608,286	608,734
Coord.	**y (m)**	4,212,328	4,208,492	4,218,760	4,218,329	4,215,237	4,212,377	4,210,809	4,209,805

EC$_e$ = Electrical Conductivity in dS/m of the Soil Paste Extract, derived from EM-38 measurements; CV = Coefficient of Variation of Data Points; UTM Zone = 13.

	Field #	22	23	24	26A	26B	27	28	29
1999	**Mean EC_e**	2.47	3.99	1.01	0.79	3.46	3.09	4.42	4.52
Early	**CV**	1.86	2.56	1.84	2.94	1.65	8.48	2.98	3.37
	# Points	31	78	71	63	49	74	50	64
1999	**Mean EC_e**	1.66	4.41	1.55	1.24	5.04	2.26	5.38	3.53
Late	**CV**	2.69	2.83	2.48	3.01	1.91	4.75	2.97	2.68
	# Points	31	49	82	69	60	76	59	68
2000	**Mean EC_e**	2.46	3.52	1.14	3.95	3.30	2.17	3.35	3.64
Early	**CV**	1.37	2.83	2.43	4.63	3.03	6.55	3.19	2.95
	# Points	36	53	91	36	36	61	61	84
2000	**Mean EC_e**	1.85	4.22	1.20	2.30	3.14	1.52	4.04	4.03
Late	**CV**	2.05	3.06	2.60	3.46	2.08	3.97	2.67	2.99
	# Points	35	58	84	65	75	80	65	102
2001	**Mean EC_e**	1.46	4.17	1.38	1.36	3.71	2.83	3.54	3.23
Early	**CV**	2.93	3.34	5.08	3.29	3.13	5.26	3.02	3.44
	# Points	27	35	41	81	72	70	73	81
2001	**Mean EC_e**	1.58	6.31	1.25	1.54		2.86	5.04	2.90
Late	**CV**	2.40	4.77	2.00	2.51		4.73	2.56	2.05
	# Points	40	30	64	81		92	49	97
UTM	**x (m)**	609,898	608,755	611,289	612,692	611,969	609,890	610,824	615,959
Coord.	**y (m)**	4,210,092	4,212,640	4,213,300	4,206,053	4,207,747	4,200,291	4,204,269	4,208,101

EC_e = Electrical Conductivity in dS/m of the Soil Paste Extract, derived from EM-38 measurements; CV = Coefficient of Variation of Data Points; UTM Zone = 13.

	Field #	30	31	33	35	36A	36B	37	38
1999	**Mean EC_e**	0.91	3.86	2.21	2.62	0.82	1.03	1.16	2.75
Early	**CV**	3.17	1.47	4.45	2.71	1.64	1.94	4.07	3.27
	# Points	46	40	55	63	72	70	84	65
1999	**Mean EC_e**	0.73	2.35	2.31	1.98	1.54	0.77	0.81	2.43
Late	**CV**	3.14	1.22	3.46	1.53	1.37	1.77	2.81	2.82
	# Points	61	66	57	75	31	71	85	74
2000	**Mean EC_e**	1.03	1.50	2.27	1.85	0.35	0.39	0.96	2.56
Early	**CV**	2.71	1.83	4.90	2.03	1.23	2.56	2.67	3.17
	# Points	36	27	43	75	34	31	34	41
2000	**Mean EC_e**	1.01	1.34	2.67	1.32	0.60	0.51	1.18	1.92
Late	**CV**	3.40	2.18	4.85	1.99	1.78	1.05	2.18	3.15
	# Points	55	50	60	84	60	60	49	40
2001	**Mean EC_e**	1.09	1.64	2.68	1.13	1.10	0.74	1.02	2.38
Early	**CV**	4.00	2.83	5.23	2.14	0.95	2.66	4.02	2.68
	# Points	48	34	51	63	60	66	57	60
2001	**Mean EC_e**	0.75	1.66	1.84	2.63	0.58	0.51	1.33	1.88
Late	**CV**	3.83	2.89	5.72	2.64	1.26	2.02	2.84	2.53
	# Points	65	40	56	80	60	65	57	65
UTM	**x (m)**	613,642	613,996	616,429	613,225	617,448	617,703	618,367	619,305
Coord.	**y (m)**	4,210,779	4,214,009	4,206,494	4,205,067	4,210,539	4,211,315	4,212,506	4,210,904

EC_e = Electrical Conductivity in dS/m of the Soil Paste Extract, derived from EM-38 measurements; CV = Coefficient of Variation of Data Points; UTM Zone = 13.

	Field #	**39**	**40**	**41**	**42**	**43**	**45**	**48**	**49**
1999	**Mean EC_e**	4.24	8.03	2.58	2.49	5.58	2.55	7.62	1.92
Early	**CV**	1.80	2.49	4.25	4.76	4.73	5.44	2.66	3.83
	# Points	65	73	70	58	71	74	29	59
1999	**Mean EC_e**	4.79	9.03	2.93	4.22	5.28	2.70	9.09	1.96
Late	**CV**	1.77	2.95	4.03	3.22	5.10	4.90	3.06	3.14
	# Points	65	78	72	64	72	74	31	65
2000	**Mean EC_e**	5.89	9.12	2.52	2.60	4.15	2.70	5.14	1.99
Early	**CV**	2.36	3.53	3.63	3.17	2.35	5.41	1.50	3.78
	# Points	48	66	64	75	95	60	71	54
2000	**Mean EC_e**	5.59	8.54	2.98	2.87	7.27	3.26	5.71	1.58
Late	**CV**	1.97	2.99	4.21	2.91	6.38	5.00	1.64	3.51
	# Points	61	65	73	76	74	101	80	43
2001	**Mean EC_e**	5.64	7.89	2.87	3.26	4.23	2.87	4.64	1.57
Early	**CV**	1.95	2.24	4.48	4.59	7.58	5.51	1.35	4.49
	# Points	36	51	73	88	69	76	54	76
2001	**Mean EC_e**	3.23	9.60	3.82	3.17	6.83	3.32	5.94	1.83
Late	**CV**	1.53	3.35	3.31	3.74	7.45	5.33	1.62	3.81
	# Points	48	69	60	40	79	61	40	40
UTM	**x (m)**	620,961	621,547	621,068	619,891	618,853	609,257	614,867	621,473
Coord.	**y (m)**	4,208,802	4,211,119	4,205,505	4,203,982	4,203,694	4,198,386	4,202,288	4,202,877

EC_e = Electrical Conductivity in dS/m of the Soil Paste Extract, derived from EM-38 measurements; CV = Coefficient of Variation of Data Points; UTM Zone = 13.

	Field #	**50**	**51**	**52**	**53**	**55**	**57**	**60A**	**61**
1999 **Early**	**Mean EC_e**	1.96	1.53	2.84	3.40		5.30	0.86	6.29
	CV	2.08	2.49	2.53	3.01		2.32	2.07	1.98
	# Points	79	75	79	78		76	61	64
1999 **Late**	**Mean EC_e**	2.19	2.55	2.99	3.71		5.34	1.55	5.77
	CV	2.19	2.72	2.57	2.73		2.79	2.46	1.64
	# Points	80	81	57	80		76	61	65
2000 **Early**	**Mean EC_e**	2.33	2.09	3.43	2.79	2.40	4.17	1.61	
	CV	2.47	3.68	3.52	2.07	1.33	3.84	1.89	
	# Points	74	48	74	62	30	54	57	
2000 **Late**	**Mean EC_e**	2.12	2.07	3.68	2.96	1.81	5.60	1.47	3.45
	CV	3.11	2.52	3.13	2.72	2.31	2.27	3.22	1.32
	# Points	72	49	80	56	32	38	65	68
2001 **Early**	**Mean EC_e**	2.50	2.28	3.28	2.70	3.20	5.17	1.69	3.18
	CV	2.23	3.25	3.44	2.23	1.39	2.58	3.27	1.23
	# Points	50	51	71	60	31	51	51	57
2001 **Late**	**Mean EC_e**	2.92	1.72	2.99	2.66	1.69	3.74	1.67	3.32
	CV	2.12	3.23	3.70	1.87	1.26	1.83	2.45	1.41
	# Points	40	60	89	90	33	48	50	61
UTM **Coord.**	**x (m)**	621,284	621,104	622,852	623,322	626,175	621,976	625,933	627,505
	y (m)	4,202,656	4,210,558	4,207,699	4,204,553	4,205,690	4,209,598	4,216,508	4,216,075

EC_e = Electrical Conductivity in dS/m of the Soil Paste Extract, derived from EM-38 measurements; CV = Coefficient of Variation of Data Points; UTM Zone = 13.

	Field #	62	65	66	67	68	69	70	71
1999	**Mean EC_e**	1.81	5.57	8.95	1.61	1.08	2.34	2.59	0.85
Early	**CV**	1.31	1.53	3.58	1.45	4.29	7.70	3.03	3.11
	# Points	71	68	53	60	69	52	67	60
1999	**Mean EC_e**	2.03	3.43	9.72	1.35	1.58	2.28	3.65	2.28
Late	**CV**	1.21	2.69	5.14	1.21	4.30	7.31	4.13	2.81
	# Points	71	54	59	62	71	60	69	63
2000	**Mean EC_e**	2.19	1.77	7.15	2.07	1.87	2.68	2.53	0.66
Early	**CV**	1.62	2.15	2.96	2.00	5.34	12.20	3.05	2.92
	# Points	65	64	63	62	63	67	65	70
2000	**Mean EC_e**	1.19	3.70	10.54	2.29	2.31	1.38	1.17	1.74
Late	**CV**	2.30	2.20	4.89	4.10	2.70	7.47	1.94	2.17
	# Points	39	51	61	64	81	64	67	73
2001	**Mean EC_e**	1.15	8.39	8.70	1.85	2.30	2.73	2.92	0.38
Early	**CV**	2.42	3.03	3.83	2.00	6.65	12.17	2.80	2.78
	# Points	65	44	61	81	51	53	48	71
2001	**Mean EC_e**	1.11	8.45	9.86	4.67	2.43	1.91	2.05	0.48
Late	**CV**	1.15	2.84	4.89	2.52	5.64	5.87	2.23	1.71
	# Points	71	48	60	60	51	48	48	55
UTM	**x (m)**	629,753	631,340	632,044	635,431	635,777	636,753	639,394	639,210
Coord.	**y (m)**	4,218,131	4,206,846	4,208,149	4,210,605	4,210,883	4,211,899	4,211,832	4,213,384

EC_e = Electrical Conductivity in dS/m of the Soil Paste Extract, derived from EM-38 measurements; CV = Coefficient of Variation of Data Points; UTM Zone = 13.

	Field #	76	77	79	82	84	85	87B	88
1999	**Mean EC_e**	8.91	1.43	1.71					
Early	**CV**	2.84	7.14	2.09					
	# Points	53	39	71					
1999	**Mean EC_e**	6.41	2.33	1.89					
Late	**CV**	1.78	8.04	1.96					
	# Points	64	36	72					
2000	**Mean EC_e**	6.10	1.15			2.25	1.90	7.24	2.24
Early	**CV**	1.61	4.18			2.08	1.70	2.55	8.72
	# Points	51	17			62	69	48	49
2000	**Mean EC_e**	1.42	2.58	1.52	1.16	2.43	1.59	3.35	1.91
Late	**CV**	1.01	6.42	2.10	3.03	2.54	0.48	2.22	3.91
	# Points	54	34	50	43	51	84	49	97
2001	**Mean EC_e**	9.96	2.01	1.42	1.43	4.78	2.54	7.83	1.80
Early	**CV**	4.17	8.10	1.99	1.98	3.07	1.80	3.05	6.57
	# Points	101	61	52	32	48	73	60	50
2001	**Mean EC_e**	5.49			1.18	2.89	1.31	6.49	3.05
Late	**CV**	1.30			1.63	2.72	1.54	1.74	5.12
	# Points	63			60	64	60	67	73
UTM	**x (m)**	614,761	614,715	619,612	614,846	624,087	611,616	629,114	616,805
Coord.	**y (m)**	4,212,856	4,210,717	4,206,116	4,209,195	4,215,679	4,202,740	4,219,522	4,209,303

EC_e = Electrical Conductivity in dS/m of the Soil Paste Extract, derived from EM-38 measurements; CV = Coefficient of Variation of Data Points; UTM Zone = 13.

	Field #	90	92	93	95	97	100	200	201
1999	**Mean EC_e**							4.90	3.23
Early	**CV**							3.40	2.76
	# Points							62	70
1999	**Mean EC_e**							4.18	2.49
Late	**CV**							2.82	2.79
	# Points							63	74
2000	**Mean EC_e**	2.28	3.28	1.47				3.56	3.16
Early	**CV**	3.25	3.39	3.04				2.96	3.69
	# Points	52	62	79				63	70
2000	**Mean EC_e**	1.61	5.42	1.68				1.69	3.39
Late	**CV**	2.16	3.93	2.76				3.36	2.55
	# Points	49	60	61				59	60
2001	**Mean EC_e**	1.44	4.72	2.18	2.29	2.55	1.22	2.84	
Early	**CV**	2.18	4.53	3.46	2.41	4.84	2.92	2.80	
	# Points	60	85	82	60	52	50	62	
2001	**Mean EC_e**	2.11	5.89	2.22	2.41	2.23	1.85	1.78	2.84
Late	**CV**	2.11	4.88	2.41	3.28	4.53	4.32	2.17	3.47
	# Points	60	74	61	60	70	53	52	60
UTM	**x (m)**	632,582	620,684	630,623	604,395	617,787	636,050	650,074	648,718
Coord.	**y (m)**	4,221,012	4,202,261	4,224,379	4,216,450	4,205,221	4,217,873	4,216,420	4,219,767

EC_e = Electrical Conductivity in dS/m of the Soil Paste Extract, derived from EM-38 measurements; CV = Coefficient of Variation of Data Points; UTM Zone = 13.

	Field #	202	203	204	205	206	207	209
1999	**Mean EC_e**	1.66	7.57	3.90	1.87	1.74	7.71	2.53
Early	**CV**	2.58	2.25	3.76	3.23	2.77	4.02	2.17
	# Points	57	63	40	55	63	66	67
1999	**Mean EC_e**	1.50	6.86	3.63	2.04	1.56	8.01	1.95
Late	**CV**	2.85	2.53	1.62	2.60	3.50	5.01	2.51
	# Points	64	62	61	55	73	59	71
2000	**Mean EC_e**	1.32	4.96	4.46	2.00	0.76	7.61	2.61
Early	**CV**	2.42	1.85	1.74	3.21	1.39	6.27	2.81
	# Points	41	42	45	58	40	68	51
2000	**Mean EC_e**	1.41	3.28	3.26	1.24	1.44	6.45	1.75
Late	**CV**	2.37	1.50	1.43	2.59	3.27	4.55	3.48
	# Points	66	42	48	69	40	53	63
2001	**Mean EC_e**	1.71	5.28	6.31	2.22	2.41	5.87	10.23
Early	**CV**	3.45	2.19	1.98	3.02	5.09	3.65	3.98
	# Points	69	53	48	63	65	101	40
2001	**Mean EC_e**	1.20	7.54	7.73	2.66	2.50	8.85	10.44
Late	**CV**	3.26	2.98	2.42	2.99	4.57	3.16	7.58
	# Points	58	53	48	68	60	60	50
UTM	**x (m)**	642,992	645,257	643,881	646,882	646,121	642,672	647,913
Coord.	**y (m)**	4,215,153	4,215,456	4,214,334	4,216,322	4,215,737	4,218,622	4,217,078

EC_e = Electrical Conductivity in dS/m of the Soil Paste Extract, derived from EM-38 measurements; CV = Coefficient of Variation of Data Points; UTM Zone = 13.

B.3 SURFACE WATER SALINITY (EC) DATA

Date	**SP 1**	**SP 2**	**SP 3**	**SP 4**	**SP 5**	**SP 6**	**SP 7**
	EC (dS/m)	**EC (dS/m)**	**EC (dS/m)**	**EC (dS/m)**	**EC (dS/m)**	**EC (dS/m)**	**EC (dS/m)**
6/7/99	0.85	1.00	0.88	0.99	2.30	0.84	0.88
6/14/99							
6/21/99	0.68	0.80	0.67	0.83	2.11	0.69	0.67
6/28/99	0.62	0.86	0.63	0.84		0.63	0.62
7/5/99	0.66	0.97	0.73	0.97	2.29	0.67	0.72
7/12/99	0.70		0.88	0.88		0.71	0.88
7/19/99		0.82	0.90	0.91	2.53		0.90
7/26/99	0.69			0.83			
8/2/99	0.65		0.81	0.70	0.91		
8/9/99	0.64	0.98		0.95			
8/16/99	0.74	1.12	0.87	1.01	2.55		
9/4/99	0.76	0.74	0.95	1.20	2.49	0.76	0.96
9/18/99	0.77	0.71	0.98	0.96	2.10		
3/3/00							
4/15/00	4.79	0.79	0.82	0.71		0.54	0.58
4/29/00	1.12	STAG	1.20	STAG	STAG	1.12	1.20
5/17/00	1.04	1.22	1.05	3.35		1.04	1.02
5/30/00	0.80	1.04	0.90	1.04	2.27	0.80	0.90
6/7/00	0.87	0.68	0.38	0.89	0.92	0.70	0.77
6/15/00	0.71	1.19	0.82	1.16		0.71	0.83
6/22/00	0.68	1.14	0.82	1.15	2.26	0.69	0.85
6/29/00	0.73	1.17	0.82	1.22	2.30	0.74	1.22
7/7/00	0.59	1.23	0.79			0.60	0.79
7/14/00	0.53	0.98	1.12	0.93	1.85	0.53	0.69
7/20/00	0.55	1.13	0.70				
7/27/00	0.65	1.41	0.76				
8/2/00	0.63	1.26	0.86				
8/11/00	0.63	1.18	0.77				
8/16/00	1.18	1.33	0.93	1.14		0.91	0.77
9/1/00	0.68	1.30	1.26	1.27	2.19	0.70	0.98
9/14/00							
9/29/00	0.93	DRY	1.18				
10/20/00	1.29	DRY	1.51				
12/1/00							
1/19/01							
3/6/01							
3/30/01	1.16	DRY	0.83	DRY	2.53	1.31	1.18
4/21/01	0.98	1.33					
5/15/01	1.08	1.31	1.05	0.99	2.50	1.08	1.18
5/30/01	0.76	0.98	0.76	0.98	2.42	0.75	0.82
6/8/01	0.69	0.60	0.81	0.69	2.33	0.67	0.82
6/14/01	0.65	1.00	0.70	1.04	2.42	0.67	0.73
6/23/01	0.64	1.00		1.02	2.32	0.64	0.78
6/29/01	0.50	0.87		0.89	1.23	0.50	0.58
7/5/01	0.58	1.04		0.98	2.22	0.57	0.72
7/12/01	0.59	1.06	0.74	1.06	2.19	0.61	0.72
7/17/01	0.58	0.83	0.66	0.83	1.47	0.59	0.67
7/25/01	0.68	0.79	0.78	1.00	2.25	0.66	0.81
8/1/01	0.65	1.00	0.77	0.98	2.22	0.65	0.76
8/10/01	0.58	1.11					
8/17/01	0.65	1.01					
9/1/01	0.71	1.11					
9/15/01	0.89	DRY					
9/29/01	1.12	DRY					
10/15/01							
10/27/01	1.01	DRY					
11/17/01							
12/18/01							

DRY = Surface water feature was dry at measurement point on given date
STAG = Water at measurement point was stagnant - reading discarded.

Date	SP 8	SP 9	SP 10	SP 11	SP 12	SP 13	SP 14
	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)
6/7/99	0.88	1.02	0.84	0.88	0.97	1.02	0.84
6/14/99							
6/21/99	0.67	0.99	0.70	0.68	0.68	0.99	0.68
6/28/99	0.63	0.86	0.63	0.63	0.69	0.88	0.64
7/5/99	0.72	0.99	0.68	0.72	0.88	1.00	0.67
7/12/99	0.88	0.96	0.71	0.88	0.95	1.26	0.71
7/19/99	0.91	0.36		0.91	0.79		
7/26/99	0.89	1.13	0.69		1.11	0.94	
8/2/99	0.80	0.60	0.58		0.68	0.78	
8/9/99	0.75	0.99	0.66		0.70	0.98	
8/16/99	0.85	1.08	0.75		1.02	1.14	
9/4/99	0.95	3.01	0.76	0.97	1.16	1.90	0.76
9/18/99	0.98	2.15	0.77		1.18	2.21	
3/3/00					1.02		
4/15/00	0.22	0.94	0.76		0.77		
4/29/00	1.21	1.14	1.14	1.21	1.43	1.99	1.13
5/17/00	1.02	2.18	1.04	1.02	1.31	2.72	1.04
5/30/00	0.90	1.03	0.80	0.90	1.06	1.03	0.79
6/7/00	0.76	0.91	0.71	0.76	0.93	0.91	0.68
6/15/00	0.84	1.17	0.71		0.97		0.71
6/22/00	0.85	1.16	0.69	0.85	1.23	1.14	0.66
6/29/00	0.85	1.24	0.75	0.85	0.93	1.26	0.76
7/7/00	0.84	1.23	0.62	0.80	0.94	1.24	0.60
7/14/00	0.69	1.07	0.54	0.70	1.58	1.07	0.55
7/20/00	0.65	1.09	0.56		0.69		
7/27/00	0.89	1.53	0.67		1.16		
8/2/00	0.60	1.25	0.71		1.27		
8/11/00	0.77	1.11	0.63		1.31		
8/16/00	1.07	1.36	0.68		1.21		
9/1/00	1.01	1.27	0.91	1.01	1.11	1.25	0.99
9/14/00					2.53		
9/29/00	1.23	2.58	0.93		1.45		
10/20/00	1.39	3.17	1.16		1.75		
12/1/00					1.83		
1/19/01					1.48		
3/6/01					2.05		
3/30/01	1.30	1.63	1.16	1.09	1.37	1.39	1.25
4/21/01	1.12	1.30			1.35		
5/15/01	0.96	1.44	1.00	1.18	1.42	1.44	1.08
5/30/01	0.82	1.10	0.77	0.82	0.81	1.08	0.76
6/8/01	0.72	1.13	0.68	0.85	0.77	1.14	0.69
6/14/01	0.74	1.15	0.67	0.76	0.99	1.12	0.68
6/23/01	0.78	1.08	0.64	0.78	0.92	1.06	0.63
6/29/01	0.58	0.92	0.50	0.58	0.81	0.94	0.50
7/5/01	0.72	0.99	0.56	0.72	0.98	0.98	0.56
7/12/01	0.72	1.09	0.62	0.72	0.93	1.07	0.64
7/17/01	0.67	0.82	0.59	0.66	0.70	0.81	0.60
7/25/01	0.81	1.11	0.65	0.80	1.03	1.10	0.65
8/1/01	0.74	1.03	0.65	0.75	0.97	1.02	0.65
8/10/01	0.70	1.08	0.59				
8/17/01	0.78	1.04	0.63		0.96		
9/1/01	0.86	1.13	0.73		1.34		
9/15/01	1.21	STAG	0.96		1.56		
9/29/01	1.28	STAG	1.11		1.46		
10/15/01							
10/27/01	1.21	3.11	1.03		1.36		
11/17/01					1.20		
12/18/01					1.05		

DRY = Surface water feature was dry at measurement point on given date
STAG = Water at measurement point was stagnant - reading discarded.

Date	SP 15	SP 16	SP 17	SP 18	SP 19	SP 20	SP 21
	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)
6/7/99	2.65	1.02	1.02	1.12	0.84	3.20	0.84
6/14/99							
6/21/99	2.14	0.95	0.95	1.22	0.67	3.13	0.68
6/28/99	1.80	0.87	0.90	1.03	0.63	2.29	0.63
7/5/99	0.99	0.99	2.08	1.06	0.74	2.58	0.67
7/12/99	1.90	1.57	1.78	1.67	0.70	1.73	0.71
7/19/99	2.56	3.02	2.74	2.63		2.33	
7/26/99	3.22	0.85	0.97		0.69	3.40	0.68
8/2/99	0.88	0.26	0.26	0.32	0.64	3.14	0.58
8/9/99	0.98	2.95	0.98	1.02	0.64		0.65
8/16/99	1.17	3.99	1.10	1.25	0.75	3.18	0.75
9/4/99	2.36		1.03	1.53	0.76	2.90	0.76
9/18/99	2.71	1.59	2.57	2.35	0.77	2.41	0.77
3/3/00							
4/15/00	2.00	0.69	0.85	0.72	0.75	1.59	0.82
4/29/00	3.53	1.65	-	1.78	1.21	3.64	1.14
5/17/00	3.60	1.70	2.05	2.13	1.00	3.86	1.04
5/30/00	2.35	1.05	1.05	1.31	0.75	2.13	0.75
6/7/00	1.60	0.90	0.90	0.98	0.68	3.39	0.58
6/15/00	2.17	1.16	1.25	1.33	0.73	3.57	0.71
6/22/00	2.00	1.17	1.20	1.26	0.68	2.44	0.68
6/29/00	3.27	1.24	1.24	1.27	0.76	3.96	
7/7/00	3.74	1.27	1.27	1.27	0.63	4.09	0.61
7/14/00	1.59	1.06		1.11	0.55	3.46	0.55
7/20/00	3.63	1.08	1.08	1.14	0.60		
7/27/00	2.63	1.37	1.40	1.42	0.66	1.75	
8/2/00	STAG	1.21	1.08	1.23	0.65	DRY	
8/11/00	2.48	1.08	1.08	1.09	0.63		
8/16/00		1.06		1.27	1.14	3.62	1.14
9/1/00	3.91	1.22	1.24	1.25	0.86	5.45	0.85
9/14/00							
9/29/00	3.16	2.54	2.81	2.96	0.93		
10/20/00	4.49	3.47	3.56	4.40	1.15		
12/1/00							
1/19/01							
3/6/01							
3/30/01	3.93	1.86	2.80	2.82	1.17	4.36	1.34
4/21/01	3.12	1.35		1.93			
5/15/01	3.65	1.36	1.45	1.55	1.02	3.18	1.04
5/30/01	2.36	1.14	1.25	1.34	0.76	2.56	0.73
6/8/01	2.02	1.07	1.22	1.35	0.68	2.12	0.70
6/14/01	2.84	1.32	1.38	1.44	0.73	2.58	0.70
6/23/01	1.99	1.11	1.16	1.23	0.63	2.34	0.63
6/29/01	2.00	0.93	1.03	1.07	0.50	2.59	0.49
7/5/01	3.40	1.00	1.17	1.21	0.56	2.86	0.55
7/12/01	3.39	1.08	1.09	1.09	0.60	STAG	0.66
7/17/01	1.75	0.82	0.88	0.94	0.62	2.27	0.60
7/25/01	2.38	1.10	1.33	1.33	0.66	2.71	0.65
8/1/01	2.24	1.02	1.04	1.04	0.66	2.80	0.65
8/10/01	2.32	1.04	1.08	1.05			
8/17/01	2.79	1.01	1.06	1.05			
9/1/01	3.69	1.20	2.08	1.86			
9/15/01	3.27	2.83	3.19	3.10			
9/29/01	2.87	2.24	2.78	2.76			
10/15/01							
10/27/01	3.94	1.79	2.44	2.00			
11/17/01							
12/18/01							

DRY = Surface water feature was dry at measurement point on given date
STAG = Water at measurement point was stagnant - reading discarded.

Date	SP 22	SP 23	SP 24	SP 25	SP 26	SP 27	SP 28
	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)
6/7/99	3.53	0.84	0.84	0.83	1.12	0.90	0.90
6/14/99							
6/21/99	1.26	0.68	0.68	0.67	1.17	0.70	0.70
6/28/99	0.81	0.64	0.64	0.63	1.05	0.63	0.64
7/5/99	1.47	0.69	0.69	0.67	1.02	0.73	0.73
7/12/99	2.62	0.70	0.70	0.70	1.65	0.90	0.96
7/19/99	3.44		0.63		2.76	1.03	
7/26/99	4.00		0.69		1.03	0.88	1.03
8/2/99	3.05		0.34		1.51	0.72	0.69
8/9/99			0.64		1.03	0.76	0.77
8/16/99	6.81		0.76		1.25	0.87	0.88
9/4/99		0.77	0.76	0.77	2.05	0.98	0.98
9/18/99	2.00		0.78		2.28	1.02	1.02
3/3/00							
4/15/00	1.68	0.71	0.70		1.24	0.72	0.68
4/29/00	3.51	1.14	1.19		1.88	1.24	1.24
5/17/00	3.17	1.03	1.01	0.99	2.03	1.07	1.05
5/30/00	STAG	0.79	0.76	0.73	1.30	0.90	0.90
6/7/00	3.04	0.68	0.78	0.67	0.95	0.78	0.77
6/15/00	3.63	0.72	0.71	0.73	1.34	0.83	0.83
6/22/00	4.78	0.68	0.68	0.68	1.26	0.86	0.86
6/29/00	5.26	0.73			1.26	0.86	0.87
7/7/00	5.48	0.61	0.61	0.63	1.27	0.80	0.78
7/14/00	DRY	0.54	0.55	0.55	1.10	0.72	0.66
7/20/00	5.39	0.57				0.67	
7/27/00	STAG	0.68				0.89	
8/2/00	DRY	0.66				0.71	
8/11/00	DRY	0.62				0.77	
8/16/00	DRY		1.15	STAG	1.27	0.80	0.84
9/1/00	2.41	0.78	1.27		1.34	0.95	0.95
9/14/00							
9/29/00	STAG	0.91				1.29	
10/20/00	4.88	1.16				1.44	
12/1/00							
1/19/01							
3/6/01							
3/30/01	STAG	1.25	1.15	0.99	2.55	1.25	1.27
4/21/01	3.47	0.98				1.12	
5/15/01	4.12	1.08	0.99	0.99	1.42	1.10	1.13
5/30/01	2.67	0.75	0.75	0.76	1.35	0.84	0.85
6/8/01	2.71	0.68	0.68	0.68	1.26	0.89	0.83
6/14/01	0.85	0.69	0.69	0.69	1.34	0.77	0.80
6/23/01	2.20	0.63	0.62	0.63	1.25	0.80	0.80
6/29/01	2.01	0.49	0.49	0.50	1.08	0.61	0.61
7/5/01	0.85	0.55	0.55	0.56	1.22	0.74	0.73
7/12/01	DRY	0.68	0.66	0.60	1.07	0.74	0.72
7/17/01	2.59	0.61	0.61	0.83	0.94	0.67	0.67
7/25/01	2.65	0.65	0.65		1.27	0.81	0.81
8/1/01	0.84	0.65	0.65	0.66	1.02	0.75	0.78
8/10/01	3.45	0.60				0.70	
8/17/01	2.03	0.60				0.77	
9/1/01	2.95	0.72				0.87	
9/15/01	STAG	1.00				1.24	
9/29/01	STAG	1.10				2.59	
10/15/01							
10/27/01	5.43	1.04				1.23	
11/17/01							
12/18/01							

DRY = Surface water feature was dry at measurement point on given date
STAG = Water at measurement point was stagnant - reading discarded.

Date	SP 29	SP 30	SP 31	SP 32	SP 33	SP 34	SP 35
	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)
6/7/99	1.12	1.11	0.90	1.12	0.84	0.90	1.10
6/14/99							
6/21/99	0.59	1.11	0.72	1.06	0.67	0.72	1.05
6/28/99	2.25	1.02	0.64	1.06	0.61	0.64	1.03
7/5/99	0.77	1.01	0.76	1.05	0.79	0.73	1.06
7/12/99		1.67	0.92	1.63	0.72	0.92	1.43
7/19/99		2.71	0.99	2.76		1.01	2.72
7/26/99	1.00	1.10		1.12	0.78	1.03	1.05
8/2/99	0.72	1.32		1.10	0.65	0.84	1.10
8/9/99	0.66	1.06		1.05	0.64	0.77	1.05
8/16/99	2.33	1.23		1.28	0.75	0.88	1.27
9/4/99	2.07	1.54	0.98	1.34	0.76	1.00	1.42
9/18/99	3.27	2.45		2.66	0.79	1.02	1.74
3/3/00							
4/15/00		0.99	0.64	1.25	0.53	0.53	0.74
4/29/00		1.87	1.24	1.76	1.22	1.24	1.75
5/17/00		2.35	1.04	1.57	0.99	1.03	1.77
5/30/00	0.73	1.29	0.90	1.30	0.74	0.90	1.27
6/7/00	1.46	0.98	0.77	1.01	0.70	0.76	0.97
6/15/00		1.37	0.85	1.42	0.73	0.84	1.43
6/22/00	DRY	1.27	0.84	1.44	0.67	0.85	1.47
6/29/00	1.96	1.23	0.86	1.23	0.76	0.87	1.17
7/7/00		1.27	0.85	1.31	0.62	0.85	1.35
7/14/00	0.71	1.02	0.66	1.04	0.51	0.66	1.06
7/20/00	DRY	1.15			0.64	0.67	1.15
7/27/00	2.10	1.27			0.64	0.89	1.46
8/2/00	0.66	1.28			0.65	0.86	0.76
8/11/00	0.64	1.08			0.62	0.77	1.11
8/16/00	1.54	1.58			1.15	0.61	1.24
9/1/00	DRY	1.23	0.44	1.27	0.83	1.06	1.20
9/14/00							
9/29/00	DRY				0.92	1.18	2.60
10/20/00	DRY	4.26			1.40	1.41	2.05
12/1/00							
1/19/01							
3/6/01							
3/30/01	2.52	3.20	1.27	3.32	1.19	1.17	2.97
4/21/01	DRY	1.98			1.01	1.13	2.02
5/15/01	1.02	1.43	1.09	1.44	0.99	1.13	1.38
5/30/01	0.74	1.32	0.86	1.27	0.73	0.86	1.31
6/8/01	0.85	1.21	0.87	1.23	0.70	0.90	1.21
6/14/01	STAG	1.27	1.33		0.71	0.80	1.37
6/23/01	1.36	1.26	0.81	1.29	0.64	1.11	0.75
6/29/01	0.56	1.10	0.61	1.10	0.51	0.62	1.14
7/5/01	STAG	1.19	0.73	1.21	0.55	0.73	1.21
7/12/01	1.07	1.03	0.71	1.03	0.60	0.71	0.99
7/17/01	DRY	0.95	0.68	1.04	0.64	0.68	1.05
7/25/01	STAG	1.26	0.81	1.28	0.65	0.81	1.29
8/1/01	1.98	1.02	0.78	1.03	0.65	0.78	1.02
8/10/01	0.70	1.10			0.61	1.08	0.70
8/17/01	0.79	1.05			0.60	0.78	1.03
9/1/01	0.87	1.31			0.72	0.87	1.17
9/15/01	1.22	1.05			0.98	1.20	1.10
9/29/01	1.56	1.35			1.05	1.49	1.06
10/15/01							
10/27/01	1.23	2.02			1.02	1.22	2.81
11/17/01							
12/18/01							

DRY = Surface water feature was dry at measurement point on given date
STAG = Water at measurement point was stagnant - reading discarded.

Date	SP 36	SP 37	SP 38	SP 39	SP 40	SP 41	SP 42
	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)
6/7/99	0.85	0.87	1.51	1.20	1.22	0.94	3.15
6/14/99							
6/21/99	0.68	0.68	3.02	2.27	1.12	0.76	2.32
6/28/99	0.63	0.63	4.27	1.07	1.06	0.67	1.88
7/5/99	0.80	0.61	1.90	1.14	1.11	0.78	1.91
7/12/99	0.69	0.73		1.26	1.26	0.94	2.04
7/19/99			4.42		3.15	1.05	3.00
7/26/99	0.79	0.79	4.23	1.15	1.31		3.51
8/2/99	0.66	0.37	1.63	0.81	0.80		0.94
8/9/99	0.65	0.66	1.85	4.22	1.21	0.80	3.52
8/16/99	0.76	0.77	1.92	1.32	1.27		1.93
9/4/99	0.76	0.77	2.69	1.49	1.56	1.01	2.90
9/18/99	0.78	0.79		1.39	1.46		1.06
3/3/00							
4/15/00	0.62	0.88		4.84	1.44	0.92	1.58
4/29/00	1.24	1.35	STAG	1.92	2.37	1.27	3.79
5/17/00	1.01	1.03		1.76	1.73	1.09	1.54
5/30/00	0.74	0.75	1.12	1.33	1.30	0.93	2.11
6/7/00	0.69	0.70	2.08	4.59	1.07	0.80	3.35
6/15/00	0.74	0.76	2.29	1.41	1.46	0.88	3.42
6/22/00	0.68	0.71	1.36	1.37	1.35	0.88	2.39
6/29/00	0.76	0.71	2.60		1.32	0.87	3.14
7/7/00	0.67	0.76	1.50	1.45	1.41	0.75	2.88
7/14/00	0.53	0.62	3.57	1.07	1.08	0.70	2.87
7/20/00			1.28	1.31		0.70	2.73
7/27/00				1.35		0.73	2.88
8/2/00				1.42		0.53	2.50
8/11/00				1.05		0.78	2.30
8/16/00	0.64	0.58		0.96	0.96	0.88	3.80
9/1/00	0.47	0.59		1.26	1.23	0.58	2.95
9/14/00							
9/29/00				1.97		1.89	3.64
10/20/00				2.05		1.42	3.58
12/1/00							
1/19/01							
3/6/01							
3/30/01	1.09	1.10	4.75	1.80	1.90	1.18	3.55
4/21/01			4.92	2.06		1.14	2.82
5/15/01	0.99	1.02	1.25	1.64	25.40	1.08	2.43
5/30/01	0.75	0.76	1.77	1.43	1.40	0.95	1.10
6/8/01	0.70	0.71	4.02	1.13	1.19	0.92	1.26
6/14/01	0.70	0.68	1.84	1.34	1.32	0.80	3.50
6/23/01			1.20	1.26		0.79	2.41
6/29/01	0.52	0.56	4.55	1.42	1.39	0.69	1.97
7/5/01	0.56	0.57	4.45	1.30	1.24	0.76	2.95
7/12/01	0.59	0.58	2.45	1.13	1.10	0.76	2.05
7/17/01	0.68	0.74	3.98		1.10	0.71	2.02
7/25/01	0.64	0.63	2.46	1.21	1.23	0.80	3.16
8/1/01	0.66	1.14	0.67	1.09	1.09	1.04	1.55
8/10/01			1.14	1.04		0.73	2.32
8/17/01			1.72	1.11		0.77	3.35
9/1/01			2.83	1.42		0.90	2.15
9/15/01			4.60			1.23	1.77
9/29/01			1.49	1.36		1.76	3.20
10/15/01							
10/27/01			3.20	1.59		1.25	3.69
11/17/01							
12/18/01							

DRY = Surface water feature was dry at measurement point on given date

STAG = Water at measurement point was stagnant - reading discarded.

Date	SP 43	SP 44	SP 45	SP 46	SP 47	SP 48	SP 49
	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)
6/7/99	1.20	1.16	0.92	0.86	1.11	0.91	
6/14/99							
6/21/99	1.12	1.14	0.73	0.70	1.04	0.72	
6/28/99	1.08	1.02	0.67	0.62	1.01	0.64	
7/5/99	1.15	1.04	0.77	0.62	1.07	0.75	
7/12/99	1.25	1.23	0.93	0.72	1.22	0.92	1.39
7/19/99	3.08	2.92	1.01		2.93	1.00	
7/26/99	1.37		0.98		1.51		1.13
8/2/99	1.07	0.78	0.99		1.81		0.95
8/9/99	1.22	1.13			1.07		
8/16/99	1.30	1.25	0.90		1.28		1.31
9/4/99	1.50	1.32	1.27		1.27	0.99	1.43
9/18/99	1.36	1.35	1.04		1.74		1.87
3/3/00							
4/15/00	1.46	1.37	0.87	0.87	1.35		1.37
4/29/00	2.25	2.07	1.31	1.33	2.19	1.25	2.14
5/17/00	1.78	1.49	1.09	1.05	1.62	1.10	1.86
5/30/00	1.36	1.26	0.90	0.75	1.27	0.90	1.29
6/7/00	1.09	1.01	0.78	0.69	1.01	0.77	1.00
6/15/00	1.35	1.41	0.81	0.76	1.37	0.85	1.33
6/22/00	1.39	1.27	0.86	0.71	1.31	0.85	1.33
6/29/00	1.35	1.27	0.86	0.73	1.29	0.87	
7/7/00	1.40	1.42	0.84	0.68	1.39	0.84	1.17
7/14/00	1.05	1.04	0.69	0.55	1.06	0.67	1.04
7/20/00		1.32		0.61	1.11	0.67	
7/27/00		1.21		0.59	1.41	0.92	
8/2/00		1.40		0.61	1.27	0.85	
8/11/00		1.09		0.64	1.11	0.77	
8/16/00	1.32	1.17	0.84	0.61	1.48	0.73	1.50
9/1/00	1.06	1.21	1.10	1.17	0.84	0.85	
9/14/00							
9/29/00		1.43		1.19	1.76	1.52	
10/20/00		1.72		1.18	1.81	1.38	
12/1/00							
1/19/01							
3/6/01							
3/30/01	1.82	1.85	1.16	1.10	2.12	1.17	1.98
4/21/01		1.93		0.97	1.88	1.12	
5/15/01	1.69	1.61	1.15	1.64	1.75	1.11	1.65
5/30/01	1.35	1.33	0.91	0.77	1.36	0.91	1.37
6/8/01	1.25	0.69	0.86	1.13	1.16	0.87	1.14
6/14/01	1.20	1.19	0.81	0.70	1.34	0.80	1.43
6/23/01	1.29	1.17		0.66	1.14	0.74	
6/29/01	1.34	1.23	0.66	0.56	1.15	0.63	1.26
7/5/01		1.09	0.73	0.57	1.10	0.73	1.16
7/12/01	1.06	1.10	0.75	0.58	1.03	0.72	1.11
7/17/01	1.10	1.12	0.70	0.71	1.09	0.68	1.08
7/25/01	1.20	1.20	0.79	0.63	1.28	0.80	1.30
8/1/01	1.11	1.04	0.76	0.67	0.99	0.77	1.14
8/10/01		1.03		0.61	1.08	0.70	
8/17/01		1.13	0.76	0.60	1.08	0.77	
9/1/01		1.29		0.74	1.23	0.86	
9/15/01		1.67		0.98	1.57	1.18	
9/29/01		STAG		1.02	3.87	1.42	
10/15/01							
10/27/01		1.28		1.04	1.61	1.22	
11/17/01							
12/18/01							

DRY = Surface water feature was dry at measurement point on given date
STAG = Water at measurement point was stagnant - reading discarded.

Date	SP 50	SP 51	SP 52	SP 53	SP 54	SP 55	SP 56
	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)
6/7/99	1.00	2.17	0.92	0.92	2.31	0.95	1.29
6/14/99							
6/21/99	0.82	1.70	0.72	0.72	2.23	0.75	1.00
6/28/99	0.79	0.93	0.67	0.67	2.10	0.70	1.12
7/5/99	0.89	1.73	0.75	0.76	1.97	0.77	1.30
7/12/99	1.05	2.27	0.93	0.90	2.05	0.92	1.20
7/19/99	1.89	3.41	0.91	0.87	2.73	0.91	0.92
7/26/99	1.13	2.11	1.05	1.05	2.89	1.00	1.06
8/2/99	1.42	4.17	1.12		0.82	1.03	1.27
8/9/99	0.87	1.52	0.78	0.77	2.31	0.82	1.25
8/16/99	0.93	1.98	0.89		2.17	0.92	0.95
9/4/99	1.15		0.99	0.99	2.41	1.02	
9/18/99	0.91	2.56	0.90		1.09	0.92	1.16
3/3/00							
4/15/00	STAG		0.87	0.87	1.33	0.95	
4/29/00	1.34		1.24	1.24	2.29	1.27	
5/17/00	1.12	1.96	1.11	1.13	1.39	1.09	1.74
5/30/00	1.03	2..1	0.90	0.90	2.12	0.94	1.02
6/7/00	0.88		0.79	0.78	2.35	0.80	
6/15/00	0.97	1.02	0.82	0.81	2.73	0.86	0.87
6/22/00	1.01	2.30	0.86	0.85	2.57	0.87	0.87
6/29/00	0.99		0.88	0.88	2.61	0.90	
7/7/00	1.00	1.64	0.86	0.87	2.44	0.84	0.83
7/14/00	0.85	1.16	0.67	0.67	2.05	0.72	1.05
7/20/00	0.79	1.55		0.67	1.38	0.70	
7/27/00	0.96	1.42		0.64	2.06	0.97	
8/2/00	1.10	2.19		0.74	2.28	0.67	
8/11/00	0.93	1.39		0.74	1.93	0.78	
8/16/00	0.95	1.36	0.81	0.82	2.39	0.85	STAG
9/1/00	1.18	1.60	0.67	1.11	2.55	1.18	1.07
9/14/00							
9/29/00	1.53	4.49		1.60	2.79	DRY	
10/20/00	1.66	2.81		1.38	2.54	1.31	
12/1/00							
1/19/01							
3/6/01							
3/30/01	1.28	2.38	1.17	1.16	2.80	1.18	DRY
4/21/01				1.41	2.75	1.29	
5/15/01	1.28	3.23	0.92	0.96	1.76	1.20	1.32
5/30/01			0.90	0.90	1.37	0.96	1.26
6/8/01	1.04	4.12	0.87		1.49	0.87	1.22
6/14/01	1.08	1.52	0.82	0.80	2.34	0.84	1.21
6/23/01	0.87	3.05		0.76	2.22	0.78	
6/29/01	0.80	1.64	0.65	0.66	1.96	0.69	0.85
7/5/01	0.82	2.15	0.71	0.71	2.05	0.74	0.75
7/12/01	0.86	1.83	0.72	0.73	2.19	0.75	0.75
7/17/01	0.81	1.67	0.69	0.69	2.12	0.72	DRY
7/25/01	0.96	1.55	0.81	0.82	2.30	0.84	DRY
8/1/01	0.93	1.29	0.75	0.75	1.99	0.79	0.79
8/10/01	0.86	1.27		0.70	2.05	0.74	
8/17/01	0.86	1.57		0.79	2.30	0.81	
9/1/01	1.10	1.72		0.86	2.55	0.93	
9/15/01	1.37	2.79		1.19	2.04	1.23	
9/29/01	1.38	3.53		1.36	2.84	1.58	
10/15/01							
10/27/01							
11/17/01							
12/18/01							

DRY = Surface water feature was dry at measurement point on given date
STAG = Water at measurement point was stagnant - reading discarded.

Date	SP 57	SP 58	SP 59	SP 60	SP 61	SP 62	SP 63
	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)
6/7/99	1.21	1.20	0.95	1.08	1.11	1.83	0.95
6/14/99							
6/21/99	1.05	0.91	0.75	1.66	0.97	1.56	0.75
6/28/99	1.12	1.13	0.71	1.76	0.91	1.65	0.71
7/5/99	1.20	1.15	0.78	1.83	1.03	1.66	0.79
7/12/99	1.47	0.99	0.92	1.86	1.13	1.90	0.93
7/19/99	DRY	DRY	0.92	2.26	2.22	1.86	1.24
7/26/99	1.61	1.31	1.05		1.25		1.05
8/2/99	1.24	1.33	STAG	1.29	2.46	1.08	0.92
8/9/99	1.15	1.15	0.82	2.02	1.01	1.90	0.81
8/16/99	1.31	1.37	0.91	1.65	1.09	1.63	0.90
9/4/99	1.58	1.60	1.06	1.97	1.23	1.95	1.03
9/18/99	1.22	1.25	0.91	1.17	0.98	1.24	0.91
3/3/00							
4/15/00	1.51	1.50	0.99	1.43	1.11	1.53	1.00
4/29/00	2.20	2.12	1.31	2.17	1.43	2.15	1.31
5/17/00	1.70	1.81	1.10	1.72	1.20	1.76	1.08
5/30/00	1.35	1.32	0.97	2.07	1.16	2.17	0.93
6/7/00	1.10	1.12	0.83	2.31	0.99	2.06	0.81
6/15/00	1.50	1.51	0.88	2.05	1.14	2.00	0.90
6/22/00	1.39	1.45	0.86	2.10	1.10	2.17	0.87
6/29/00	1.29			1.65	1.10	1.96	0.92
7/7/00	1.44	1.40	0.76		1.12	1.79	0.80
7/14/00	1.05	1.02	0.72	1.82	0.54	2.60	0.72
7/20/00	1.32			1.26	0.93	1.51	0.71
7/27/00	1.39			2.11	1.15	2.15	
8/2/00	1.40			2.13	1.16	2.13	0.72
8/11/00	1.04	0.98	0.90	1.85	0.99	1.79	0.84
8/16/00	1.31	1.25	0.85	1.52	1.04	1.68	0.81
9/1/00	1.21	1.19	0.89	1.95	1.23	1.75	0.95
9/14/00							
9/29/00	DRY			2.48	1.60	1.58	DRY
10/20/00	2.15			2.22	1.59	1.31	1.32
12/1/00							
1/19/01							
3/6/01							
3/30/01	1.67	1.96	1.17	1.86	1.39	1.15	1.18
4/21/01	2.06				1.17	1.99	1.16
5/15/01	1.64	1.68	1.18	1.80	1.40	1.92	
5/30/01	1.46	1.40	0.94	0.96		1.62	0.96
6/8/01	1.25	1.31	0.85	1.51	1.08	1.58	0.86
6/14/01	1.42	1.03	0.85	1.89	1.19	1.70	0.79
6/23/01	1.22			1.56	0.97	1.71	0.78
6/29/01	1.45	1.36	0.68	1.63	0.87	1.86	0.68
7/5/01	1.31	1.31	0.75	1.96	0.95		0.74
7/12/01	1.08	1.05	0.75	1.36	0.96	1.90	0.72
7/17/01	1.13	1.17	0.72	1.74	0.89		0.72
7/25/01	1.23	1.27	0.88	1.93	1.03	1.79	0.89
8/1/01	1.10	1.10	0.80	1.75	0.99	1.60	0.83
8/10/01	1.05			1.89	0.90	1.72	0.76
8/17/01	1.07			1.79	0.93	1.73	0.80
9/1/01	1.42			1.89	1.15	1.87	0.93
9/15/01	1.28			2.15	1.42	1.98	
9/29/01	1.49			2.07	1.42	2.26	
10/15/01						1.79	
10/27/01	2.00			1.98	1.32	2.06	1.29
11/17/01						2.20	
12/18/01							

DRY = Surface water feature was dry at measurement point on given date
STAG = Water at measurement point was stagnant - reading discarded.

Date	SP 64	SP 65	SP 66	SP 67	SP 68	SP 69	SP 70
	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)
6/7/99	0.95	1.12	1.49	1.23	1.24	DRY	1.22
6/14/99			1.49				
6/21/99	0.77	1.01	1.49	1.11	1.11	DRY	1.08
6/28/99	0.71	0.90	1.49	1.09	1.05	1.02	1.10
7/5/99	0.80	0.90	1.49	1.02	0.98	STAG	1.17
7/12/99	0.96	1.44	1.49	DRY	STAG	DRY	DRY
7/19/99	1.15	1.41	1.49	DRY	STAG	DRY	DRY
7/26/99	1.03	1.24	1.49	STAG	STAG	STAG	2.80
8/2/99	1.30	1.88	1.49	1.35	1.40	1.42	1.37
8/9/99	1.29	1.39	1.49	1.14	1.15	1.18	1.18
8/16/99	0.90	1.01	1.49	1.26	1.22	1.23	1.27
9/4/99	1.04	1.34	1.49	1.32	1.78	3.06	1.35
9/18/99	0.90	0.95	1.49	1.32	1.27	1.25	1.45
3/3/00							
4/15/00	1.02	1.22	1.86	1.54	1.57	STAG	1.53
4/29/00	1.30	1.53	STAG	STAG	STAG	STAG	STAG
5/17/00	1.09	1.13	2.95	STAG	STAG	STAG	1.94
5/30/00	0.93	1.03	1.95	1.42	1.45	STAG	1.34
6/7/00	0.84	1.18	1.74	1.23	1.19		1.15
6/15/00	0.87	1.10	2.00	1.47	1.43	DRY	1.38
6/22/00	0.90	1.08	1.31	1.39	1.13	DRY	1.40
6/29/00	0.93	1.13	2.98	1.34	1.26	2.60	1.37
7/7/00	0.97	1.31	3.13				1.29
7/14/00	0.83	0.99	2.27	0.93	0.94	DRY	1.06
7/20/00	0.72	0.91	2.88	DRY	DRY	DRY	DRY
7/27/00	1.07	1.22	1.89				1.50
8/2/00	0.76	0.98	2.94				1.04
8/11/00	0.83	0.90	2.32	1.22	1.04	DRY	1.19
8/16/00	0.97	1.08	2.32	STAG	DRY	STAG	STAG
9/1/00	0.69	0.78	DRY	1.10	DRY	2.08	1.09
9/14/00							
9/29/00	DRY	2.99	3.19				DRY
10/20/00	1.34	2.30	DRY				DRY
12/1/00							
1/19/01							
3/6/01							
3/30/01	1.18	1.51	1.72	1.89	DRY	DRY	1.65
4/21/01	1.37	1.52					
5/15/01	1.07	1.14	2.67	1.62	1.62	DRY	1.54
5/30/01	0.97	1.16	2.25	1.42	STAG	DRY	1.35
6/8/01	0.87	1.40	1.83	1.19	1.13	DRY	1.21
6/14/01	1.01	2.09	1.85	1.09	1.10	DRY	1.17
6/23/01	0.81	1.14	1.45				1.16
6/29/01	0.77	1.72	STAG	1.25	STAG	DRY	1.33
7/5/01	0.77	1.16	2.95	1.25	STAG	DRY	1.17
7/12/01	1.00	0.94	1.84	DRY	STAG	DRY	1.12
7/17/01	0.73	0.88	2.11	1.23	1.35	DRY	1.23
7/25/01	0.86	1.01	2.84	0.46	0.40	DRY	0.49
8/1/01	0.83	0.90	1.59	1.11	1.08	DRY	1.11
8/10/01	0.77	1.11	1.36				1.09
8/17/01	0.82	1.01	3.35				1.12
9/1/01	0.95	1.38	3.17				DRY
9/15/01	1.57	1.35	2.82				2.38
9/29/01	DRY	2.48	3.36				1.71
10/15/01	1.21	1.78	3.74				1.72
10/27/01	1.24	1.42	3.27				DRY
11/17/01	DRY	1.56	2.70				1.15
12/18/01							

DRY = Surface water feature was dry at measurement point on given date
STAG = Water at measurement point was stagnant - reading discarded.

Date	SP 71	SP 72	SP 73	SP 74	SP 75	SP 76	SP 77
	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)
6/7/99	1.41	DRY	1.67	1.55	1.77	5.08	DRY
6/14/99					1.77		
6/21/99	1.43	DRY	1.61	1.81	1.77	4.46	DRY
6/28/99	1.19	DRY	1.47	1.47	1.77	4.90	DRY
7/5/99	1.41	DRY	1.64	1.61	1.77	4.86	DRY
7/12/99	2.23	DRY	2.21	1.76	1.77	4.93	DRY
7/19/99	1.99	DRY	2.13	2.96	1.77	4.49	DRY
7/26/99					1.77	5.42	
8/2/99	1.19	DRY	1.31	1.64	1.77	4.31	DRY
8/9/99	2.45	DRY	2.15	1.89	1.77	3.67	DRY
8/16/99	1.19	DRY	1.54	1.47	1.77	4.95	DRY
9/4/99	1.77	DRY	2.01	1.92	1.77	5.13	DRY
9/18/99	1.14	DRY	1.34	1.32	1.77	2.95	DRY
3/3/00							
4/15/00	1.43		1.69	1.80			
4/29/00	1.35	STAG	1.31	1.21	STAG	STAG	STAG
5/17/00	1.25	STAG	2.15	1.42	3.38	5.09	STAG
5/30/00	1.48	DRY	1.77	1.70	1.85	4.53	DRY
6/7/00	1.88	DRY	1.81	1.83	2.40	4.62	DRY
6/15/00	1.47	DRY	1.53	0.90	1.50	5.81	DRY
6/22/00	DRY		1.79	1.83	4.25	DRY	
6/29/00	0.59	DRY	1.56	1.52	4.98	DRY	DRY
7/7/00	1.54		1.71	1.71	2.38	4.23	
7/14/00	1.43	DRY	1.42	1.80	4.13	6.33	DRY
7/20/00	1.14	DRY		1.35	3.12	4.45	DRY
7/27/00	1.75	DRY		1.60	2.15	4.53	DRY
8/2/00	1.74	DRY		1.53	3.67	5.00	DRY
8/11/00	1.49	DRY	1.72	1.47	3.03	4.25	DRY
8/16/00	1.76	DRY	1.60	1.74	2.37	4.76	DRY
9/1/00	1.14	DRY	1.24	1.31	2.38	2.42	DRY
9/14/00							
9/29/00	3.04	DRY	2.93	2.92	3.29	3.58	DRY
10/20/00	2.51	DRY	2.46	3.11	3.41	3.62	DRY
12/1/00							
1/19/01							
3/6/01							
3/30/01	1.84	1.60	1.76		3.24	5.29	DRY
4/21/01	1.67	1.93		2.12	4.09	4.74	DRY
5/15/01	1.33	STAG	1.50	1.60	3.12	5.00	DRY
5/30/01	1.10	1.26	1.48	1.42	2.71	3.66	DRY
6/8/01	1.85	1.71	2.07	1.88	2.66	4.64	DRY
6/14/01	2.42	DRY	2.26	1.90	2.50	5.22	DRY
6/23/01	1.43	1.35		1.78	2.81	4.61	DRY
6/29/01	1.42	1.41	2.10	2.02	2.61	4.82	DRY
7/5/01	1.60	DRY	1.62	DRY	4.44	2.75	
7/12/01	1.21	STAG	1.33	1.06	2.81	2.10	DRY
7/17/01	1.24	1.15	1.35	1.57	2.87	2.10	
7/25/01	1.20	STAG	1.29	1.26	2.29	3.06	DRY
8/1/01	1.07	DRY	1.12	2.06	2.99	4.33	DRY
8/10/01	1.59	DRY		1.42	1.93	3.26	DRY
8/17/01	1.45	DRY		1.50	3.22	5.08	DRY
9/1/01	0.94	1.69		1.66	3.20	4.66	DRY
9/15/01	2.47	DRY		1.86	3.19	5.12	DRY
9/29/01	2.82	DRY		3.06	3.76	3.94	DRY
10/15/01	2.69	1.18		2.01	3.47	3.79	DRY
10/27/01	1.72	STAG		1.76	3.83	3.85	DRY
11/17/01	2.20	2.09		2.80	3.15	3.50	DRY
12/18/01							

DRY = Surface water feature was dry at measurement point on given date
STAG = Water at measurement point was stagnant - reading discarded.

Date	SP 78	SP 79	SP 80	SP 81	SP 82	SP 83	SP 84
	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)
6/7/99	0.96	0.93	0.87				
6/14/99				14.44	13.02	15.01	2.37
6/21/99	STAG	0.79	0.73	15.75	14.57	14.70	1.46
6/28/99	0.74	0.77	0.73	13.54	14.41	15.59	3.80
7/5/99	0.85	0.86	0.80	13.51	14.07	14.61	STAG
7/12/99	0.93	0.99	0.92	14.43	14.30	13.15	3.72
7/19/99	DRY	DRY	0.79	15.80	14.94	14.64	STAG
7/26/99		1.06	1.02	15.04	12.08	15.92	STAG
8/2/99	1.81	0.82	0.76	9.88	11.88	14.75	STAG
8/9/99		0.73	0.68	14.77	12.90	13.30	3.23
8/16/99			0.95	15.20	14.34	14.43	
9/4/99	1.20	1.24	1.24	11.43	10.37	11.21	STAG
9/18/99	1.21	1.00	1.00	13.27	14.05	14.18	3.45
3/3/00							
4/15/00	0.86	0.81	0.77	13.60	10.05	13.65	STAG
4/29/00	1.34	1.34	1.28	14.10	13.50	14.41	STAG
5/17/00	1.10	1.08	1.08	14.75	13.25	14.69	4.30
5/30/00	0.99	1.00	0.98	14.50	12.68	12.88	STAG
6/7/00	0.78	0.81	0.80	13.71	13.75	13.72	1.78
6/15/00				14.70	14.33	13.26	3.64
6/22/00	0.98	0.96	0.95	14.60	13.92	13.71	STAG
6/29/00	0.90	0.90	0.88	13.70	13.04	13.68	1.02
7/7/00	0.97	0.96	0.84	14.52	14.46	14.31	4.88
7/14/00		1.33	1.20	14.10	14.20	13.38	1.26
7/20/00		0.38		12.77	12.45	13.28	STAG
7/27/00		1.00		12.93	10.51	12.07	STAG
8/2/00		1.10	1.03	15.52	14.68	13.83	STAG
8/11/00		0.91		15.92	10.90	15.74	STAG
8/16/00	0.97			14.52	11.04	13.05	STAG
9/1/00	1.10	1.01	1.00	12.18	11.22	13.71	STAG
9/14/00							
9/29/00		1.44		13.32	12.81	13.52	STAG
10/20/00		1.34		9.05	9.07	9.14	DRY
12/1/00							
1/19/01							
3/6/01							
3/30/01		1.27		13.30	13.30	13.10	DRY
4/21/01				12.52		14.34	DRY
5/15/01	1.21	1.13	1.19	16.11	14.01	16.15	2.38
5/30/01	0.96	0.93	0.87	12.82	11.68	16.50	STAG
6/8/01	1.03	1.03	0.94	15.52	9.35	15.95	STAG
6/14/01	0.73		0.84	13.76	14.18	15.33	STAG
6/23/01		0.86		15.87	15.20	15.86	STAG
6/29/01	0.79		0.68	15.61	14.45	15.45	STAG
7/5/01	0.84			15.65	12.51	15.46	STAG
7/12/01	0.85	0.88	0.86	15.82		15.63	STAG
7/17/01	0.77	0.79	0.77	15.39	14.69	15.50	STAG
7/25/01	0.76	0.94	0.92	15.37	14.96	15.36	STAG
8/1/01	0.93	0.93	0.92	15.39	12.90	15.44	STAG
8/10/01							
8/17/01		0.89		15.68	14.91	15.81	3.95
9/1/01		1.00		16.05	15.91	16.01	STAG
9/15/01		1.30		16.20	15.77	16.23	DRY
9/29/01		1.40		16.33	15.60	16.32	DRY
10/15/01							
10/27/01		1.26		17.00	16.60	17.13	DRY
11/17/01		1.06		16.92	16.80	17.02	DRY
12/18/01							

DRY = Surface water feature was dry at measurement point on given date

STAG = Water at measurement point was stagnant - reading discarded.

Date	SP 85	SP 86	SP 87	SP 88	SP 89	SP 90	SP 91
	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)
6/7/99							
6/14/99	0.73	N/A	0.73	1.47	DRY	0.73	2.34
6/21/99	0.68	N/A	0.68	1.58	DRY	0.65	2.43
6/28/99	0.61	N/A	0.61	1.10	DRY	0.61	2.45
7/5/99	0.72	2.31	0.72	1.41	DRY	0.72	2.40
7/12/99	0.85	0.88	2.18	2.03	DRY	0.85	2.25
7/19/99	STAG	1.64	DRY	3.44	DRY	DRY	1.62
7/26/99	DRY	DRY	STAG	2.48	DRY	DRY	STAG
8/2/99	0.78	STAG	0.75	1.18	DRY	0.78	STAG
8/9/99	0.67	2.37	0.71	2.40	DRY	0.82	2.46
8/16/99	0.71	STAG	0.71	4.55	DRY	1.02	STAG
9/4/99	0.93	2.31	1.02	1.39	STAG	0.93	2.35
9/18/99	DRY				3.60		1.72
3/3/00							
4/15/00		1.10	0.86	3.94	2.08	0.90	0.99
4/29/00	DRY	DRY	DRY	4.75	2.30	DRY	DRY
5/17/00	0.99	2.28	1.00	1.59	2.57	1.00	2.38
5/30/00	0.86	2.23	0.88	1.52	2.06	0.87	2.35
6/7/00	0.67	0.68	0.70	2.30	2.34	0.70	2.46
6/15/00	0.83	2.45	DRY	4.19	2.57	DRY	2.56
6/22/00	DRY	1.93	0.71	3.77	1.67	0.69	2.12
6/29/00	0.71	2.03	DRY	3.26	1.39	0.78	2.16
7/7/00		2.73		4.61			2.10
7/14/00	DRY	2.33	DRY	3.34	2.35	1.25	2.31
7/20/00	0.62		0.63	3.02	2.41	0.70	
7/27/00	STAG		0.92		1.60	0.95	
8/2/00	1.51		1.48		2.35	1.41	
8/11/00	DRY		DRY		2.75	DRY	
8/16/00	0.55	2.35	0.66		DRY	0.83	2.68
9/1/00	STAG	STAG	STAG		2.34	STAG	STAG
9/14/00							
9/29/00	DRY		DRY		DRY	STAG	
10/20/00	DRY		DRY		DRY	DRY	
12/1/00							
1/19/01							
3/6/01							
3/30/01	DRY		DRY	DRY	DRY	DRY	
4/21/01	1.22		1.34	3.70	DRY	1.28	
5/15/01	1.39	2.28	1.41	5.59	2.20	2.26	1.39
5/30/01	0.77	2.72	0.78	1.34	2.33	0.64	2.40
6/8/01	0.80	2.31	0.81	0.91	2.32	0.62	2.34
6/14/01	1.07		1.06	1.53	2.01	1.07	2.06
6/23/01	DRY		DRY	3.29	2.46	DRY	
6/29/01	DRY	2.24	DRY	3.89	2.40	DRY	2.33
7/5/01	DRY	2.34	0.67	3.93	DRY	0.67	2.45
7/12/01	DRY	2.26	1.25	3.19	2.51	1.25	2.23
7/17/01	1.21	2.00	1.19	3.97	2.09	1.17	2.10
7/25/01	DRY	STAG	DRY	3.26	1.90	DRY	STAG
8/1/01	0.78	STAG	0.78	3.75	2.10	0.78	STAG
8/10/01							
8/17/01	DRY		DRY	2.91	2.12	DRY	
9/1/01	DRY		DRY	3.71	DRY	DRY	
9/15/01	DRY		DRY	3.78	DRY	DRY	
9/29/01	DRY		DRY	3.93	DRY	DRY	
10/15/01							
10/27/01	DRY		DRY	4.27	DRY	DRY	
11/17/01	DRY		DRY	4.25	DRY	DRY	
12/18/01							

DRY = Surface water feature was dry at measurement point on given date
STAG = Water at measurement point was stagnant - reading discarded.

Date	SP 92	SP 93	SP 94	SP 95	SP 96	SP 98	SP 99
	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)
6/7/99							
6/14/99	4.58	0.81	0.81	0.86	0.82	3.39	4.19
6/21/99	4.94	0.68	0.82	0.82	0.82	0.68	4.04
6/28/99	4.70	0.62	0.75	0.85	0.76	3.49	1.80
7/5/99	4.48		1.03	1.71	1.03	0.73	1.89
7/12/99	4.14	0.93	1.26	0.75	1.26	0.83	2.25
7/19/99	4.21		0.83	1.13	0.83	3.36	STAG
7/26/99	4.68	STAG	1.27	1.90	1.28	1.81	DRY
8/2/99	4.58	0.88			0.74	0.88	STAG
8/9/99	4.86	0.97	-	0.93	0.87	0.98	5.47
8/16/99	4.88	0.84		1.41	1.146	0.91	3.04
9/4/99	4.04	1.05		1.68		1.06	1.86
9/18/99	3.62	DRY		1.72	1.3	DRY	4.92
3/3/00				1.50			
4/15/00	4.82	1.24		2.07	0.93	1.10	3.82
4/29/00	6.31	2.15	1.58	1.51	1.58	DRY	DRY
5/17/00	6.48	1.48	1.41	1.83	1.4	1.50	2.44
5/30/00	5.23	0.86	1.41	1.95	1.41	0.85	3.26
6/7/00	4.94	1.24	0.89	0.99	0.87	1.26	2.67
6/15/00	5.30	1.57	1.11	1.42	1.09	1.73	3.92
6/22/00	5.12	1.68	1.28	1.82	1.28	STAG	3.06
6/29/00	5.23	1.35	1.35	1.68	1.346	1.38	2.98
7/7/00	5.77		0.94	1.85	0.96		4.14
7/14/00	5.70	1.39	1.57	2.42	1.63	1.16	3.44
7/20/00		0.84	0.81	1.28		0.74	
7/27/00		STAG	1.49	2.05		1.60	
8/2/00		STAG	1.61	1.99		1.69	
8/11/00		DRY	1.54	1.76	1.61	DRY	
8/16/00	7.01	0.70	1.28	1.93	1.28	0.79	STAG
9/1/00	6.12		1.36	1.30	0.97	STAG	STAG
9/14/00				3.42			
9/29/00		DRY	1.70	1.93		DRY	
10/20/00		DRY	1.87	2.10		DRY	
12/1/00				2.16			
1/19/01				2.62			
3/6/01				2.38			
3/30/01		DRY	1.49			DRY	
4/21/01	11.20	STAG	1.63	2.07		1.52	
5/15/01	10.03	1.39	1.44	1.74	1.43	1.41	7.75
5/30/01	7.15	7.05	0.60	1.01	0.58	0.75	7.79
6/8/01	5.16	0.86	0.93	1.10	0.74	0.77	3.93
6/14/01	6.17	0.75	1.17	1.35	1.16	1.19	5.53
6/23/01			0.94	1.45		1.80	
6/29/01	5.67	DRY	0.78	0.92	0.93	DRY	5.33
7/5/01	6.26	DRY		1.29		0.67	4.45
7/12/01	7.36	1.42	1.51	1.98	1.15	1.39	3.09
7/17/01	7.51	DRY	0.78	1.08	0.78		3.05
7/25/01	7.19	DRY	1.17	1.34	1.30	DRY	3.20
8/1/01	6.70	1.13	1.24	2.14	1.24	1.11	2.92
8/10/01							
8/17/01			1.09	1.23		1.21	
9/1/01			1.58	1.67		DRY	
9/15/01			1.84	2.08		DRY	
9/29/01			1.58	1.60		DRY	
10/15/01			1.62	1.81			
10/27/01			1.64	1.72		DRY	
11/17/01			1.69	1.82		DRY	
12/18/01				1.30			

DRY = Surface water feature was dry at measurement point on given date
STAG = Water at measurement point was stagnant - reading discarded.

Date	SP 100	SP 101	SP 102	SP 103	SP 104	SP 105	SP 106
	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)
6/7/99							
6/14/99		2.22	0.74	2.39		1.74	6.69
6/21/99	0.67	2.45	0.66	2.52	2.69	1.77	6.46
6/28/99	0.60	1.90	0.60	2.53	DRY	2.88	3.52
7/5/99	0.73	2.22	0.72	2.42	3.50	3.50	6.02
7/12/99	0.84	2.36	0.85	2.38	0.83	3.86	5.60
7/19/99	DRY	1.34	DRY	DRY	DRY	DRY	4.80
7/26/99	STAG	STAG	DRY	STAG	DRY	DRY	5.37
8/2/99	0.78	DRY	0.69	STAG	0.97	1.68	5.19
8/9/99	0.81	2.65	0.75	2.43	DRY	DRY	5.54
8/16/99	0.94	2.12	0.88	STAG	DRY	2.18	5.81
9/4/99	0.93	ST			STAG	1.96	5.47
9/18/99	DRY	2.59	DRY	2.54	STAG	5.58	
3/3/00							
4/15/00	0.90	0.69	0.95	0.98	to DRY	3.19	4.67
4/29/00	DRY	DRY	DRY	DRY	DRY	DRY	DRY
5/17/00	1.00	2.14	1.00	2.46	DRY	1.79	5.26
5/30/00	0.85	2.52	0.86	2.65	9.47	5.94	6.38
6/7/00	0.70	2.46	0.71	2.47	DRY	DRY	5.75
6/15/00	0.73	2.60	DRY	2.57	DRY	4.02	7.06
6/22/00	0.71	2.15	0.70	2.14	DRY	DRY	4.31
6/29/00	0.77	2.11	0.78	2.20	12.48	5.48	4.30
7/7/00		2.50		2.62		5.96	5.62
7/14/00	0.99	1.97	1.00	1.99	5.63	4.83	5.78
7/20/00	0.57				DRY	6.08	5.70
7/27/00	0.91				DRY	6.06	6.33
8/2/00	1.49				STAG	3.81	6.80
8/11/00	DRY				DRY	6.80	5.44
8/16/00	0.75	3.51	2.53	2.53	DRY	DRY	5.27
9/1/00	0.74	2.31			STAG	STAG	5.98
9/14/00							
9/29/00	1.12				DRY	DRY	6.13
10/20/00	DRY				DRY	DRY	DRY
12/1/00							
1/19/01							
3/6/01							
3/30/01	DRY				DRY	DRY	DRY
4/21/01	1.29				DRY	1.45	DRY
5/15/01	1.42	2.17	1.41	2.29	DRY	5.39	7.47
5/30/01	0.77	2.02	0.85	2.33	DRY	DRY	7.05
6/8/01	0.92	1.85	0.94	2.42	DRY	DRY	6.88
6/14/01	1.09	2.04	1.04	2.36	DRY	DRY	6.07
6/23/01	STAG		DRY		DRY	DRY	6.16
6/29/01	DRY	2.27	DRY	2.39	DRY	DRY	6.16
7/5/01	0.66	2.50	0.66	2.55	DRY	DRY	6.36
7/12/01	1.23	2.06	1.25	2.27	DRY	DRY	3.74
7/17/01	1.16	1.86	1.19	2.10	DRY	DRY	5.86
7/25/01	0.69	1.96	0.66	2.16	DRY	DRY	6.05
8/1/01	0.79	STAG	0.78	STAG	DRY	DRY	5.97
8/10/01							
8/17/01	DRY		DRY		DRY	DRY	2.71
9/1/01	DRY		DRY		DRY	DRY	STAG
9/15/01	DRY		DRY		DRY	DRY	STAG
9/29/01	DRY		DRY		DRY	DRY	STAG
10/15/01							
10/27/01	DRY		DRY		DRY	DRY	STAG
11/17/01	DRY		DRY		DRY	DRY	STAG
12/18/01							

DRY = Surface water feature was dry at measurement point on given date
STAG = Water at measurement point was stagnant - reading discarded.

Date	SP 107	SP 108	SP 109	SP 110	SP 111	SP 112	SP 113
	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)
6/7/99							
6/14/99	0.74	1.73	2.83	0.82	0.81	1.80	0.78
6/21/99	0.66	1.83	2.96	0.67	0.67		0.65
6/28/99	0.60	1.80	2.75	0.61	0.61	0.62	DRY
7/5/99	0.74	STAG	2.21		0.76	0.76	0.76
7/12/99	0.84	1.79	2.43	0.85	0.84	0.86	DRY
7/19/99	0.84	1.04	4.90	1.87	DRY	1.72	1.68
7/26/99	0.97	STAG	3.99	1.75	1.85	1.97	1.90
8/2/99	STAG	0.78	6.19	0.88	0.89	0.88	
8/9/99	0.78	1.85	3.83	0.78	0.76	0.97	DRY
8/16/99	0.89	STAG	3.35	1.24	1.36	1.47	1.11
9/4/99	0.90	ST	2.91	1.04	1.06	1.07	0.78
9/18/99				DRY	DRY		DRY
3/3/00							
4/15/00	0.52	0.97	4.71	0.74	1.00	0.92	STAG
4/29/00			STAG	STAG	STAG	2.06	STAG
5/17/00	1.00	1.84	2.30	1.51	1.32	1.51	1.30
5/30/00	0.82	1.75	2.80	0.83	0.83	0.82	0.82
6/7/00	0.69	2.47	1.83	1.24	1.25	1.21	1.14
6/15/00	0.73	1.85	1.80	1.78	1.81	1.81	1.65
6/22/00	0.77	2.21	1.98	0.81	0.81	0.81	DRY
6/29/00	0.78	1.59	2.31	1.40	1.40	1.39	1.29
7/7/00		1.81	3.07				
7/14/00	1.01	1.02	1.20	1.19	1.22	1.27	1.43
7/20/00		0.33					0.67
7/27/00		1.20					1.65
8/2/00		STAG					1.70
8/11/00		STAG					DRY
8/16/00	0.75	1.25	STAG	0.83	0.82	0.73	1.30
9/1/00			STAG	STAG	STAG	1.06	1.24
9/14/00							
9/29/00		DRY					DRY
10/20/00		DRY					DRY
12/1/00							
1/19/01							
3/6/01							
3/30/01		DRY					DRY
4/21/01							1.97
5/15/01	1.40	1.72	3.55	1.41	1.41	1.41	1.40
5/30/01	0.77	2.30	6.54	0.71	0.58	0.76	0.68
6/8/01	1.88	0.85	5.00	0.85	0.80	0.85	0.72
6/14/01	0.87	1.28	4.10	0.91	1.07	1.01	0.98
6/23/01		1.68					2.02
6/29/01	DRY	1.71	10.67	1.79	1.80	1.46	1.77
7/5/01	0.67	1.71	DRY	0.67	0.67	0.67	0.67
7/12/01	1.23	1.71	2.39	1.40	1.41	1.40	1.44
7/17/01	0.74	1.66	2.96				0.91
7/25/01	0.72	STAG	1.44	DRY	DRY	DRY	DRY
8/1/01	0.81	STAG	1.43	1.11	1.11	1.10	0.89
8/10/01							
8/17/01		DRY					1.12
9/1/01		STAG					DRY
9/15/01		DRY					DRY
9/29/01		DRY					DRY
10/15/01							
10/27/01		DRY					DRY
11/17/01		DRY					DRY
12/18/01							

DRY = Surface water feature was dry at measurement point on given date
STAG = Water at measurement point was stagnant - reading discarded.

Date	SP 114	SP 115	SP 116	SP 117	SP 118	SP 119	SP 120
	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)
6/7/99							
6/14/99	1.62	0.74	1.19	0.73	0.74	0.74	1.33
6/21/99	1.55	0.62	0.99	0.86	0.62	0.62	1.33
6/28/99	1.54	0.61	1.30	0.61	0.61	0.61	1.34
7/5/99	STAG	0.74	1.26	0.73	0.73	0.72	1.34
7/12/99	1.29	0.81	1.73	1.57	0.81	0.81	1.30
7/19/99	DRY	DRY	STAG	3.42	DRY	0.95	1.26
7/26/99	ST	DRY	3.44	STAG	1.10		1.31
8/2/99	DRY	0.88	1.27	1.19	0.68	0.79	1.29
8/9/99	1.48	0.69	1.20	1.13	0.67	0.68	1.33
8/16/99	1.24	0.90	1.92	1.95	0.90	0.91	1.29
9/4/99	1.04	0.62	1.30	1.22	0.97	0.63	1.36
9/18/99	STAG	DRY	2.60	4.90	DRY		0.96
3/3/00							
4/15/00	0.86	0.85	1.23	1.19	0.89	0.87	1.53
4/29/00	1.96	DRY	DRY	DRY	DRY	DRY	4.23
5/17/00	1.51	DRY	1.50	1.52	DRY	DRY	1.50
5/30/00	1.52	DRY	STAG	2.78	1.51	0.84	1.52
6/7/00	1.91	DRY	3.25	1.45	1.58	0.70	1.41
6/15/00	1.95	DRY	4.40	4.75	2.88		1.48
6/22/00	0.81	DRY	1.41	1.39	STAG	0.80	1.39
6/29/00	1.42	0.91	1.41	1.42	0.84	0.84	1.41
7/7/00	2.05		3.80	4.24			1.08
7/14/00	1.30	1.02	1.47	1.54	1.00	1.01	1.23
7/20/00	1.44	0.58	1.33			0.56	0.83
7/27/00	1.66	DRY	0.67				1.19
8/2/00	1.65	DRY	1.70				1.76
8/11/00	STAG	DRY	STAG				1.58
8/16/00	1.24	DRY	1.66	1.52	DRY		1.41
9/1/00	1.67	STAG	3.02	2.74	STAG		1.41
9/14/00							
9/29/00	DRY	DRY	2.83				1.25
10/20/00	DRY	DRY	3.83				2.96
12/1/00							
1/19/01							
3/6/01							
3/30/01	DRY	DRY	DRY			DRY	1.30
4/21/01	1.40	DRY	1.36				1.39
5/15/01	1.51	DRY	2.50	2.12	DRY	DRY	1.40
5/30/01	1.20	DRY	1.49	2.92	DRY	DRY	1.31
6/8/01	1.49	0.66	1.23	1.86	0.80	0.78	1.05
6/14/01	1.38	0.93	0.95	1.49	1.10	0.95	1.02
6/23/01	2.02	DRY	4.65			DRY	1.28
6/29/01	1.16	1.77	1.24	1.19	0.63	0.62	1.16
7/5/01	1.17	DRY	1.18	1.18	DRY	DRY	1.17
7/12/01	1.19	DRY	1.20	1.19	DRY	DRY	1.18
7/17/01	1.45	0.63	1.08	1.42	0.62	0.62	1.29
7/25/01	1.18	0.71	1.21	1.21	0.71	0.71	1.14
8/1/01	1.21	1.23	1.61	1.75	1.23	1.23	1.36
8/10/01							
8/17/01	1.43	DRY	2.75			DRY	1.37
9/1/01	STAG	DRY	4.59			DRY	1.57
9/15/01	DRY	DRY	STAG			DRY	1.66
9/29/01	STAG	DRY	5.68			DRY	1.85
10/15/01							
10/27/01	DRY	DRY	STAG			DRY	2.22
11/17/01	DRY	DRY	DRY			DRY	2.46
12/18/01							

DRY = Surface water feature was dry at measurement point on given date
STAG = Water at measurement point was stagnant - reading discarded.

Date	SP 121	SP 122	SP 123	SP 124	SP 125	SP 126	SP 127
	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)
6/7/99							
6/14/99	1.33	0.73	0.73	1.54	1.31	0.73	0.81
6/21/99	1.32	0.64	0.64	1.57		0.63	0.73
6/28/99	1.34	0.61	0.61	0.60	1.34	0.60	0.78
7/5/99	1.33	0.73	0.72	0.73	N/A	0.71	0.73
7/12/99	1.28	0.83	0.83	0.83	1.27	0.80	1.08
7/19/99	1.25	0.88	0.89	DRY	1.27	DRY	1.01
7/26/99	1.31	1.07	1.91	DRY	1.31	1.10	
8/2/99	1.28	0.78	STAG	0.77	1.28	0.79	0.96
8/9/99	1.34	0.69	0.63	0.70	1.31	0.69	0.89
8/16/99	1.30	0.89	0.86	0.88	-		
9/4/99	1.35	0.77	0.85	0.92	1.39	0.95	1.35
9/18/99	1.09				1.61	DRY	1.34
3/3/00							1.01
4/15/00	1.52	0.88	0.86	0.87	1.53	0.79	1.23
4/29/00	4.30			DRY	4.31		
5/17/00	1.49	1.00	1.00	1.00	1.52	DRY	1.37
5/30/00	1.52	0.70	0.80	0.80	1.53	DRY	1.12
6/7/00	1.42	0.72	1.39	0.71	1.40	DRY	1.06
6/15/00	1.49	0.76	1.63	DRY	1.48	DRY	1.14
6/22/00	1.40	0.79	0.78	0.79	1.41	DRY	1.62
6/29/00	1.40	0.81	0.82	0.80	1.46	0.91	1.10
7/7/00	1.62				1.78		1.12
7/14/00	1.20	1.02	1.03	1.00	1.28	1.03	
7/20/00		0.59		0.56	1.13	0.36	0.92
7/27/00		0.89		0.87	0.89	DRY	1.33
8/2/00		1.45		1.51	1.78	DRY	1.51
8/11/00		DRY		DRY	1.68	DRY	1.41
8/16/00	1.41	0.82	0.79	0.78		DRY	1.23
9/1/00			1.21			STAG	1.11
9/14/00							3.22
9/29/00		DRY		DRY	1.41	DRY	1.16
10/20/00		DRY		DRY	3.12	DRY	2.30
12/1/00							2.17
1/19/01							2.82
3/6/01							
3/30/01		DRY		DRY	1.31	DRY	1.35
4/21/01	1.37			1.29	1.45		1.77
5/15/01	1.40	1.39	1.39	1.39	1.14	DRY	1.57
5/30/01	1.26	0.76	1.41	0.76	1.23	DRY	
6/8/01	1.31	0.80	0.79	0.74	0.68	0.76	1.20
6/14/01	1.12	1.02	0.89	1.00	1.17	1.07	1.23
6/23/01		DRY		DRY	1.24	DRY	1.35
6/29/01	1.16				1.18	0.61	0.93
7/5/01	1.18	0.68	0.69	0.68	1.18	DRY	1.34
7/12/01	1.19	1.21	1.23	1.21	1.22	DRY	1.21
7/17/01	1.21	0.62	0.62	0.63	1.23	0.61	1.34
7/25/01	1.23	0.72	0.72	0.72	1.23	0.71	
8/1/01	1.36	1.24	1.23	1.23	1.29	1.22	1.56
8/10/01							
8/17/01		DRY		DRY	DRY	DRY	1.39
9/1/01		DRY		DRY	1.53	DRY	1.69
9/15/01		DRY		DRY	1.82	DRY	1.93
9/29/01		DRY		DRY	1.81	DRY	1.94
10/15/01							
10/27/01		DRY		DRY	1.22	DRY	1.90
11/17/01		DRY		DRY	2.38	DRY	1.69
12/18/01							1.52

DRY = Surface water feature was dry at measurement point on given date

STAG = Water at measurement point was stagnant - reading discarded.

Date	SP 128	SP 129	SP 130	SP 132	SP 133	SP 134	SP 135
	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)
6/7/99							
6/14/99	0.74	2.27	0.74	1.38	0.74	0.74	0.74
6/21/99	0.64	2.20	0.62	1.81	0.63	0.64	0.64
6/28/99	0.60	0.60	1.70	1.67	0.60	0.59	0.60
7/5/99	0.71	STAG	0.71	1.69	0.68		
7/12/99	0.81	1.69	0.81	1.52	0.80	-	0.79
7/19/99	DRY		STAG	STAG	0.99	0.95	0.75
7/26/99	1.14		STAG	STAG	0.99	1.19	1.00
8/2/99	0.68	STAG	0.69	STAG	0.91	0.69	0.68
8/9/99	0.66	DRY	0.61	1.46	0.69	0.47	0.51
8/16/99	0.91	STAG	0.89	1.76	0.93	0.90	0.81
9/4/99	0.97	STAG	0.77	1.56	0.92	0.75	0.91
9/18/99	DRY	DRY	DRY	1.52	STAG		
3/3/00							
4/15/00	0.82	0.60	0.84	0.82	0.79	0.67	
4/29/00							
5/17/00	DRY	DRY	DRY	STAG	1.02	1.02	1.02
5/30/00	DRY	1.77	DRY	STAG	0.77	0.78	0.79
6/7/00	DRY	2.59	DRY	3.00	0.70	0.70	0.71
6/15/00	DRY		DRY	1.46	0.76	1.07	1.30
6/22/00	DRY	DRY	DRY	1.30	0.80	0.80	0.80
6/29/00	0.83	1.21	0.84	1.23	0.78	0.83	0.82
7/7/00				1.51	1.02		
7/14/00	1.02			STAG	1.76		
7/20/00						0.62	
7/27/00			STAG			0.81	
8/2/00			STAG			1.42	
8/11/00			DRY			DRY	
8/16/00	DRY	3.21		1.06	0.86	0.84	0.83
9/1/00	STAG	1.13	1.19	1.15	0.73	0.76	
9/14/00							
9/29/00			DRY			DRY	
10/20/00			DRY			DRY	
12/1/00							
1/19/01							
3/6/01							
3/30/01			1.40			DRY	
4/21/01		DRY	DRY	1.49	1.30	1.33	
5/15/01	1.39	DRY	1.39	1.50	1.41	1.39	1.39
5/30/01	STAG	DRY	STAG	2.02	0.78	0.77	0.75
6/8/01	0.85	DRY	0.85	1.80	0.83	0.69	0.65
6/14/01	1.05	DRY	1.02	1.43	1.12	1.01	1.01
6/23/01			DRY				
6/29/01	0.60	DRY	0.60	STAG			
7/5/01	DRY	DRY	DRY	STAG	0.70	0.69	0.69
7/12/01	DRY	DRY	DRY	STAG	1.23	1.22	1.22
7/17/01	0.60	DRY	0.61	STAG	0.61	0.61	0.61
7/25/01	DRY	DRY	DRY	STAG	0.72	0.72	0.71
8/1/01	1.22	DRY	1.21	STAG	1.21	1.22	1.22
8/10/01							
8/17/01			DRY				
9/1/01			DRY				
9/15/01			DRY				
9/29/01			DRY				
10/15/01							
10/27/01			DRY				
11/17/01			DRY				
12/18/01							

DRY = Surface water feature was dry at measurement point on given date
STAG = Water at measurement point was stagnant - reading discarded.

Date	SP 136	SP 137	SP 138	SP 139	SP 140	SP 141	SP 142
	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)
6/7/99							
6/14/99	2.00	1.97	2.05	Too DRY	2.90	0.73	
6/21/99		1.40	2.16	ST, SH	STAG	0.66	0.62
6/28/99	1.65	1.56	1.34	3.36	2.18	0.68	0.59
7/5/99	STAG	STAG	STAG	STAG	STAG	0.82	0.67
7/12/99	DRY	DRY	STAG	STAG	3.36	0.87	0.77
7/19/99	STAG	STAG	DRY	DRY	STAG	0.74	STAG
7/26/99					STAG	1.09	0.91
8/2/99	STAG	STAG	STAG	STAG	STAG	0.78	0.69
8/9/99	STAG	STAG	STAG	STAG	3.35	0.72	0.67
8/16/99	1.46	STAG	STAG	STAG	STAG	1.05	0.87
9/4/99	1.51	1.32	1.21	2.34	3.54	1.15	0.92
9/18/99	0.93	STAG	STAG	STAG	3.50	1.17	
3/3/00					0.98		
4/15/00	0.86	0.88	0.82	0.78	0.77	0.74	0.71
4/29/00	STAG	STAG	STAG	STAG	STAG	1.30	STAG
5/17/00	1.96	1.21	1.10	STAG	STAG	1.30	0.98
5/30/00	STAG	STAG	STAG	STAG	STAG	1.33	0.85
6/7/00	2.79	2.46	2.79	2.80	3.13	0.79	0.68
6/15/00	1.58	1.57	1.36	DRY	3.54	0.93	0.74
6/22/00	1.80	0.97	STAG	STAG	3.28	1.12	0.80
6/29/00	1.65	1.49	1.16	4.07	3.50	0.85	0.78
7/7/00					3.81	0.90	
7/14/00	STAG	STAG	STAG	STAG	STAG	1.60	1.82
7/20/00		STAG			0.81	0.65	0.62
7/27/00		STAG			2.02	1.05	0.87
8/2/00		STAG			STAG	1.36	1.50
8/11/00		STAG			2.98	1.14	DRY
8/16/00	3.12	2.89	2.51	3.10	3.21	1.02	1.06
9/1/00	1.17				1.22	1.06	
9/14/00						2.42	
9/29/00		STAG			STAG	1.44	DRY
10/20/00		DRY			DRY	1.33	DRY
12/1/00						1.69	
1/19/01						2.48	
3/6/01						1.69	
3/30/01		1.26			1.11		DRY
4/21/01					2.64	1.33	
5/15/01	2.35	STAG	STAG	STAG	STAG	1.30	1.41
5/30/01	STAG	STAG	STAG	STAG	STAG	0.79	0.86
6/8/01	STAG	STAG	STAG	STAG	STAG	0.93	0.87
6/14/01	STAG	STAG	STAG	STAG	STAG	0.86	0.55
6/23/01		STAG			STAG	0.79	DRY
6/29/01	STAG	STAG	STAG	STAG	STAG	0.70	
7/5/01	STAG	STAG	STAG	STAG	STAG	0.85	0.72
7/12/01	STAG	STAG	STAG	STAG	STAG	0.83	1.22
7/17/01	STAG	STAG	STAG	STAG	STAG	0.67	0.61
7/25/01	STAG	STAG	STAG	STAG	STAG	0.89	0.74
8/1/01	STAG	STAG	STAG	STAG	STAG	0.94	1.19
8/10/01							
8/17/01		1.12			DRY	0.88	DRY
9/1/01		STAG			STAG	1.14	DRY
9/15/01		STAG			STAG	1.47	DRY
9/29/01		STAG			STAG	1.41	DRY
10/15/01							
10/27/01		DRY			DRY	1.35	DRY
11/17/01		DRY			DRY	1.29	DRY
12/18/01						1.14	

DRY = Surface water feature was dry at measurement point on given date
STAG = Water at measurement point was stagnant - reading discarded.

Date	SP 143	SP 144	SP 145	SP 146	SP 147	SP 148	SP 149
	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)
6/7/99							
6/14/99					0.72	0.71	0.71
6/21/99	0.63	0.63	0.63	2.28	0.62	0.62	0.62
6/28/99	0.60	0.60	0.60	DRY	0.59	0.63	0.63
7/5/99	0.68	0.68	0.68	STAG	0.72	0.72	0.70
7/12/99	0.78	0.78	0.81	1.58	0.70	0.76	0.76
7/19/99	STAG	0.76	0.95	0.41	0.89	STAG	STAG
7/26/99	0.90	1.18	0.95	STAG	0.90	0.87	0.91
8/2/99	0.69	0.69	0.69	STAG		0.69	0.69
8/9/99	0.69	0.68	0.68	STAG	0.68	0.66	0.67
8/16/99	0.87	0.87	0.88		0.88	0.88	0.87
9/4/99	0.92	0.92	0.92	1.83	0.92	0.92	0.92
9/18/99				STAG			
3/3/00							
4/15/00	0.72	0.74	0.71	0.84	0.73	0.71	0.74
4/29/00	STAG	STAG	STAG		2.83	2.06	2.05
5/17/00	0.99	0.98	0.98	STAG	0.98	0.97	0.99
5/30/00	0.88	0.88	0.88	2.66	0.88	0.88	0.88
6/7/00	0.68	0.69	0.69	2.82	0.68	0.68	0.67
6/15/00	0.74	0.75	0.75	3.15	0.73	0.73	0.75
6/22/00	0.80	0.80	0.80	1.72	0.80	0.80	0.80
6/29/00	0.78	0.78	0.78	1.89	0.78	0.78	0.76
7/7/00				1.90	1.23	1.17	
7/14/00	1.75	1.72		1.75	1.30	1.81	1.65
7/20/00			0.62				0.58
7/27/00			0.63				1.28
8/2/00			1.49				1.41
8/11/00			DRY				DRY
8/16/00	1.10	1.02	0.91		1.16	1.16	1.16
9/1/00			STAG		0.79	1.20	1.20
9/14/00							
9/29/00			DRY				DRY
10/20/00			DRY				DRY
12/1/00							
1/19/01							
3/6/01							
3/30/01			1.16				DRY
4/21/01	1.32				1.31		1.29
5/15/01	1.41	1.41	1.42		1.42	1.42	1.43
5/30/01	0.74	0.82	0.80		0.76	0.74	0.75
6/8/01	0.85	0.79	0.84		0.85	0.77	0.84
6/14/01	1.04	1.00	1.03	1.30	1.01	1.02	1.02
6/23/01			DRY		DRY		DRY
6/29/01				STAG			
7/5/01		0.71	0.67	STAG	0.72	0.72	0.72
7/12/01	1.23	1.25	1.24	STAG	1.23	1.22	1.21
7/17/01	0.61	0.61	0.56	STAG	0.61	0.60	0.61
7/25/01	0.74	0.73	0.73	STAG	0.74	0.75	0.76
8/1/01	1.18	1.19	1.19	STAG	1.21	1.20	1.19
8/10/01							
8/17/01			1.18		DRY		DRY
9/1/01			DRY		DRY		DRY
9/15/01			DRY		DRY		DRY
9/29/01			DRY		DRY		DRY
10/15/01							
10/27/01			DRY		DRY		DRY
11/17/01			DRY		DRY		DRY
12/18/01							

DRY = Surface water feature was dry at measurement point on given date

STAG = Water at measurement point was stagnant - reading discarded.

Date	SP 150	SP 151	SP 152	SP 153	SP 154	SP 155	SP 156
	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)
6/7/99							
6/14/99	0.71	0.71	0.71	0.71	0.72	0.72	0.71
6/21/99	0.73	0.73	0.73	0.73	0.73	0.73	0.72
6/28/99	0.76	0.76	0.76	0.76	0.76	0.76	0.76
7/5/99	1.05	1.05	1.05	1.05	1.05	1.05	1.05
7/12/99	1.26	1.26	1.26	1.26	1.25	1.26	1.26
7/19/99	0.85	0.85	0.84	0.85	0.85	0.85	0.85
7/26/99	1.08		1.18		1.18		1.20
8/2/99	0.77		0.76		0.75		0.75
8/9/99	0.86	-	0.88	-	0.88	-	0.87
8/16/99	1.16		1.13		1.21		1.19
9/4/99	1.20		1.45		1.30		1.43
9/18/99	1.30		1.30		1.29		1.31
3/3/00							
4/15/00	1.10		1.12		1.12		1.14
4/29/00	1.59	1.59	1.59	1.59	1.58	1.57	1.58
5/17/00	1.39	1.40	1.41	1.41	1.40	1.41	1.41
5/30/00	1.40	1.42	1.43	1.43	1.43	1.43	1.43
6/7/00	0.80	0.85	0.85	0.85	0.85	0.85	0.85
6/15/00	1.20	1.21	1.20	1.20	1.18	1.17	1.16
6/22/00	1.29	1.28	1.28	1.28	1.29	1.28	1.28
6/29/00	1.35			1.35		1.35	
7/7/00	1.03	0.98	0.97	0.97	0.96	0.96	0.96
7/14/00	1.61	1.61	1.64	1.64	1.63	1.26	1.66
7/20/00	0.80			0.80		0.83	
7/27/00	1.49			1.55		1.24	
8/2/00	1.59			1.61		1.60	
8/11/00	1.52	1.51	1.49	1.53	1.55	1.56	1.51
8/16/00	1.32	1.32	1.31	1.30	1.30	1.29	1.29
9/1/00	1.34	1.38	1.39	1.36	1.38	1.36	1.45
9/14/00							
9/29/00	1.65			1.68		1.70	
10/20/00	1.92			1.91		1.90	
12/1/00							
1/19/01							
3/6/01							
3/30/01	1.68	1.57					
4/21/01	1.48					1.48	
5/15/01	1.43	1.43	1.43	1.43	1.43	1.43	1.43
5/30/01	0.93	0.94	0.95	0.91	0.94	0.70	0.94
6/8/01	0.96	0.82	0.99	0.98	0.99	0.95	0.98
6/14/01	1.20	1.20	1.19	1.19	1.19	1.18	1.17
6/23/01	1.00			0.98		0.96	
6/29/01	0.83	0.83	0.82	0.82	0.82	0.81	0.81
7/5/01							
7/12/01	1.51	1.51		1.52	1.49	1.51	1.51
7/17/01	0.84	0.85	0.84	0.84	0.85	0.85	0.86
7/25/01	1.26	1.27	1.27	1.27	1.27	1.28	1.28
8/1/01	1.17	1.17	1.19	1.21	1.22	1.24	1.24
8/10/01							
8/17/01	1.07			1.09		1.10	
9/1/01	1.65			1.63		1.66	
9/15/01	1.96			1.95		1.98	
9/29/01	1.59			1.58		1.59	
10/15/01	1.66			1.65		1.63	
10/27/01	1.68			1.68		1.69	
11/17/01	1.67			1.64		1.68	
12/18/01							

DRY = Surface water feature was dry at measurement point on given date
STAG = Water at measurement point was stagnant - reading discarded.

Date	SP 157	SP 158	SP 160	SP 161	SP 162	SP 163	SP 164
	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)
6/7/99							
6/14/99	0.71	0.71	0.71				
6/21/99	0.72	0.73		0.66			
6/28/99	0.76	0.76	0.76	0.84	0.93	N/A	
7/5/99	1.03	1.03	1.02	0.69	1.73	N/A	
7/12/99	1.26	1.26	1.27	0.86	1.35	N/A	
7/19/99	0.84	0.83	0.89		1.14	N/A	
7/26/99		1.21	1.32	1.01	1.96		0.90
8/2/99		0.75	0.73	0.77		0.60	0.56
8/9/99	-	0.88	0.88				
8/16/99		1.18	1.21	0.90	1.34	0.76	0.83
9/4/99		1.41	1.40	0.95	1.57	0.61	0.89
9/18/99		1.30	1.33	1.10	1.72	0.93	1.08
3/3/00					1.71	0.84	0.86
4/15/00		1.10	1.10		1.85		0.71
4/29/00	1.58	1.58	1.58	1.21	1.55	1.20	1.22
5/17/00	1.41	1.40	1.40	1.02	1.91	1.00	1.02
5/30/00	1.42	1.42	1.42	0.91	2.04	0.84	0.87
6/7/00	0.85	0.87	0.87	0.76	1.09	0.79	0.71
6/15/00	1.14	1.12	1.12	0.85	2.08	0.81	0.82
6/22/00	1.29	1.28	1.28	0.82	1.28	0.81	0.82
6/29/00	1.35			0.80	1.91	0.99	0.78
7/7/00	0.95	0.94	0.94	0.80	1.79	0.74	0.79
7/14/00	1.64	1.68	1.68	1.25		1.01	1.12
7/20/00	0.81			0.49	1.13	0.68	0.56
7/27/00	1.33			0.91	1.27	0.74	
8/2/00	1.51			0.98	2.01	0.73	0.89
8/11/00	1.53	1.48	1.48	0.81	1.80	0.76	
8/16/00	1.29	1.29	1.29	1.04	1.88	1.01	0.95
9/1/00	1.38	1.35	1.35	0.92	1.54	0.92	0.92
9/14/00				-	3.47	1.91	2.01
9/29/00	1.70			1.20	1.97	1.56	
10/20/00	1.89			1.54	2.09	1.80	
12/1/00				1.65	2.18	1.49	
1/19/01					2.66	2.42	2.40
3/6/01					2.20	1.80	1.39
3/30/01	1.53		1.45	1.09		1.10	
4/21/01			1.58		2.26		
5/15/01	1.43	1.43	1.48	1.09	1.85	1.05	1.08
5/30/01	0.91	1.02	0.94		1.07	0.82	0.74
6/8/01	0.95	0.94	1.05	0.89	1.14	0.87	0.88
6/14/01	1.17	1.16	1.15	0.71	1.70	0.80	0.69
6/23/01	0.95			0.73		0.91	
6/29/01	0.79	0.79	0.91	0.57	0.98	0.58	0.51
7/5/01							
7/12/01	1.50	1.50	1.21	0.57	1.89	0.82	0.69
7/17/01	0.84	0.78	0.81	0.69	1.24	1.03	0.65
7/25/01	1.29	1.30	1.32	0.78	1.20	0.87	0.77
8/1/01	1.25	1.25	1.28	0.82	1.69	0.80	0.80
8/10/01							
8/17/01	1.09		1.05				0.75
9/1/01	1.35			0.89		0.93	
9/15/01	2.03			1.15		1.06	
9/29/01	1.58			1.31		1.34	
10/15/01	1.63				1.75		
10/27/01	1.84			1.36		1.30	
11/17/01	1.67			1.29		1.22	
12/18/01							

DRY = Surface water feature was dry at measurement point on given date
STAG = Water at measurement point was stagnant - reading discarded.

Date	SP 165	SP 166	SP 167	SP 201	SP 202	SP 203	SP 204
	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)
6/7/99							
6/14/99							
6/21/99							
6/28/99							
7/5/99							
7/12/99							
7/19/99							
7/26/99	1.08	0.77					
8/2/99	0.86	-					
8/9/99	0.77	DRY					
8/16/99	0.94						
9/4/99	1.20	DRY					
9/18/99		0.74					
3/3/00							
4/15/00	0.88	0.95					
4/29/00	1.33	STAG		4.11	1.44	1.44	1.44
5/17/00	1.10	1.04		2.29	1.34	1.33	1.34
5/30/00	1.00	0.81		3.59	1.26	1.29	1.32
6/7/00	0.79	DRY		1.32	0.97	0.98	0.94
6/15/00	1.01	0.72		3.00	1.10	1.20	1.36
6/22/00	0.97	DRY		3.17	1.27	1.27	1.28
6/29/00	0.93	0.64	0.90	2.98	1.06	1.11	1.34
7/7/00	0.94	DRY	0.82	3.25	1.41	1.36	1.31
7/14/00	0.84	DRY	1.33	4.30	1.22	1.62	DRY
7/20/00	0.75	DRY	0.46	1.68	0.92	0.92	0.84
7/27/00	1.22	DRY	0.68	3.35	1.20	1.48	1.56
8/2/00	1.07	0.62	1.15	3.17	1.55	1.51	1.53
8/11/00	0.77	0.60	0.93	1.94	1.49	1.41	1.46
8/16/00	0.90	DRY	0.94	3.07	1.52	1.54	1.57
9/1/00	0.92	DRY	0.93	2.06	1.39	1.34	1.36
9/14/00			2.15				
9/29/00	1.47	DRY	1.21	2.58	1.70	1.70	1.70
10/20/00	1.57	DRY	1.21	2.99	1.89	1.88	1.88
12/1/00				2.53			
1/19/01			2.52	2.55			
3/6/01			1.47	2.56			
3/30/01	1.27	DRY	1.10	3.02			
4/21/01	1.26	0.95		3.16	1.41		
5/15/01	0.93	0.99	1.23	2.59	1.45	1.45	1.46
5/30/01	0.99	0.78	0.78	1.27	0.95	0.95	0.94
6/8/01	0.99	0.73	0.91	1.21	0.98	0.91	0.98
6/14/01	1.02	STAG	0.84	2.28	1.29		1.25
6/23/01	1.11	DRY	0.84				
6/29/01	0.75	0.68	0.70	1.25	1.25	1.21	1.27
7/5/01	0.83	STAG		1.53	1.29	1.30	1.30
7/12/01	0.84	0.59	0.89	1.42	1.30	1.30	1.30
7/17/01	0.77	0.57	0.77	1.46	0.93	0.93	0.92
7/25/01	0.94	DRY	0.97				
8/1/01	0.93	0.66	1.01	2.28	1.39	1.40	1.41
8/10/01	0.89	0.68					
8/17/01	0.84	DRY		1.37	1.20	1.20	1.21
9/1/01	1.11	0.70	0.97	2.00			
9/15/01	1.38	DRY	1.40	3.07			
9/29/01	1.39	DRY	1.39	2.76			
10/15/01				2.67			
10/27/01	1.28	DRY	1.28	2.35			
11/17/01			1.28	2.62			
12/18/01				2.22			

DRY = Surface water feature was dry at measurement point on given date
STAG = Water at measurement point was stagnant - reading discarded.

Date	SP 205	SP 206	SP 207	SP 208	SP 209
	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)	EC (dS/m)
6/7/99					
6/14/99					
6/21/99					
6/28/99					
7/5/99					
7/12/99					
7/19/99					
7/26/99					
8/2/99					
8/9/99					
8/16/99					
9/4/99					
9/18/99					
3/3/00					
4/15/00					
4/29/00	1.44	1.46	6.22	1.50	
5/17/00	1.40	1.39	5.13	1.37	2.19
5/30/00	1.36	1.36	4.57	1.36	2.06
6/7/00	0.86	0.85	3.04	0.84	1.14
6/15/00	1.31	1.34	5.84	1.31	2.08
6/22/00	1.28	1.28	5.16	1.28	1.92
6/29/00	1.27	1.24	3.25	1.25	1.90
7/7/00	1.20	1.18	3.72	1.01	1.93
7/14/00	1.66	1.70	4.16	1.25	1.86
7/20/00	0.84	0.85	1.92	0.80	1.22
7/27/00	1.52	1.53	4.58	1.61	2.10
8/2/00	1.52	1.55	4.87	1.14	2.13
8/11/00	1.45	1.45	5.58	1.52	1.35
8/16/00	1.58	1.38	5.41	1.30	2.01
9/1/00	1.35	1.38	3.45	1.34	1.77
9/14/00					
9/29/00	1.73	1.72	3.68	1.69	1.96
10/20/00	1.85	1.86	3.64	1.90	2.16
12/1/00					2.24
1/19/01					2.61
3/6/01					2.23
3/30/01					2.04
4/21/01	1.38		2.95		2.21
5/15/01	1.46	1.47	1.49	1.42	1.89
5/30/01	0.92	0.91	3.61	0.91	
6/8/01	0.98	0.99	2.24	0.98	
6/14/01		1.25	2.82	1.24	
6/23/01					
6/29/01	0.88	0.88	4.08	0.78	
7/5/01	1.27	1.28	4.08	1.28	
7/12/01	1.08	1.08	3.33	1.12	
7/17/01	0.88	0.88	2.95	0.89	
7/25/01					
8/1/01	1.43	1.44	3.03	1.33	
8/10/01					
8/17/01	1.00	1.00	3.40	0.99	1.21
9/1/01					1.65
9/15/01					1.96
9/29/01					2.13
10/15/01					
10/27/01					1.91
11/17/01					2.04
12/18/01					

DRY = Surface water feature was dry at measurement point on given date
STAG = Water at measurement point was stagnant - reading discarded.

APPENDIX C: SIMPLIFIED UNSATURATED ZONE SALINITY MODELING – THEORY AND PROCEDURES FOR MODIFICATION OF MT3DMS CODE

GOALS

(1) Estimate and keep track of soil water salinity concentration in the unsaturated zone (C_{sw}) given initial conditions and irrigation water salinity concentration (C_I).

(2) Calculate the salinity concentration of recharge into the underlying water table aquifer (C_w) based on the estimated C_{sw} and input C_I.

GOVERNING EQUATIONS

(1) *Soil Salt Balance*

$$\left(C_I q_I + C_p q_p + C_A q_u\right) - C_w q_w + X = \frac{\Delta\left(C_{sw} S_{sw}\right)}{\Delta t} = \frac{\left(C_{sw} S_{sw}\right)_{t+1} - \left(C_{sw} S_{sw}\right)_t}{\Delta t}$$

where:

C_I = irrigation water salinity conc. (mg/L = g/m^3)
q_I = infiltrated irrig. water amount (m^3)
C_p = precipitation salinity conc.(mg/L = g/m^3)
q_p = infiltrated precip. amount (m^3)
C_A = upflux water salinity conc. (mg/L = g/m^3) (assumed to be equal to the salinity of the water table aquifer)
q_u = upflux water amount (m^3)
C_w = recharge salinity conc. (mg/L = g/m^3)
q_w = recharge amount (m^3)
X = dissolution salinity contribution (g)
C_{sw} = soil water salinity conc. (mg/L = g/m^3)
S_{sw} = soil water storage (m^3)
t = time (week)
Δt = $(t+1) - (t)$ = computational time step (week)

(note: units must be compatible and terms should result in mass units)

(2) *Leaching Efficiency*

$$C_w = E_L C_{sw} + (1 - E_L)C_I$$

where: E_L = leaching efficiency (fraction between 0 and 1)

(3) *Soil Water Balance*

$$(q_I + q_p + q_u) - (q_{ET} + q_w) = \frac{\Delta S_{sw}}{\Delta t}$$

where: q_{ET} = evapotranspiration amount (m^3)

ASSUMPTIONS

1. The salinity concentration of precipitation is near zero.
2. The dissolution salinity concentration contribution (X) will initially be assumed to be zero (adjustments to this assumption may be made during calibration).
3. The leaching efficiency will remain constant over time.
4. No deficit irrigation is taking place -- an irrigation event will at least totally fill the soil profile (i.e. any time there is recharge, the soil profile is completely filled).

MODELING PROCEDURE

1. Assign values to new static variables: E_L, specific yield (S_y), height of capillary fringe (h_c) (specified based on value of S_y), height of capillary rise (h_R) (specified based on value of S_y), effective (drainable) porosity (Φ), and computational cell surface area (Area). The capillary fringe is generally defined as the zone above the water table in which the soil is saturated but the soil water is under negative pressure. The height of the capillary rise is defined by the maximum height that soil water extends above the water table due to adhesive and cohesive forces. The soil profile shown in Figure C-1 depicts the capillary region which defines the unsaturated zone.
2. Assign initial conditions to calculated variables: S_{sw}, C_{sw}.
3. Assign values to new dynamic variables: C_I, average depth of infiltrated irrigation (D_I), average depth of effective precipitation (D_p), ET extinction depth ($D_{extinct}$), maximum ET rate (ET_{max}), and crop type (T_{crop}).
4. Specify values of h_c and h_R based on assigned value of S_y. Based on information taken from Kasenow (1997) and McWhorter and Sunada (1977), the following approximations are used:

    - For $S_y \leq 0.20$; $h_c = 1.0$ m, $h_R = 2.0$ m.
    - For $S_y \geq 0.30$; $h_c = 0.2$ m, $h_R = 0.5$ m.
    - For $0.20 < S_y < 0.30$; $h_c = 0.05$ m, $h_R = 0.1$ m.

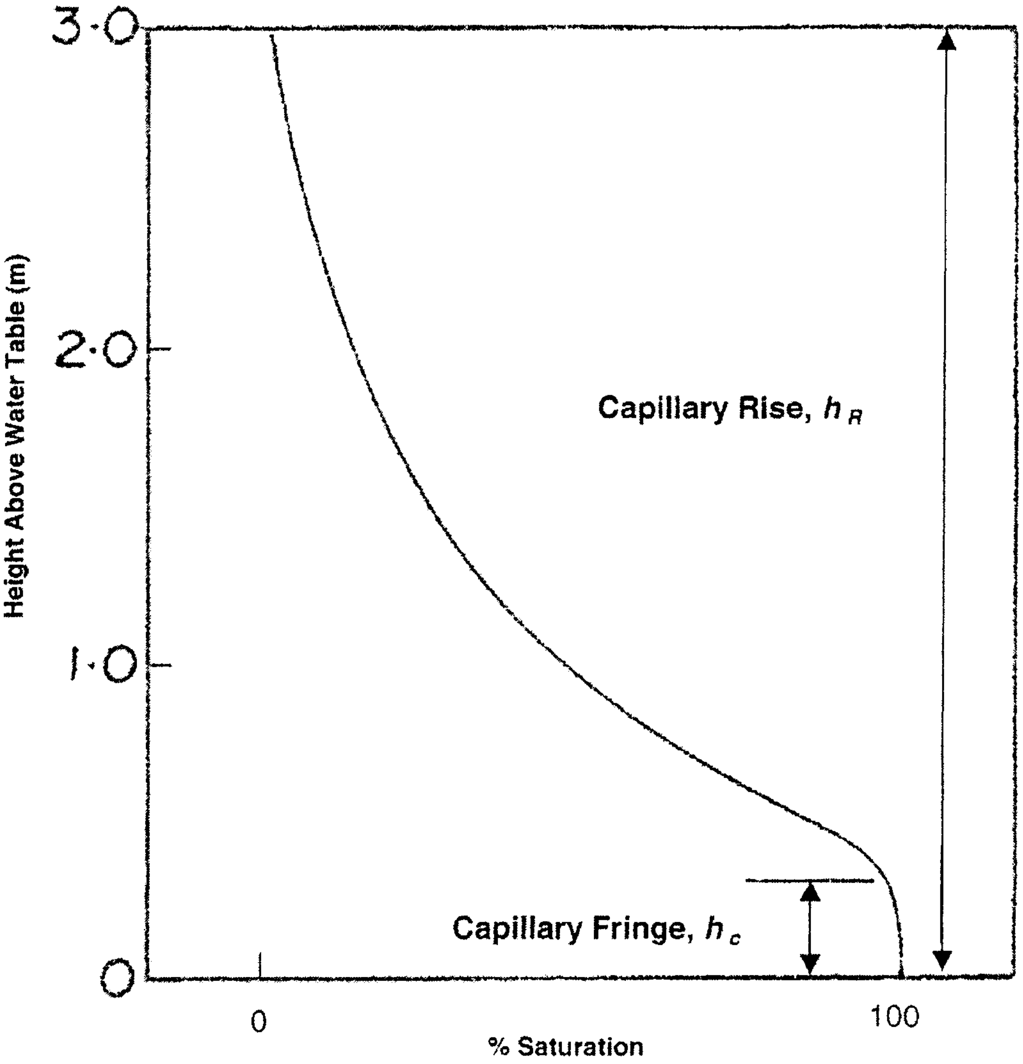


Figure C-1. Schematic Depiction of Unsaturated Zone Showing Capillary Region

(5) Calculate maximum unsaturated zone water volume (i.e. volume at field capacity) based on h_c, h_R, Φ, and *Area* and a simplified unsaturated zone geometry. This calculation is based on a linear approximation of the profile given in Figure C-1. The following equation is used to calculate the maximum soil water volume (S_{max}) in m^3:

$$S_{\max} = Area\left(h_c\Phi + \frac{1}{2}\left(h_R - h_c\right)\Phi\right)$$

(6) Calculate maximum ET volume $ETvol_{max}$ (m^3) for time t based on ET_{max} for time t and $Area$ where:

$$ETvol_{\max}^{(t)} = ET_{\max}^{(t)} Area$$

(7) Calculate adjusted ET volume (ET_{vol}) considering salinity impacts based on the calculated C_{sw} and $ETvol_{max}$ from the previous time step and on T_{crop}. The relationships used are based on Houk (2003).

(8) Further adjust ET_{vol} to account for waterlogging impacts based on the calculated water table depth from the current time step and on T_{crop}. The relationships used are based on Houk (2003).

(9) Calculate $C_w^{(t)}$ based on the leaching efficiency equation:

$$C_w^{(t)} = E_L C_{sw}^{(t)} + (1 - E_L) C_I^{(t)}$$

(10) Calculate $S_{sw}^{(t+1)}$ based on the appropriate cell condition:

a) **Condition 1** – Soil water profile begins full (i.e at field capacity); ends full – Deep water table – Recharge occurs.
   - Depth to water table is greater than h_R.
   - No change in S_{sw} occurs.
   - The following equation controls:

$$S_{sw}^{(t+1)} = S_{sw}^{(t)} = S_{\max} = Area\left(h_c\Phi + \frac{1}{2}(h_R - h_c)\Phi\right)$$

b) **Condition 2** - Soil water profile begins full; ends full – Shallow water table – Recharge occurs.
   - Capillary fringe intersects ground surface; therefore, water is lost as runoff due to siphoning ($Vol_{siphoned}$).
   - Change in S_{sw} occurs with change in water table elevation.
   - The following equation controls:

$$S_{sw}^{(t+1)} = S_{sw}^{(t)} + \Delta Vol_{siphoned}$$

where: $Vol_{siphoned} = Area(h_c - D_{WT})\Phi$

D_{WT} = Depth to water table (m)

c) **Condition 3** - Soil water profile begins full; ends less than full – Deep water table – No recharge occurs.
   - Depth to water table is greater than h_R.
   - Change in S_{sw} occurs due to ET volume removed (ET_{vol}).

- The following equation controls:

$$S_{sw}^{(t+1)} = S_{\max} - ET_{vol} + Area(q_p)$$

d) **Condition 4** - Soil water profile begins full; ends less than full – Shallow water table – No recharge occurs.

- Capillary fringe intersects ground surface.
- Change in S_{sw} occurs with change in water table elevation.
- Change in S_{sw} occurs due to ET volume removed.
- The following equation controls:

$$S_{sw}^{(t+1)} = S_{sw}^{(t)} + \Delta Vol_{siphoned} - ET_{vol} + Area(q_p)$$

e) **Condition 5** - Soil water profile begins less than full; ends full – Deep water table – Recharge occurs.

- Depth to water table is greater than h_R.
- Change in S_{sw} occurs due to filling of the soil water profile through irrigation/precipitation infiltration (full conditions result).
- The following equation controls:

$$S_{sw}^{(t+1)} = S_{\max} = Area\left(h_c\Phi + \frac{1}{2}(h_R - h_c)\Phi\right)$$

f) **Condition 6** - Soil water profile begins less than full; ends full – Shallow water table – Recharge occurs.

- Capillary fringe intersects ground surface.
- Change in S_{sw} occurs due to filling of the soil water profile through irrigation/precipitation infiltration (full conditions result).
- Change in S_{sw} occurs with change in water table elevation.
- The following equation controls:

$$S_{sw}^{(t+1)} = Area\left(h_c\Phi + \frac{1}{2}(h_R - h_c)\Phi\right) - Vol_{siphoned}$$

g) **Condition 7** - Soil water profile begins less than full; ends less than full – Deep water table – No recharge occurs.

- Depth to water table is greater than h_R.
- Change in S_{sw} occurs due to ET volume removed.
- The following equation controls:

$$S_{sw}^{(t+1)} = S_{sw}^{(t)} - ET_{vol} + Area(q_p)$$

h) **Condition 8** - Soil water profile begins less than full; ends less than full – Shallow water table – No recharge occurs.
   - Capillary fringe intersects ground surface.
   - Change in S_{sw} occurs due to ET volume removed.
   - Change in S_{sw} occurs with change in water table elevation.
   - The following equation controls:

$$S_{sw}^{(t+1)} = S_{sw}^{(t)} + \Delta Vol_{siphoned} - ET_{vol} + Area(q_p)$$

(11) Calculate $C_{sw(t+1)}$ from the salt balance based on the following equation:

$$C_{sw}^{(t+1)} = \frac{(C_I q_I + C_A q_u - C_w q_w)\Delta t + C_{sw}^{(t)} S_{sw}^{(t)}}{S_{sw}^{(t+1)}}$$

(12) Repeat process for each time step.

REQUIRED MODIFICATIONS TO MT3DMS CODE

(1) Add static variables (E_L, h_c, h_R, S_y, and $Area$) as model input parameters.
(2) Add calculated variables (S_{sw}, C_{sw}, and C_w) as model input parameters and specify their initial conditions (if required) as model input.
(3) Add dynamic variables (C_I, q_I, q_w, q_p, $D_{extinct}$, and ET_{max}) as model input parameters.
(4) Add model algorithm to code (create new module and modify SSM package).
(5) Output must be modified to include resultant C_{sw} and C_w for each time step.

REQUIRED NEW MT3DMS INPUT

(1) E_L
(2) h_c
(3) h_R
(4) S_y
(5) $Area$
(6) S_{sw}
(7) C_{sw}
(8) C_w
(9) C_I
(10) D_I
(11) D_p
(12) $D_{extinct}$
(13) ET_{max}
(14) T_{crop}

NEW MT3DMS OUTPUT GENERATED

(1) C_{sw} (for each time step)
(2) C_w (for each time step)

Note: The salt balance produced at the end of each time step appears in the same format as produced by the existing code. Additionally, a GMS data file (2-D ASCII format) is generated for post-processing.

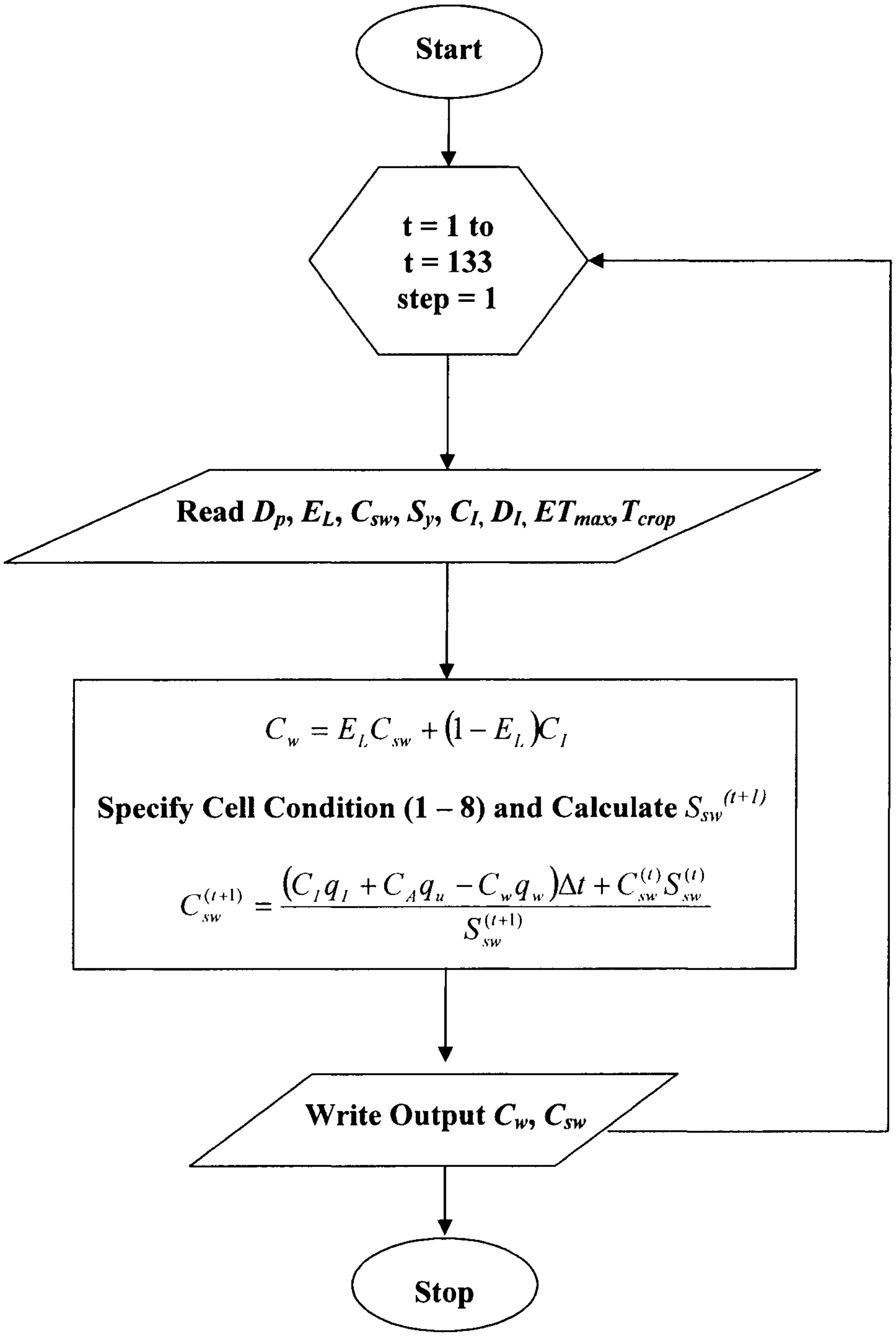
APPENDIX C REFERENCES

Houk, E. E. 2003. *Economic assessment of water management in agriculture: Managing salinity and waterlogging in the Arkansas River Basin and environmental water shortages in the Platte River Basin.* PhD thesis, Dept. Ag. Resour. Economics, Colorado State University, Fort Collins, Colo.

Kasenow, M. 1997. *Applied ground-water hydrology and well hydraulics.* Water Resources Publications, Highlands Ranch, Colo.

McWhorter, D. B., and Sunada, D. K. 1977. *Ground-water hydrology and hydraulics.* Water Resources Publications, Fort Collins, Colo.

Coding Flowchart (Applied to Each Computational Cell):



APPENDIX D: UNSATURATED MODULE CODE

```
      SUBROUTINE UNSAT(NCOL,NROW,NCOMP,NLAY,KPER,HTOP,PRSITY,
     & DELR,DELC,RECH,CRCH,EVTR,CNEW,DH,DZ,CSW,ETMAX,DIRRIG,CIRRIG,
     & STORSW,THKOLD,SSWOLD,BOTTOM,SY,CPCODE,ICBUND)
C *****************************************************************
C THIS SUBROUTINE CALCULATES STORAGE IN THE UNSATURATED ZONE
C Developed by P. Burkhalter, Colorado State University
C Last modified:  July 6, 2003 -- Simplified ET Adjustment Added
C *****************************************************************
C Model is based on mass balance principles and assumes no reactive
C processes occur.  Model originally intended for salt transport.
C New variables used include:
C
C CV             Case select structure control variable
C STORMX         Maximum root zone water storage volume (cell)
C STORSW         Root zone stored water volume (cell)
C HCAP           Height of capillary fringe for a cell based on SY
C HRISE          Height of capillary rise for a cell based on SY
C VOLET          Volume of required ET for a cell based on ETMAX
C DPCP           Depth of effective precipitation
C SAREA          Surface area (X-Y) of cell
C SSWOLD         Previous stress period root zone stored water volume
C CSW            Soil-water (in the root zone) concentration
C BOTTOM         Bottom elevation of cell
C SATTHK         Saturated thickness of the aquifer at column (J,I)
C ETMAX          Required ET rate (L) of cell (input in ssm file)
C CIRRIG         Concentration of applied irrigation water (input in
C                ssm file)
C DIRRIG         Depth of applied irrigation water (input in ssm file)
C SY             Specific yield of cell (input in ssm file)
C CSWMIN         Minimum allowable calculated soil-water concentration
C CSWMAX         Maximum allowable calculated soil-water concentration
C FUNSAT         Flag for unsaturated module
C SWADJ          Soil water volume adjustment factor used in calibration
C CPCODE         Crop type code
C
      IMPLICIT   NONE
      INTEGER    NCOL,NROW,NCOMP,NLAY,INDEX,I,J,KPER,CV,ICBUND
      REAL       PRSITY,STORMX,STORSW(NCOL,NROW),HCAP,HRISE,
     &           RECH,CRCH,EVTR,CNEW,HTOP(NCOL,NROW),VOLET,
     &           DELR,DELC,DH,DPCP,THKOLD(NCOL,NROW),DZ(NCOL,NROW,NLAY),
     &           SAREA,SSWOLD(NCOL,NROW),CSW(NCOL,NROW,NCOMP),
     &           BOTTOM(NCOL,NROW),ETMAX(NCOL,NROW,NCOMP),
     &           CIRRIG(NCOL,NROW,NCOMP),DIRRIG(NCOL,NROW,NCOMP),
     &           SY(NCOL,NROW,NCOMP),CSWMIN,CSWMAX,SATTHK,SWADJ,
     &           CPCODE(NCOL,NROW,NCOMP)
      LOGICAL    FUNSAT
      DIMENSION  RECH(NCOL,NROW),CRCH(NCOL,NROW,NCOMP),EVTR(NCOL,NROW),
     &           CNEW(NCOL,NROW,NLAY,NCOMP),PRSITY(NCOL,NROW,NLAY),
```

```
&          DELR(NCOL),DELC(NROW),DH(NCOL,NROW,NLAY),
     &          ICBUND(NCOL,NROW,NLAY,NCOMP)
      COMMON    FUNSAT,DPCP
C
C--Set CSWMIN and CSWMAX to appropriate values.  Currently set to
reflect
C--values specific for salinity in the Arkansas River basin, CO.
C
      CSWMIN=500.0
      CSWMAX=9000.0
C
C--Set value of SWADJ
C
      SWADJ=1.0
C
C--Write output file header.  This header is specific to the Groundwater
C--Modeling System (GMS 3.1) interface 2-D data file input structure.
C
      IF(KPER.EQ.1) THEN
        WRITE(20,*) 'DATASET'
        WRITE(20,*) 'OBJTYPE "grid2d"'
        WRITE(20,*) 'BEGSCL'
        WRITE(20,*) 'ND ',NCOL*NROW
        WRITE(20,*) 'NC ',NCOL*NROW
        WRITE(20,*) 'NAME "usat component"'
      ENDIF
        WRITE(20,*) 'TS 1',KPER
C
C--In accordance with GMS file structure, active cells are identified
C--with a "1" and inactive cells are identified with a "0".
C
      DO INDEX=1,NCOMP
        DO I=1,NROW
          DO J=1,NCOL
            IF(ICBUND(J,I,2,INDEX).NE.0) THEN
              WRITE(20,*) '1'
            ELSE
              WRITE(20,*) '0'
            ENDIF
          ENDDO
        ENDDO
      ENDDO
C
C--Perform analysis over all layer 1 cells for all components.  Note
C--that the model has not been tested for multi-component runs; but
C--has been coded to comply with mult-component structure and should
C--work fine.
C
      DO INDEX=1,NCOMP
        DO I=1,NROW
          DO J=1,NCOL
C
C--Write CSW to output file.  This is updated each stress period.
C
            WRITE(20,*) CSW(J,I,INDEX)
C
C--Assign cell an HCAP and HRISE based on SY.
```

```
C
            IF(SY(J,I,INDEX).LE.0.20) THEN
              HCAP=1.0
              HRISE=2.0
            ENDIF
            IF(SY(J,I,INDEX).GE.0.30) THEN
              HCAP=0.2
              HRISE=0.5
            ENDIF
            IF(SY(J,I,INDEX).GT.0.20.AND.SY(J,I,INDEX).LT.0.30) THEN
              HCAP=0.05
              HRISE=0.1
            ENDIF
C
C--Calculate SAREA for the cell.
C
            SAREA=DELC(I)*DELR(J)
C
C--Calculate STORMX based on the assigned HCAP, HRISE, calculated
C--SAREA and cell porosity (PRSITY(J,I,1)).
C
            STORMX=SAREA*(HCAP*PRSITY(J,I,1)
     &      +0.5*(HRISE-HCAP)*PRSITY(J,I,1))
C
C--Calculate VOLET based on SAREA and input ETMAX.
C
            VOLET=SAREA*ETMAX(J,I,INDEX)
C
C
C--Adjust VOLET to account for reductions due to high salinity levels
C
            IF(CPCODE(J,I,INDEX).EQ.0.0.AND.CSW(J,I,INDEX).GT.3440.6)
     &        VOLET=VOLET*((100-0.0060077
     &        *(CSW(J,I,INDEX)-3440.6))/100)
            IF(CPCODE(J,I,INDEX).EQ.1.0.AND.CSW(J,I,INDEX).GT.1764.4)
     &        VOLET=VOLET*((100-0.0082747676
     &        *(CSW(J,I,INDEX)-1764.4))/100)
            IF(CPCODE(J,I,INDEX).EQ.2.0.AND.CSW(J,I,INDEX).GT.1499.7)
     &        VOLET=VOLET*((100-0.0136023577
     &        *(CSW(J,I,INDEX)-1499.7))/100)
            IF(CPCODE(J,I,INDEX).EQ.3.0.AND.CSW(J,I,INDEX).GT.882.2)
     &        VOLET=VOLET*((100-0.00952165
     &        *(CSW(J,I,INDEX)-882.2))/100)
            IF(CPCODE(J,I,INDEX).EQ.4.0.AND.CSW(J,I,INDEX).GT.882.2)
     &        VOLET=VOLET*((100-0.009068238
     &        *(CSW(J,I,INDEX)-882.2))/100)
            IF(CPCODE(J,I,INDEX).EQ.5.0.AND.CSW(J,I,INDEX).GT.5293.2)
     &        VOLET=VOLET*((100-0.00804806
     &        *(CSW(J,I,INDEX)-5293.2))/100)
            IF(CPCODE(J,I,INDEX).EQ.6.0.AND.CSW(J,I,INDEX).GT.5999.0)
     &        VOLET=VOLET*((100-0.018136477
     &        *(CSW(J,I,INDEX)-5999.0))/100)
            IF(CPCODE(J,I,INDEX).EQ.7.0.AND.CSW(J,I,INDEX).GT.882.2)
     &        VOLET=VOLET*((100-0.021537066
     &        *(CSW(J,I,INDEX)-882.2))/100)
C
C--Calculate cell bottom elevation.
```

```
C
            BOTTOM(J,I)=HTOP(J,I)-DZ(J,I,1)-DZ(J,I,2)
C
C--Calculate saturated thickness of aquifer, accounting for
C--layer 1 possibly being dry (MT3DMS assigns default DH of
C--1.00000002E+30 when dry)
C
            IF(DH(J,I,1).EQ.1.00000002E+30) THEN
              SATTHK=DH(J,I,2)
            ELSE
              SATTHK=DH(J,I,1)+DH(J,I,2)
            ENDIF
C
C--Adjust VOLET to account for reductions due to waterlogging
C
            IF(CPCODE(J,I,INDEX).EQ.0.0.AND.HTOP(J,I)-(BOTTOM(J,I)
     &      +SATTHK).LT.0.3) VOLET=VOLET*((100-392.0
     &        *(0.3-(HTOP(J,I)-(BOTTOM(J,I)+SATTHK))))/100)
            IF(CPCODE(J,I,INDEX).EQ.1.0.AND.HTOP(J,I)-(BOTTOM(J,I)
     &      +SATTHK).LT.1.34) VOLET=VOLET*((100-38.4
     &        *(1.34-(HTOP(J,I)-(BOTTOM(J,I)+SATTHK))))/100)
            IF(CPCODE(J,I,INDEX).EQ.2.0.AND.HTOP(J,I)-(BOTTOM(J,I)
     &      +SATTHK).LT.1.13) VOLET=VOLET*((100-66.1
     &        *(1.13-(HTOP(J,I)-(BOTTOM(J,I)+SATTHK))))/100)
            IF(CPCODE(J,I,INDEX).EQ.3.0.AND.HTOP(J,I)-(BOTTOM(J,I)
     &      +SATTHK).LT.1.00) VOLET=VOLET*((100-83.7
     &        *(1.00-(HTOP(J,I)-(BOTTOM(J,I)+SATTHK))))/100)
            IF(CPCODE(J,I,INDEX).EQ.4.0.AND.HTOP(J,I)-(BOTTOM(J,I)
     &      +SATTHK).LT.0.56) VOLET=VOLET*((100-230.0
     &        *(0.56-(HTOP(J,I)-(BOTTOM(J,I)+SATTHK))))/100)
            IF(CPCODE(J,I,INDEX).EQ.5.0.AND.HTOP(J,I)-(BOTTOM(J,I)
     &      +SATTHK).LT.0.85) VOLET=VOLET*((100-36.0
     &        *(0.85-(HTOP(J,I)-(BOTTOM(J,I)+SATTHK))))/100)
            IF(CPCODE(J,I,INDEX).EQ.6.0.AND.HTOP(J,I)-(BOTTOM(J,I)
     &      +SATTHK).LT.0.96) VOLET=VOLET*((100-110.0
     &        *(0.96-(HTOP(J,I)-(BOTTOM(J,I)+SATTHK))))/100)
            IF(CPCODE(J,I,INDEX).EQ.7.0.AND.HTOP(J,I)-(BOTTOM(J,I)
     &      +SATTHK).LT.1.48) VOLET=VOLET*((100-18.9
     &        *(1.48-(HTOP(J,I)-(BOTTOM(J,I)+SATTHK))))/100)
C
C--Adjust for potential negative values of VOLET
C
            IF(VOLET.LT.0) THEN
              VOLET=0
            ENDIF
C
C
C--Set values for STORSW and THKOLD for first stress period.
C--It is assumed that the soil-water profile begins 1/2 full (STORMX).
C
            IF(KPER.EQ.1) THEN
              STORSW(J,I)=0.5*STORMX
              THKOLD(J,I)=SATTHK
            ENDIF
C
C--Assess condition of each cell and assign select case accordingly.
C--The 8 cases are defined in more detailed in the assosciated
```

```
C--write up.
C
            IF(STORSW(J,I).EQ.STORMX.AND.HTOP(J,I).GE.BOTTOM(J,I)
     &        +SATTHK+HCAP.AND.RECH(J,I).NE.0) CV=1
            IF(STORSW(J,I).EQ.STORMX.AND.HTOP(J,I).LT.BOTTOM(J,I)
     &        +SATTHK+HCAP.AND.RECH(J,I).NE.0) CV=2
            IF(STORSW(J,I).EQ.STORMX.AND.HTOP(J,I).GE.BOTTOM(J,I)
     &        +SATTHK+HCAP.AND.RECH(J,I).EQ.0) CV=3
            IF(STORSW(J,I).EQ.STORMX.AND.HTOP(J,I).LT.BOTTOM(J,I)
     &        +SATTHK+HCAP.AND.RECH(J,I).EQ.0) CV=4
            IF(STORSW(J,I).LT.STORMX.AND.HTOP(J,I).GE.BOTTOM(J,I)
     &        +SATTHK+HCAP.AND.RECH(J,I).NE.0) CV=5
            IF(STORSW(J,I).LT.STORMX.AND.HTOP(J,I).LT.BOTTOM(J,I)
     &        +SATTHK+HCAP.AND.RECH(J,I).NE.0) CV=6
            IF(STORSW(J,I).LT.STORMX.AND.HTOP(J,I).GE.BOTTOM(J,I)
     &        +SATTHK+HCAP.AND.RECH(J,I).EQ.0) CV=7
            IF(STORSW(J,I).LT.STORMX.AND.HTOP(J,I).LT.BOTTOM(J,I)
     &        +SATTHK+HCAP.AND.RECH(J,I).EQ.0) CV=8
C
C--Select case structure to calculate new stored soil-water volume.
C--STORSW is calculated differently based on the condition of the
C--cell as specified above.
C
            SELECT CASE (CV)
C
            CASE(1)
              STORSW(J,I)=STORMX
C
            CASE(2)
              IF(HTOP(J,I).GE.BOTTOM(J,I)+THKOLD(J,I)+HCAP) THEN
                STORSW(J,I)=STORSW(J,I)-((BOTTOM(J,I)+SATTHK+HCAP)
     &          -HTOP(J,I))*SAREA*PRSITY(J,I,1)
              ENDIF
              IF(HTOP(J,I).LT.BOTTOM(J,I)+THKOLD(J,I)+HCAP) THEN
                STORSW(J,I)=STORSW(J,I)-(THKOLD(J,I)-SATTHK)*SAREA
     &          *PRSITY(J,I,1)
              ENDIF
C
            CASE(3)
              STORSW(J,I)=STORMX-VOLET+SAREA*(DPCP-EVTR(J,I))
C
            CASE(4)
              IF(HTOP(J,I).GE.BOTTOM(J,I)+THKOLD(J,I)+HCAP) THEN
                STORSW(J,I)=STORSW(J,I)-(((BOTTOM(J,I)+SATTHK
     &          +HCAP)-HTOP(J,I))*SAREA*PRSITY(J,I,1))-VOLET+SAREA
     &          *(DPCP-EVTR(J,I))
              ENDIF
              IF(HTOP(J,I).LT.BOTTOM(J,I)+THKOLD(J,I)+HCAP) THEN
                STORSW(J,I)=STORSW(J,I)-((THKOLD(J,I)-SATTHK)
     &          *SAREA*PRSITY(J,I,1))-VOLET+SAREA*(DPCP-EVTR(J,I))
              ENDIF
C
            CASE(5)
              STORSW(J,I)=STORMX
C
            CASE(6)
              STORSW(J,I)=(HTOP(J,I)-(BOTTOM(J,I)+SATTHK))*SAREA
```

```
     &        *PRSITY(J,I,1)
C
            CASE(7)
              STORSW(J,I)=STORSW(J,I)-VOLET+SAREA*(DPCP-EVTR(J,I))
C
            CASE(8)
              IF(HTOP(J,I).GE.BOTTOM(J,I)+THKOLD(J,I)+HCAP) THEN
                STORSW(J,I)=STORSW(J,I)-(((BOTTOM(J,I)+SATTHK
     &          +HCAP)-HTOP(J,I))*SAREA*PRSITY(J,I,1))-VOLET+SAREA
     &          *(DPCP-EVTR(J,I))
              ELSE
                STORSW(J,I)=STORSW(J,I)-((THKOLD(J,I)-SATTHK)
     &          *SAREA*PRSITY(J,I,1))-VOLET+SAREA*(DPCP-EVTR(J,I))
              ENDIF
C
            CASE DEFAULT
              WRITE(*,*) ' ERROR IN UNSATURATED MODULE '
              CALL STOPFILE
            END SELECT
C
C--Multiply STORSW by adjustment factor SWADJ for calibration purposes
C
            STORSW(J,I)=STORSW(J,I)*SWADJ
C
C--Check upper and lower limit of calculated STORSW.
C
            IF(STORSW(J,I).LT.0) STORSW(J,I)=0
            IF(STORSW(J,I).GT.STORMX) STORSW(J,I)=STORMX
C
C--Assign THKOLD as current saturated thickness for use in next stress
C--period.
C
            THKOLD(J,I)=SATTHK
C
C--Set value of SSWOLD for first stress period as current STORSW.
C
            IF(KPER.EQ.1) SSWOLD(J,I)=STORSW(J,I)
C
C--Calculate new CSW when STORSW is greater than zero.
C
            IF(STORSW(J,I).NE.0) THEN
              CSW(J,I,INDEX)=(CIRRIG(J,I,INDEX)*DIRRIG(J,I,INDEX)
     &        *SAREA+CNEW(J,I,2,INDEX)*(-EVTR(J,I))*SAREA
     &        -CRCH(J,I,INDEX)*RECH(J,I)*SAREA+CSW(J,I,INDEX)
     &        *SSWOLD(J,I))/STORSW(J,I)
            ENDIF
C
C--Check calculated CSW to make sure it falls within the max/min
C--limits.
C
            IF(CSW(J,I,INDEX).LT.CSWMIN) THEN
              CSW(J,I,INDEX)=CSWMIN
            ELSEIF(CSW(J,I,INDEX).GT.CSWMAX) THEN
              CSW(J,I,INDEX)=CSWMAX
            ENDIF
C
C
```

```
C--Set value of SSWOLD to current STORSW for use in next stress period.
C
            SSWOLD(J,I)=STORSW(J,I)
          ENDDO
        ENDDO
      ENDDO
      RETURN
      END
```

APPENDIX E: REVISED MT3DMS SSM FILE FORMAT (INCORPORATING ADDITIONAL INPUT FOR THE UNSATURATED ZONE MODEL)

D1 Record: FWEL, FDRN, FRCH, FEVT, FRIV, FGHB (*unchanged*)

D2 Record: FUNSAT
Format: I10

- FUNSAT is a flag which indicates whether or not to use the Unsaturated Zone Model

D3 Record: MXSS (*unchanged*)

(Enter D4 for each species if FUNSAT = T)
D4 Record: CSW(NCOL,NROW)
Format: RARRAY

- CSW is the array of initial soil water concentration of the specified component. It is used exclusively in the unsaturated zone model.

(Enter D5 for each species if FUNSAT = T)
D5 Record: SY(NCOL,NROW)
Format: RARRAY

- SY is the array of specific yield values for the unsaturated zone material. The user could specify a different specific yield for each modeled component, although this does not make sense physically; however, this could be useful in the calibration process.

For each stress period:

(Enter D6 if FRCH = T and FUNSAT = F)
D6 Record: INCRCH (*unchanged*)

(Enter D7 for each species if FRCH = T, FUNSAT = F and INCIRG $\geq$ 0)
D7 Record: CRCH(NCOL,NROW) (*unchanged*)

(Enter D8 if FUNSAT = T)
D8 Record: DPCP
Format: F6.4

- DPCP is the depth of effective precipitation for the stress period.

(Enter D9 if FUNSAT = T)

D9 Record: INCIRG
Format: I10

- INCIRG is a flag indicating whether an array containing the concentration of the irrigation water for each species will be read for the current stress period.

  If INCIRG ≥ 0, an array containing the concentration of the irrigation water for each species will be read.

  If INCIRG < 0, the concentration of the irrigation water will be reused from the last stress period. If INCIRG < 0 is specified for the first stress period, then, by default, the concentration of the irrigation water is set to zero.

(Enter D10 for each species if FUNSAT = T and INCIRG ≥ 0)
D10 Record: CIRRIG(NCOL,NROW)
Format: RARRAY

- CIRRIG is the concentration of the irrigation water for a particular species.

(Enter D11 if FUNSAT = T)
D11 Record: INDIRG
Format: I10

- INDIRG is a flag indicating whether an array containing the depth of the irrigation water for each species will be read for the current stress period.

  If INDIRG ≥ 0, an array containing the depth of the irrigation water for each species will be read.

  If INDIRG < 0, the depth of the irrigation water will be reused from the last stress period. If INDIRG < 0 is specified for the first stress period, then, by default, the depth of the irrigation water is set to zero.

(Enter D12 for each species if FUNSAT = T and INDIRG ≥ 0)
D12 Record: DIRRIG(NCOL,NROW)
Format: RARRAY

- DIRRIG is the depth of the irrigation water for a particular species. Although, in reality, this should be the same for all species, different values may be entered for calibration or some other purpose.

(Enter D13 if FUNSAT = T)
D13 Record: INLECH
Format: I10

- INLECH is a flag indicating whether an array containing the leaching efficiency for each species will be read for the current stress period.

  If INLECH ≥ 0, an array containing the leaching efficiency for each species will be read.

  If INLECH < 0, the leaching efficiency will be reused from the last stress period. If INLECH < 0 is specified for the first stress period, then, by default, the leaching efficiency is set to zero.

(Enter D14 for each species if FUNSAT = T and INLECH ≥ 0)

D14 Record: ELEACH(NCOL,NROW)
Format: RARRAY

- ELEACH is the leaching efficiency for a particular species. Although, in reality, this should be the same for all species, different values may be entered for calibration or some other purpose.

(Enter D15 if FUNSAT = T)

D15 Record: INETMX
Format: I10

- INETMX is a flag indicating whether an array containing the maximum evapotranspiration rate (in terms of depth) for each species will be read for the current stress period.

  If INETMX ≥ 0, an array containing the evapotranspiration rate for each species will be read.

  If INETMX < 0, the evapotranspiration rate will be reused from the last stress period. If INETMX < 0 is specified for the first stress period, then, by default, the evapotranspiration rate is set to zero.

(Enter D16 for each species if FUNSAT = T and INETMX ≥ 0)

D16 Record: ETMAX(NCOL,NROW)
Format: RARRAY

- ETMAX is the maximum evapotranspiration rate for a particular species. Although, in reality, this should be the same for all species, different values may be entered for calibration or some other purpose.

(Enter D17 if FUNSAT = T)

D17 Record: INCPCD
Format: I10

- INCPCD is a flag indicating whether an array containing the crop type codes for each species will be read for the current stress period.

  If INCPCD ≥ 0, an array containing the crop type code for each species will be read.

  If INCPCD < 0, the crop type codes will be reused from the last stress period. If INCPCD < 0 is specified for the first stress period, then, by default, the crop type code is set to zero.

(Enter D18 for each species if FUNSAT = T and INCPCD ≥ 0)

D18 Record: CPCODE(NCOL,NROW)

Format: RARRAY

- CPCODE is the crop type code for a particular species. Although, in reality, this should be the same for all species, different values may be entered for calibration or some other purpose.
- The current configuration of the model accepts the following codes for the corresponding crop types:

Code	*Crop Type*
0	Non-crop Area, Fallow, Wildlife Area, Pasture
1	Alfalfa, Barley
2	Corn
3	Cantaloupe, Watermelon, Gourds, Pumpkin
4	Onions, Peppers, Other Vegetables
5	Wheat, Oats
6	Sorghum
7	Beans

(Enter D19 if FEVT = T)

D19 Record: INCEVT (*unchanged)*

(Enter D20 for each species if FEVT = T and INCEVT ≥ 0)

D20 Record: CEVT(NCOL,NROW) (*unchanged)*

D21 Record: NSS (*unchanged)*

(Enter D22 NSS times if NSS > 0)

D22 Record: KSS, ISS, JSS, CSS, ITYPE, (CSSMS(n), n=1, NCOMP) (*unchanged)*

NOTE: See original MT3DMS documentation for all parameters marked as unchanged. The concentration of the recharge (CRECH) is only specified if FUNSAT = F. If FUNSAT = T, the concentration of the recharge becomes a calculated (i.e. not an input) parameter.

APPENDIX F: RECHARGE ESTIMATION PROCEDURES

This appendix describes procedures that were followed to arrive at the final estimates of weekly aquifer recharge volumes. Spreadsheet tools were used to generate these estimates and are saved on the CD found in the back sleeve of this document. Separate spreadsheet workbooks were generated for each canal command area for each modeled irrigation season (1999, 2000, and 2001) and for each modeled off-season (1999-2000 and 2000-2001). To conserve space on the CD, all recharge files were compressed into a WinZip archive called "Recharge.zip". Files must be extracted from this archive before they can be viewed. Filenames begin with the word "Recharge" and are followed by the analysis period and canal name. All files are in MS Excel™ format. The procedures described below were performed to generate each of the analysis spreadsheets.

Arrival at the final recharge estimates required completion of the following steps:

1. *Calculate a weekly mean irrigation application efficiency through regional water balance analysis*. This application efficiency assumes that 20% of the total canal diversion volume is lost during transit (primarily through seepage out of the canal) and also accounts for effective precipitation. It is meant to describe the percentage of applied irrigation water for a field that contributes to meeting the crop evapotranspiration (ET) demands.

Daily estimates of ET were produced for all major crop types over the entire study period using a soil water modeling software package known as CropFlex98 (Broner and Lorenz 1998). These daily values were aggregated into weekly totals for model input. Used primarily as an irrigation and fertilization scheduling tool, CropFlex98 also has the functionality to directly import meteorological data and calculate the daily reference ET using the Kimberly-Penman combination method. CropFlex98 contains a database of crop types and associated growing parameters and allows users to edit the data for application in a specific region or to add additional crop types. Utilizing the crop data, and accounting for soil water conditions, CropFlex98 can then estimate actual ET. For use in the present study it was assumed that adequate soil water was present at all times during the irrigation season to satisfy crop needs (i.e. no deficit irrigation practices are occurring). Therefore, the CropFlex98 results represent the crop's maximum potential ET.

The water balance calculations were performed outside of the recharge estimation spreadsheet as a part of a separate water balance analysis. Water balance analyses were performed for the study region for each of the three modeled years based on diversion data obtained from the Colorado Division of Water Resources, precipitation data from the National Climate Data Center (NCDC), the derived ET estimates, and the canal conveyance losses assumption mentioned above.

2. *Translate the mean application efficiency into a truncated normal distribution.* The limits of the possible values were assumed to be 0.15 (15%) minimum and 0.85 (85%) maximum. The resultant truncated normal distribution was generated in a normalized CDF form for later use in the recharge estimation calculations.

3. *Import weekly crop ET demand for each crop type.* As mentioned previously, these weekly ET demand estimates were derived using CropFlex98.

4. *Import weekly effective precipitation values.* These values (based on the precipitation data obtained from the NCDC) assume that, for daily precipitation readings that are less than 50 mm, 30% of the recorded precipitation amount is realized as surface runoff and 70% enters the soil profile. For daily precipitation readings that are greater than 50 mm, it is assumed that 50% of the recorded precipitation amount contributes to surface runoff and 50% enters the soil profile.

5. *Estimate overall leaching fraction.* The leaching fraction represents the portion of the irrigation losses that contributes to aquifer recharge (deep percolation). Based on a study by Walter (1995) conducted in the South Platte River Valley in northeastern Colorado, it was assumed that 70% of irrigation losses are in the form of deep percolation.

6. *Assign an irrigation frequency to each crop type.* All crop types were classified as receiving irrigations either monthly, bi-weekly, or weekly. Information on the

actual irrigation practices was obtained from the Colorado State University Cooperative Extension office in Rocky Ford, CO, and was used to develop this classification.

7. *Assign each field polygon a real random number between 0.0 – 1.0 using a uniform distribution.* This random number is used to assign irrigation and recharge characteristics to the field. It is assumed that these characteristics remain fairly constant over time; therefore, this number was fixed throughout the modeled time period.

8. *Assign each field polygon a set of weekly irrigation application efficiency values based on the assigned random number and the calculated irrigation application efficiency distribution (which is based on the overall water balance analysis).* As mentioned previously, the minimum possible value is assumed to be 0.15 (15%) and the maximum possible value is assumed to be 0.85 (85%).

9. *Calculate the "Required Irrigation" for each field polygon based on the estimated weekly crop ET demand adjusted for any effective precipitation.* If there was no effective precipitation within a given week, then the required irrigation is equivalent to the weekly crop ET.

10. *Calculate the "Irrigation Application" amount based on the required irrigation and the assigned irrigation efficiency value.* This value is simply the required

irrigation amount divided by the assigned application efficiency value (ranging from 0.0 to 1.0).

11. *Assign a leaching fraction to each field polygon based on the assigned random number.* As mentioned previously, it was assumed that 70% of the application losses (the magnitude of which is defined by the assigned irrigation efficiency) are attributable to recharge (deep percolation).

12. *Calculate the un-aggregated weekly recharge for each field polygon based on the calculated irrigation application, the effective precipitation amount, and the assigned leaching fraction.* These weekly values are aggregated (step 15) when the particular crop's irrigation frequency is larger than a weekly interval.

13. *Assign each field polygon an irrigation frequency based on crop type.*

14. *Assign each field polygon an irrigation timing code based on an assigned random number (using the MS Excel™ RANDBETWEEN function) when a start week must be determined (i.e. when the irrigation interval is greater than weekly).*

15. *Assign each field polygon the final weekly recharge amount by aggregating the weekly recharge amounts derived in Step 12 in accordance with the assigned irrigation timing parameters.*

16. *Export the final recharge values into a GIS polygon coverage (refer to Appendix H for further information on this step and the use of GIS utilities).*

17. *Import the GIS coverage into GMS and use software functions to translate data into the correct MODFLOW recharge package input format (refer to Appendix I for further information).*

APPENDIX G: PROJECT PHOTOGRAPHS

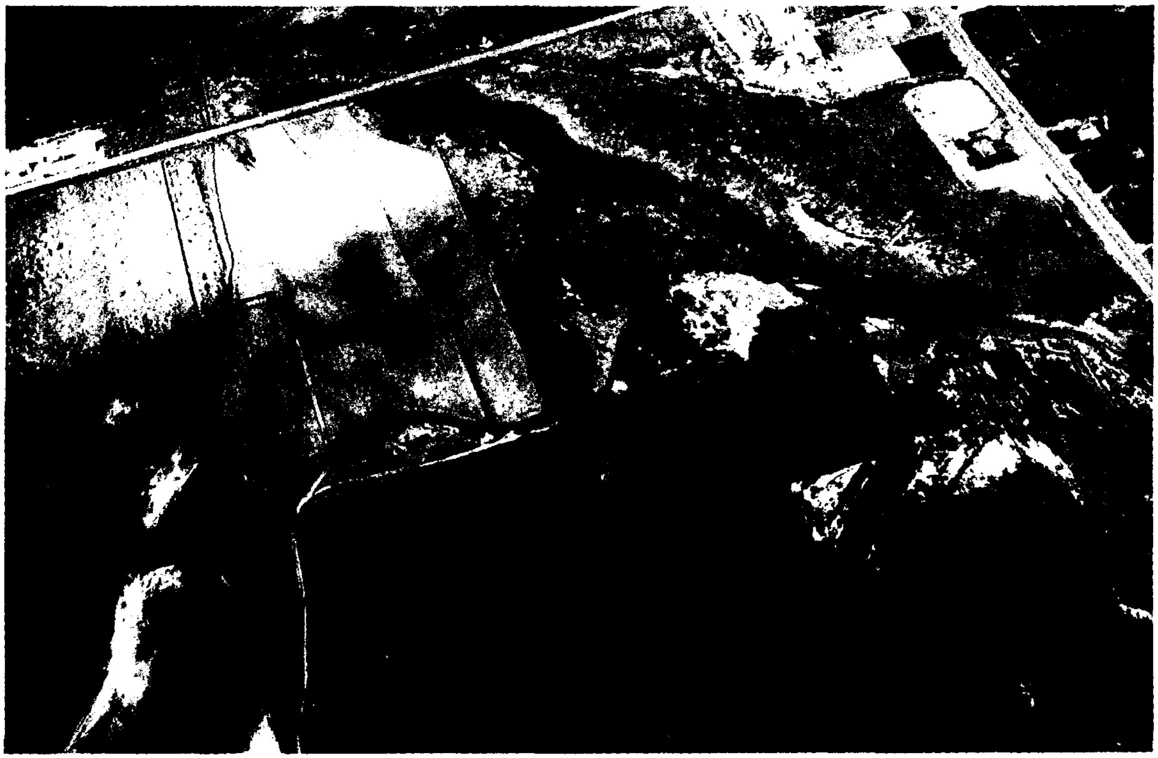


Figure G-1. Visible Evidence of Soil Salinity Within the Study Area – Aerial View

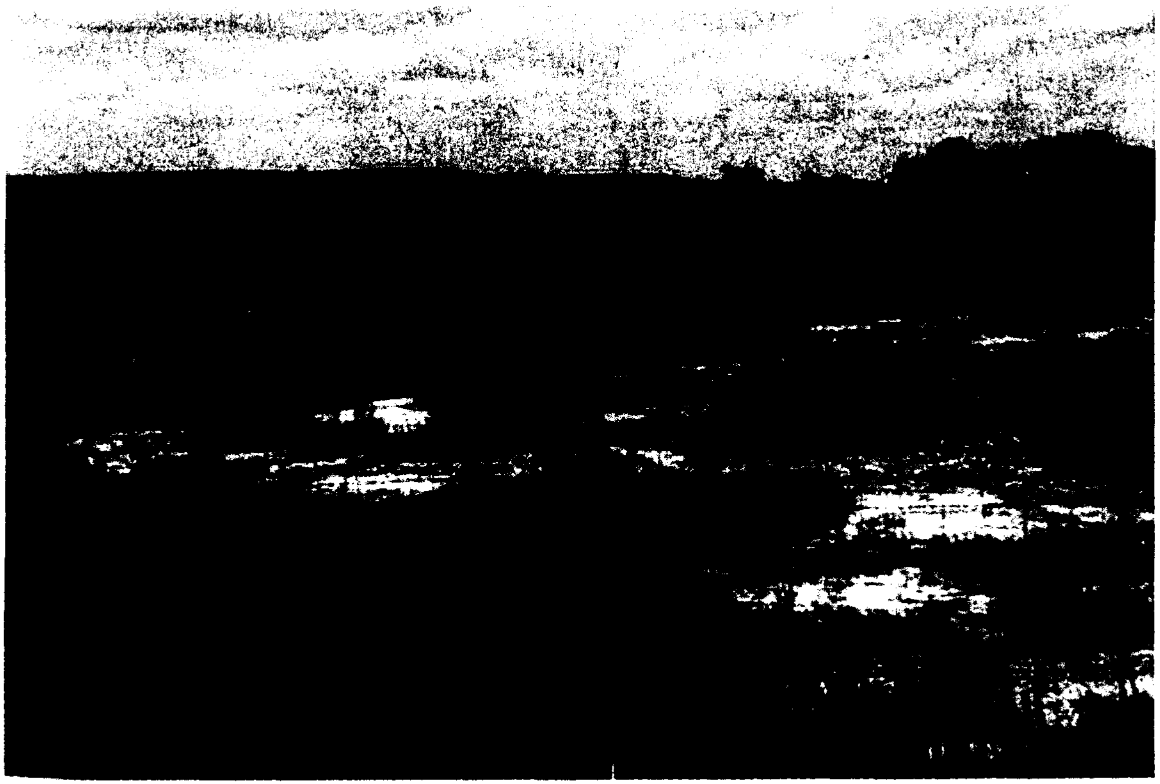


Figure G-2. Visible Evidence of Soil Salinity Within the Study Area

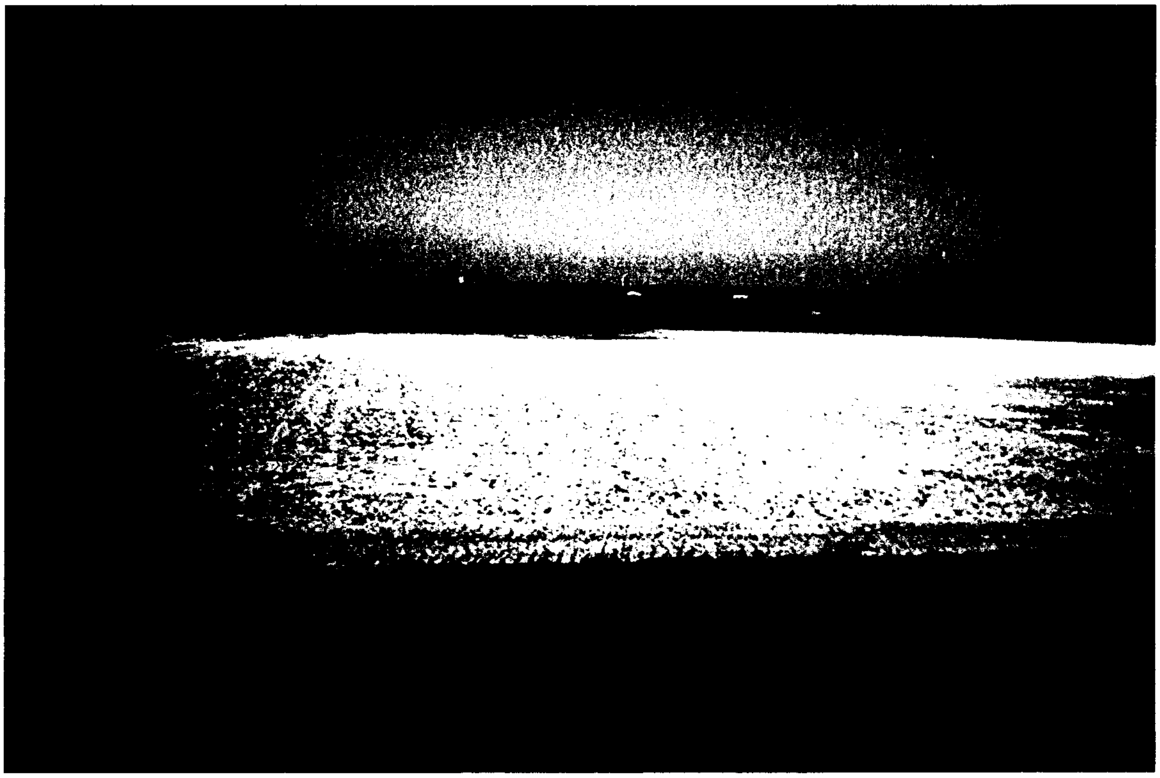


Figure G-3. Visible Evidence of Soil Salinity Within the Study Area

Figure G-4. Visible Evidence of Soil Salinity Within the Study Area

Figure G-5. Visible Evidence of Soil Salinity Within the Study Area

Figure G-6. Visible Evidence of Soil Salinity Within the Study Area

Figure G-7. Visible Evidence of Soil Salinity Within the Study Area

Figure G-8. Visible Evidence of Soil Salinity Within the Study Area

Figure G-9. Visible Evidence of Soil Salinity Within the Study Area

Figure G-10. Visible Evidence of Soil Salinity Within the Study Area

Figure G-11. Tile Drain Outlet Located Within the Study Area

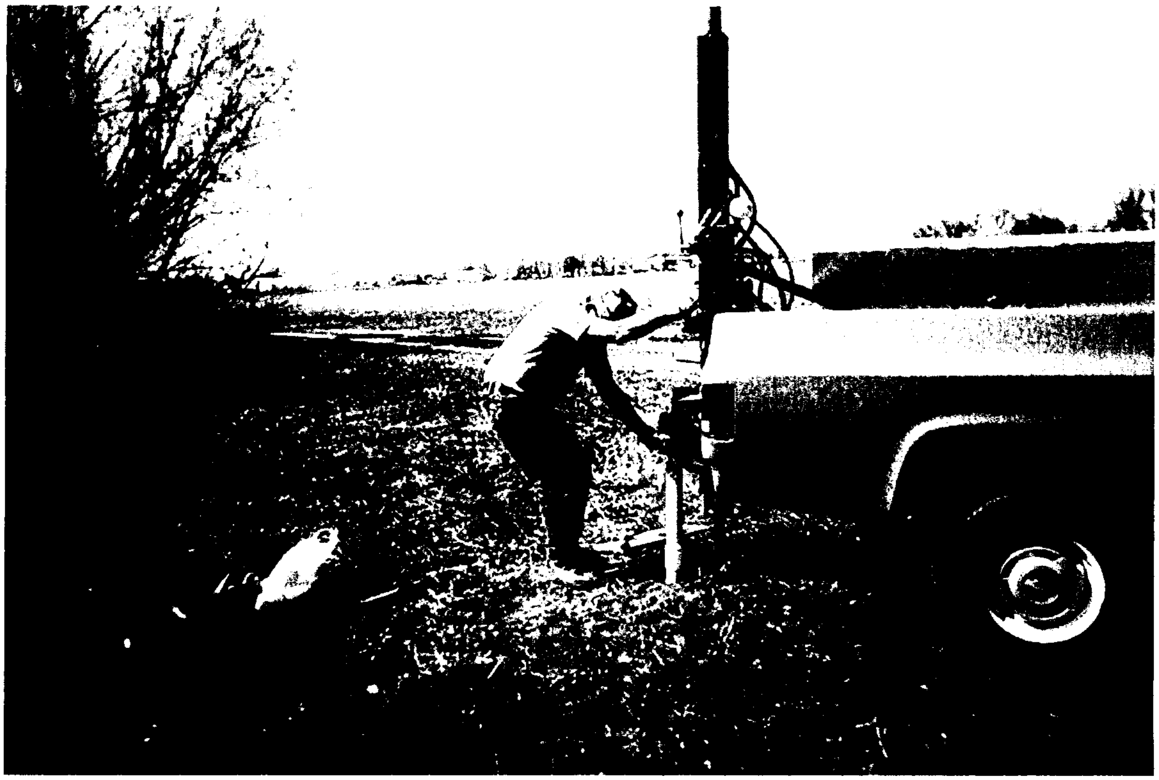


Figure G-12. Installation of Monitoring Well Adjacent to Edge of Irrigated Field

Figure G-13. Pressure Transducer and Data Logger Used to Conduct Slug Tests

Figure G-14. Truck-Mounted Drill Rig Used to Install Groundwater Monitoring Wells

Figure G-15. Using the EM-38 Meter to Monitor Soil Salinity

Figure G-16. Measuring Groundwater Conductivity at Monitoring Well Site

Figure G-17. Measuring Surface Water Conductivity in Drainage Within the Study Area

Figure G-18. GPS Surveying of Land Elevation Within the Study Area

Figure G-19. GPS Surveying of Surface Water Elevation Reference Point Along Fort Lyon Canal

Figure G-20. Measuring Discharge in Fort Lyon Canal for Seepage Analysis

Figure G-21. Arkansas River Near La Junta, Colorado

APPENDIX H: GIS ANALYSIS AND INPUT DATA PREPARATION

Geographic Information Systems (GIS) technology was critical to the success of the current study. Over the course of the project, multiple GIS software packages were utilized. Additionally, the model interface software (GMS ver. 3.1) used to construct the groundwater flow and salt transport numerical models and process model output has GIS features incorporated as a part of its functionality. This appendix summarizes three major project tasks that were completed using three separate GIS software packages. Other minor tasks also were completed using these tools, but the items presented were crucial to project success and, likely, could not have been performed without the aid of GIS.

SATELLITE DATA IMAGE PROCESSING

Landsat 7 Thematic Mapper (TM) data were purchased from the USGS Earth Resources Observation Systems (EROS) data center for use in creation of a background image upon which to build the conceptual model of the study region. The goal was to create a false-color image that would reveal areas of high soil water content/dense vegetation as red. From this image, regularly irrigated fields could be identified. Also, locations of surface features were verified using this image. After review of available field data and the corresponding meteorological data, an image taken on July 19, 1999 was selected for purchase.

Once obtained, the GIS software package known as IDRISI (Clark Labs) was used for data processing. IDRISI was selected for this particular image processing task because the available version included a feature specifically designed for processing satellite data in Band Sequential (BSQ) format such as the acquired Landsat TM data. The raw Landsat data were collected in seven data bands, i.e. spectral ranges, in a 30-meter raster format (although band 6 is collected in 60-meter resolution only). To create the false-color image, bands 3, 4, and 5 were used. The following steps were used in IDRISI to complete the image creation:

1. Import Landsat BSQ band data into the working GIS directory.
2. Specify the associated Landsat metadata (including raster grid size, coordinate system, number of rows, number of columns, etc.) within IDRISI's raster grid processing menu.
3. Create an initial false-color image using IDRISI's satellite image processing function. Band 3 was specified as the Red band, Band 4 was specified as the Blue band, and Band 5 was specified as the Green band.
4. Iteratively stretch (using IDRISI's stretch feature) the appropriate band to modify the output image color tone and brightness. Regenerate the image.
5. After final image is created, export in TIFF format for use in GMS.

The final image created using IDRISI is shown in Figure H-1.

FIELD POLYGON COVERAGE GENERATION

An important component of the current study was the representation of agricultural fields as polygons and the storage and management of the associated field data (acreage, crop

Figure H-1. Final Landsat Satellite Image (July 19, 1999)

type, field ID, estimated recharge, ET, etc.). To create this polygon layer, field boundary data were obtained from the USDA's Farm Service Agency (FSA) in Rocky Ford, CO, in the form of aerial photographs. An example of one of these photographs is shown in Figure H-2. Included on these photographs were field ID numbers that were used as an index within the associated field coverage databases. Crop type data relating crops that were grown to the corresponding field ID numbers were also obtained from the Farm Service Agency (FSA) several times over the course of the study for entry into the underlying polygon coverage database.

The field data were originally transferred from the aerial photographs into electronic form using a manual digitizer tablet connected to the Unix-based ArcInfo™ GIS package (ESRI). Once the original polygon coverage had been created, subsequent changes and

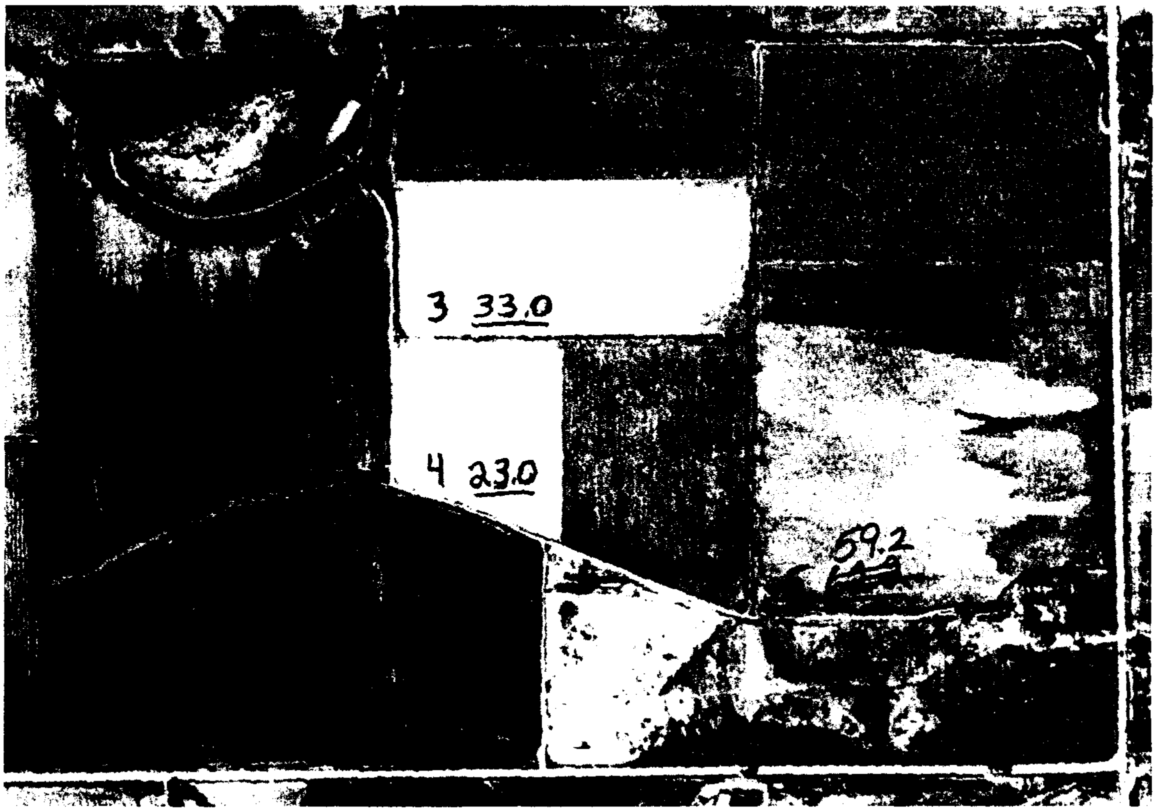


Figure H-2. Sample Aerial Photo Obtained from the FSA

database updates were performed in the Windows-based desktop version of ArcView™ 3.1 (ESRI). The field polygons were verified by overlaying the polygon coverage onto the derived Landsat image. Only a few minor modifications to the polygon coverage were required following this check, and most of these changes related to digitizer entry errors. The final field polygon coverage is shown in Figure H-3.

MODEL INPUT DATA PREPARATION

Following the creation of the satellite image and the generation of the field polygon coverage, ArcView™ 3.1 was used to create a polygon coverage that represented natural/non-farm areas within the study region. This coverage, along with the previously

Figure H-3. Final Field Polygon Coverage

created field polygon coverage, was then used to prepare a number of spatial data sets for numerical model input. This was accomplished by entering field polygon data directly into the coverage databases. Typically, MS Excel™ was used to accomplish this outside of the ArcView™ database manager. The field ID numbers mentioned previously were used to index all data and to relate the data to the specific polygon locations.

The data sets that were processed in this manner are listed in Table H-1. Each of these data sets was stored in ArcView™'s shapefile format. Shapefiles were generated for each of the three irrigation seasons within the modeled time period (April – Oct. 1999, April – Oct. 2000, and April – Oct. 2001) and the two modeled non-irrigation "off-seasons" (Nov. 1999 – March 2000 and Nov. 2000 – March 2001). These time periods were separated out into individual shapefiles simply to reduce file size and to reduce the data processing burden. Each of these shapefiles could store several time steps if required for the particular data type. The shapefiles were then directly imported into the GMS interface using the Map Module features and were translated into the appropriate numerical model input format using either the Map → MODFLOW or the Map → MT3DMS command.

Table H-1. Input Data Sets Prepared Using GIS Outside of GMS Interface

Input Data Set	*Model Application*
Recharge Rate	MODFLOW
ET Rate (Upflux Rate)	MODFLOW/Unsaturated Zone Salinity Module
ET Extinction Depth	MODFLOW
Crop Type	Unsaturated Zone Salinity Module
Irrigation Application Rate	Unsaturated Zone Salinity Module
Irrigation Water Salinity	Unsaturated Zone Salinity Module
Leaching Efficiency	Unsaturated Zone Salinity Module

APPENDIX I: SPECIAL GMS PROCEDURES AND NOTES

This appendix describes a special procedure for using GMS 3.1 features to build the transient model input files. It is presented because it is not a typical method described in the GMS manual. Although other methods were available within the GMS interface and using outside means, the procedures described here were found to be the most efficient. The steps presented were used to translate all input data associated with the modeled field polygons (as well as natural/non-irrigated area polygons) into the correct format for input into MODFLOW, MT3DMS, or the Unsaturated Zone module.

Prior to implementing the steps listed below, the polygon data should be processed using GIS and saved in shapefile format. Also, depending upon the number of model cells, to limit the size of the associated GMS files, it may be necessary to set up a temporary GMS project which incorporates only one or two specified stress periods. The steps used using GMS 3.1 to translate the shapefile data into the correct model format are as follows:

1. **Create a new coverage within the *Map Module*.** This coverage should be specified as coverage type *MODF/MT3D/MODP*, and the option *MODF/MT3D Areal attributes* should be selected. A screen shot of the GMS interface showing these menus is shown in Figure I-1 on page I-4.

2. **Import the shapefile data into the created coverage using the *Import* command within the *Coverage* command window (as shown in Figure I-2 on page I-5).** Within the *Import* pop-up window, the feature type (which should be incorporated into the shapefile database) and imported data set should be mapped to the GMS coverage data fields as shown in Figure I-3 on page I-6. Typically, the *Recharge* field was used to store the new data set, although any of the GMS data fields could be used.

3. **Run the *Map to MODFLOW* command under the *Coverage* menu.**

4. **If data set is for use in MODFLOW, save the temporary MODFLOW model files using the *Save Simulation* command under the *MODFLOW* menu of the *3-D Grid module*.** The data array can then be copied into the transient model input file which is being built. For data intended for use in MT3DMS or the Unsaturated Zone module, proceed to steps 5 – 7.

5. **If data set is for use in MT3DMS or the Unsaturated Zone module, then the data set must be transferred from the *3-D Grid module* into 2-D data set format.** If data were saved in the *Recharge* data field of MODFLOW, this would be accomplished by using the *Array → 2-D Data Set* command in the *MODFLOW Recharge Package* dialog box. Figure I-4 on page I-7 shows a screen shot of this step.

6. **Under the *MT3D* menu of the *3-D Grid module*, within the *Source/Sink mixing package* dialog window, import the created 2-D data set into an array using one of the data field buttons within the *Areally distributed sources/sinks* command box**. After selecting a data field, import the 2-D data set using the *Data Set* → *Array* command. An example GMS screen shot using the *Recharge* data field is given in Figure I-5 on page I-8.

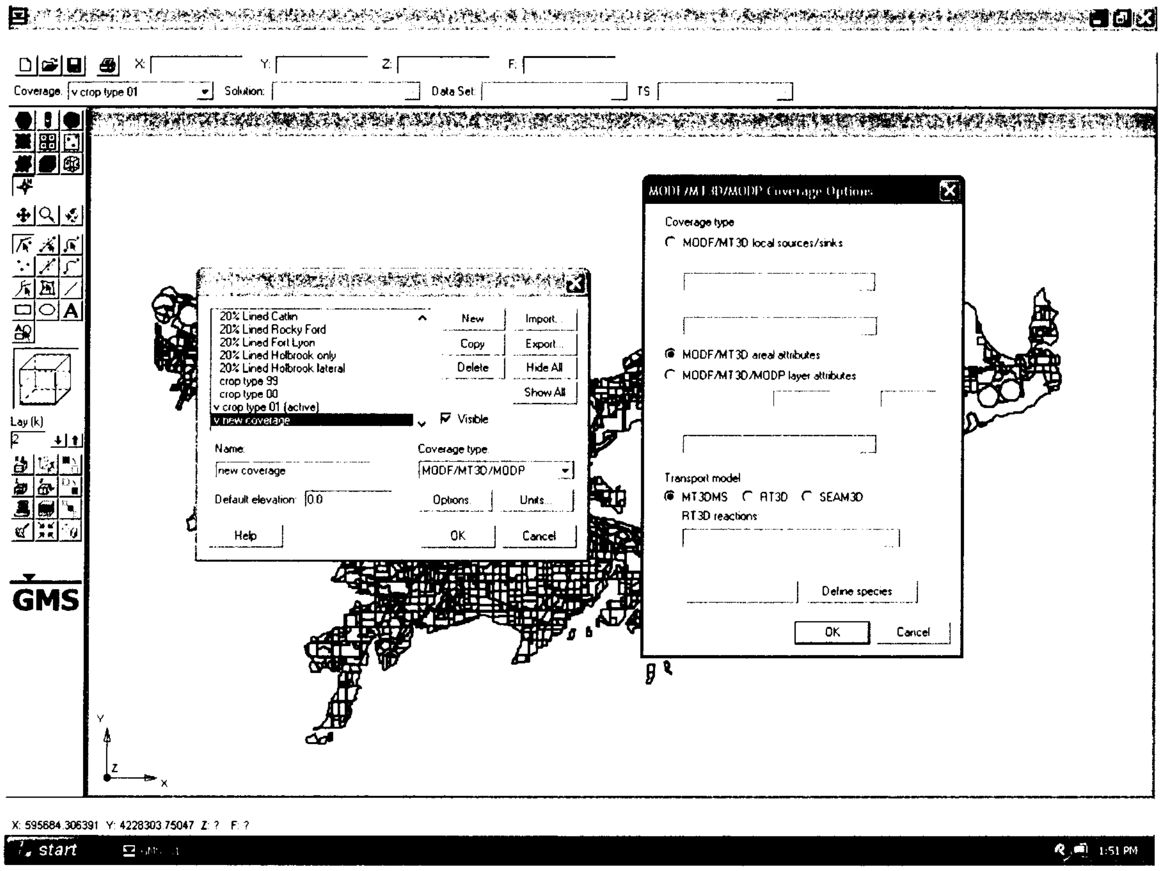
7. **Save the temporary MT3DMS model files using the *Save Simulation* command under the *MT3D* menu of the *3-D Grid module*.** The data array can now be copied from the temporary *.ssm file into the appropriate transient model input file.

GMS 3.1 NOTES

In general, the standard procedures documented in the GMS Users Manual for model construction were followed; however, it was found that the data entry procedures recommended for transient model construction were not practical for the model size required in the current study. Specifically, the manual data entry requirements for some transient data sets are cumbersome when several stress periods are specified. Therefore, procedures, such as that described above, that incorporate tools outside of GMS were devised.

The data calculator functions in both the *2-D Grid module* and the *3-D Grid module* were useful in processing model input and output. Limitations do exist, however, on the number of data sets that can be incorporated in a single calculation. Because of these limits, often a temporary intermediate file or files would be required.

Over the course of the project, bugs in the GMS software were occasionally encountered. Typically, the bugs would result in the aborting of the program during some process. In a few other instances, however, the software bugs resulted in model input file formatting errors. In these cases, these errors were ultimately corrected outside of the GMS interface.



Coverage: v crop type 01

20% Lined Catlin
20% Lined Rocky Ford
20% Lined Fort Lyon
20% Lined Holbrook only
20% Lined Holbrook lateral
crop type 99
crop type 00
v crop type 01 (active)
v new coverage

☑ Visible

Name: new coverage

Coverage type: MODF/MT3D/MODP

Default elevation: 0.0

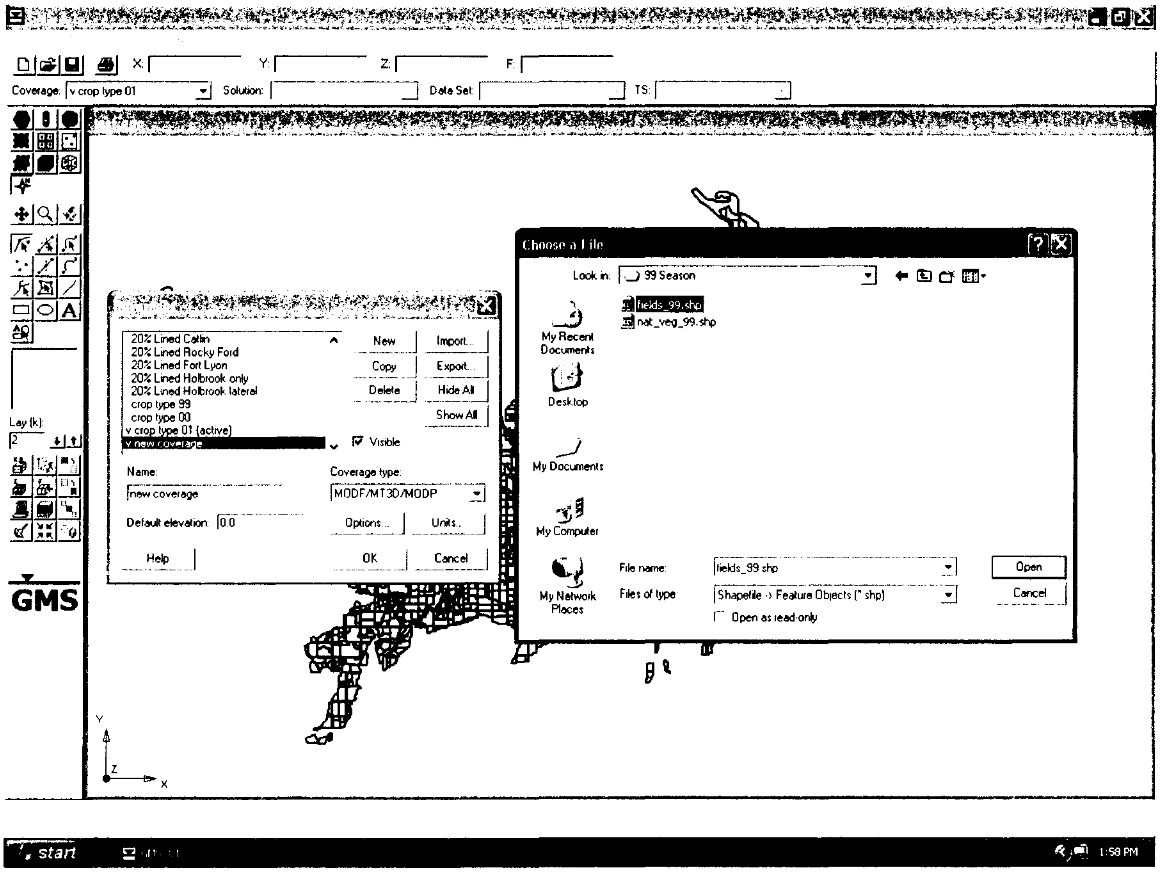
MODF/MT3D/MODP Coverage Options

Coverage type
○ MODF/MT3D local sources/sinks
● MODF/MT3D areal attributes
○ MODF/MT3D/MODP layer attributes

Transport model
● MT3DMS ○ RT3D ○ SEAM3D
RT3D reactions:

X: 595684.306391 Y: 4228303.75047 Z: ? F: ?

Figure I-1. Step 1 Screen Shot of GMS 3.1 Interface



Coverage: v crop type 01

Lay (k): 2

20% Lined Catlin
20% Lined Rocky Ford
20% Lined Fort Lyon
20% Lined Holbrook only
20% Lined Holbrook lateral
crop type 99
crop type 00
v crop type 01 (active)
v new coverage

☑ Visible

Name: new coverage

Coverage type: MODF/MT3D/MODP

Default elevation: 0.0

Look in: 99 Season

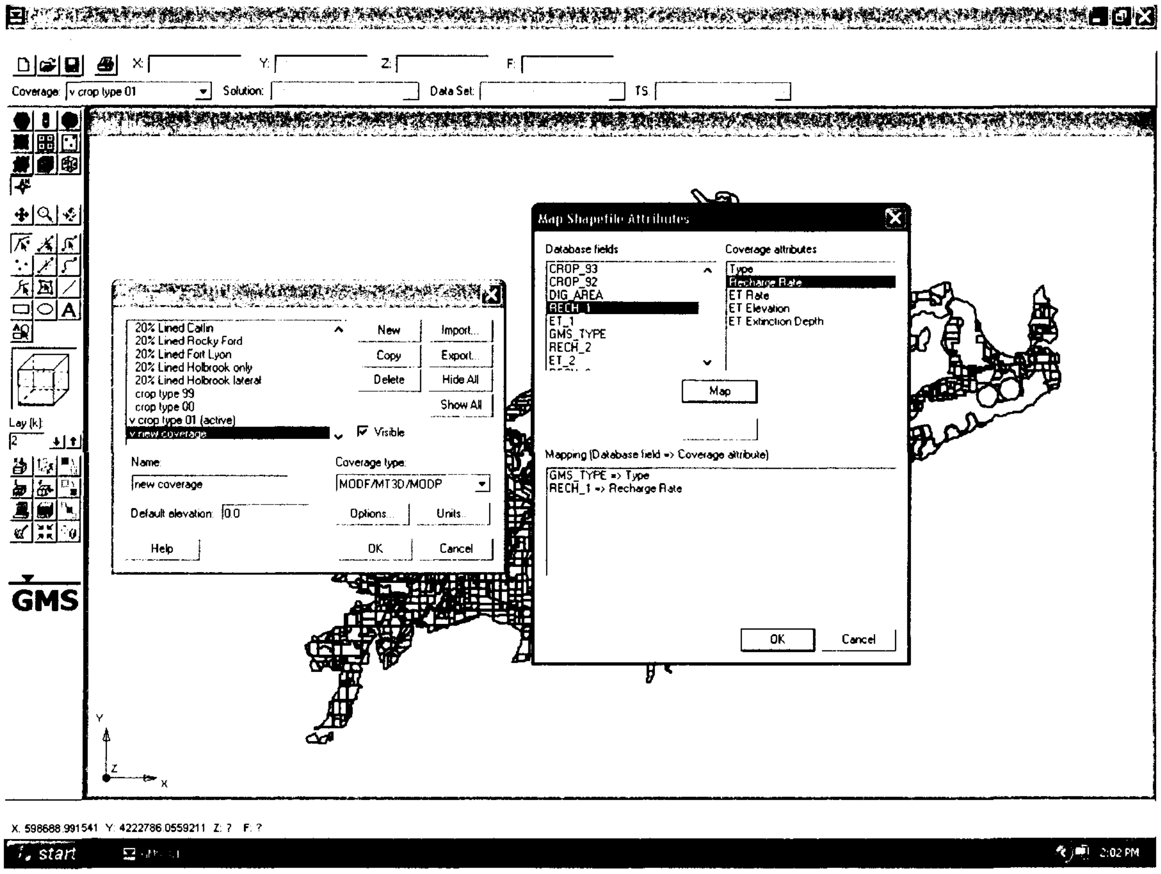
fields_99.shp
nat_veg_99.shp

File name: fields_99 shp

Files of type: Shapefile -> Feature Objects (* shp)

☐ Open as read-only

Figure I-2. Step 2 (Import Data) Screen Shot of GMS 3.1 Interface



Coverage: v crop type 01

20% Lined Catlin
20% Lined Rocky Ford
20% Lined Fort Lyon
20% Lined Holbrook only
20% Lined Holbrook lateral
crop type 99
crop type 00
v crop type 01 (active)
v new coverage

☑ Visible

Name: new coverage

Coverage type: MODF/MT3D/MODP

Default elevation: 0.0

Map Shapefile Attributes

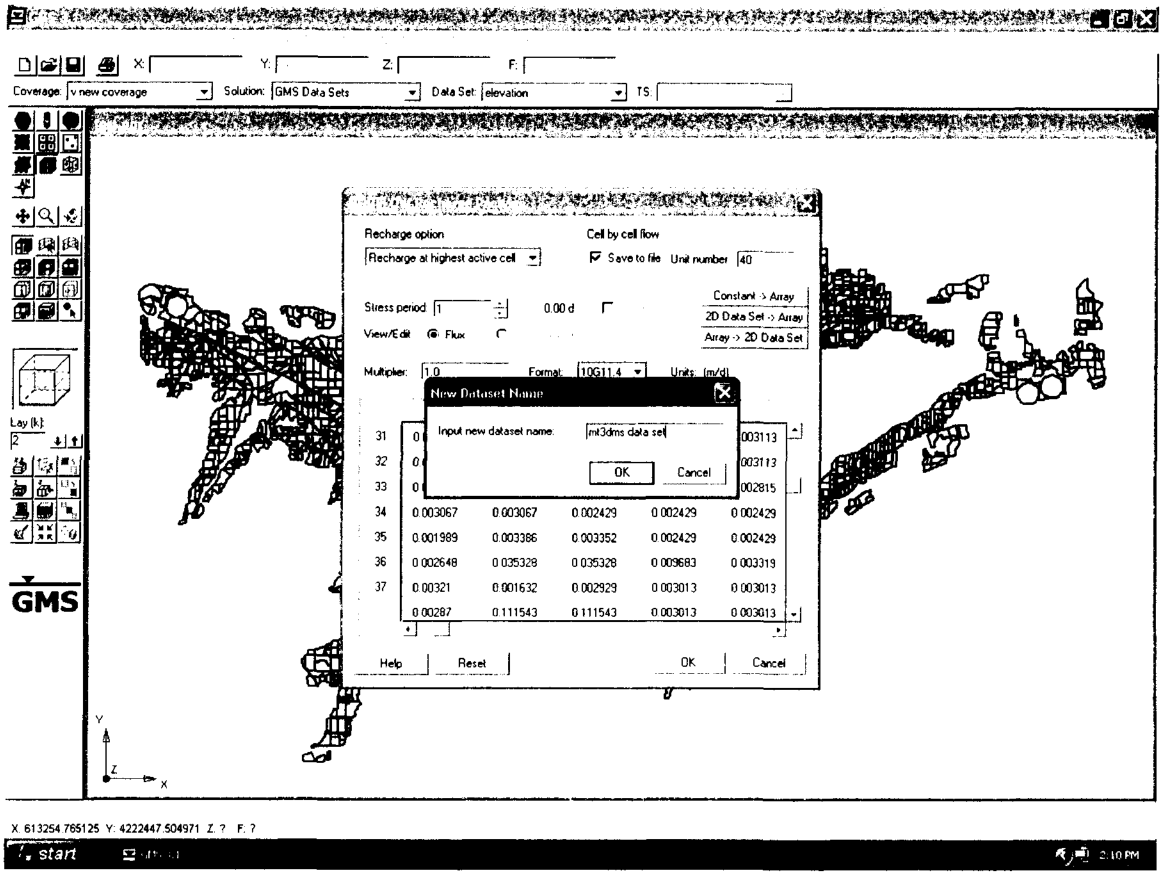
Database fields
CROP_93
CROP_92
DIG_AREA
RECH_1
ET_1
GMS_TYPE
RECH_2
ET_2

Coverage attributes
Type
Recharge Rate
ET Rate
ET Elevation
ET Extinction Depth

Mapping (Database field => Coverage attribute)
GMS_TYPE => Type
RECH_1 => Recharge Rate

X: 598688.991541 Y: 4222786.0559211 Z: ? F: ?

Figure I-3. Step 2 (Map data fields) Screen Shot of GMS 3.1 Interface



Coverage: v new coverage

Solution: GMS Data Sets

Data Set: elevation

Recharge option: Recharge at highest active cell

Cell by cell flow: ☑ Save to file

Unit number: 40

Stress period: 1

0.00 d ☐

View/Edit: ● Flux ○

Multiplier: 1.0

Format: 10G11.4

Units: (m/d)

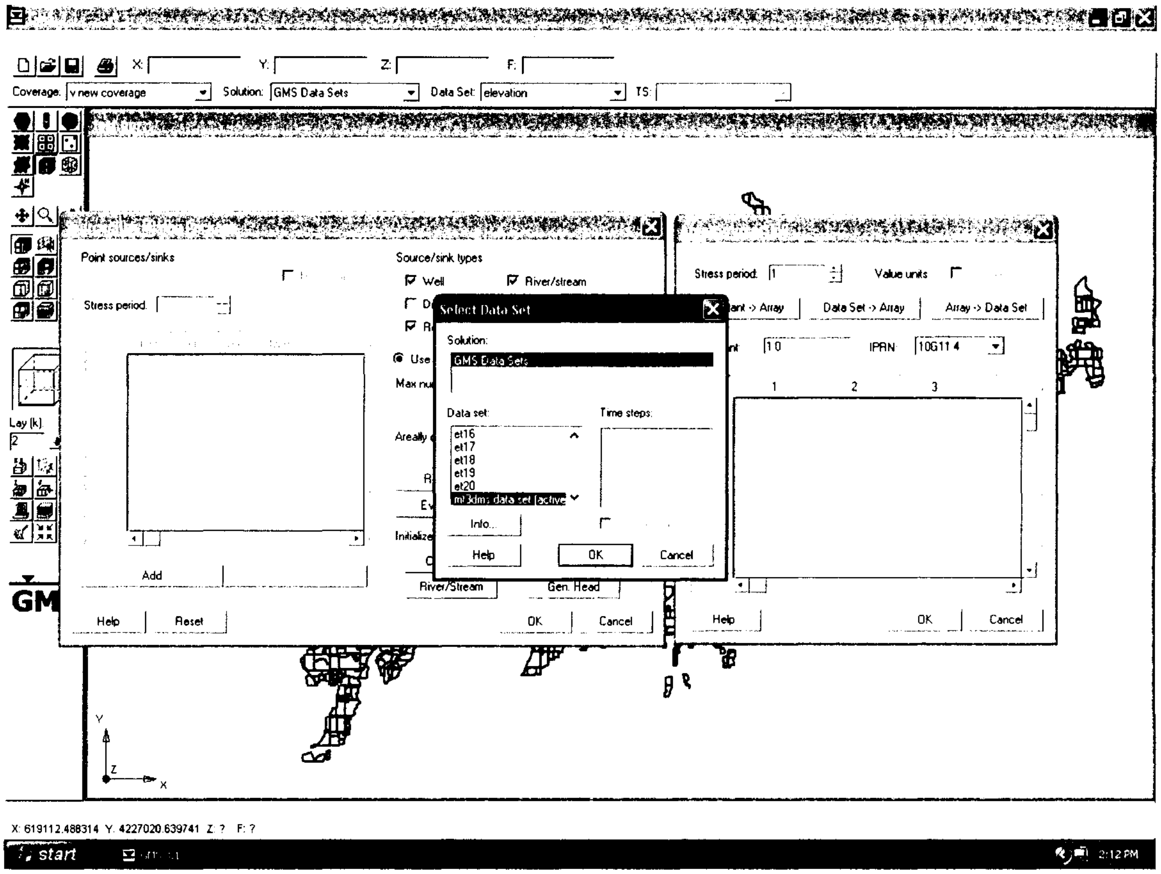
New Dataset Name

Input new dataset name: mt3dms data set

31	0				003113
32	0				003113
33	0				002815
34	0.003067	0.003067	0.002429	0.002429	0.002429
35	0.001989	0.003386	0.003352	0.002429	0.002429
36	0.002648	0.035328	0.035328	0.009683	0.003319
37	0.00321	0.001632	0.002929	0.003013	0.003013
	0.00287	0.111543	0.111543	0.003013	0.003013

X 613254.765125 Y: 4222447.504971 Z ? F ?

Figure I-4. Step 5 Screen Shot of GMS 3.1 Interface



Coverage: v new coverage
Solution: GMS Data Sets
Data Set: elevation

Lay (k): 2

Source/sink types
☑ Well
☑ River/stream

Stress period: 1
IPRN: 10G11.4

Select Data Set
Solution: GMS Data Sets
Data set: et16, et17, et18, et19, et20, m/3dm: data set (active

X: 619112.488314 Y: 4227020.639741 Z: ? F: ?

Figure I-5. Step 6 Screen Shot of GMS 3.1 Interface

APPENDIX J: ADDITIONAL CALIBRATION RESULTS – WATER TABLE DEPTH

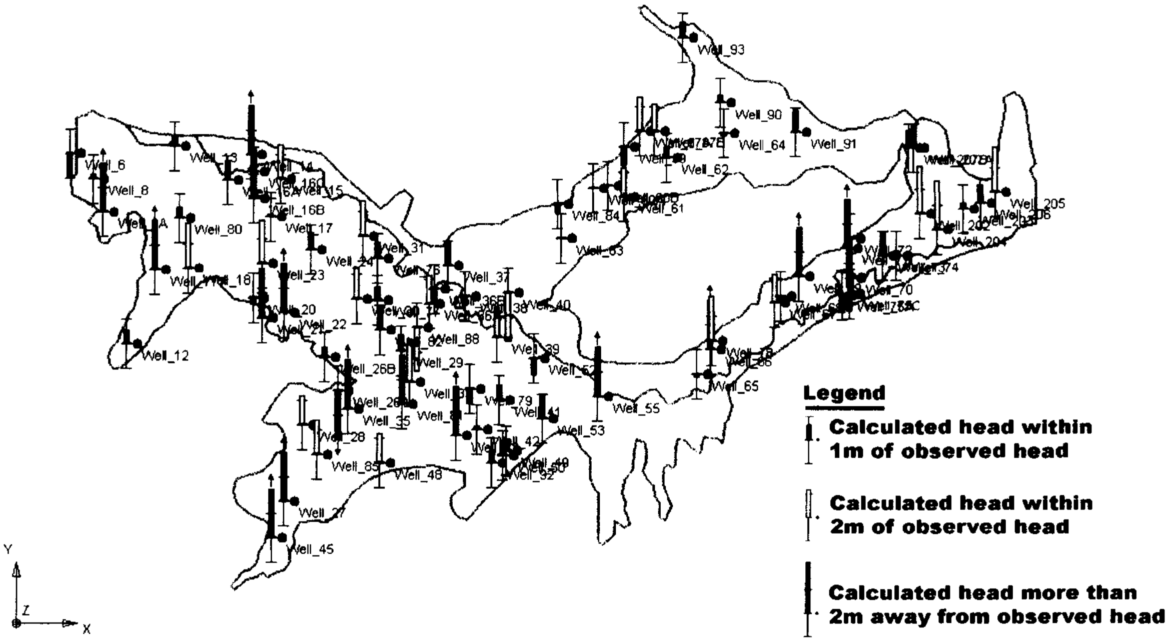


Figure J-1. Water Table Depth Calibration Results – Time Step 4

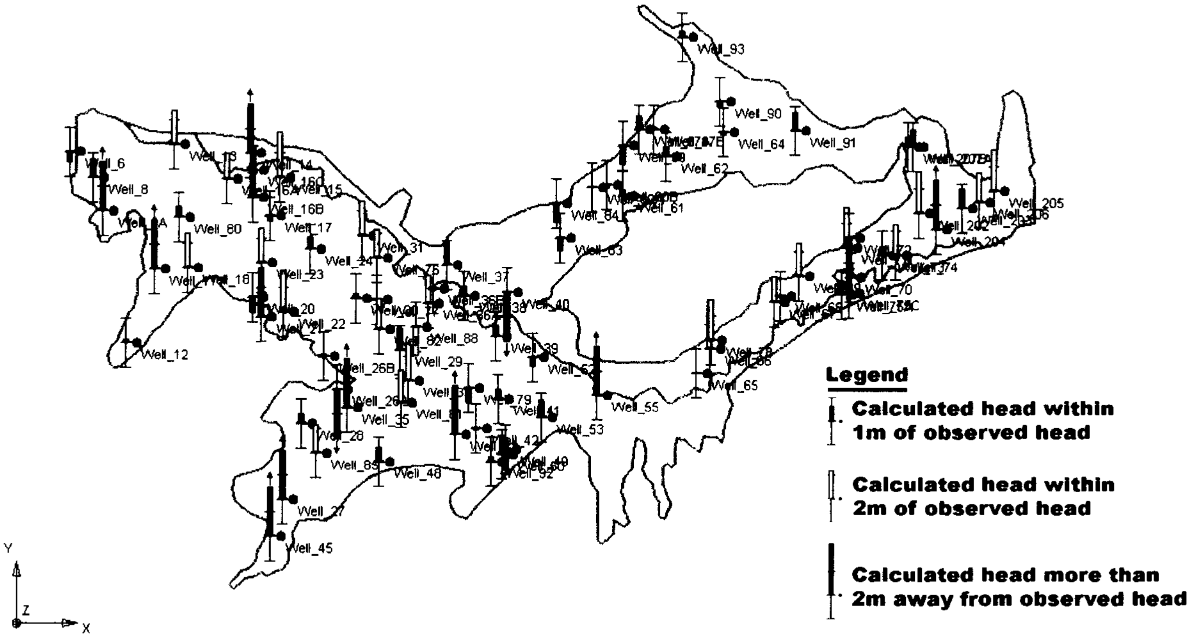


Figure J-2. Water Table Depth Calibration Results – Time Step 6

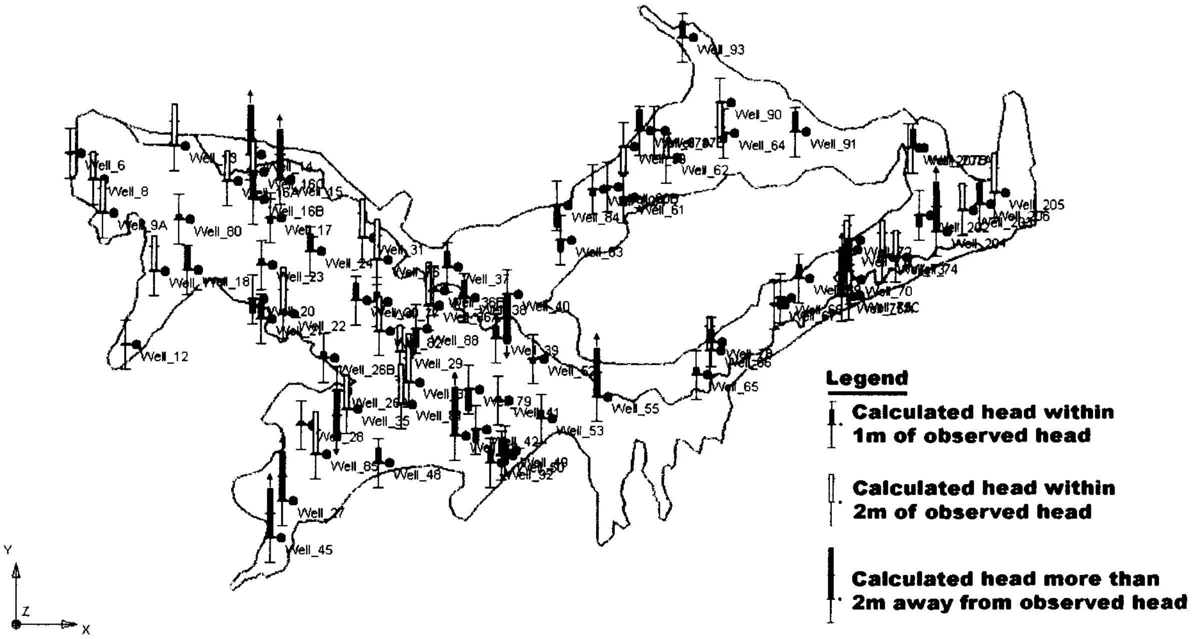


Figure J-3. Water Table Depth Calibration Results – Time Step 9

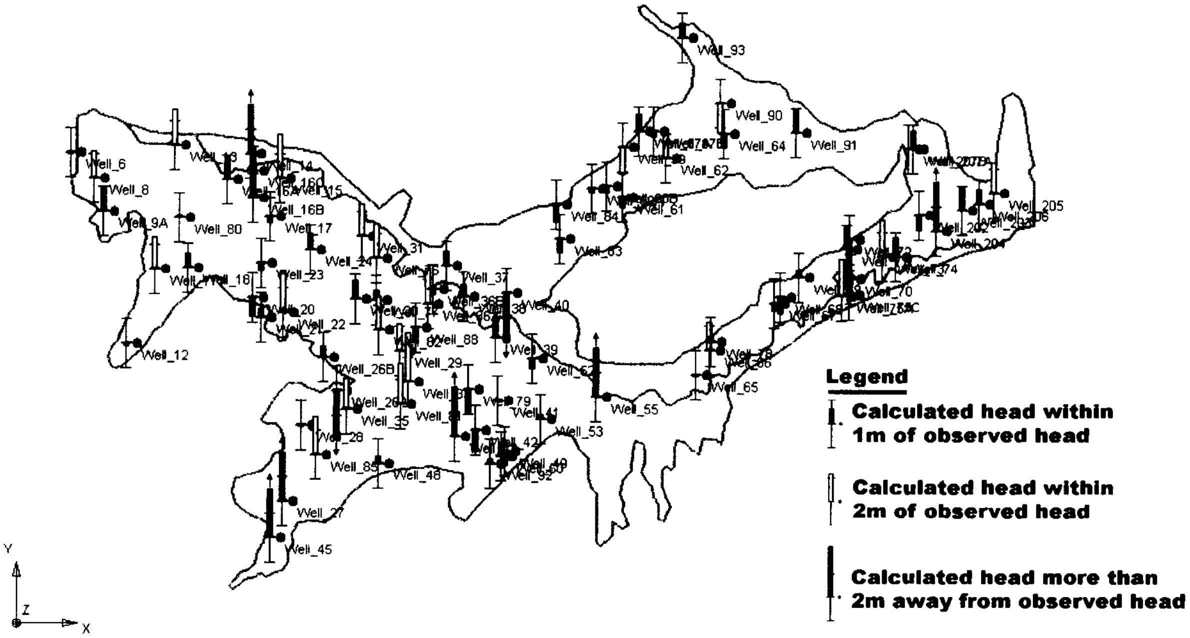


Figure J-4. Water Table Depth Calibration Results – Time Step 10

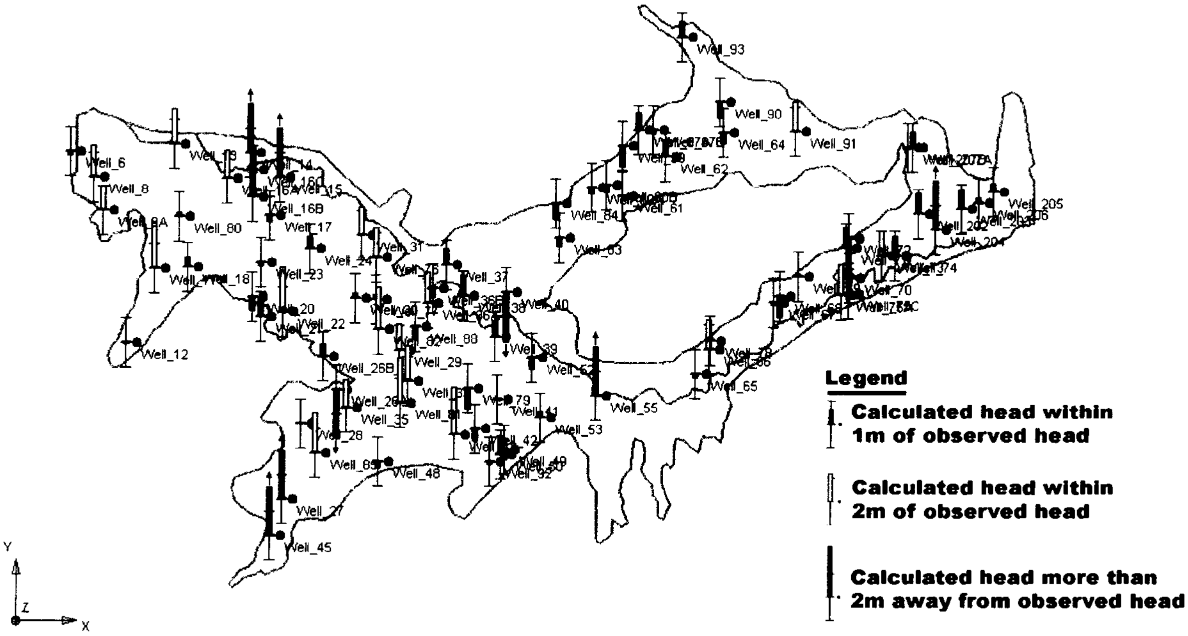


Figure J-5. Water Table Depth Calibration Results – Time Step 11

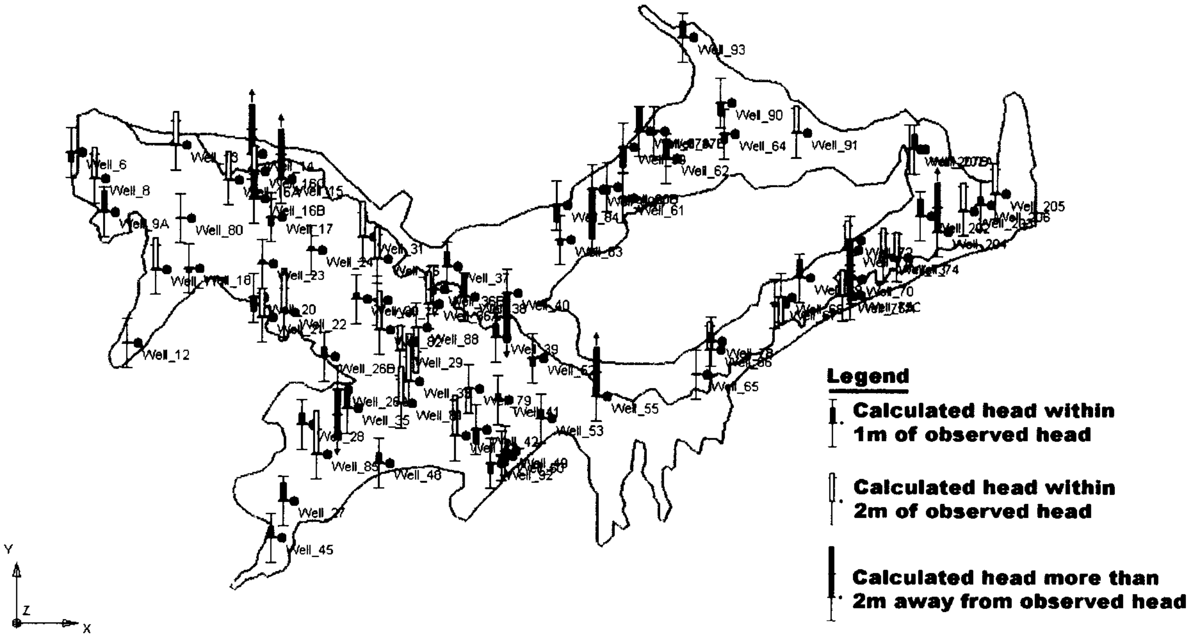


Figure J-6. Water Table Depth Calibration Results – Time Step 12

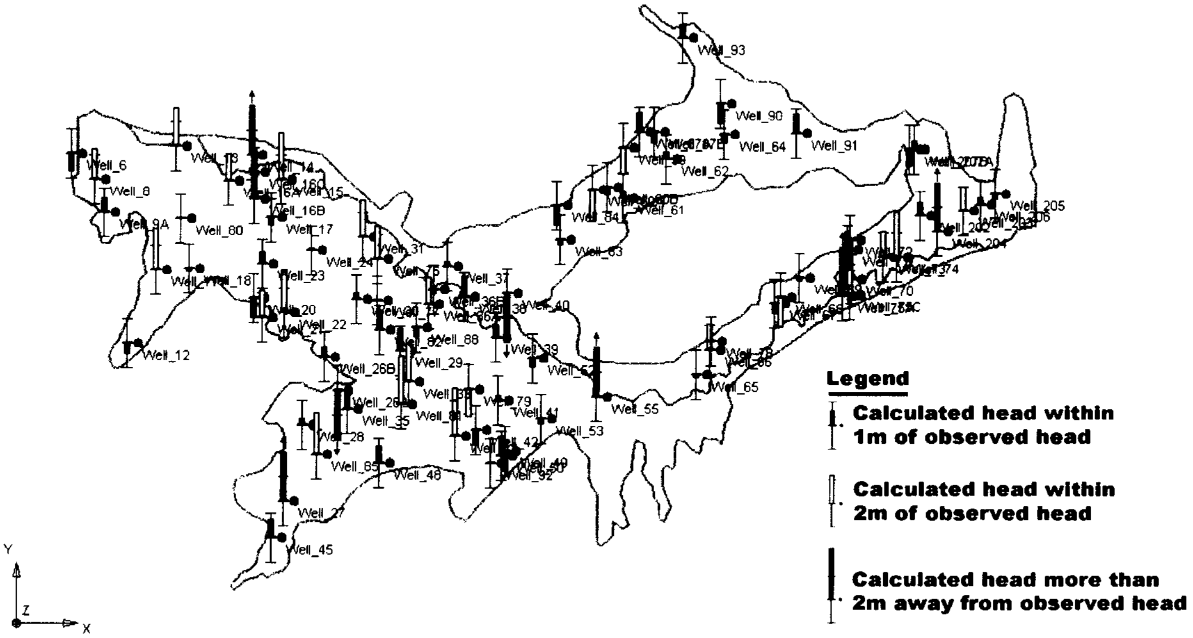


Figure J-7. Water Table Depth Calibration Results – Time Step 13

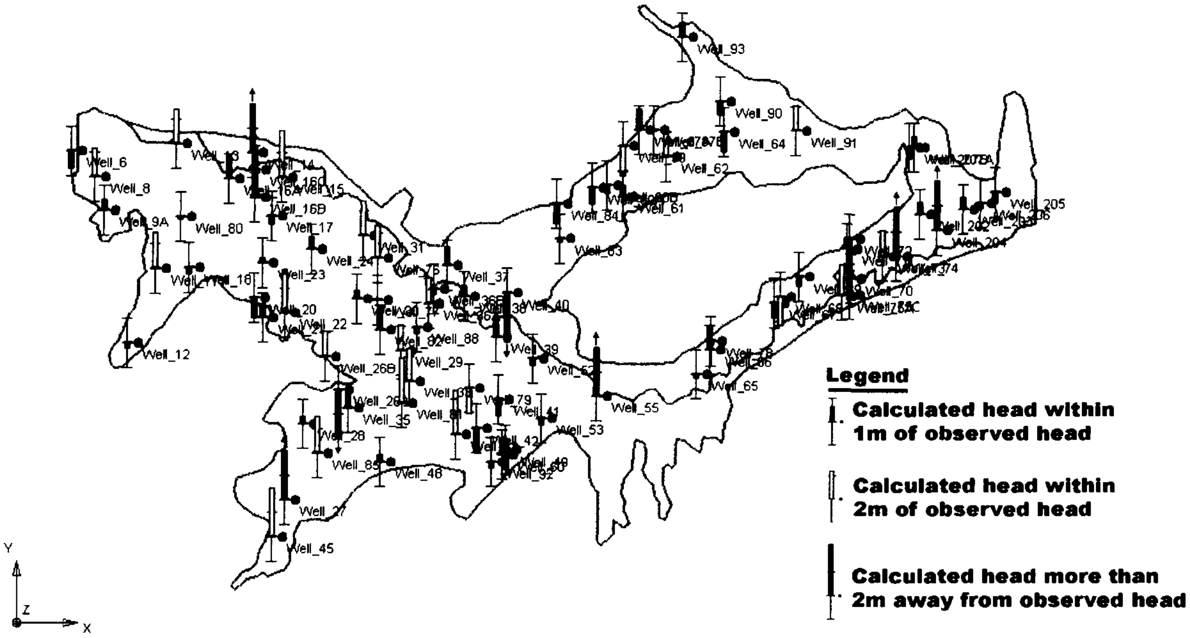


Figure J-8. Water Table Depth Calibration Results – Time Step 14

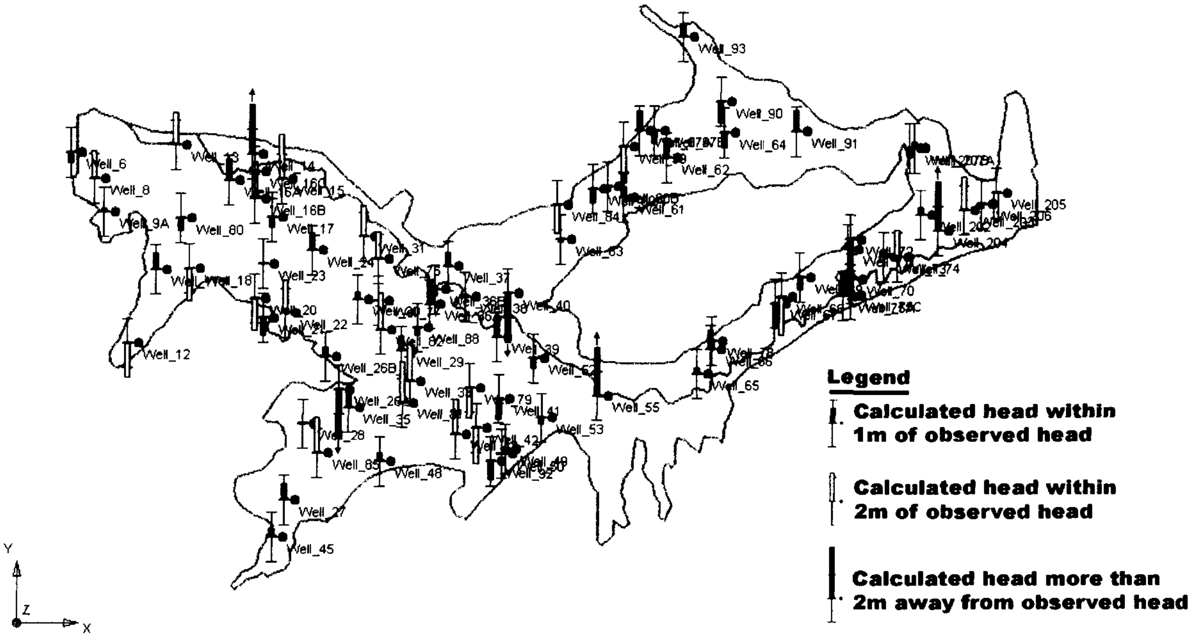


Figure J-9. Water Table Depth Calibration Results – Time Step 15

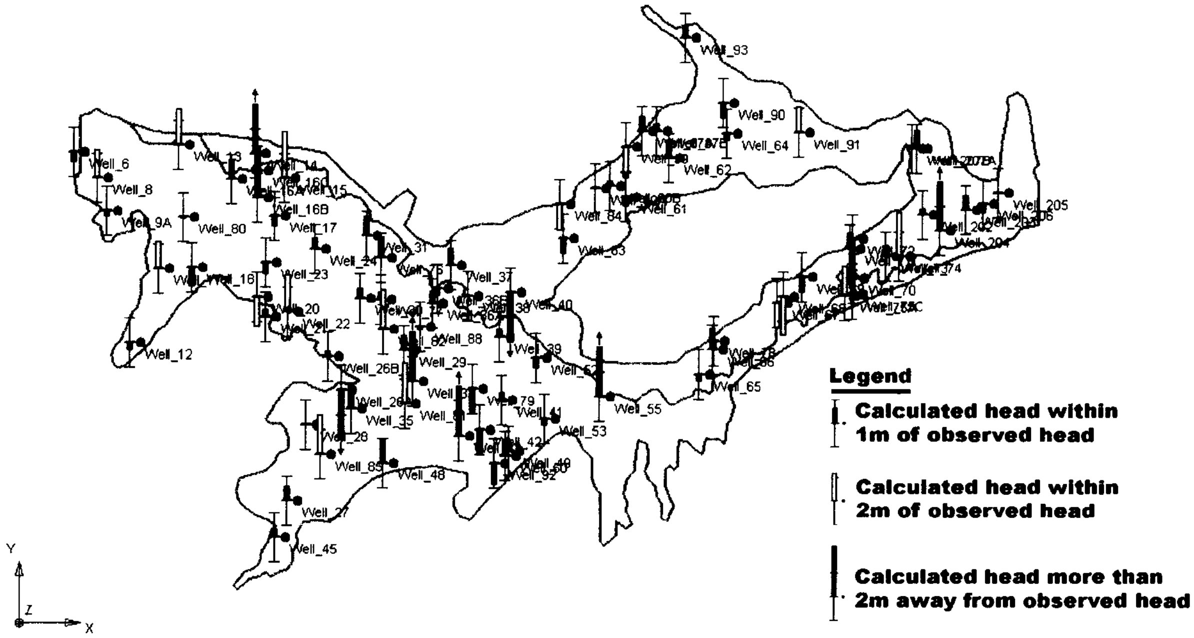


Figure J-10. Water Table Depth Calibration Results – Time Step 16

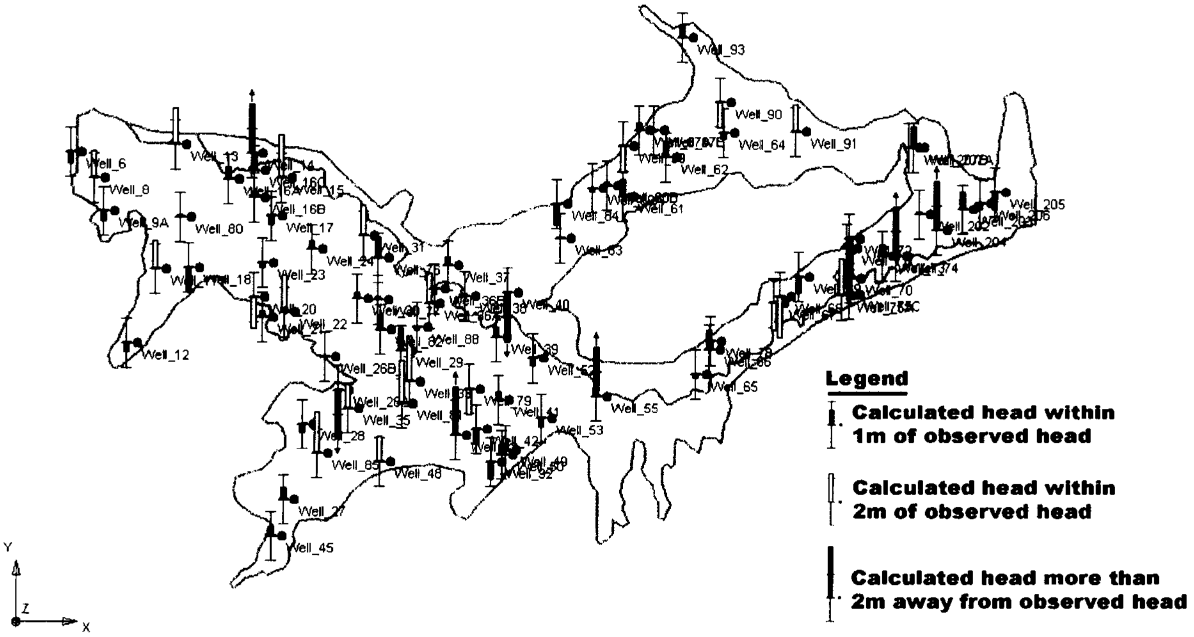


Figure J-11. Water Table Depth Calibration Results – Time Step 17

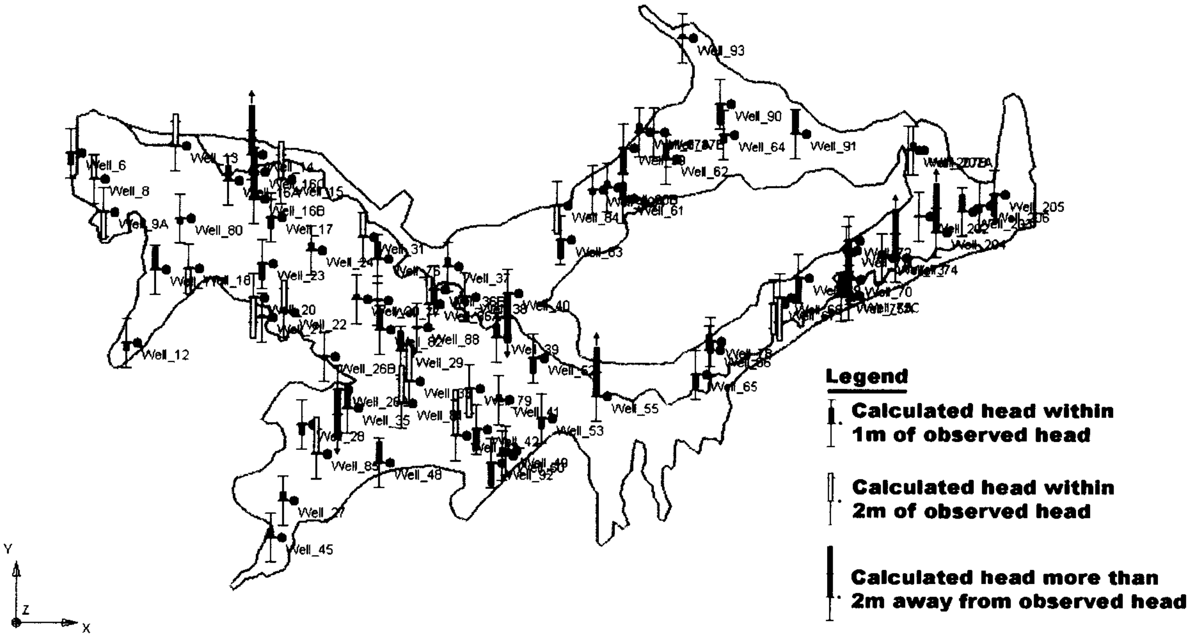


Figure J-12. Water Table Depth Calibration Results – Time Step 18

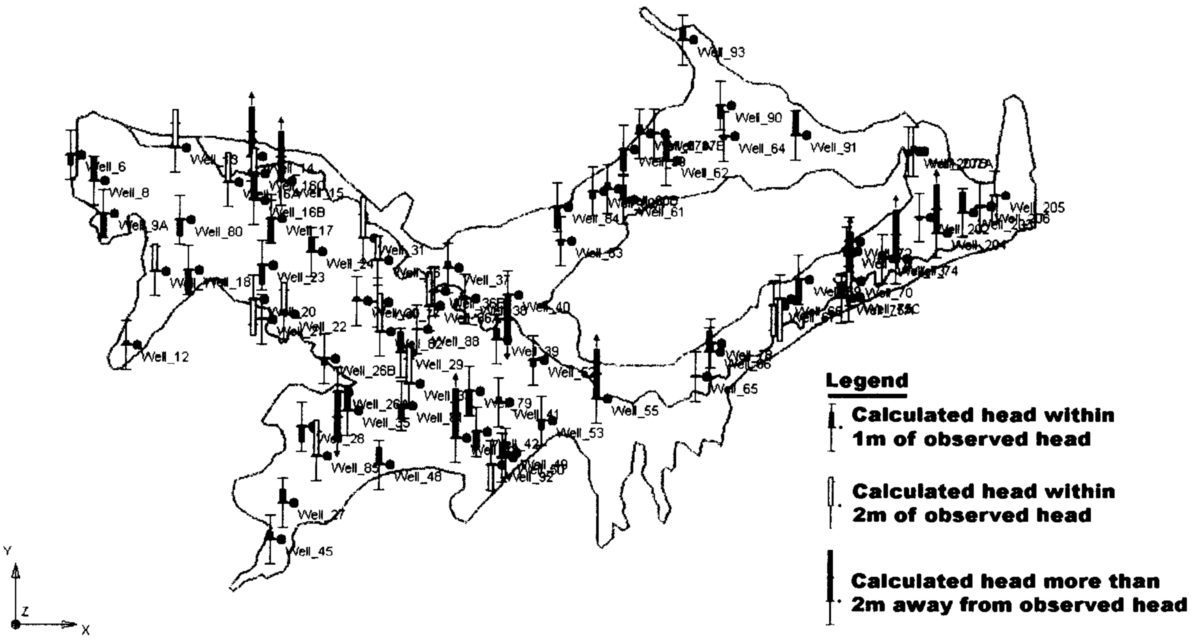
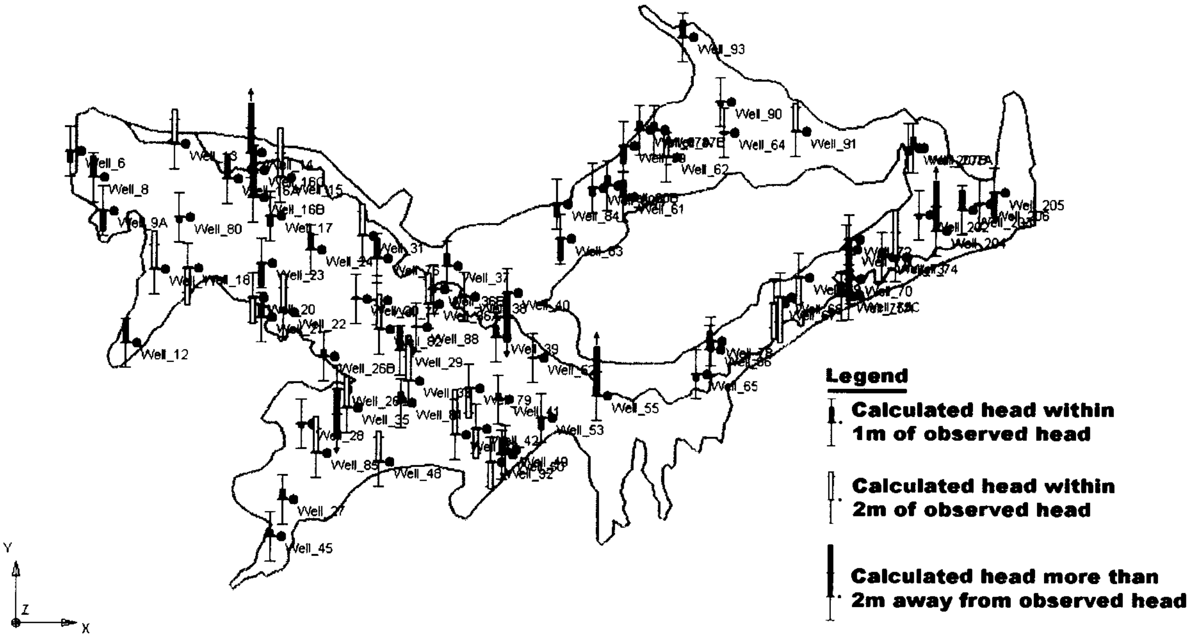


Figure J-13. Water Table Depth Calibration Results – Time Step 19



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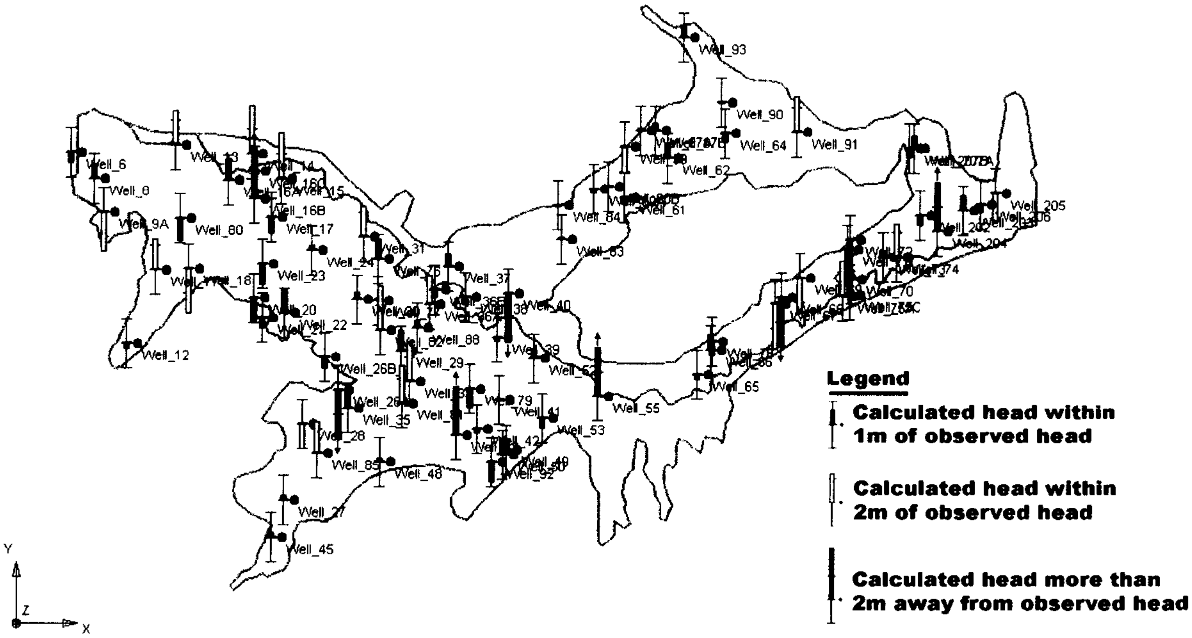


Figure J-15. Water Table Depth Calibration Results – Time Step 23

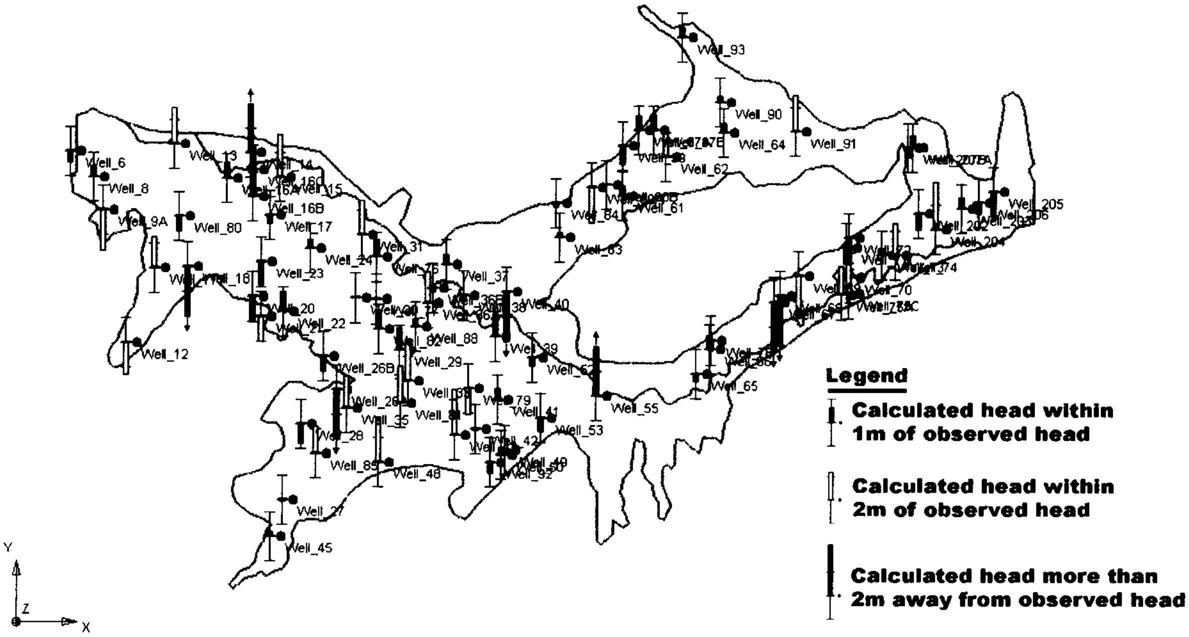
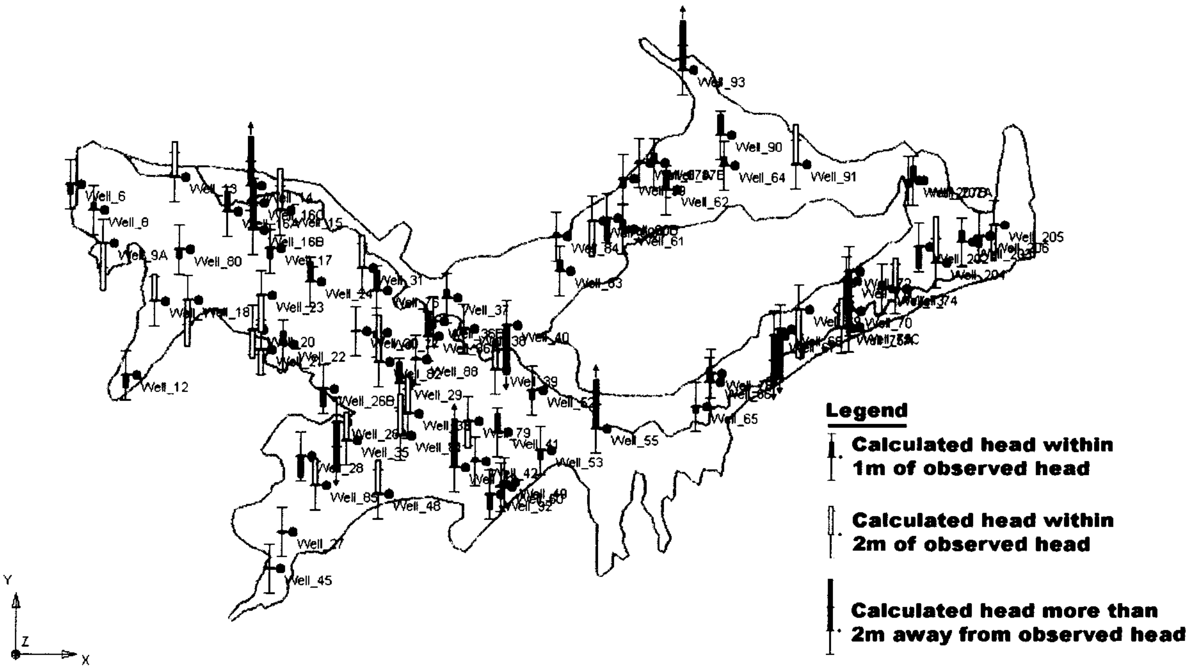


Figure J-16. Water Table Depth Calibration Results – Time Step 25



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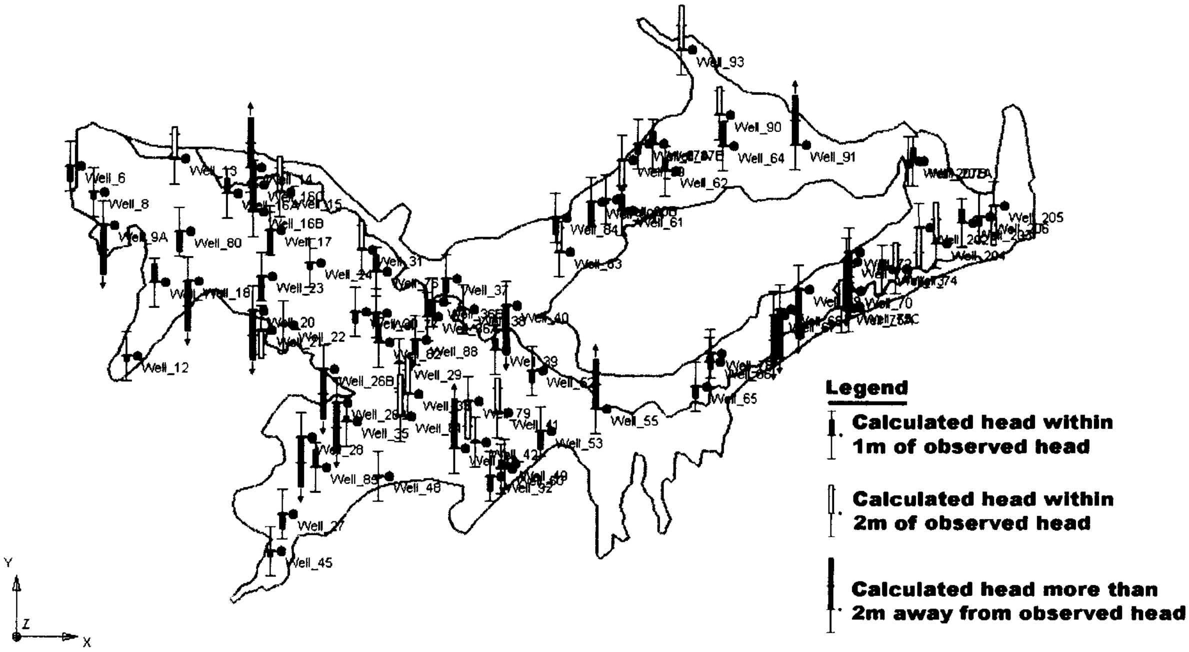


Figure J-18. Water Table Depth Calibration Results – Time Step 33

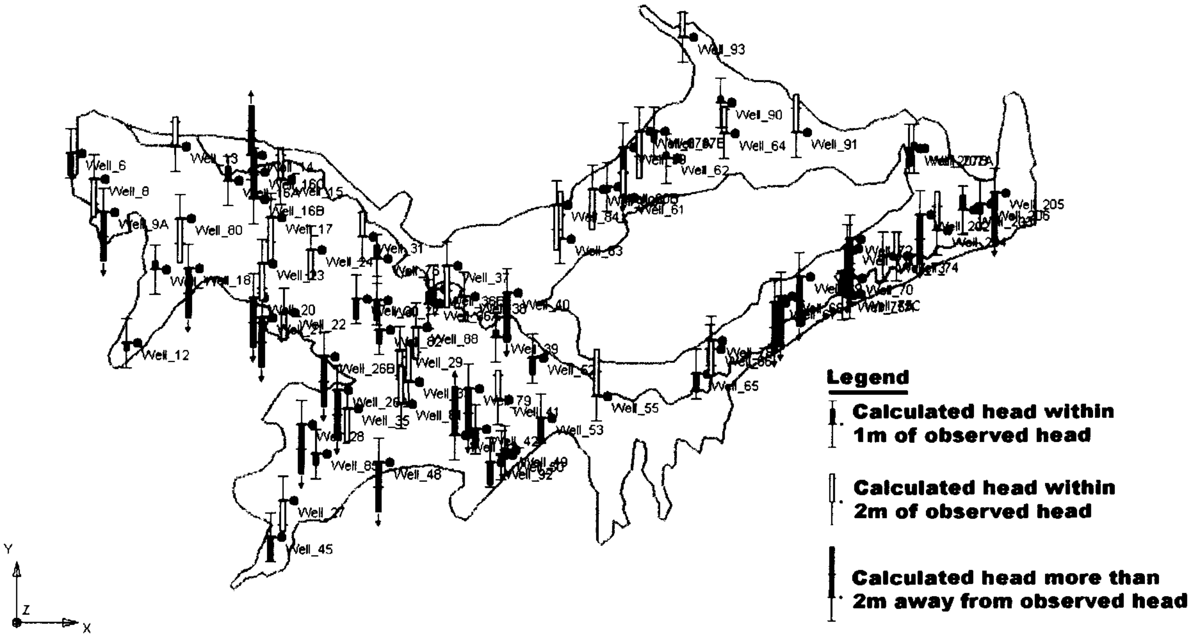
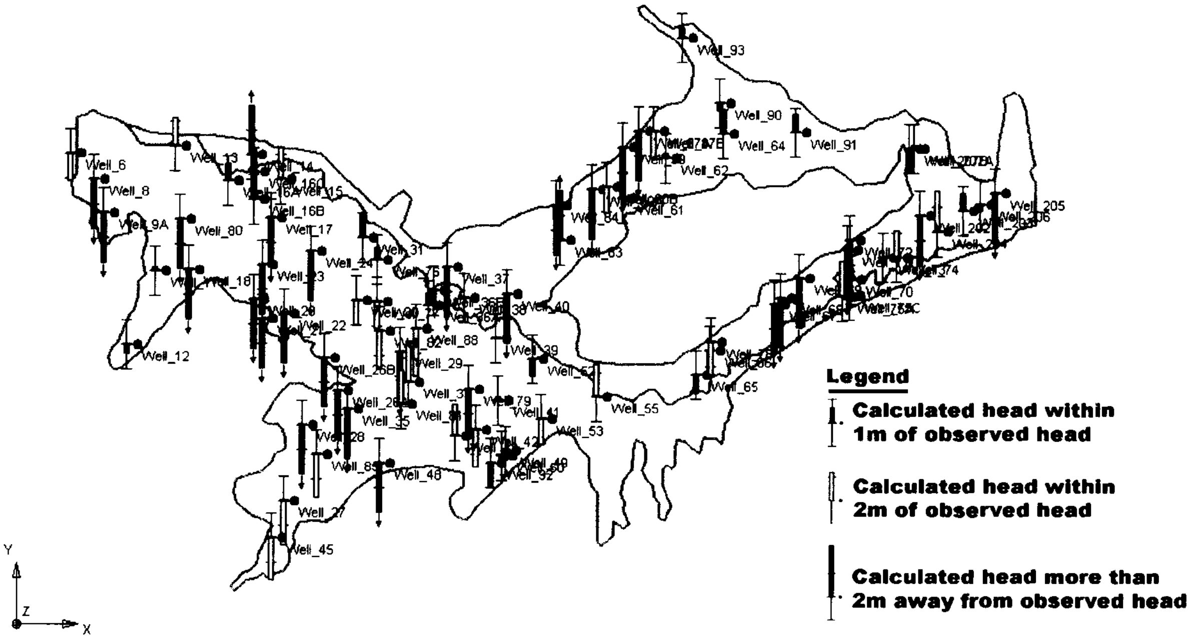


Figure J-19. Water Table Depth Calibration Results – Time Step 40



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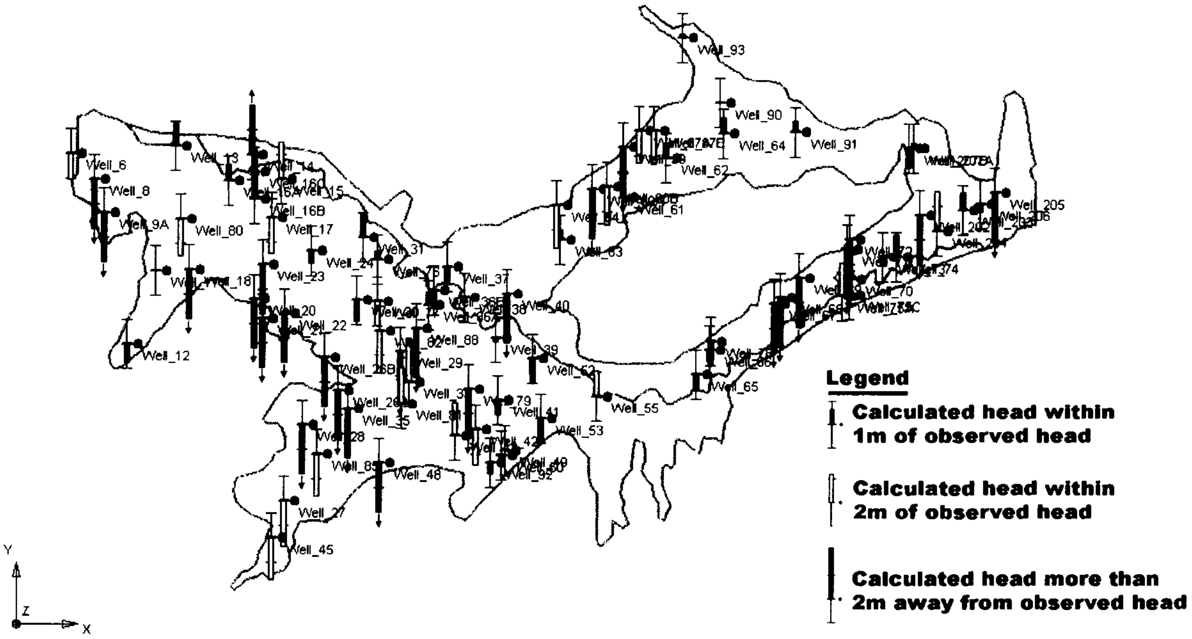

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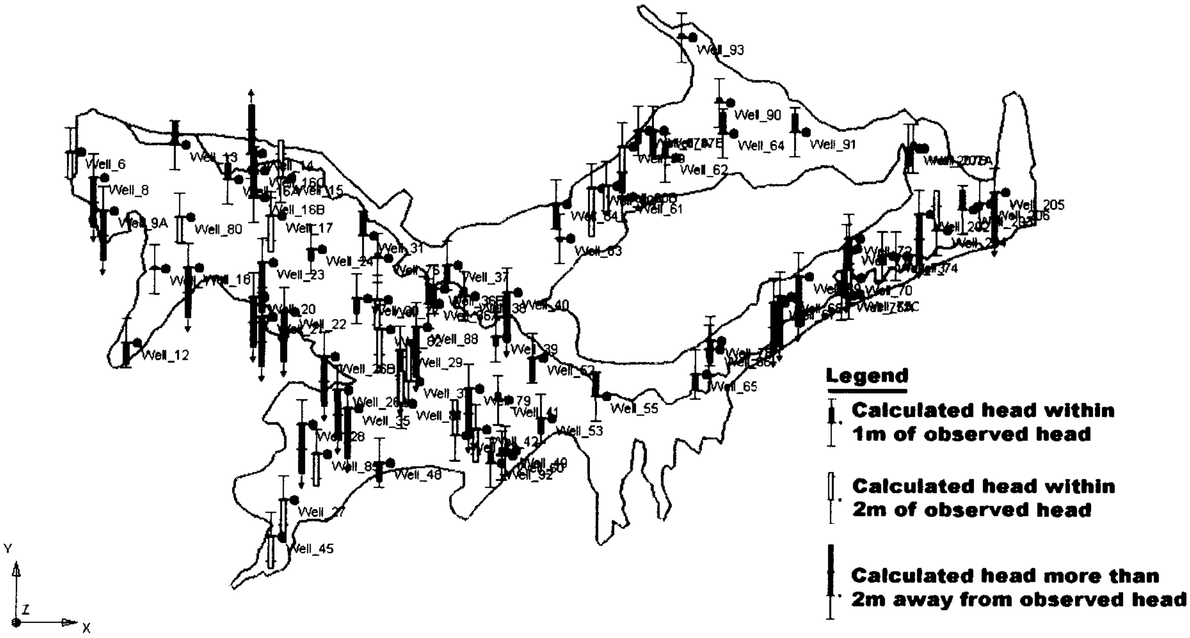


Figure J-22. Water Table Depth Calibration Results – Time Step 55

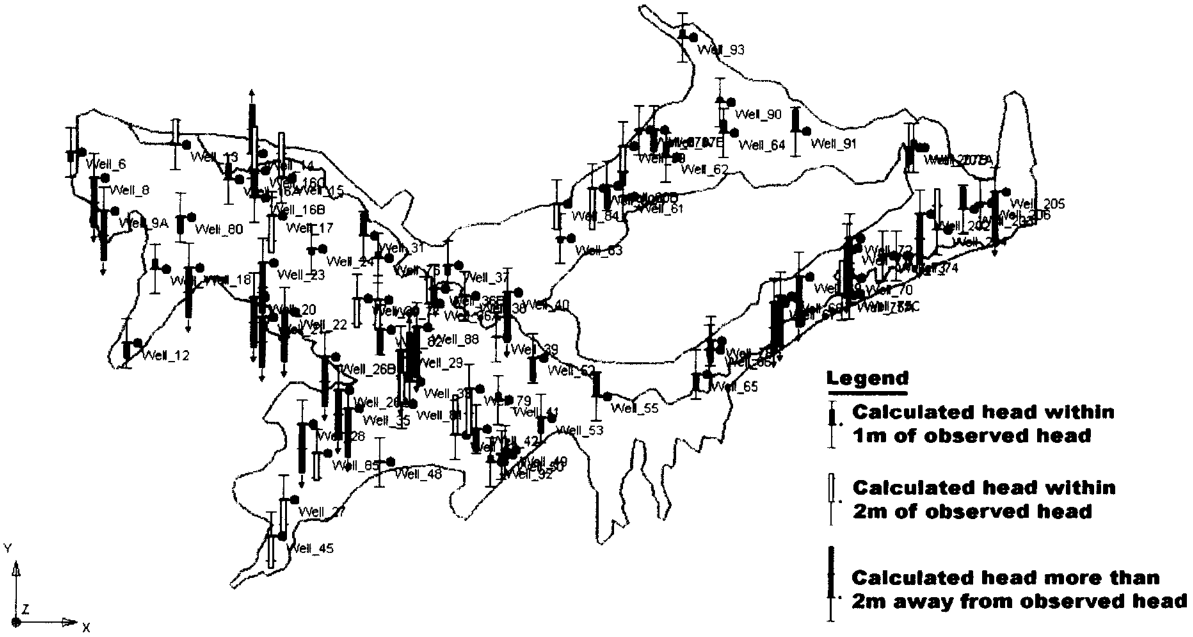


Figure J-23. Water Table Depth Calibration Results – Time Step 57

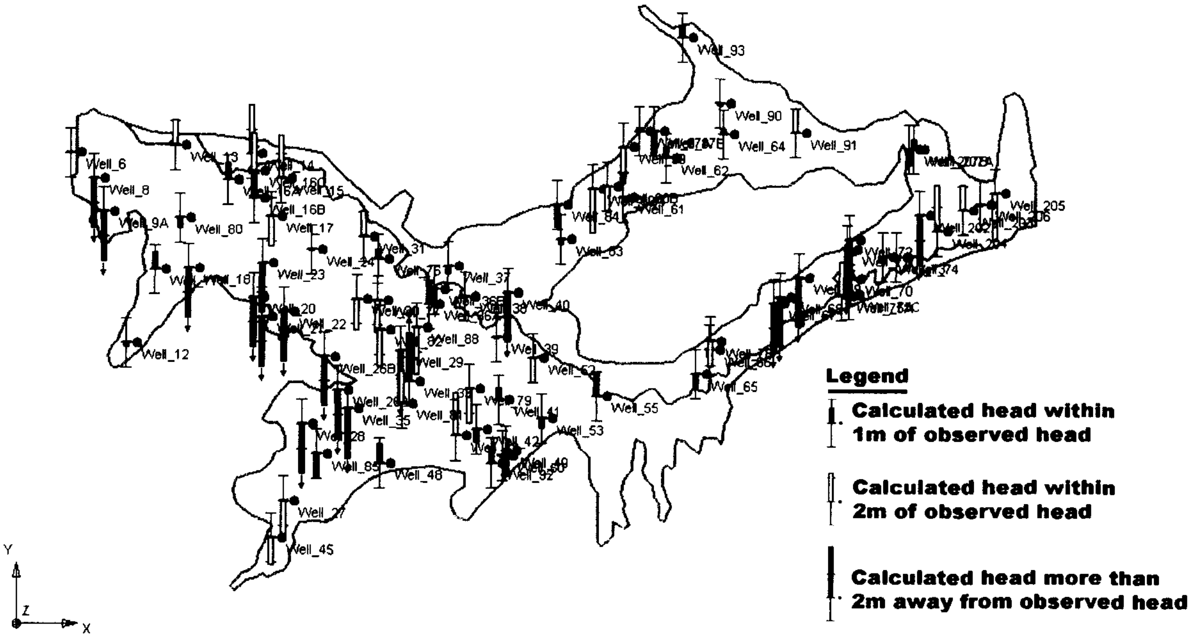


Figure J-24. Water Table Depth Calibration Results – Time Step 59

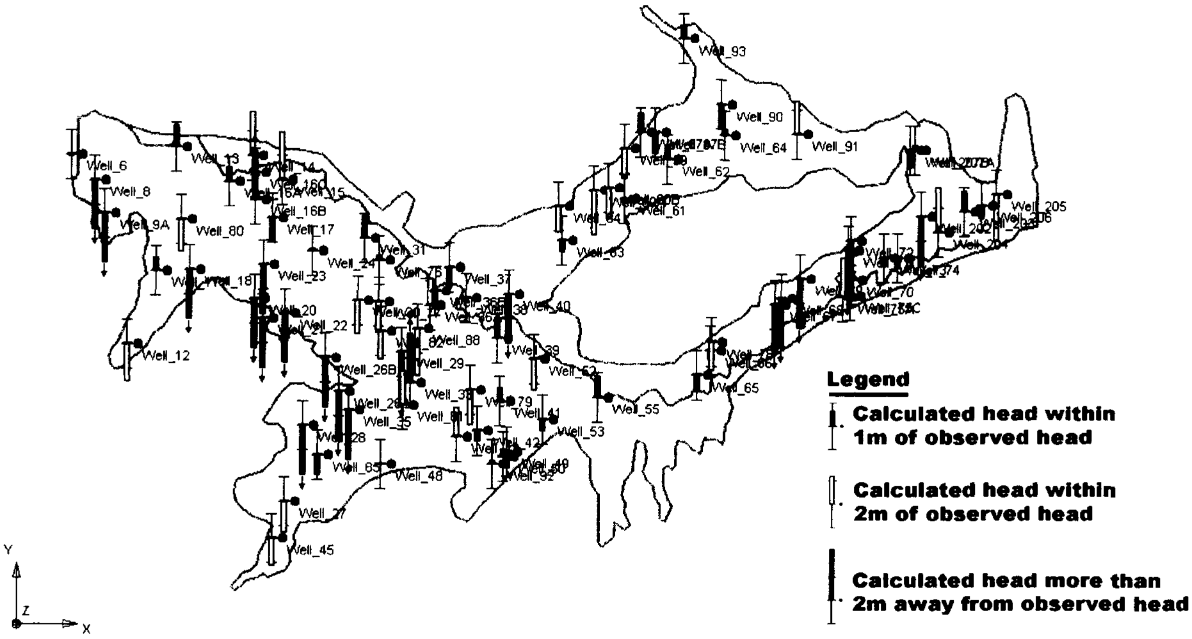


Figure J-25. Water Table Depth Calibration Results – Time Step 61

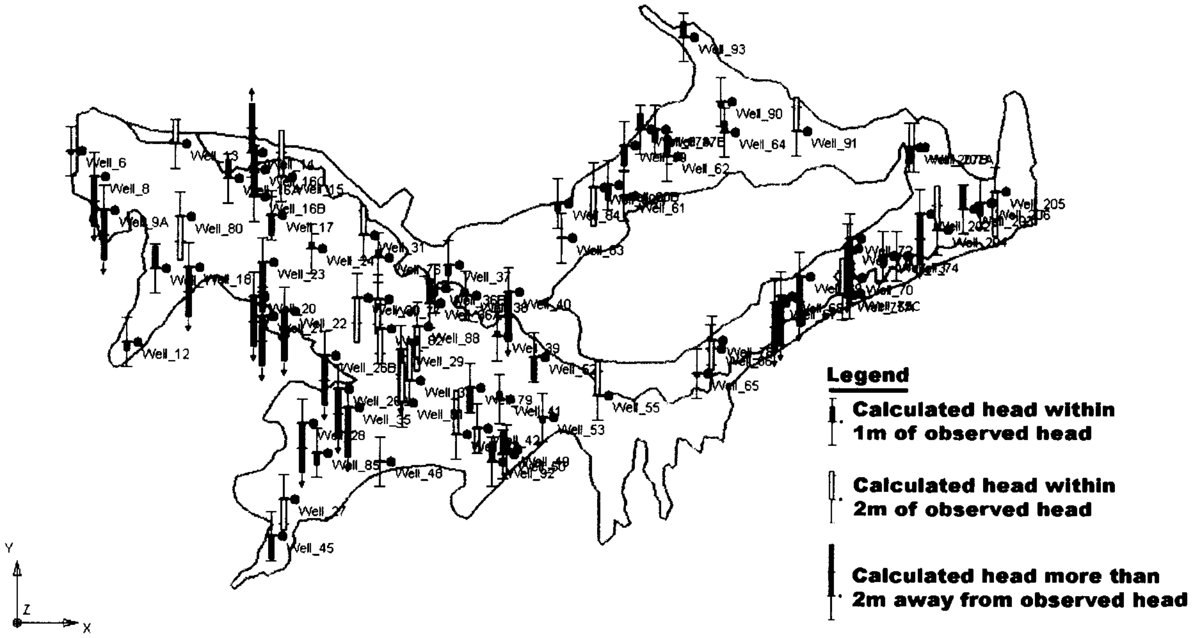


Figure J-26. Water Table Depth Calibration Results – Time Step 62

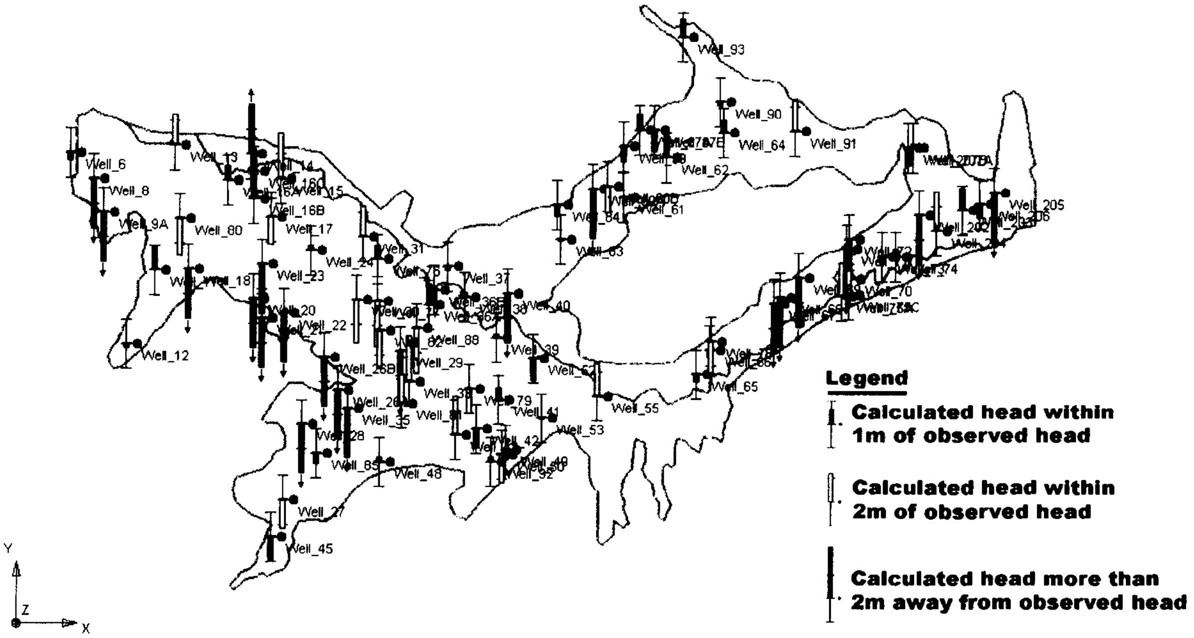
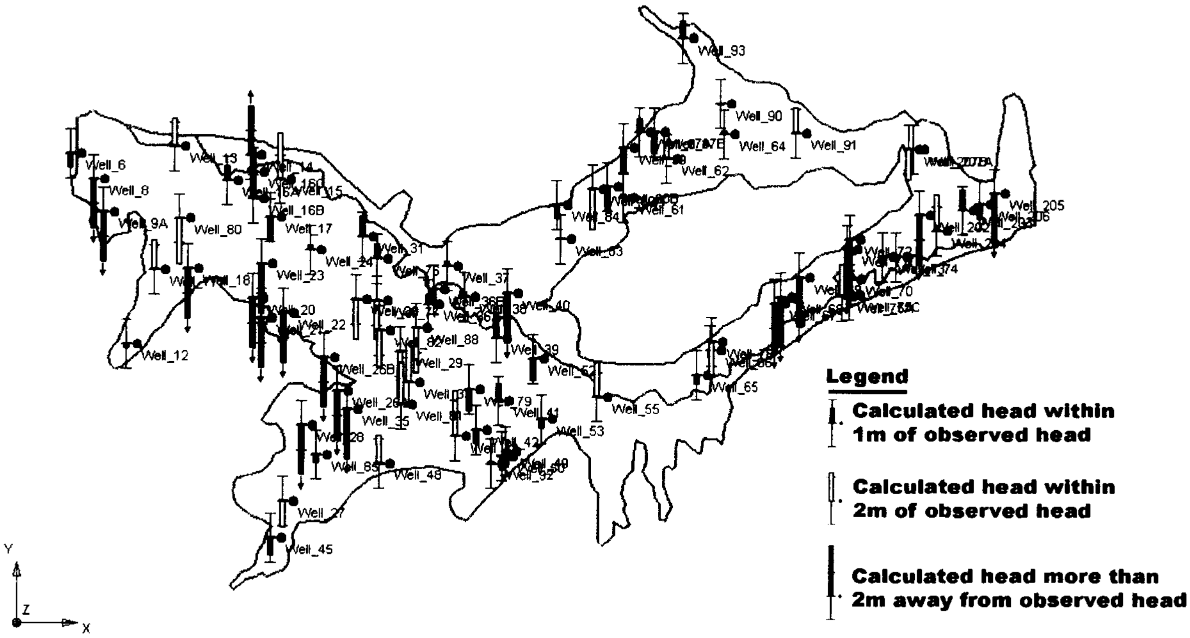


Figure J-27. Water Table Depth Calibration Results – Time Step 63



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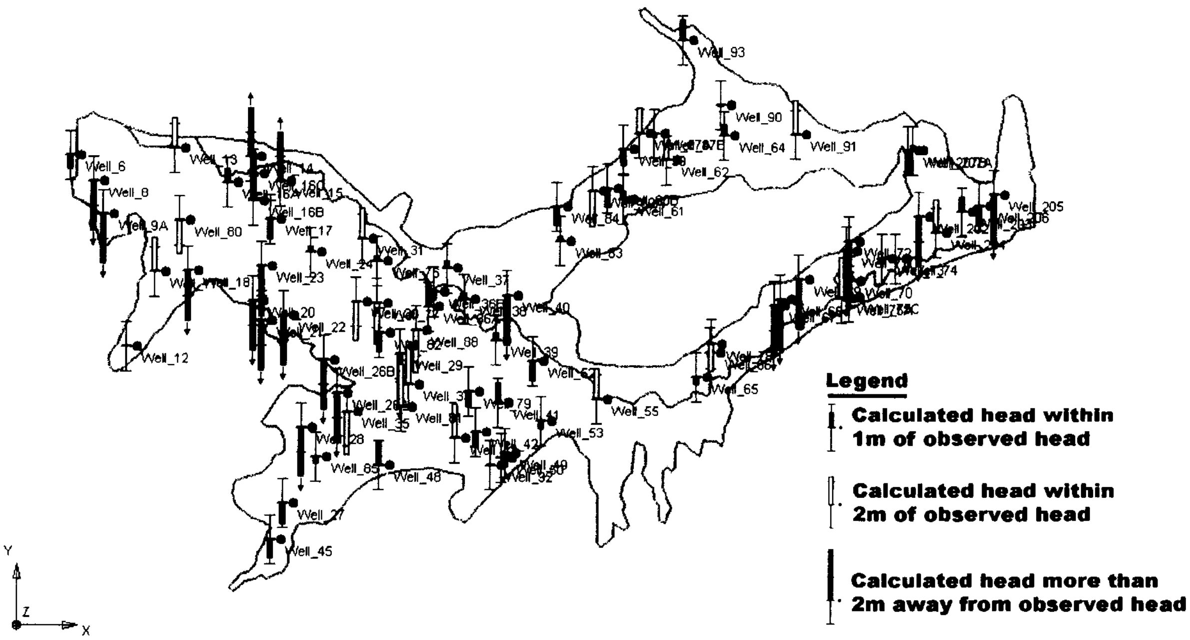


Figure J-29. Water Table Depth Calibration Results – Time Step 65

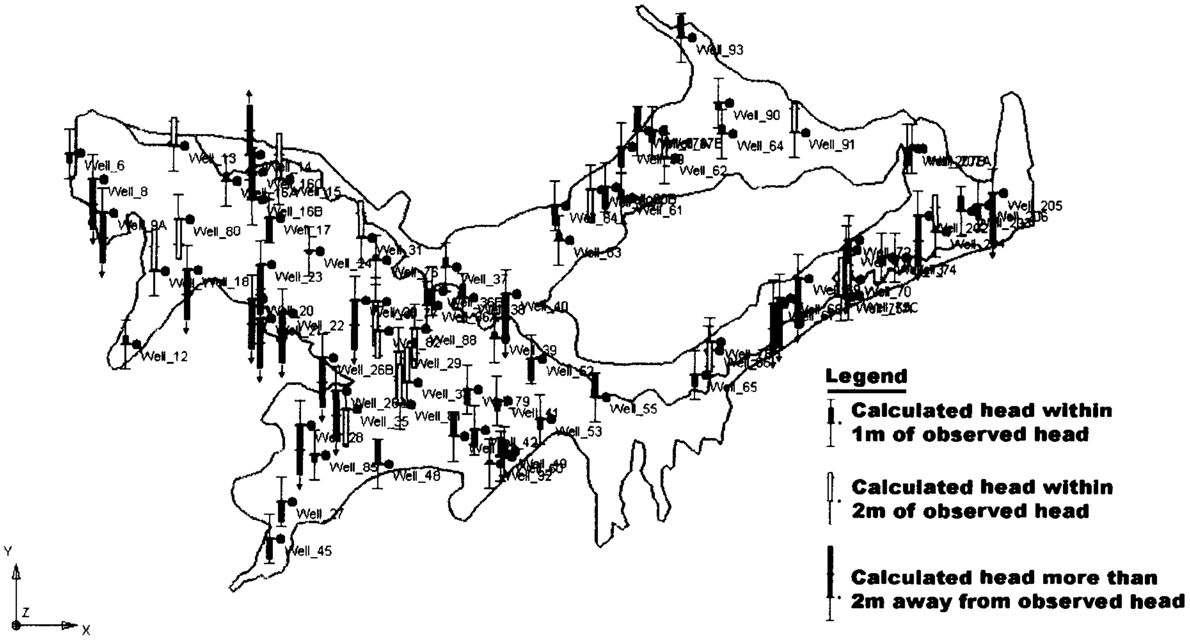


Figure J-30. Water Table Depth Calibration Results – Time Step 66

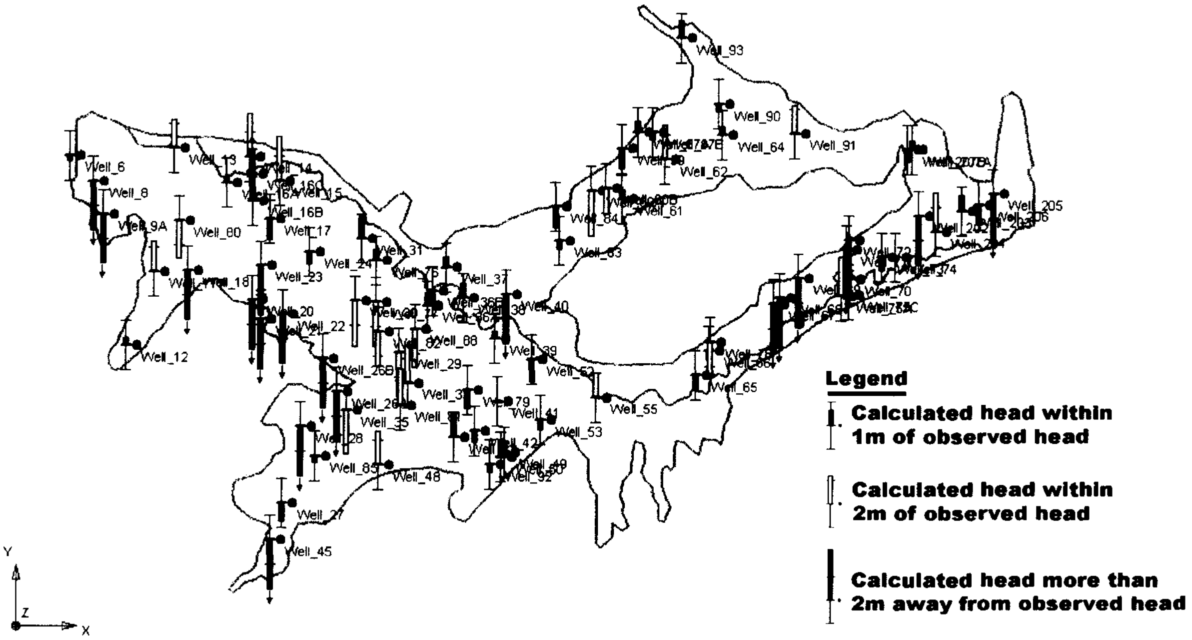


Figure J-31. Water Table Depth Calibration Results – Time Step 67

APPENDIX K: ADDITIONAL CALIBRATION RESULTS – GROUNDWATER SALINITY

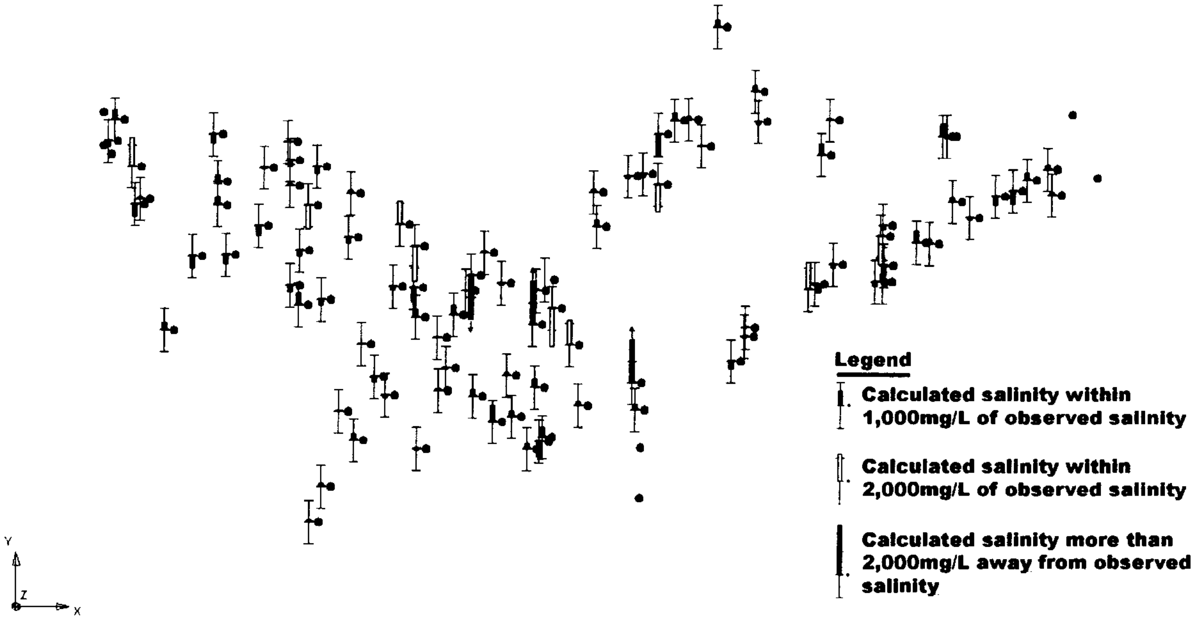


Figure K-1. Groundwater Salinity Calibration Results – Time Step 4

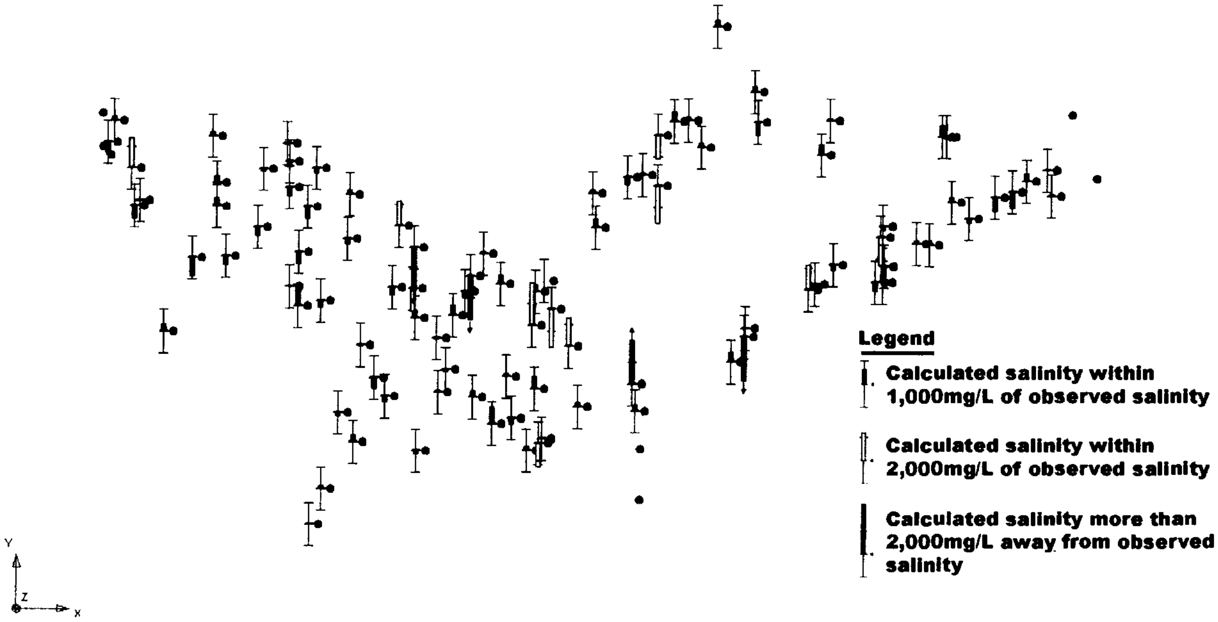


Figure K-2. Groundwater Salinity Calibration Results – Time Step 6

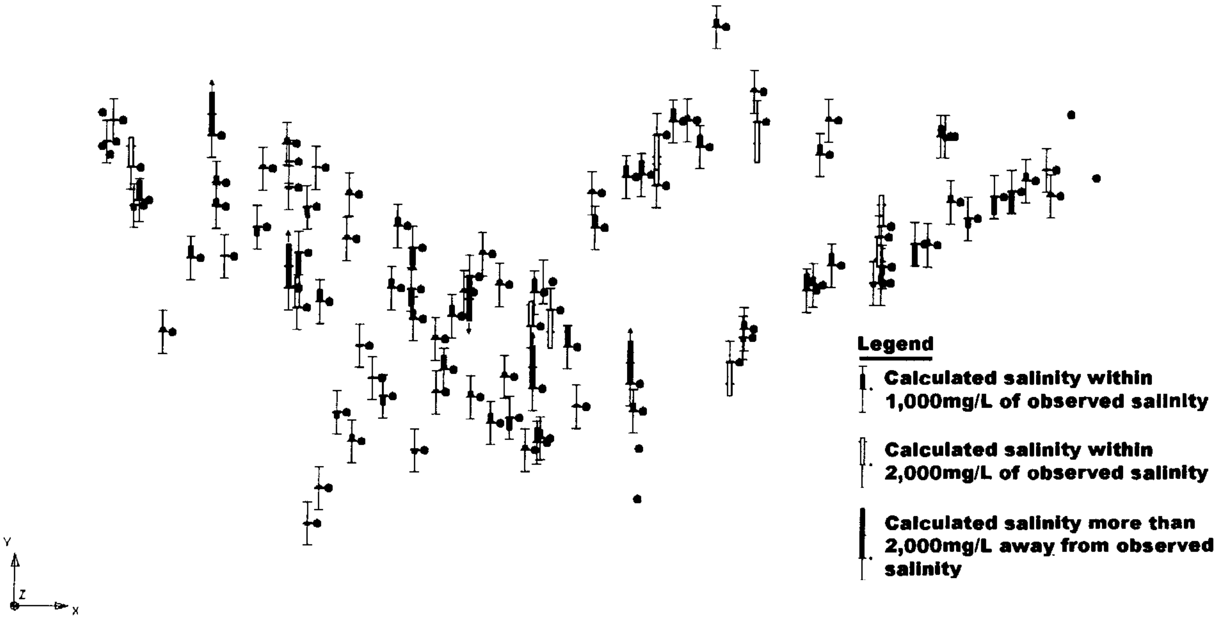


Figure K-3. Groundwater Salinity Calibration Results – Time Step 9

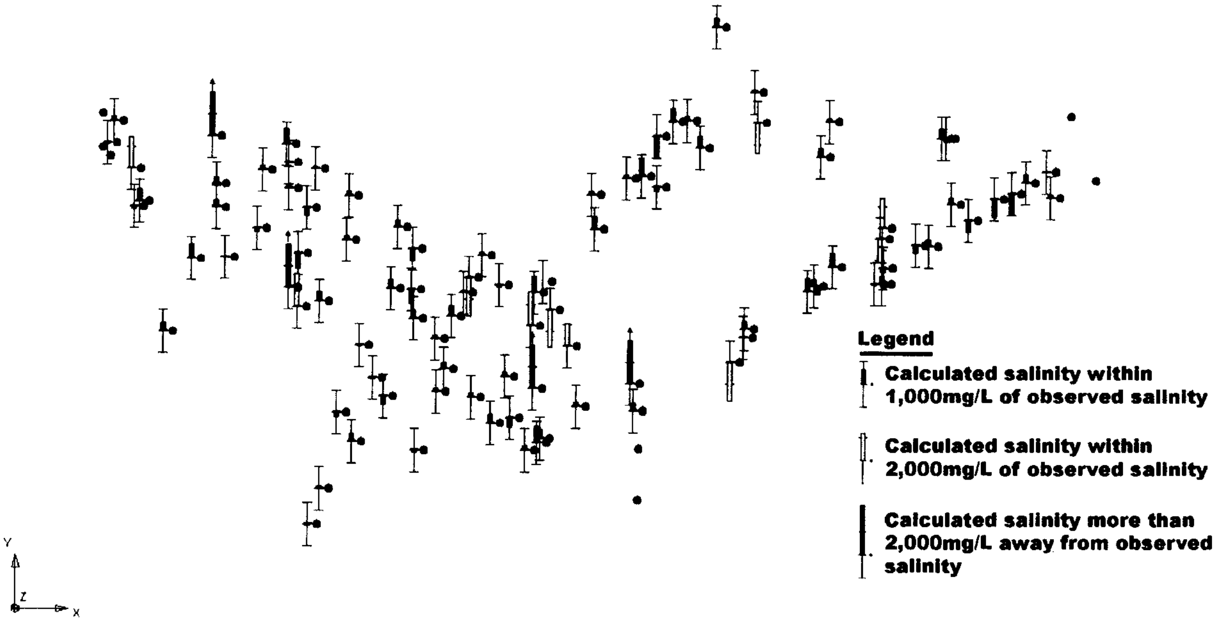


Figure K-4. Groundwater Salinity Calibration Results – Time Step 10

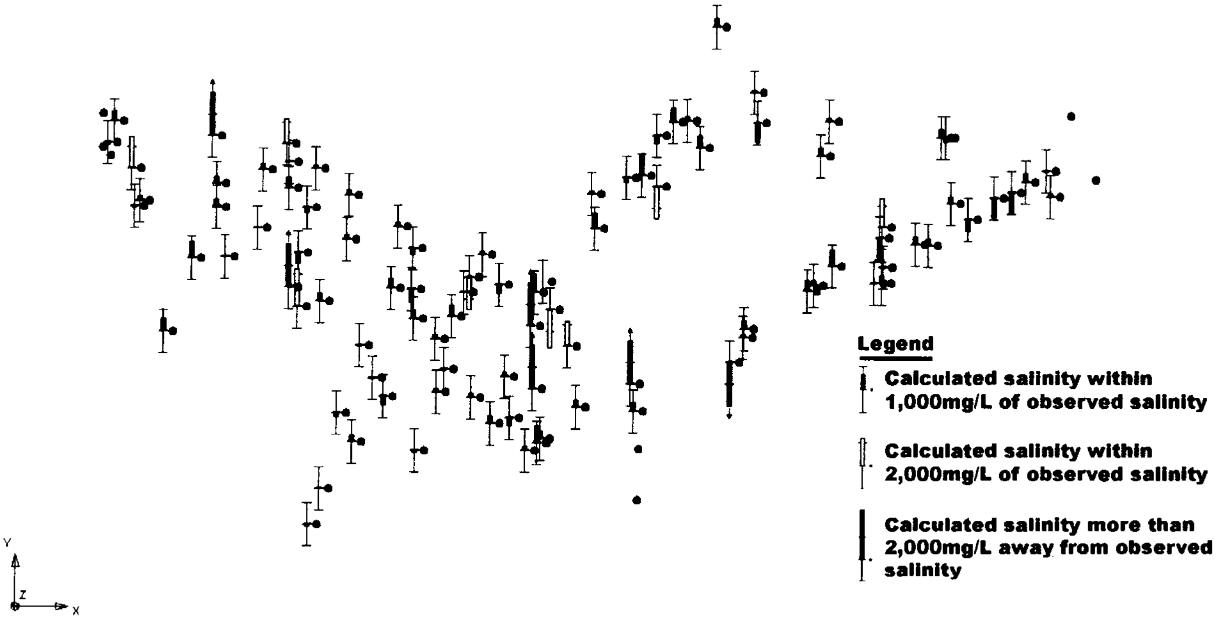


Figure K-5. Groundwater Salinity Calibration Results – Time Step 11

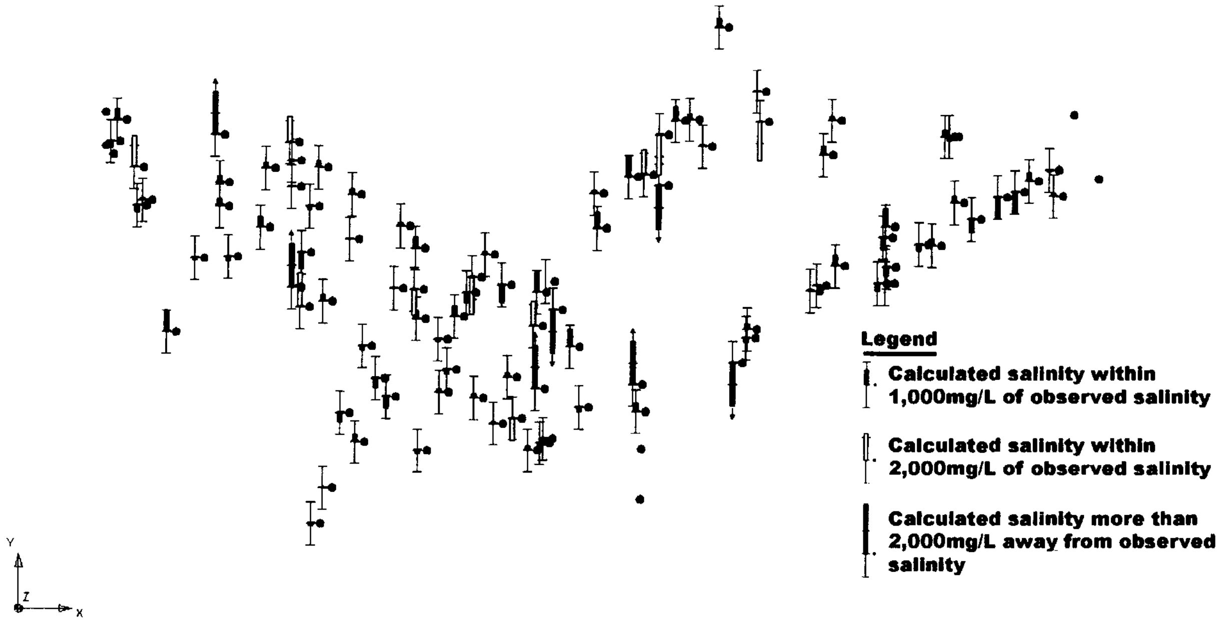


Figure K-6. Groundwater Salinity Calibration Results – Time Step 12

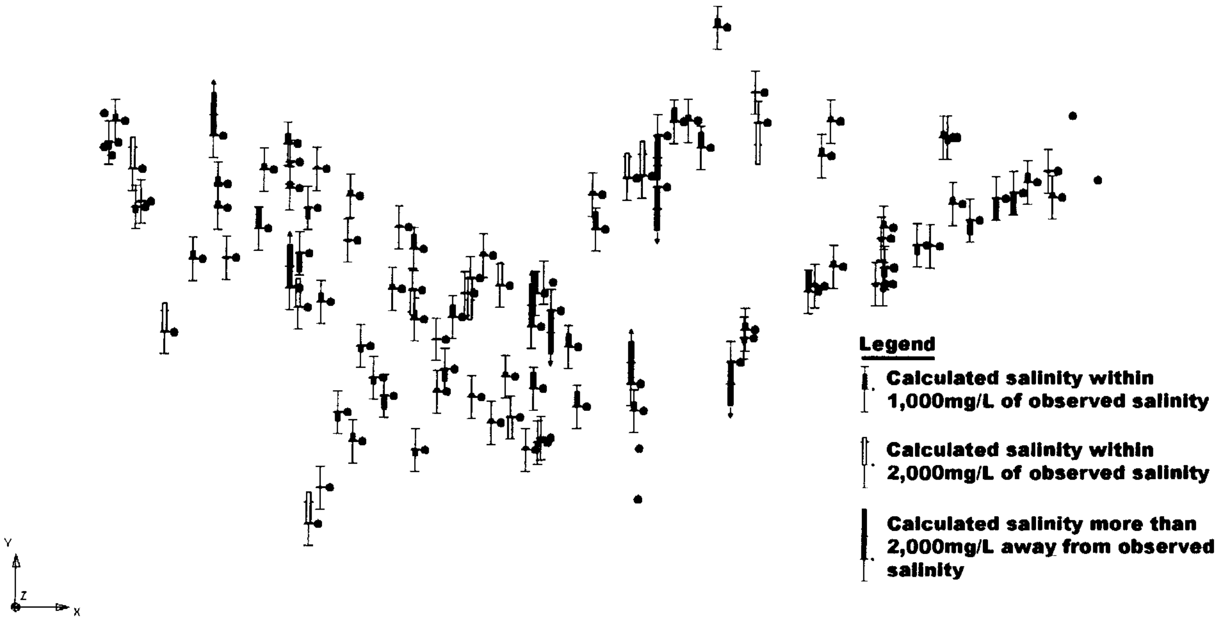


Figure K-7. Groundwater Salinity Calibration Results – Time Step 13

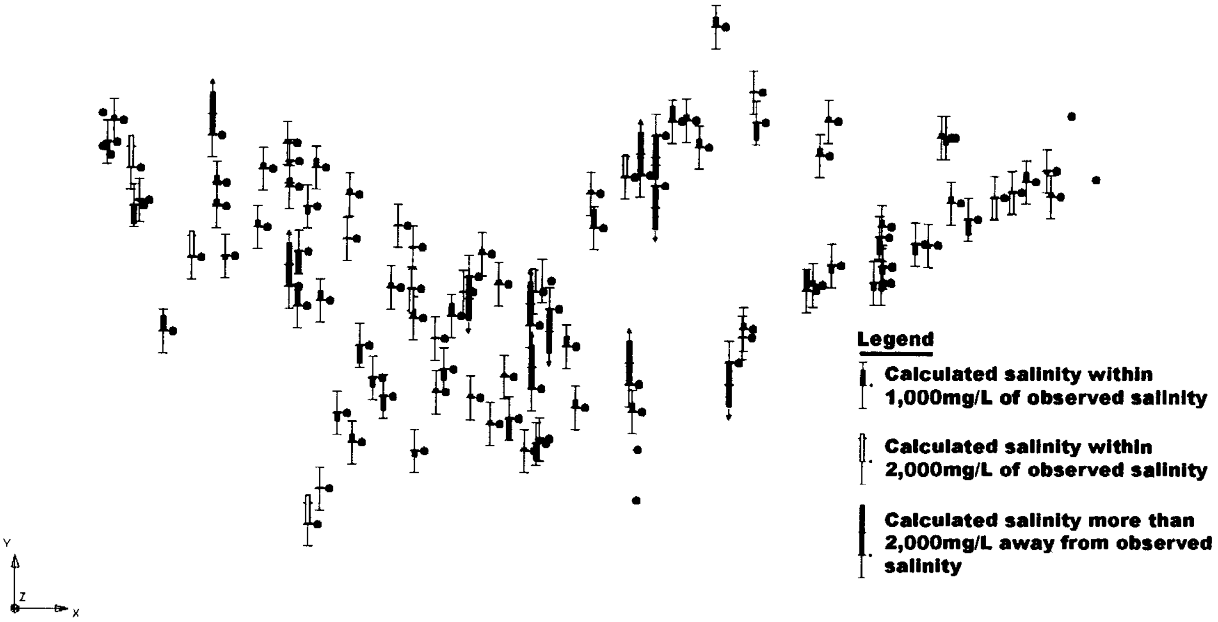


Figure K-8. Groundwater Salinity Calibration Results – Time Step 14

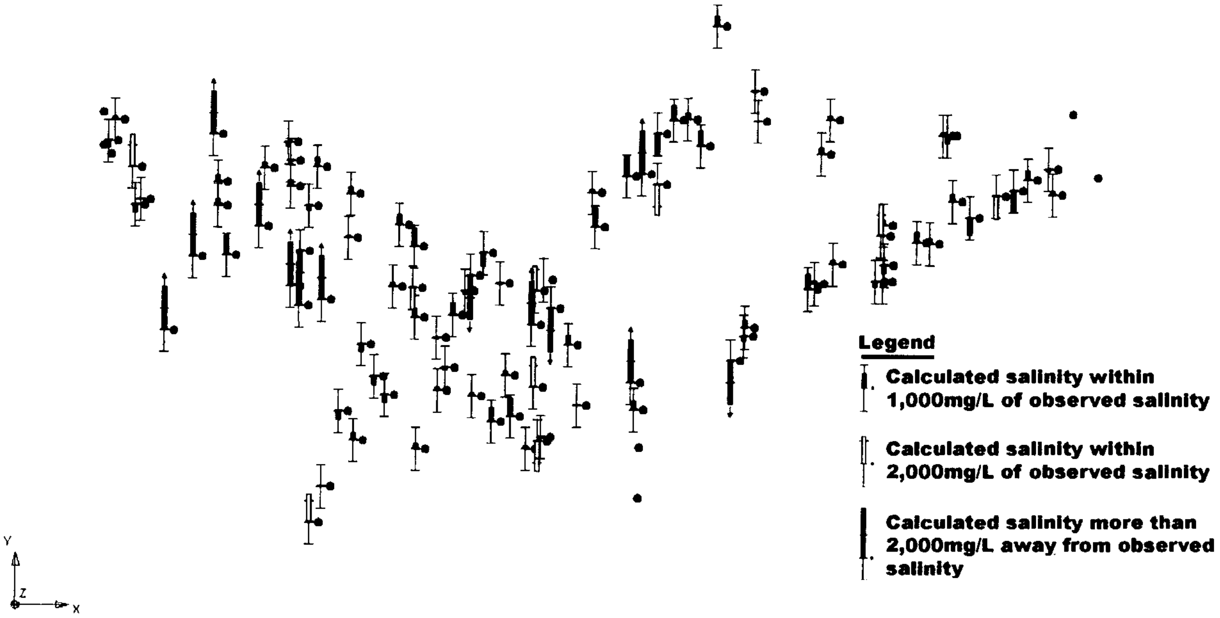


Figure K-9. Groundwater Salinity Calibration Results – Time Step 15

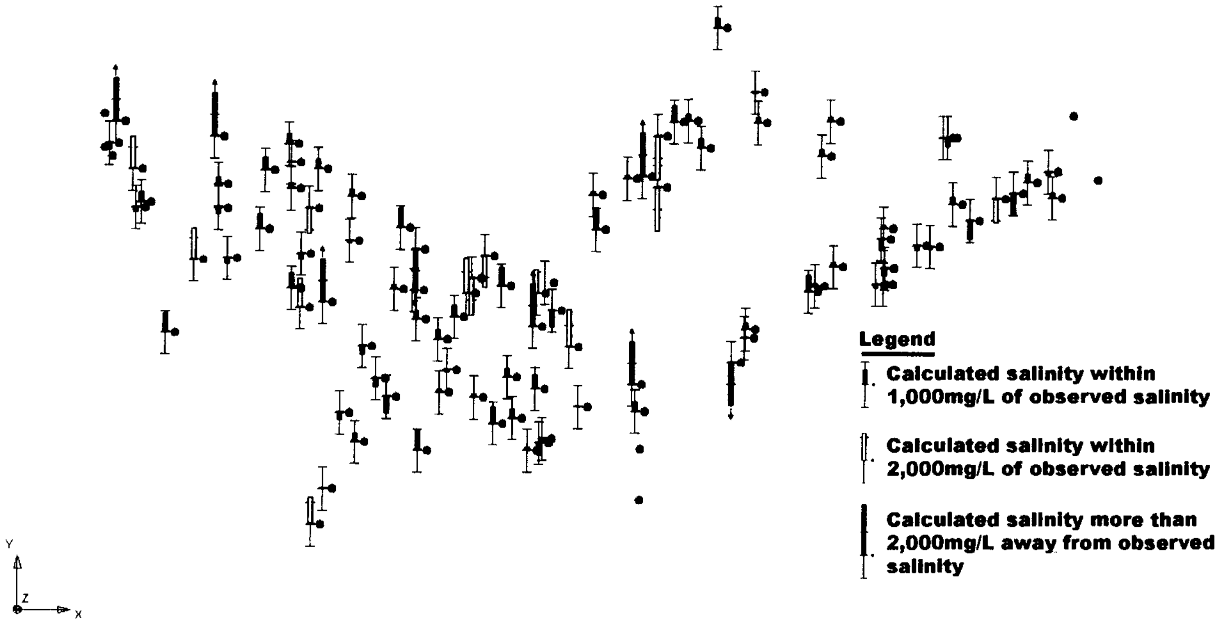


Figure K-10. Groundwater Salinity Calibration Results – Time Step 16

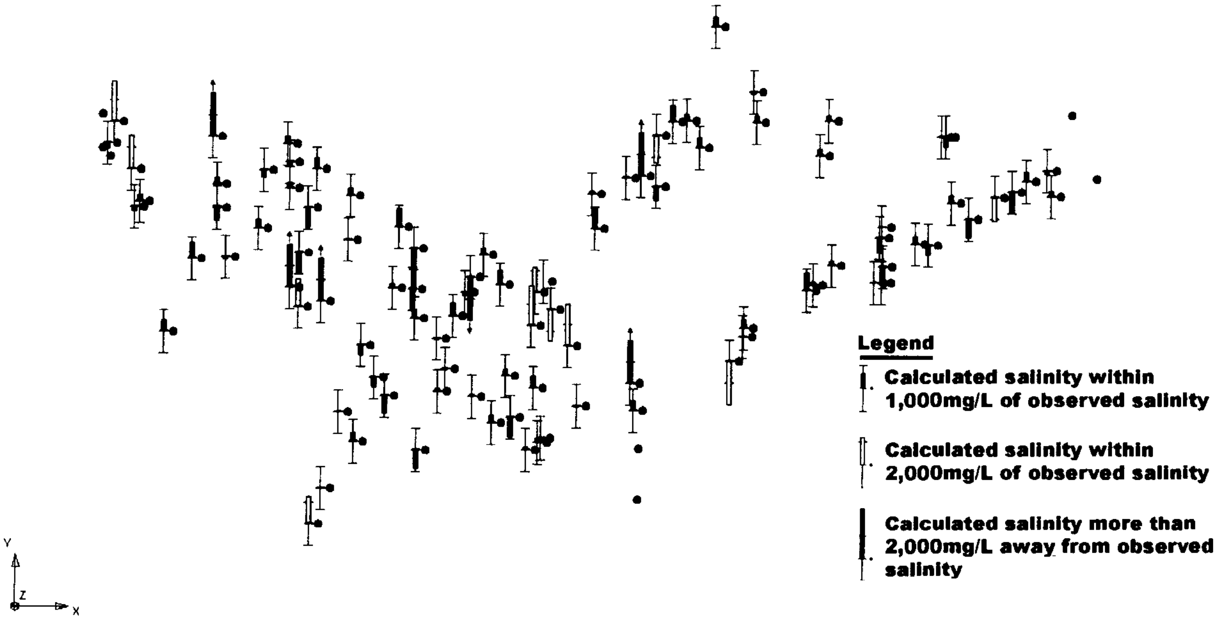


Figure K-11. Groundwater Salinity Calibration Results – Time Step 17

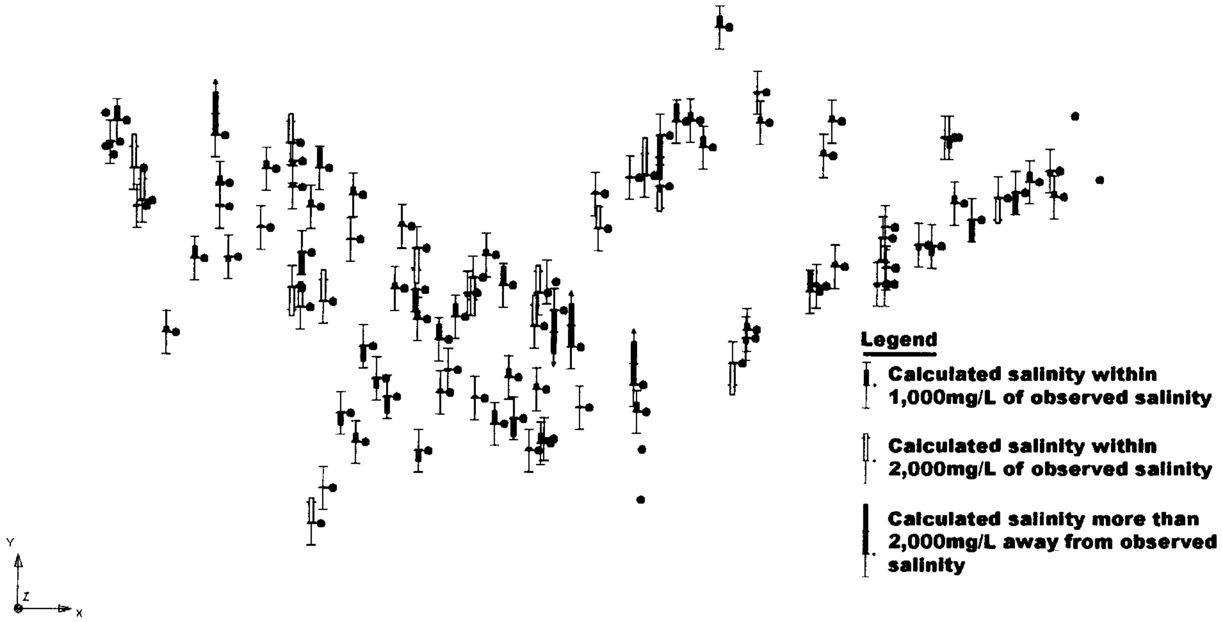


Figure K-12. Groundwater Salinity Calibration Results – Time Step 18

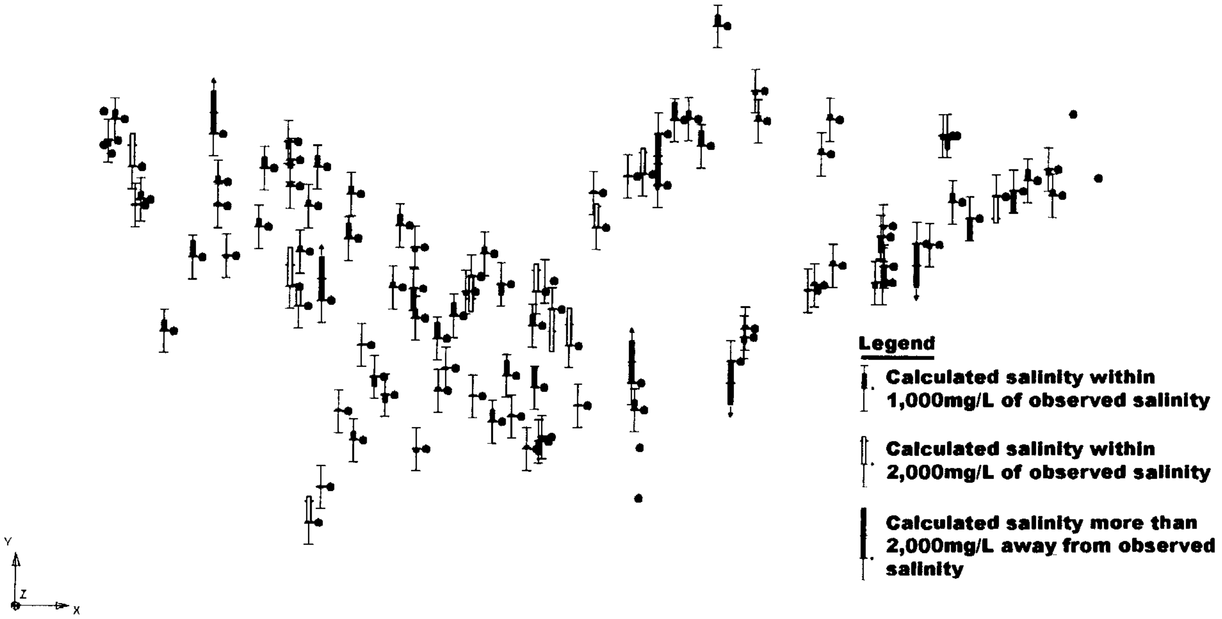


Figure K-13. Groundwater Salinity Calibration Results – Time Step 19

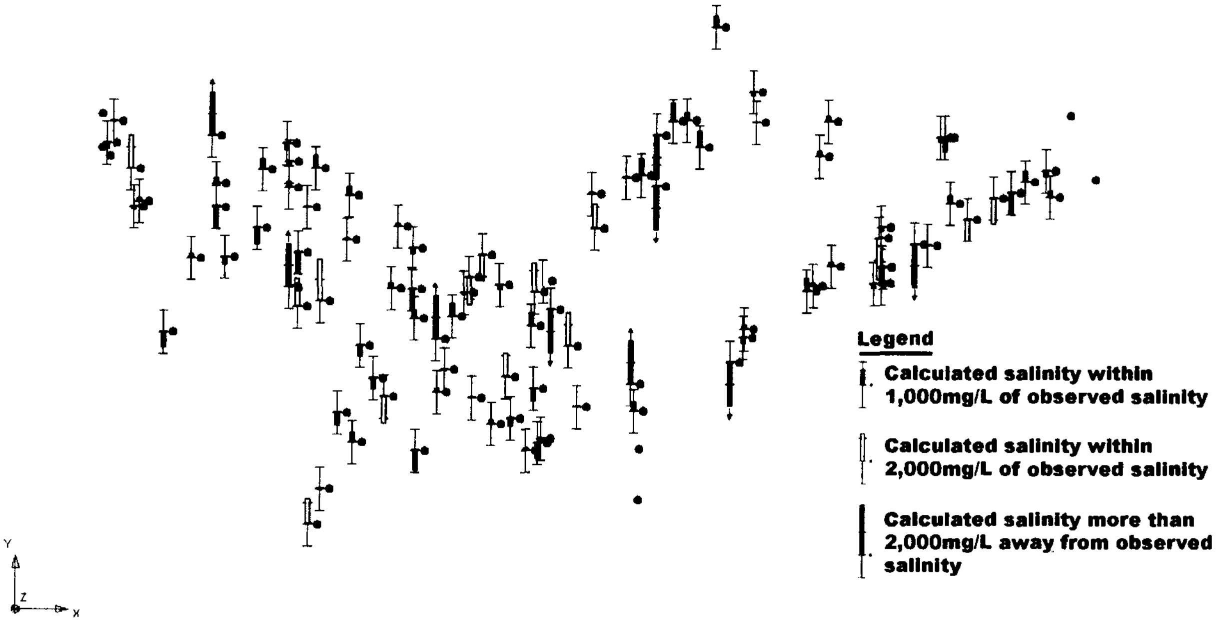


Figure K-14. Groundwater Salinity Calibration Results – Time Step 20

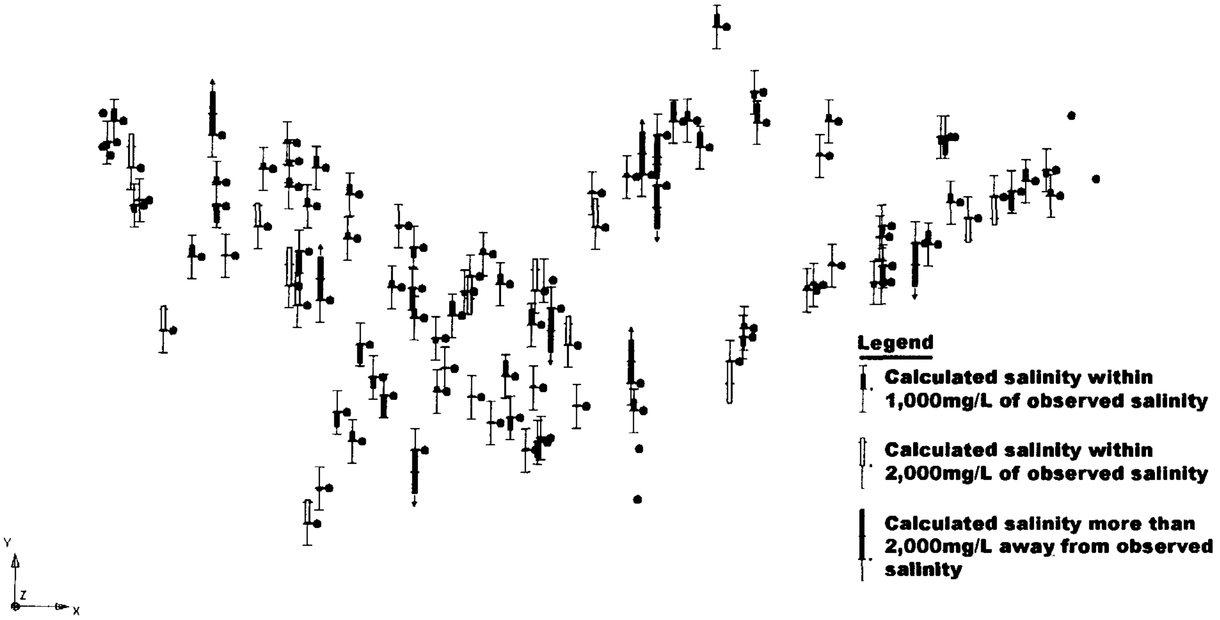


Figure K-15. Groundwater Salinity Calibration Results – Time Step 23

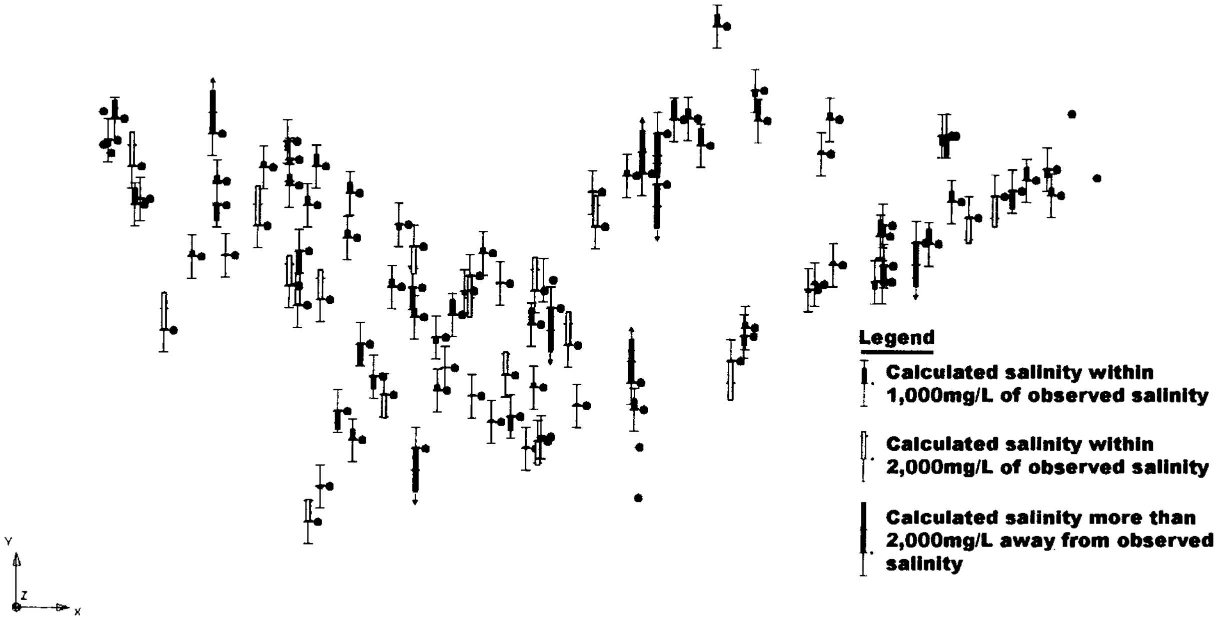


Figure K-16. Groundwater Salinity Calibration Results – Time Step 25

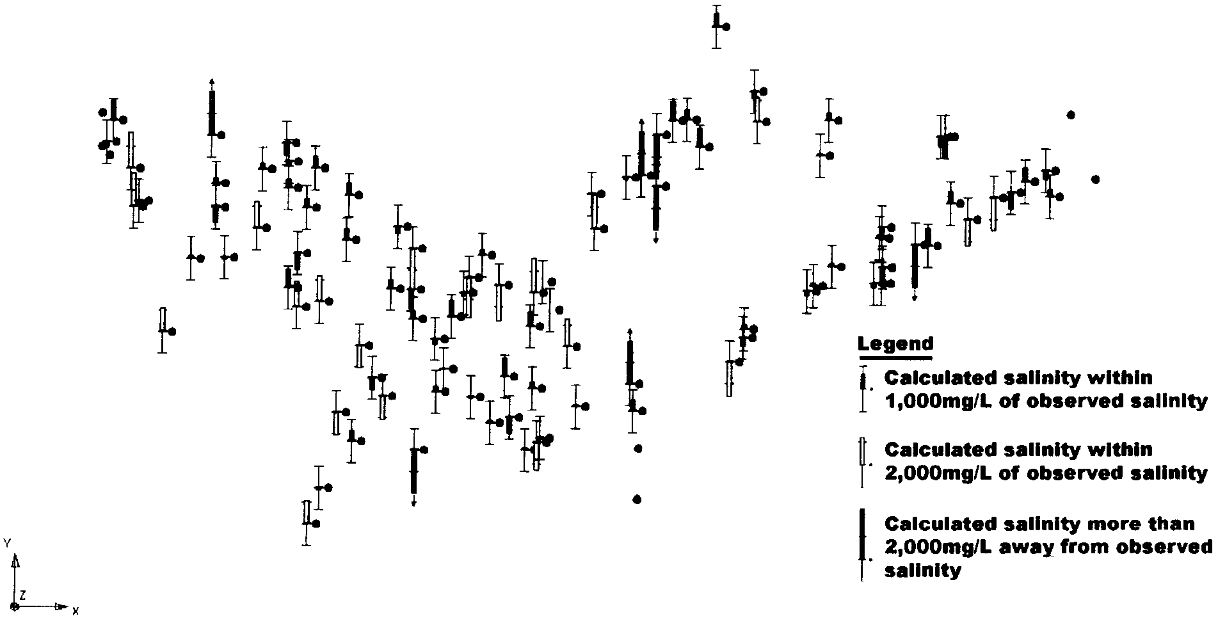


Figure K-17. Groundwater Salinity Calibration Results – Time Step 27

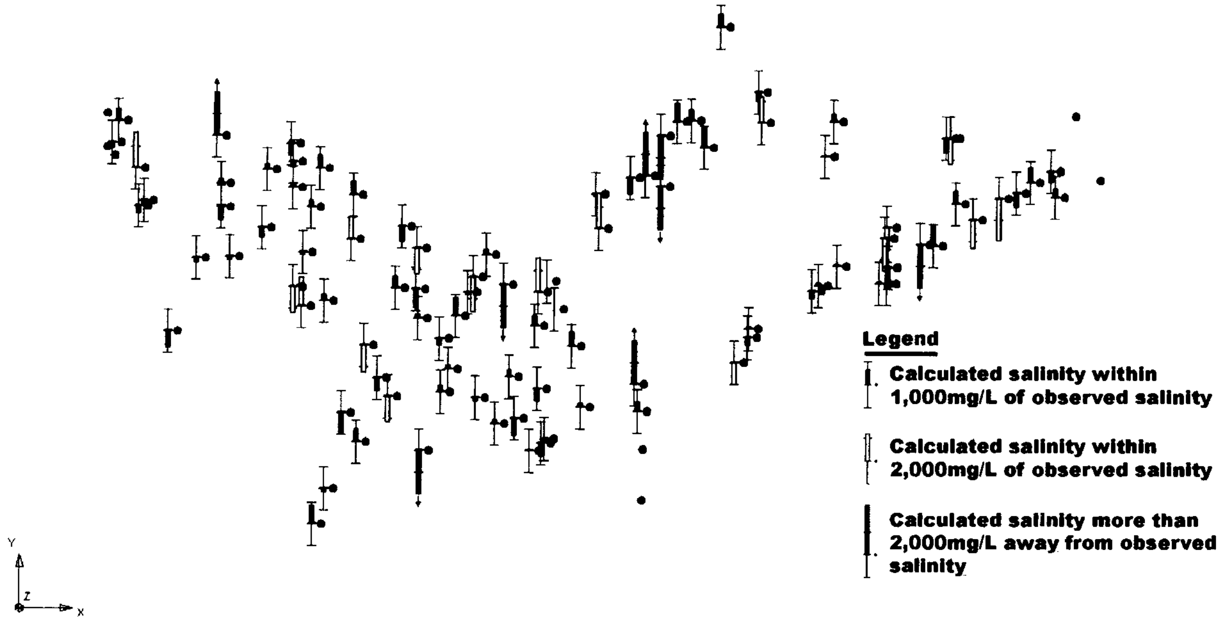


Figure K-18. Groundwater Salinity Calibration Results – Time Step 33

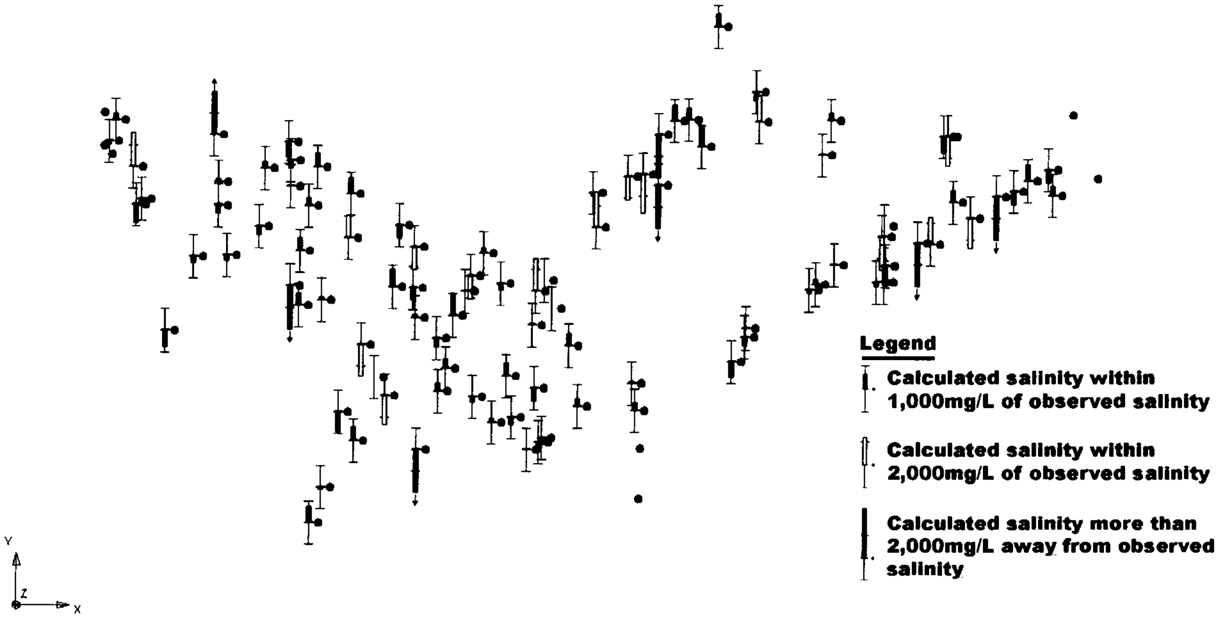


Figure K-19. Groundwater Salinity Calibration Results – Time Step 40

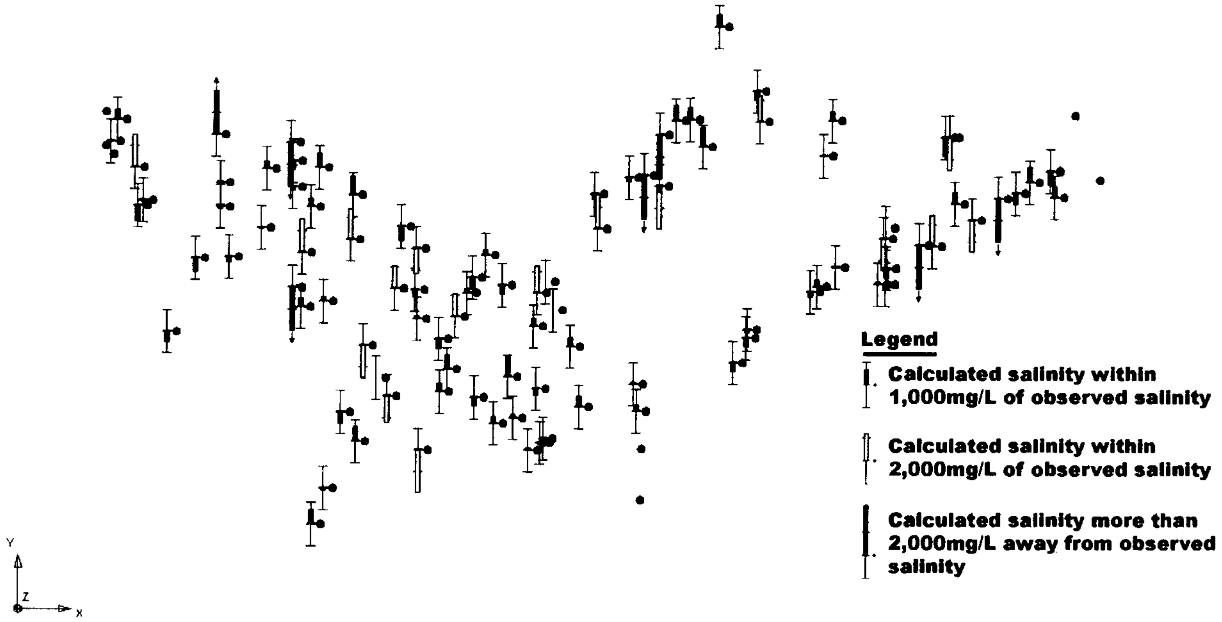


Figure K-20. Groundwater Salinity Calibration Results – Time Step 47

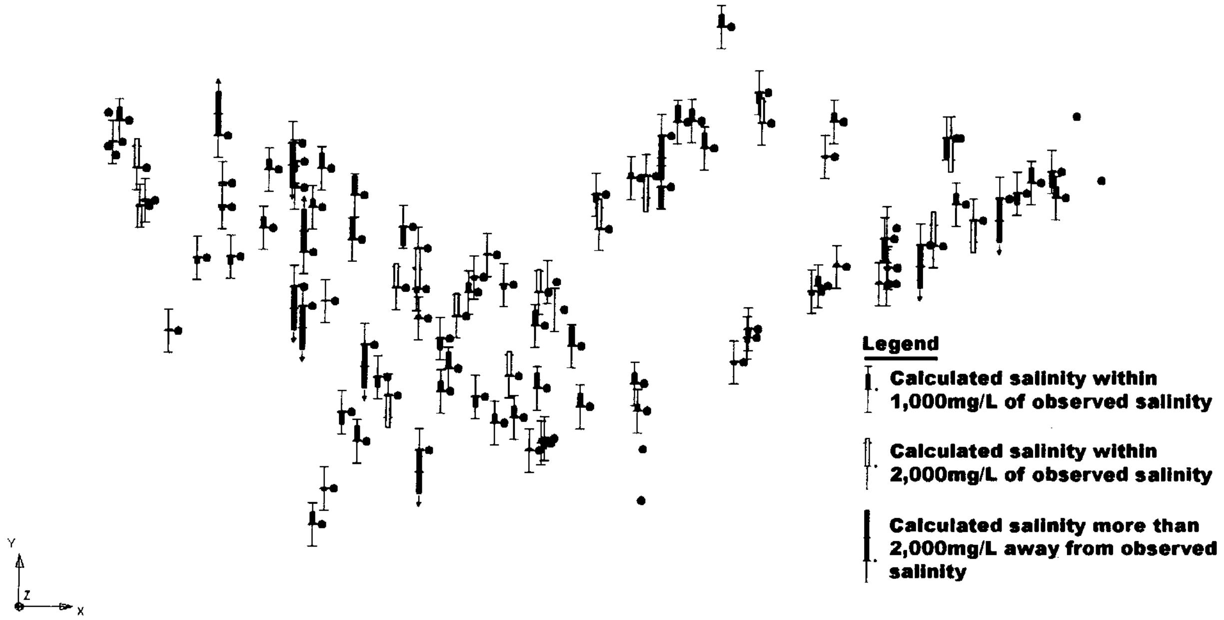


Figure K-21. Groundwater Salinity Calibration Results – Time Step 52

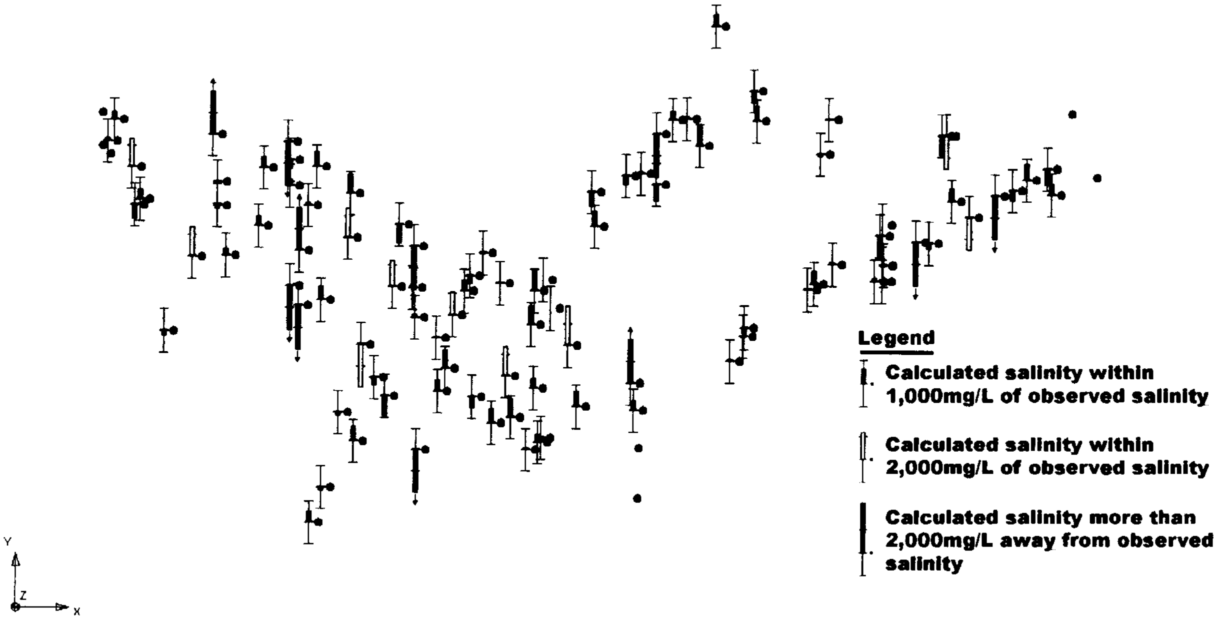


Figure K-22. Groundwater Salinity Calibration Results – Time Step 55

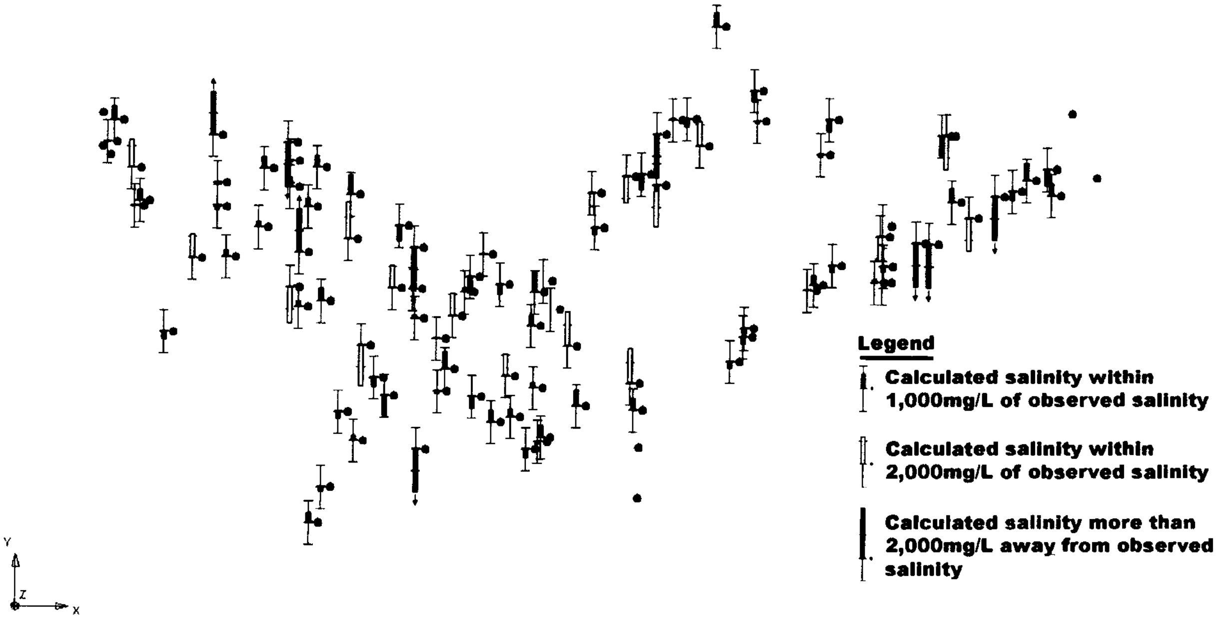


Figure K-23. Groundwater Salinity Calibration Results – Time Step 57

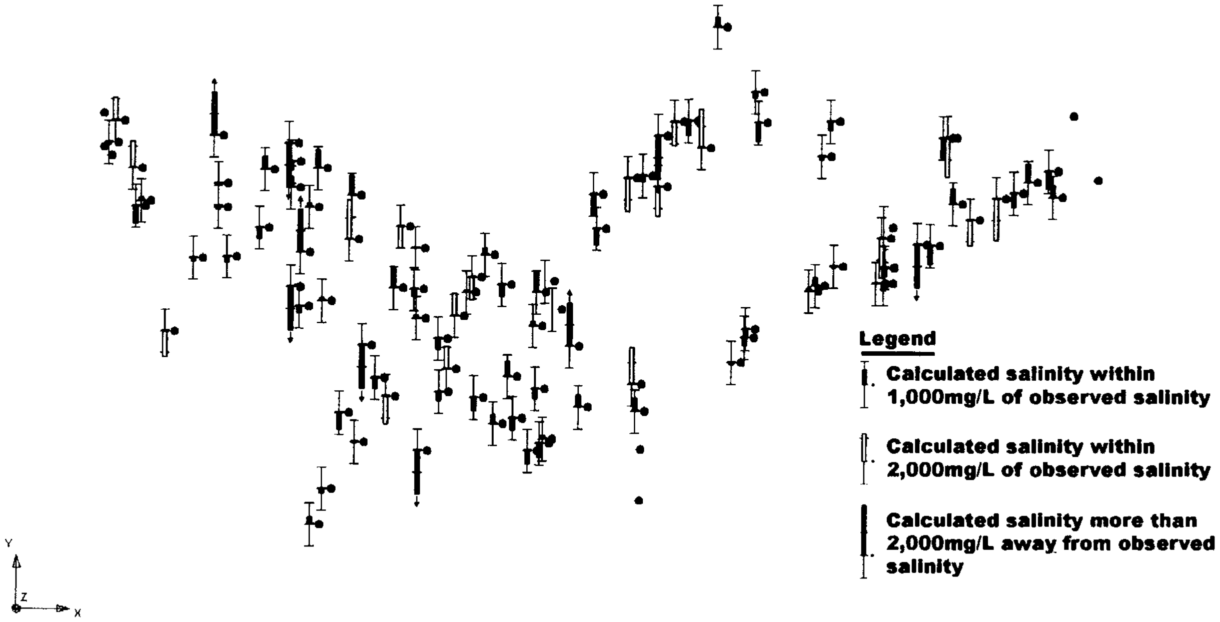


Figure K-24. Groundwater Salinity Calibration Results – Time Step 59

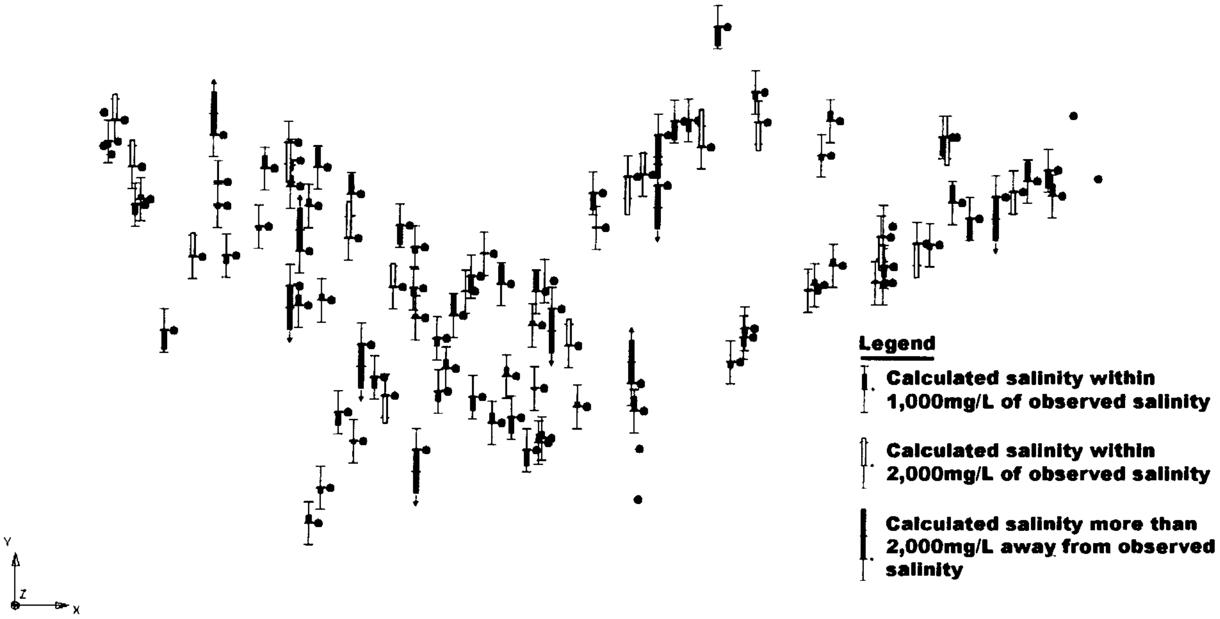


Figure K-25. Groundwater Salinity Calibration Results – Time Step 61

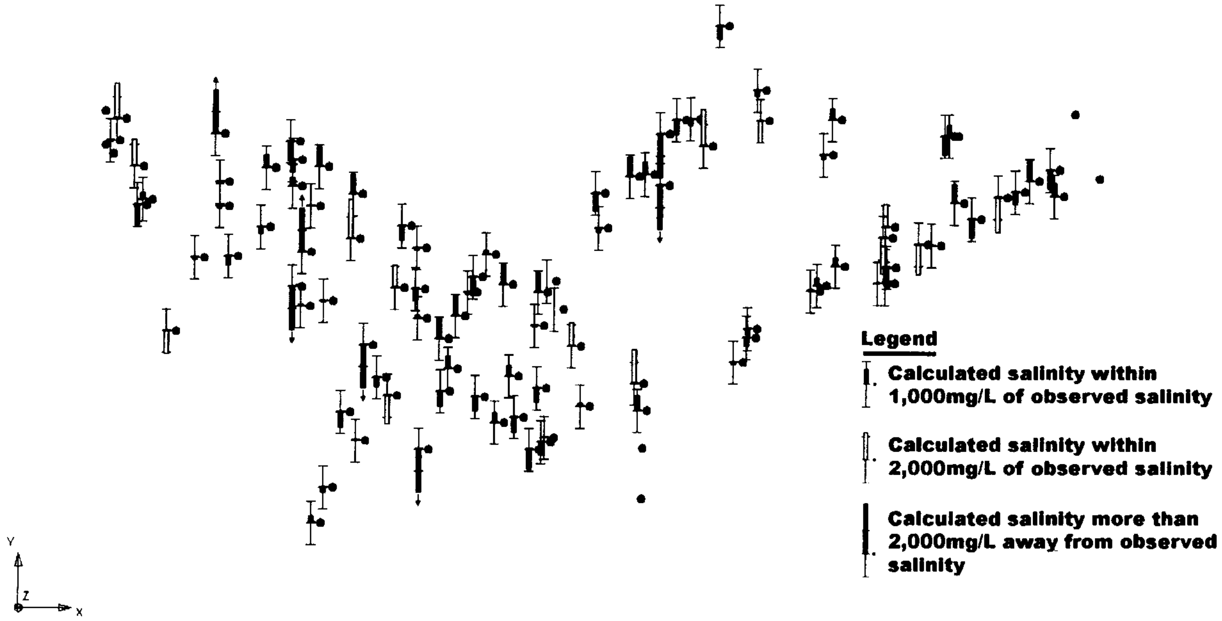


Figure K-26. Groundwater Salinity Calibration Results – Time Step 62

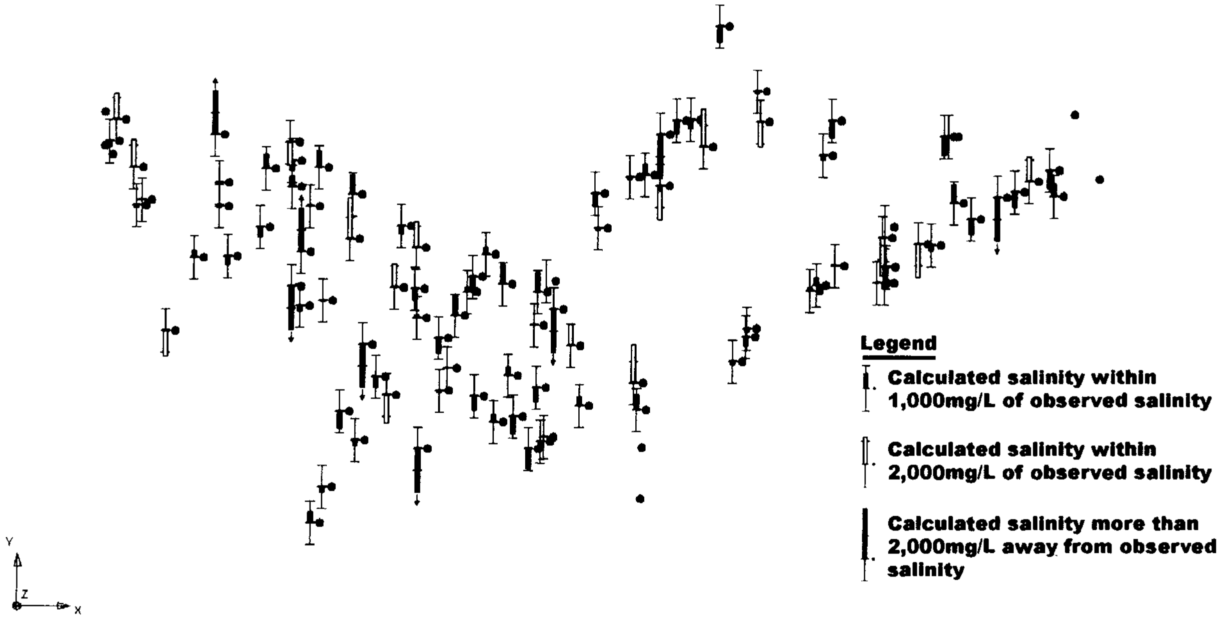


Figure K-27. Groundwater Salinity Calibration Results – Time Step 63

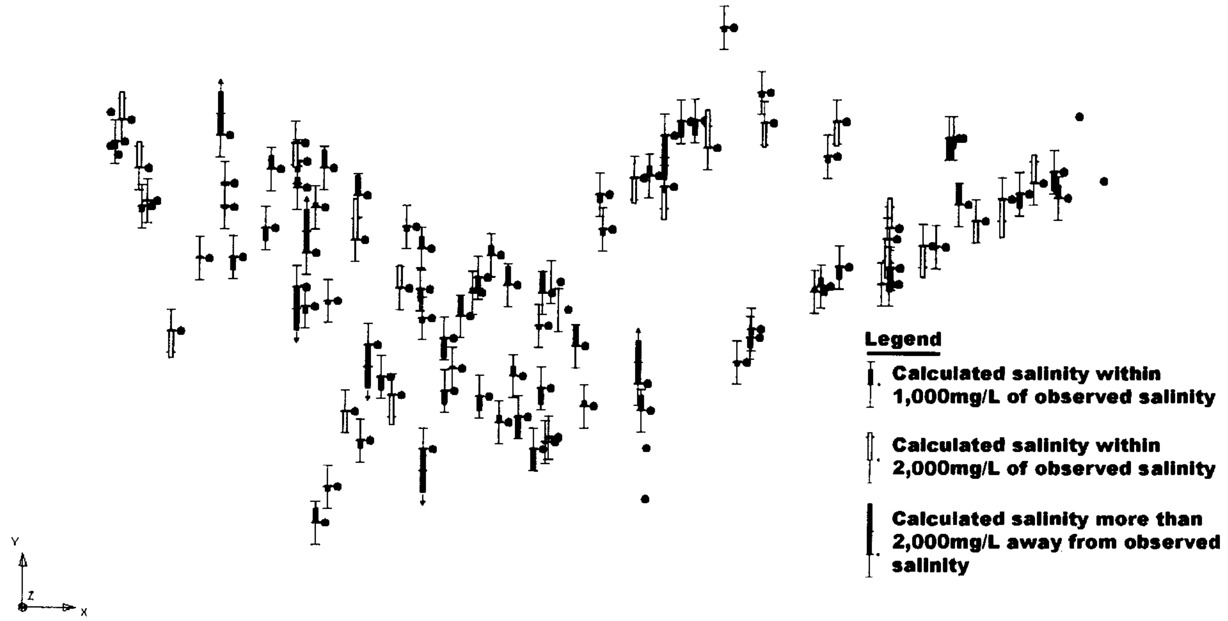


Figure K-28. Groundwater Salinity Calibration Results – Time Step 64

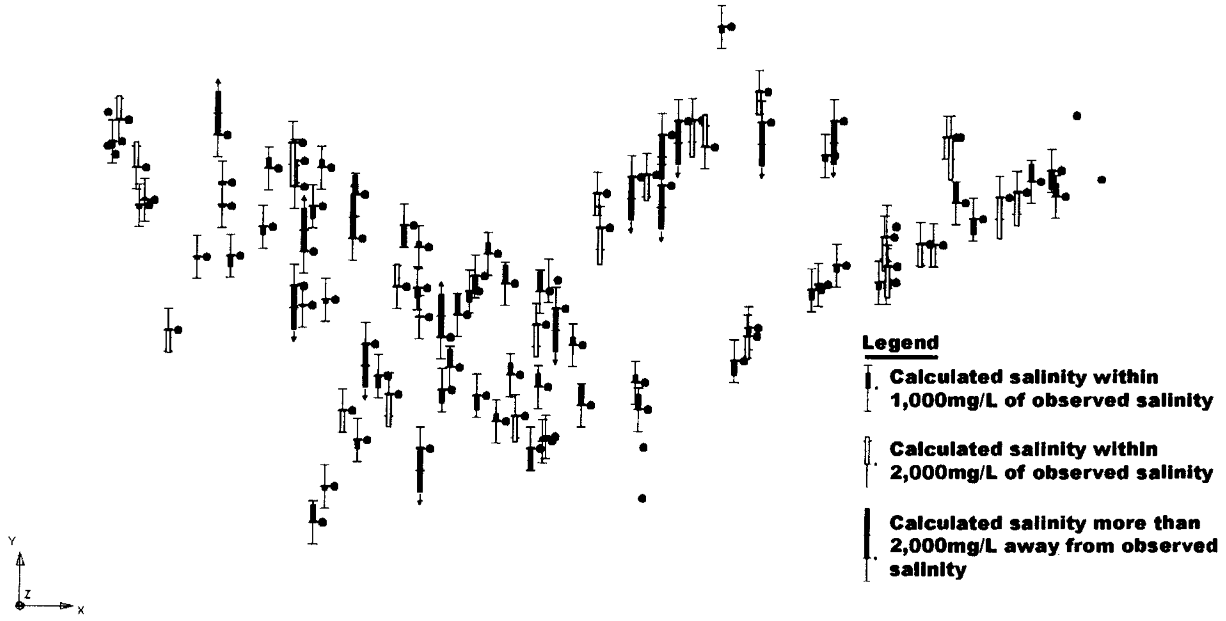


Figure K-29. Groundwater Salinity Calibration Results – Time Step 65

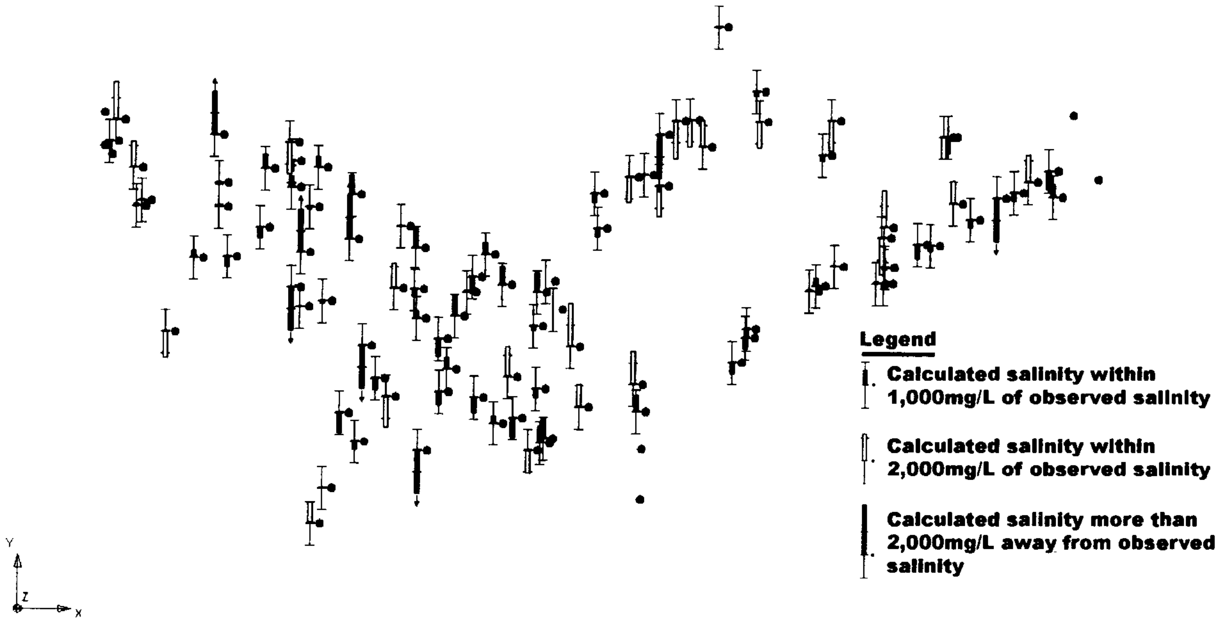


Figure K-30. Groundwater Salinity Calibration Results – Time Step 66

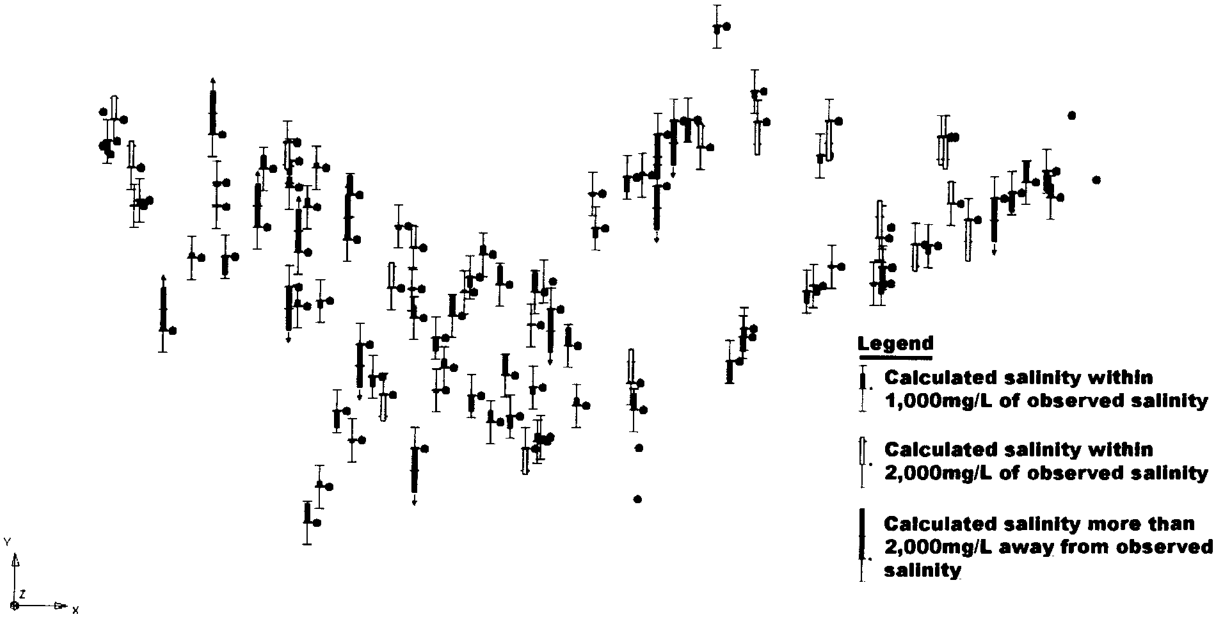


Figure K-31. Groundwater Salinity Calibration Results – Time Step 67

APPENDIX L: ADDITIONAL MODELING RESULTS

Table L-1. Summary of Modeling Output for Recharge Reduction Scenarios

ET Reduction Factor

Recharge Reduction %	*Avg. ET Reduct. Fact. - Irrigated Area*			*Avg. ET Reduct. Fact. - Total Area*		
	1999	2000	2001	1999	2000	2001
0 (baseline)	0.892	0.866	0.813	0.925	0.910	0.869
10	0.920	0.884	0.833	0.949	0.924	0.883
20	0.918	0.896	0.852	0.944	0.930	0.896
30	0.923	0.901	0.863	0.948	0.934	0.903
40	0.926	0.906	0.871	0.950	0.937	0.910
50	0.934	0.907	0.873	0.956	0.938	0.912
60	0.930	0.909	0.876	0.953	0.939	0.914
70	0.931	0.906	0.873	0.953	0.937	0.912
80	0.930	0.900	0.864	0.953	0.934	0.907
90	0.929	0.892	0.852	0.953	0.929	0.899

Soil Salinity

Recharge Reduction %	*Avg. Soil Salinity (mg/L) - Irrigated Area*			*Avg. Soil Salinity (mg/L) - Total Area*		
	1999	2000	2001	1999	2000	2001
0 (baseline)	2487	3108	3864	2431	2865	3479
10	2444	2992	3667	2393	2777	3338
20	2391	2886	3481	2349	2696	3193
30	2347	2810	3378	2313	2638	3080
40	2318	2764	3237	2290	2601	3003
50	2212	2744	3186	2190	2583	2958
60	2286	2748	3173	2261	2579	2945
70	2288	2794	3213	2259	2604	2965
80	2305	2880	3316	2267	2658	3031
90	2330	3007	3479	2282	2738	3139

GW Salinity

Recharge Reduction %	*Avg. GW Salinity (mg/L) - Irrigated Area*			*Avg. GW Salinity (mg/L) - Total Area*		
	1999	2000	2001	1999	2000	2001
0 (baseline)	3016	2805	2681	2983	2783	2700
10	3019	2809	2674	2985	2784	2694
20	3025	2816	2675	2989	2789	2701
30	3031	2826	2704	2993	2798	2709
40	3036	2842	2704	2996	2810	2721
50	3043	2859	2723	3001	2822	2739
60	3049	2881	2761	3005	2838	2767
70	3055	2907	2804	3008	2858	2800
80	3061	2932	2859	3011	2873	2841
90	3068	2969	2924	3015	2896	2885

WT Depth

Recharge Reduction %	*Avg. WT Depth (m) - Irrigated Area*			*Avg. WT Depth (m) - Total Area*		
	1999	2000	2001	1999	2000	2001
0 (baseline)	4.07	5.75	6.10	4.17	5.97	6.27
10	4.17	5.85	6.21	4.25	6.06	6.36
20	4.25	6.00	6.33	4.32	6.19	6.47
30	4.34	6.04	6.41	4.38	6.22	6.53
40	4.42	6.18	6.54	4.46	6.32	6.61
50	4.50	6.30	6.65	4.52	6.41	6.71
60	4.59	6.42	6.74	4.60	6.51	6.79
70	4.68	6.55	6.89	4.67	6.62	6.93
80	4.76	6.67	7.04	4.74	6.71	7.05
90	4.85	6.80	7.16	4.81	6.83	7.16

Table L-2. Summary of Modeling Output Expressed as Change in Regional Average Value from Baseline for Recharge Reduction Scenarios

ET Reduction Factor

Recharge Reduction %	*Avg. Change in ET Reduct. Fact. - Irrigated Area*			*Avg. Change in ET Reduct. Fact. - Total Area*		
	1999	2000	2001	1999	2000	2001
0 (baseline)	-	-	-	-	-	-
10	0.028	0.018	0.020	0.024	0.013	0.015
20	0.026	0.030	0.039	0.019	0.020	0.027
30	0.031	0.035	0.050	0.022	0.023	0.035
40	0.034	0.040	0.058	0.024	0.027	0.041
50	0.042	0.041	0.060	0.030	0.027	0.043
60	0.038	0.043	0.063	0.028	0.029	0.045
70	0.039	0.040	0.060	0.028	0.027	0.044
80	0.038	0.034	0.051	0.028	0.023	0.038
90	0.037	0.026	0.038	0.027	0.018	0.030

Soil Salinity

Recharge Reduction %	*Avg. Reduction in Soil Salinity (mg/L) - Irrigated Area*			*Avg. Reduction in Soil Salinity (mg/L) - Total Area*		
	1999	2000	2001	1999	2000	2001
0 (baseline)	-	-	-	-	-	-
10	43	117	197	38	88	141
20	96	222	383	82	169	286
30	141	298	486	119	227	400
40	170	344	627	142	264	476
50	276	365	678	242	282	521
60	201	360	691	171	286	534
70	199	314	651	173	261	514
80	183	228	548	164	207	448
90	157	101	385	149	127	340

GW Salinity

Recharge Reduction %	*Avg. Reduction in GW Salinity (mg/L) - Irrigated Area*			*Avg. Reduction in GW Salinity (mg/L) - Total Area*		
	1999	2000	2001	1999	2000	2001
0 (baseline)	-	-	-	-	-	-
10	-4	-4	7	-2	0	5
20	-9	-11	6	-6	-6	-1
30	-15	-21	-23	-10	-14	-10
40	-20	-37	-23	-13	-27	-22
50	-27	-54	-42	-18	-39	-39
60	-34	-76	-80	-21	-55	-67
70	-40	-103	-123	-24	-74	-100
80	-46	-127	-178	-28	-89	-141
90	-52	-164	-243	-32	-113	-185

WT Depth

Recharge Reduction %	*Avg. Increase in WT Depth (m) - Irrigated Area*			*Avg. Increase in WT Depth (m) - Total Area*		
	1999	2000	2001	1999	2000	2001
0 (baseline)	-	-	-	-	-	-
10	0.10	0.10	0.10	0.08	0.09	0.08
20	0.18	0.25	0.23	0.16	0.21	0.20
30	0.27	0.29	0.31	0.22	0.24	0.26
40	0.35	0.43	0.44	0.29	0.34	0.34
50	0.43	0.55	0.55	0.35	0.44	0.43
60	0.52	0.66	0.64	0.43	0.53	0.52
70	0.61	0.79	0.78	0.50	0.65	0.65
80	0.69	0.92	0.94	0.57	0.74	0.77
90	0.78	1.04	1.06	0.64	0.86	0.88

Table L-3. Summary of Modeling Output Expressed as Percent Change from Baseline for Recharge Reduction Scenarios

ET Reduction Factor

Recharge Reduction %	*Avg. Change in ET (%) - Irrigated Area*			*Avg. Change in ET (%) - Total Area*		
	1999	2000	2001	1999	2000	2001
0 (baseline)	-	-	-	-	-	-
10	3.18%	2.08%	2.41%	2.58%	1.46%	1.69%
20	2.87%	3.52%	4.81%	2.01%	2.18%	3.12%
30	3.50%	4.08%	6.10%	2.42%	2.56%	3.99%
40	3.81%	4.64%	7.14%	2.64%	2.93%	4.74%
50	4.74%	4.74%	7.43%	3.28%	3.00%	4.94%
60	4.30%	4.95%	7.76%	2.97%	3.15%	5.22%
70	4.36%	4.63%	7.36%	3.03%	2.97%	5.01%
80	4.30%	3.94%	6.27%	3.00%	2.57%	4.36%
90	4.19%	3.00%	4.72%	2.94%	2.02%	3.43%

Soil Salinity

Recharge Reduction %	*Reduction in Soil Salinity (%) - Irrigated Area*			*Reduction in Soil Salinity (%) - Total Area*		
	1999	2000	2001	1999	2000	2001
0 (baseline)	-	-	-	-	-	-
10	1.75%	3.75%	5.09%	1.57%	3.06%	4.06%
20	3.88%	7.16%	9.92%	3.39%	5.88%	8.21%
30	5.65%	9.58%	12.59%	4.88%	7.91%	11.48%
40	6.82%	11.07%	16.24%	5.84%	9.21%	13.69%
50	11.09%	11.73%	17.55%	9.94%	9.85%	14.99%
60	8.09%	11.58%	17.89%	7.02%	9.99%	15.35%
70	8.00%	10.10%	16.84%	7.10%	9.11%	14.78%
80	7.35%	7.34%	14.19%	6.75%	7.23%	12.88%
90	6.31%	3.25%	9.95%	6.14%	4.43%	9.77%

GW Salinity

Recharge Reduction %	*Reduction in GW Salinity (%) - Irrigated Area*			*Reduction in GW Salinity (%) - Total Area*		
	1999	2000	2001	1999	2000	2001
0 (baseline)	-	-	-	-	-	-
10	-0.12%	-0.13%	0.25%	-0.07%	-0.01%	0.20%
20	-0.30%	-0.40%	0.22%	-0.19%	-0.22%	-0.04%
30	-0.50%	-0.75%	-0.86%	-0.33%	-0.52%	-0.35%
40	-0.68%	-1.33%	-0.85%	-0.44%	-0.97%	-0.80%
50	-0.90%	-1.93%	-1.57%	-0.59%	-1.40%	-1.45%
60	-1.12%	-2.73%	-2.99%	-0.72%	-1.96%	-2.50%
70	-1.32%	-3.66%	-4.59%	-0.82%	-2.67%	-3.70%
80	-1.51%	-4.53%	-6.65%	-0.94%	-3.21%	-5.21%
90	-1.73%	-5.84%	-9.07%	-1.08%	-4.05%	-6.84%

WT Depth

Recharge Reduction %	*Change in WT Depth (%) - Irrigated Area*			*Change in WT Depth (%) - Total Area*		
	1999	2000	2001	1999	2000	2001
0 (baseline)	-	-	-	-	-	-
10	2.48%	1.67%	1.68%	2.00%	1.49%	1.34%
20	4.53%	4.28%	3.79%	3.73%	3.58%	3.17%
30	6.55%	5.09%	5.00%	5.18%	4.02%	4.11%
40	8.65%	7.45%	7.15%	6.93%	5.72%	5.36%
50	10.66%	9.53%	8.98%	8.40%	7.36%	6.93%
60	12.78%	11.53%	10.46%	10.28%	8.92%	8.23%
70	14.99%	13.81%	12.83%	12.10%	10.87%	10.39%
80	17.04%	15.91%	15.34%	13.73%	12.38%	12.30%
90	19.23%	18.14%	17.37%	15.45%	14.31%	14.05%

Table L-4. Summary of Modeling Output for Seepage Reduction Scenarios

ET Reduction Factor

90% Seepage Reduction	*Avg. ET Reduct. Fact. - Irrigated Area*			*Avg. ET Reduct. Fact. - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline (No Seep. Red.)	0.892	0.866	0.813	0.925	0.910	0.869
90% Reduction - All	0.922	0.883	0.834	0.947	0.921	0.882
70% Reduction - All	0.920	0.882	0.830	0.946	0.920	0.879
50% Reduction - All	0.917	0.881	0.826	0.943	0.919	0.877
90% Red - Catlin Only	0.905	0.874	0.818	0.934	0.913	0.870
90% Red - Ft. Lyon Only	0.904	0.873	0.817	0.934	0.913	0.869
90% Red -Holbrook Only	0.911	0.882	0.825	0.939	0.920	0.876
90% Red - Otero Only	0.907	0.874	0.818	0.935	0.913	0.870
90% Red - Highline Only	0.904	0.875	0.821	0.934	0.914	0.872
90% Red - Rocky Ford Only	0.903	0.874	0.818	0.932	0.913	0.870
20% Lined at 90% Red	0.909	0.875	0.819	0.937	0.914	0.871

Soil Salinity

90% Seepage Reduction	*Avg. Soil Salinity (mg/L) - Irrigated Area*			*Avg. Soil Salinity (mg/L) - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline (No Seep. Red.)	2487	3108	3864	2431	2865	3479
90% Reduction - All	2400	3092	3723	2353	2862	3387
70% Reduction - All	2416	3103	3788	2367	2869	3430
50% Reduction - All	2434	3112	3834	2384	2871	3463
90% Red - Catlin Only	2505	3125	3888	2446	2881	3508
90% Red - Ft. Lyon Only	2511	3137	3897	2448	2891	3518
90% Red -Holbrook Only	2466	3103	3847	2405	2863	3471
90% Red - Otero Only	2493	3134	3886	2439	2891	3507
90% Red - Highline Only	2509	3113	3835	2450	2873	3475
90% Red - Rocky Ford Only	2518	3127	3888	2456	2882	3507
20% Lined at 90% Red	2472	3131	3872	2418	2880	3490

GW Salinity

90% Seepage Reduction	*Avg. GW Salinity (mg/L) - Irrigated Area*			*Avg. GW Salinity (mg/L) - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline (No Seep. Red.)	3016	2805	2681	2983	2783	2700
90% Reduction - All	3084	3070	3078	3051	3037	3625
70% Reduction - All	3066	2976	2922	3033	2945	2929
50% Reduction - All	3051	2916	2843	3018	2888	2854
90% Red - Catlin Only	3022	2822	2711	2985	2798	2730
90% Red - Ft. Lyon Only	3021	2815	2695	2985	2796	2738
90% Red -Holbrook Only	3030	2848	2752	3006	2850	2804
90% Red - Otero Only	3032	2841	2718	2991	2811	2731
90% Red - Highline Only	3031	2874	2754	2990	2831	2755
90% Red - Rocky Ford Only	3020	2806	2678	2983	2785	2703
20% Lined at 90% Red	3038	2860	2770	3006	2846	3365

WT Depth

90% Seepage Reduction	*Avg. WT Depth (m) - Irrigated Area*			*Avg. WT Depth (m) - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline (No Seep. Red.)	4.07	5.75	6.10	4.17	5.97	6.27
90% Reduction - All	4.48	6.69	7.19	4.54	6.79	7.22
70% Reduction - All	4.38	6.41	6.91	4.46	6.54	6.96
50% Reduction - All	4.30	6.25	6.65	4.38	6.41	6.76
90% Red - Catlin Only	4.10	5.91	6.30	4.17	6.09	6.41
90% Red - Ft. Lyon Only	4.09	5.77	6.10	4.18	5.98	6.25
90% Red -Holbrook Only	4.16	5.97	6.31	4.28	6.20	6.49
90% Red - Otero Only	4.14	5.94	6.31	4.20	6.10	6.41
90% Red - Highline Only	4.14	5.98	6.34	4.20	6.13	6.43
90% Red - Rocky Ford Only	4.06	5.79	6.15	4.15	5.98	6.28
20% Lined at 90% Red	4.16	5.94	6.30	4.26	6.17	6.46

Table L-5. Summary of Modeling Output Expressed as Change in Regional Average Value from Baseline for Seepage Reduction Scenarios

ET Reduction Factor

90% Seepage Reduction	*Avg. Change in ET Reduct. Fact. - Irrigated Area*			*Avg. Change in ET Reduct. Fact. - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline (No Seep. Red.)	-	-	-	-	-	-
90% Reduction - All	0.030	0.017	0.021	0.022	0.010	0.013
70% Reduction - All	0.028	0.017	0.016	0.020	0.010	0.010
50% Reduction - All	0.025	0.015	0.013	0.018	0.009	0.008
90% Red - Catlin Only	0.013	0.008	0.005	0.008	0.003	0.001
90% Red - Ft. Lyon Only	0.012	0.007	0.004	0.008	0.002	0.000
90% Red -Holbrook Only	0.019	0.016	0.012	0.014	0.009	0.007
90% Red - Otero Only	0.015	0.008	0.005	0.010	0.002	0.001
90% Red - Highline Only	0.012	0.009	0.008	0.008	0.003	0.003
90% Red - Rocky Ford Only	0.011	0.008	0.005	0.007	0.003	0.001
20% Lined at 90% Red	0.017	0.009	0.006	0.012	0.004	0.003

Soil Salinity

90% Seepage Reduction	*Avg. Reduction in Soil Salinity (mg/L) - Irrigated Area*			*Avg. Reduction in Soil Salinity (mg/L) - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline (No Seep. Red.)	-	-	-	-	-	-
90% Reduction - All	88	16	141	78	3	92
70% Reduction - All	72	5	76	64	-4	49
50% Reduction - All	53	-4	30	48	-6	16
90% Red - Catlin Only	-17	-17	-24	-14	-16	-29
90% Red - Ft. Lyon Only	-24	-29	-33	-17	-26	-39
90% Red -Holbrook Only	22	5	17	27	2	9
90% Red - Otero Only	-6	-26	-22	-8	-26	-28
90% Red - Highline Only	-22	-5	29	-18	-8	4
90% Red - Rocky Ford Only	-30	-19	-24	-25	-17	-28
20% Lined at 90% Red	16	-23	-8	14	-15	-10

GW Salinity

90% Seepage Reduction	*Avg. Reduction in GW Salinity (mg/L) - Irrigated Area*			*Avg. Reduction in GW Salinity (mg/L) - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline (No Seep. Red.)	-	-	-	-	-	-
90% Reduction - All	-68	-265	-397	-68	-254	-926
70% Reduction - All	-51	-171	-241	-50	-162	-230
50% Reduction - All	-36	-112	-162	-35	-105	-154
90% Red - Catlin Only	-6	-18	-30	-1	-15	-30
90% Red - Ft. Lyon Only	-6	-10	-14	-2	-13	-38
90% Red -Holbrook Only	-14	-44	-71	-22	-66	-104
90% Red - Otero Only	-16	-36	-37	-8	-28	-31
90% Red - Highline Only	-16	-69	-73	-7	-47	-56
90% Red - Rocky Ford Only	-4	-1	3	0	-2	-3
20% Lined at 90% Red	-23	-55	-89	-23	-63	-665

WT Depth

90% Seepage Reduction	*Avg. Increase in WT Depth (m) - Irrigated Area*			*Avg. Increase in WT Depth (m) - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline (No Seep. Red.)	-	-	-	-	-	-
90% Reduction - All	0.41	0.94	1.08	0.38	0.81	0.94
70% Reduction - All	0.32	0.66	0.80	0.29	0.57	0.69
50% Reduction - All	0.23	0.50	0.55	0.21	0.44	0.49
90% Red - Catlin Only	0.03	0.16	0.20	0.01	0.11	0.14
90% Red - Ft. Lyon Only	0.02	0.02	-0.01	0.01	0.01	-0.03
90% Red -Holbrook Only	0.09	0.22	0.21	0.11	0.22	0.22
90% Red - Otero Only	0.07	0.18	0.20	0.04	0.13	0.13
90% Red - Highline Only	0.07	0.23	0.24	0.04	0.15	0.16
90% Red - Rocky Ford Only	-0.01	0.04	0.05	-0.02	0.00	0.00
20% Lined at 90% Red	0.10	0.19	0.20	0.09	0.19	0.18

Table L-6. Summary of Modeling Output Expressed as Percent Change from Baseline for Seepage Reduction Scenarios

ET Reduction Factor

90% Seepage Reduction	*Avg. Change in ET (%) - Irrigated Area*			*Avg. Change in ET (%) - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline (No Seep. Red.)	-	-	-	-	-	-
90% Reduction - All	3.38%	2.01%	2.53%	2.36%	1.12%	1.49%
70% Reduction - All	3.11%	1.91%	2.02%	2.17%	1.07%	1.19%
50% Reduction - All	2.75%	1.75%	1.64%	1.92%	0.97%	0.95%
90% Red - Catlin Only	1.46%	0.97%	0.63%	0.90%	0.31%	0.16%
90% Red - Ft. Lyon Only	1.39%	0.85%	0.44%	0.91%	0.23%	0.01%
90% Red -Holbrook Only	2.15%	1.83%	1.48%	1.51%	1.04%	0.86%
90% Red - Otero Only	1.68%	0.88%	0.63%	1.06%	0.26%	0.16%
90% Red - Highline Only	1.39%	1.06%	1.02%	0.89%	0.37%	0.39%
90% Red - Rocky Ford Only	1.21%	0.98%	0.56%	0.75%	0.32%	0.12%
20% Lined at 90% Red	1.91%	1.01%	0.76%	1.26%	0.43%	0.30%

Soil Salinity

90% Seepage Reduction	*Reduction in Soil Salinity (%) - Irrigated Area*			*Reduction in Soil Salinity (%) - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline (No Seep. Red.)	-	-	-	-	-	-
90% Reduction - All	3.53%	0.51%	3.65%	3.22%	0.11%	2.66%
70% Reduction - All	2.88%	0.18%	1.98%	2.64%	-0.15%	1.41%
50% Reduction - All	2.13%	-0.14%	0.78%	1.97%	-0.22%	0.46%
90% Red - Catlin Only	-0.69%	-0.55%	-0.63%	-0.58%	-0.56%	-0.83%
90% Red - Ft. Lyon Only	-0.96%	-0.93%	-0.86%	-0.68%	-0.90%	-1.13%
90% Red -Holbrook Only	0.88%	0.16%	0.43%	1.09%	0.07%	0.25%
90% Red - Otero Only	-0.23%	-0.84%	-0.56%	-0.31%	-0.90%	-0.81%
90% Red - Highline Only	-0.88%	-0.15%	0.75%	-0.75%	-0.29%	0.13%
90% Red - Rocky Ford Only	-1.22%	-0.61%	-0.61%	-1.03%	-0.59%	-0.80%
20% Lined at 90% Red	0.62%	-0.75%	-0.20%	0.56%	-0.54%	-0.30%

GW Salinity

90% Seepage Reduction	*Reduction in GW Salinity (%) - Irrigated Area*			*Reduction in GW Salinity (%) - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline (No Seep. Red.)	-	-	-	-	-	-
90% Reduction - All	-2.26%	-9.45%	-14.81%	-2.26%	-9.12%	-34.28%
70% Reduction - All	-1.68%	-6.11%	-9.01%	-1.66%	-5.80%	-8.51%
50% Reduction - All	-1.19%	-3.98%	-6.05%	-1.16%	-3.77%	-5.71%
90% Red - Catlin Only	-0.21%	-0.62%	-1.13%	-0.04%	-0.52%	-1.11%
90% Red - Ft. Lyon Only	-0.19%	-0.35%	-0.50%	-0.06%	-0.47%	-1.41%
90% Red -Holbrook Only	-0.48%	-1.55%	-2.66%	-0.75%	-2.38%	-3.85%
90% Red - Otero Only	-0.53%	-1.29%	-1.39%	-0.27%	-0.99%	-1.15%
90% Red - Highline Only	-0.52%	-2.47%	-2.72%	-0.24%	-1.70%	-2.06%
90% Red - Rocky Ford Only	-0.14%	-0.02%	0.12%	0.02%	-0.06%	-0.12%
20% Lined at 90% Red	-0.76%	-1.98%	-3.32%	-0.76%	-2.25%	-24.62%

WT Depth

90% Seepage Reduction	*Change in WT Depth (%) - Irrigated Area*			*Change in WT Depth (%) - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline (No Seep. Red.)	-	-	-	-	-	-
90% Reduction - All	10.08%	16.39%	17.76%	9.03%	13.60%	15.04%
70% Reduction - All	7.75%	11.44%	13.15%	6.97%	9.53%	11.00%
50% Reduction - All	5.59%	8.62%	9.01%	5.10%	7.35%	7.82%
90% Red - Catlin Only	0.66%	2.72%	3.29%	0.13%	1.86%	2.23%
90% Red - Ft. Lyon Only	0.41%	0.32%	-0.12%	0.28%	0.09%	-0.40%
90% Red -Holbrook Only	2.21%	3.84%	3.39%	2.73%	3.69%	3.47%
90% Red - Otero Only	1.81%	3.20%	3.31%	0.88%	2.15%	2.13%
90% Red - Highline Only	1.77%	3.95%	3.86%	0.86%	2.59%	2.57%
90% Red - Rocky Ford Only	-0.14%	0.64%	0.74%	-0.45%	0.08%	0.07%
20% Lined at 90% Red	2.36%	3.35%	3.21%	2.15%	3.20%	2.94%

Table L-7. Summary of Modeling Output for Subsurface Drainage Installation Scenarios

ET Reduction Factor

Drainage Spacing	*Avg. ET Reduct. Fact. - Irrigated Area*			*Avg. ET Reduct. Fact. - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline (No Drainage)	0.892	0.866	0.813	0.925	0.910	0.869
50 m	0.932	0.878	0.825	0.954	0.917	0.875
75 m	0.930	0.877	0.823	0.952	0.916	0.874
100 m	0.928	0.876	0.821	0.951	0.916	0.873
150 m	0.925	0.874	0.820	0.949	0.915	0.872

Soil Salinity

Drainage Spacing	*Avg. Soil Salinity (mg/L) - Irrigated Area*			*Avg. Soil Salinity (mg/L) - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline (No Drainage)	2487	3108	3864	2431	2865	3479
50 m	2330	3147	3836	2299	2920	3492
75 m	2351	3166	3864	2316	2928	3506
100 m	2368	3180	3886	2329	2935	3521
150 m	2393	3195	3903	2348	2942	3529

GW Salinity

Drainage Spacing	*Avg. GW Salinity (mg/L) - Irrigated Area*			*Avg. GW Salinity (mg/L) - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline (No Drainage)	3016	2805	2681	2983	2783	2700
50 m	2988	2728	2601	2960	2718	2631
75 m	2990	2731	2601	2962	2722	2630
100 m	2991	2731	2604	2963	2723	2633
150 m	2991	2735	2600	2964	2726	2630

WT Depth

Drainage Spacing	*Avg. WT Depth (m) - Irrigated Area*			*Avg. WT Depth (m) - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline (No Drainage)	4.07	5.75	6.10	4.17	5.97	6.27
50 m	4.40	6.06	6.35	4.45	6.25	6.48
75 m	4.34	6.02	6.31	4.41	6.20	6.45
100 m	4.31	5.96	6.27	4.37	6.16	6.42
150 m	4.25	5.91	6.22	4.33	6.11	6.38

Table L-8. Summary of Modeling Output Expressed as Change in Regional Average Value from Baseline for Subsurface Drainage Installation Scenarios

ET Reduction Factor

Drainage Spacing	*Avg. Change in ET Reduct. Fact. - Irrigated Area*			*Avg. Change in ET Reduct. Fact. - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline (No Drainage)	-	-	-	-	-	-
50 m	0.040	0.012	0.012	0.028	0.006	0.006
75 m	0.038	0.011	0.010	0.027	0.006	0.005
100 m	0.036	0.010	0.008	0.026	0.005	0.004
150 m	0.033	0.008	0.007	0.024	0.004	0.003

Soil Salinity

Drainage Spacing	*Avg. Reduction in Soil Salinity (mg/L) - Irrigated Area*			*Avg. Reduction in Soil Salinity (mg/L) - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline (No Drainage)	-	-	-	-	-	-
50 m	158	-39	28	132	-55	-13
75 m	136	-58	0	116	-63	-27
100 m	119	-72	-22	103	-70	-42
150 m	94	-87	-39	84	-77	-50

GW Salinity

Drainage Spacing	*Avg. Reduction in GW Salinity (mg/L) - Irrigated Area*			*Avg. Reduction in GW Salinity (mg/L) - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline (No Drainage)	-	-	-	-	-	-
50 m	27	77	80	24	66	69
75 m	25	74	80	21	62	69
100 m	24	73	77	20	60	67
150 m	24	70	81	19	57	70

WT Depth

Drainage Spacing	*Avg. Increase in WT Depth (m) - Irrigated Area*			*Avg. Increase in WT Depth (m) - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline (No Drainage)	-	-	-	-	-	-
50 m	0.33	0.31	0.25	0.28	0.27	0.21
75 m	0.28	0.27	0.21	0.24	0.22	0.18
100 m	0.24	0.21	0.17	0.21	0.18	0.15
150 m	0.18	0.16	0.12	0.16	0.13	0.11

Table L-9. Summary of Modeling Output Expressed as Percent Change from Baseline for Subsurface Drainage Installation Scenarios

ET Reduction Factor

Drainage Spacing	*Avg. Change in ET (%) - Irrigated Area*			*Avg. Change in ET (%) - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline (No Drainage)	-	-	-	-	-	-
50 m	4.45%	1.41%	1.46%	3.06%	0.70%	0.69%
75 m	4.25%	1.31%	1.24%	2.93%	0.65%	0.58%
100 m	4.07%	1.15%	1.00%	2.80%	0.57%	0.44%
150 m	3.74%	0.96%	0.87%	2.58%	0.47%	0.37%

Soil Salinity

Drainage Spacing	*Reduction in Soil Salinity (%) - Irrigated Area*			*Reduction in Soil Salinity (%) - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline (No Drainage)	-	-	-	-	-	-
50 m	6.34%	-1.25%	0.73%	5.44%	-1.93%	-0.38%
75 m	5.47%	-1.85%	0.01%	4.76%	-2.20%	-0.76%
100 m	4.80%	-2.32%	-0.58%	4.23%	-2.45%	-1.21%
150 m	3.79%	-2.79%	-1.00%	3.45%	-2.69%	-1.42%

GW Salinity

Drainage Spacing	*Reduction in GW Salinity (%) - Irrigated Area*			*Reduction in GW Salinity (%) - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline (No Drainage)	-	-	-	-	-	-
50 m	0.90%	2.73%	2.97%	0.79%	2.36%	2.55%
75 m	0.84%	2.62%	2.99%	0.70%	2.21%	2.57%
100 m	0.81%	2.62%	2.88%	0.67%	2.15%	2.47%
150 m	0.80%	2.49%	3.04%	0.64%	2.06%	2.59%

WT Depth

Drainage Spacing	*Change in WT Depth (%) - Irrigated Area*			*Change in WT Depth (%) - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline (No Drainage)	-	-	-	-	-	-
50 m	8.10%	5.41%	4.04%	6.71%	4.59%	3.36%
75 m	6.77%	4.62%	3.45%	5.70%	3.73%	2.84%
100 m	5.82%	3.62%	2.78%	4.92%	3.06%	2.40%
150 m	4.41%	2.77%	1.97%	3.77%	2.21%	1.69%

Table L-10. Summary of Modeling Output for Pumping Volume Increase Scenarios

ET Reduction Factor

Pumping Increase Scen.	*Avg. ET Reduct. Fact. - Irrigated Area*			*Avg. ET Reduct. Fact. - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline (No Increase)	0.892	0.866	0.813	0.925	0.910	0.869
25% Increase	0.911	0.814	0.726	0.940	0.876	0.810
50% Increase	0.911	0.814	0.725	0.940	0.876	0.810
100% Increase	0.911	0.814	0.726	0.940	0.876	0.811
200% Increase	0.908	0.877	0.822	0.938	0.917	0.874

Soil Salinity

Pumping Increase Scen.	*Avg. Soil Salinity (mg/L) - Irrigated Area*			*Avg. Soil Salinity (mg/L) - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline (No Increase)	2487	3108	3864	2431	2865	3479
25% Increase	2485	3131	3876	2426	2889	3505
50% Increase	2482	3131	3872	2423	2889	3502
100% Increase	2478	3127	3863	2419	2886	3496
200% Increase	2483	3243	3857	2422	2991	3488

GW Salinity

Pumping Increase Scen.	*Avg. GW Salinity (mg/L) - Irrigated Area*			*Avg. GW Salinity (mg/L) - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline (No Increase)	3016	2805	2681	2983	2783	2700
25% Increase	3014	2802	2677	2982	2779	2697
50% Increase	3014	2799	2673	2981	2777	2693
100% Increase	3013	2801	2679	2981	2779	2698
200% Increase	3012	2808	2703	2980	2783	2717

WT Depth

Pumping Increase Scen.	*Avg. WT Depth (m) - Irrigated Area*			*Avg. WT Depth (m) - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline (No Increase)	4.07	5.75	6.10	4.17	5.97	6.27
25% Increase	4.11	5.79	6.11	4.21	6.01	6.29
50% Increase	4.12	5.79	6.13	4.22	6.02	6.30
100% Increase	4.15	5.83	6.17	4.24	6.05	6.33
200% Increase	4.17	5.89	6.24	4.26	6.09	6.39

Table L-11. Summary of Modeling Output Expressed as Change in Regional Average Value from Baseline for Pumping Volume Increase Scenarios

ET Reduction Factor

Pumping Increase Scen.	*Avg. Change in ET Reduct. Fact. - Irrigated Area*			*Avg. Change in ET Reduct. Fact. - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline (No Increase)	-	-	-	-	-	-
25% Increase	0.019	-0.052	-0.088	0.015	-0.034	-0.058
50% Increase	0.019	-0.052	-0.088	0.015	-0.034	-0.059
100% Increase	0.019	-0.052	-0.087	0.015	-0.034	-0.058
200% Increase	0.016	0.011	0.009	0.012	0.006	0.005

Soil Salinity

Pumping Increase Scen.	*Avg. Reduction in Soil Salinity (mg/L) - Irrigated Area*			*Avg. Reduction in Soil Salinity (mg/L) - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline (No Increase)	-	-	-	-	-	-
25% Increase	2	-23	-12	5	-24	-26
50% Increase	6	-23	-8	9	-24	-23
100% Increase	10	-19	1	12	-21	-16
200% Increase	5	-135	7	9	-127	-9

GW Salinity

Pumping Increase Scen.	*Avg. Reduction in GW Salinity (mg/L) - Irrigated Area*			*Avg. Reduction in GW Salinity (mg/L) - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline (No Increase)	-	-	-	-	-	-
25% Increase	2	3	4	1	4	3
50% Increase	2	6	8	2	6	7
100% Increase	3	4	2	2	4	2
200% Increase	3	-3	-22	3	0	-17

WT Depth

Pumping Increase Scen.	*Avg. Increase in WT Depth (m) - Irrigated Area*			*Avg. Increase in WT Depth (m) - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline (No Increase)	-	-	-	-	-	-
25% Increase	0.04	0.04	0.01	0.04	0.04	0.02
50% Increase	0.06	0.04	0.03	0.05	0.05	0.03
100% Increase	0.08	0.08	0.07	0.07	0.07	0.06
200% Increase	0.10	0.14	0.14	0.09	0.11	0.12

Table L-12. Summary of Modeling Output Expressed as Percent Change from Baseline for Pumping Volume Increase Scenarios

ET Reduction Factor

Pumping Increase Scen.	*Avg. Change in ET (%) - Irrigated Area*			*Avg. Change in ET (%) - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline (No Increase)	-	-	-	-	-	-
25% Increase	2.11%	-6.02%	-10.77%	1.62%	-3.75%	-6.73%
50% Increase	2.11%	-6.04%	-10.79%	1.62%	-3.76%	-6.76%
100% Increase	2.12%	-6.04%	-10.69%	1.63%	-3.76%	-6.68%
200% Increase	1.81%	1.26%	1.14%	1.31%	0.67%	0.61%

Soil Salinity

Pumping Increase Scen.	*Reduction in Soil Salinity (%) - Irrigated Area*			*Reduction in Soil Salinity (%) - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline (No Increase)	-	-	-	-	-	-
25% Increase	0.08%	-0.74%	-0.32%	0.22%	-0.85%	-0.75%
50% Increase	0.23%	-0.74%	-0.20%	0.35%	-0.83%	-0.67%
100% Increase	0.39%	-0.61%	0.03%	0.50%	-0.75%	-0.47%
200% Increase	0.18%	-4.34%	0.18%	0.38%	-4.42%	-0.27%

GW Salinity

Pumping Increase Scen.	*Reduction in GW Salinity (%) - Irrigated Area*			*Reduction in GW Salinity (%) - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline (No Increase)	-	-	-	-	-	-
25% Increase	0.05%	0.11%	0.13%	0.05%	0.16%	0.12%
50% Increase	0.06%	0.21%	0.29%	0.06%	0.22%	0.24%
100% Increase	0.09%	0.13%	0.06%	0.08%	0.16%	0.07%
200% Increase	0.11%	-0.11%	-0.81%	0.11%	0.01%	-0.64%

WT Depth

Pumping Increase Scen.	*Change in WT Depth (%) - Irrigated Area*			*Change in WT Depth (%) - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline (No Increase)	-	-	-	-	-	-
25% Increase	1.07%	0.68%	0.19%	1.00%	0.67%	0.25%
50% Increase	1.36%	0.74%	0.50%	1.15%	0.76%	0.48%
100% Increase	1.90%	1.33%	1.15%	1.63%	1.18%	0.91%
200% Increase	2.47%	2.37%	2.27%	2.17%	1.85%	1.86%

Table L-13. Summary of Modeling Output for Combination Scenarios

ET Reduction Factor

Scenario	*Avg. ET Reduct. Fact. - Irrigated Area*			*Avg. ET Reduct. Fact. - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline	0.892	0.866	0.813	0.925	0.910	0.869
Rech 30%_Seep 50%	0.932	0.905	0.870	0.954	0.936	0.908
Rech 50%_Seep 90%	0.937	0.915	0.890	0.958	0.943	0.923
Rech 80%_Seep 90%	0.936	0.903	0.875	0.957	0.936	0.914
Rech 30%_Drain 100m	0.936	0.903	0.867	0.957	0.935	0.906
Rech 50%_Drain 50m	0.940	0.912	0.880	0.959	0.940	0.916
Rech 80%_Drain 50m	0.937	0.903	0.868	0.958	0.935	0.909
Seep 50%_Drain 100m	0.931	0.879	0.825	0.953	0.918	0.875
Seep 90%_Drain 50m	0.935	0.883	0.834	0.956	0.920	0.882
Rech 30%_Seep 50%_Drain 100m	0.939	0.906	0.871	0.959	0.936	0.908
Rech 50%_Seep 90%_Drain 50m	0.941	0.916	0.891	0.961	0.943	0.923
Rech 80%_Seep 90%_Drain 50m	0.938	0.903	0.875	0.959	0.935	0.914

Soil Salinity

Scenario	*Avg. Soil Salinity (mg/L) - Irrigated Area*			*Avg. Soil Salinity (mg/L) - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline	2487	3108	3864	2431	2865	3479
Rech 30%_Seep 50%	2275	2779	3239	2257	2619	3011
Rech 50%_Seep 90%	2227	2645	2948	2212	2516	2781
Rech 80%_Seep 90%	2259	2822	3146	2227	2618	2898
Rech 30%_Drain 100m	2247	2811	3287	2234	2647	3052
Rech 50%_Drain 50m	2205	2699	3099	2199	2560	2905
Rech 80%_Drain 50m	2247	2846	3261	2221	2644	2999
Seep 50%_Drain 100m	2339	3141	3833	2307	2906	3475
Seep 90%_Drain 50m	2298	3081	3696	2272	2871	3382
Rech 30%_Seep 50%_Drain 100m	2226	2769	3220	2216	2616	3003
Rech 50%_Seep 90%_Drain 50m	2181	2611	2914	2175	2503	2765
Rech 80%_Seep 90%_Drain 50m	2231	2815	3123	2204	2623	2891

GW Salinity

Scenario	*Avg. GW Salinity (mg/L) - Irrigated Area*			*Avg. GW Salinity (mg/L) - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline	3016	2805	2681	2983	2783	2700
Rech 30%_Seep 50%	3071	2957	2857	3032	2919	2872
Rech 50%_Seep 90%	3130	3220	3266	3082	3155	3242
Rech 80%_Seep 90%	3164	3395	3615	3103	3280	3506
Rech 30%_Drain 100m	3011	2762	2613	2977	2745	2646
Rech 50%_Drain 50m	3023	2792	2654	2983	2767	2680
Rech 80%_Drain 50m	3044	2876	2797	2996	2827	2790
Seep 50%_Drain 100m	3028	2848	2764	3000	2833	2787
Seep 90%_Drain 50m	3060	3004	3006	3032	2983	3014
Rech 30%_Seep 50%_Drain 100m	3052	2889	2785	3016	2867	2808
Rech 50%_Seep 90%_Drain 50m	3109	3162	3205	3065	3108	3188
Rech 80%_Seep 90%_Drain 50m	3148	3361	3593	3089	3254	3480

WT Depth

Scenario	*Avg. WT Depth (m) - Irrigated Area*			*Avg. WT Depth (m) - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline	4.07	5.75	6.10	4.17	5.97	6.27
Rech 30%_Seep 50%	4.57	6.65	7.06	4.60	6.74	7.10
Rech 50%_Seep 90%	4.96	7.43	7.98	4.94	7.38	7.87
Rech 80%_Seep 90%	5.25	7.91	8.57	5.18	7.79	8.35
Rech 30%_Drain 100m	4.51	6.27	6.57	4.53	6.40	6.67
Rech 50%_Drain 50m	4.73	6.49	6.79	4.71	6.58	6.83
Rech 80%_Drain 50m	4.96	6.83	7.18	4.91	6.85	7.16
Seep 50%_Drain 100m	4.49	6.43	6.79	4.54	6.58	6.90
Seep 90%_Drain 50m	4.74	6.89	7.35	4.76	6.96	7.37
Rech 30%_Seep 50%_Drain 100m	4.72	6.74	7.12	4.72	6.80	7.13
Rech 50%_Seep 90%_Drain 50m	5.14	7.51	8.03	5.09	7.46	7.93
Rech 80%_Seep 90%_Drain 50m	5.40	7.98	8.60	5.31	7.85	8.38

Table L-14. Summary of Modeling Output Expressed as Change in Regional Average Value from Baseline for Combination Scenarios

ET Reduction Factor

Scenario	*Avg. Change in ET Reduct. Fact. - Irrigated Area*			*Avg. Change in ET Reduct. Fact. - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline	-	-	-	-	-	-
Rech 30%_Seep 50%	0.040	0.039	0.056	0.028	0.025	0.039
Rech 50%_Seep 90%	0.045	0.049	0.077	0.032	0.032	0.054
Rech 80%_Seep 90%	0.044	0.037	0.062	0.032	0.025	0.045
Rech 30%_Drain 100m	0.044	0.037	0.054	0.032	0.024	0.037
Rech 50%_Drain 50m	0.048	0.046	0.067	0.034	0.030	0.047
Rech 80%_Drain 50m	0.045	0.037	0.055	0.032	0.025	0.040
Seep 50%_Drain 100m	0.039	0.013	0.012	0.028	0.007	0.007
Seep 90%_Drain 50m	0.043	0.017	0.021	0.031	0.010	0.013
Rech 30%_Seep 50%_Drain 100m	0.047	0.040	0.057	0.033	0.026	0.040
Rech 50%_Seep 90%_Drain 50m	0.049	0.051	0.078	0.035	0.033	0.055
Rech 80%_Seep 90%_Drain 50m	0.046	0.037	0.062	0.033	0.025	0.045

Soil Salinity

Scenario	*Avg. Reduction in Soil Salinity (mg/L) - Irrigated Area*			*Avg. Reduction in Soil Salinity (mg/L) - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline	-	-	-	-	-	-
Rech 30%_Seep 50%	212	329	625	175	246	468
Rech 50%_Seep 90%	261	463	916	220	349	698
Rech 80%_Seep 90%	229	286	718	205	247	581
Rech 30%_Drain 100m	240	297	577	197	218	427
Rech 50%_Drain 50m	283	409	765	233	305	574
Rech 80%_Drain 50m	240	262	603	210	221	480
Seep 50%_Drain 100m	148	-33	31	124	-41	4
Seep 90%_Drain 50m	189	27	168	160	-7	98
Rech 30%_Seep 50%_Drain 100m	262	340	644	215	249	477
Rech 50%_Seep 90%_Drain 50m	306	498	950	256	361	714
Rech 80%_Seep 90%_Drain 50m	256	294	741	228	242	588

GW Salinity

Scenario	*Avg. Reduction in GW Salinity (mg/L) - Irrigated Area*			*Avg. Reduction in GW Salinity (mg/L) - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline	-	-	-	-	-	-
Rech 30%_Seep 50%	-56	-152	-176	-49	-136	-172
Rech 50%_Seep 90%	-114	-415	-585	-98	-372	-542
Rech 80%_Seep 90%	-148	-590	-934	-120	-496	-807
Rech 30%_Drain 100m	5	43	68	7	39	53
Rech 50%_Drain 50m	-7	13	27	0	16	20
Rech 80%_Drain 50m	-29	-71	-116	-13	-43	-90
Seep 50%_Drain 100m	-13	-43	-83	-17	-49	-88
Seep 90%_Drain 50m	-45	-199	-325	-48	-199	-315
Rech 30%_Seep 50%_Drain 100m	-36	-84	-104	-33	-83	-108
Rech 50%_Seep 90%_Drain 50m	-93	-357	-524	-82	-324	-488
Rech 80%_Seep 90%_Drain 50m	-132	-556	-912	-106	-470	-781

WT Depth

Scenario	*Avg. Increase in WT Depth (m) - Irrigated Area*			*Avg. Increase in WT Depth (m) - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline	-	-	-	-	-	-
Rech 30%_Seep 50%	0.50	0.90	0.95	0.43	0.76	0.82
Rech 50%_Seep 90%	0.89	1.67	1.87	0.77	1.41	1.60
Rech 80%_Seep 90%	1.18	2.16	2.46	1.01	1.82	2.08
Rech 30%_Drain 100m	0.45	0.51	0.47	0.37	0.42	0.39
Rech 50%_Drain 50m	0.66	0.73	0.68	0.54	0.61	0.56
Rech 80%_Drain 50m	0.89	1.07	1.08	0.74	0.88	0.89
Seep 50%_Drain 100m	0.42	0.68	0.69	0.37	0.61	0.63
Seep 90%_Drain 50m	0.67	1.13	1.25	0.60	0.99	1.10
Rech 30%_Seep 50%_Drain 100m	0.65	0.99	1.01	0.56	0.82	0.86
Rech 50%_Seep 90%_Drain 50m	1.07	1.76	1.93	0.92	1.48	1.65
Rech 80%_Seep 90%_Drain 50m	1.33	2.23	2.49	1.14	1.88	2.11

Table L-15. Summary of Modeling Output Expressed as Percent Change from Baseline for Combination Scenarios

ET Reduction Factor

Scenario	*Avg. Change in ET (%) - Irrigated Area*			*Avg. Change in ET (%) - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline	-	-	-	-	-	-
Rech 30%_Seep 50%	4.45%	4.49%	6.95%	3.06%	2.79%	4.52%
Rech 50%_Seep 90%	5.06%	5.65%	9.43%	3.50%	3.53%	6.22%
Rech 80%_Seep 90%	4.91%	4.33%	7.60%	3.43%	2.76%	5.21%
Rech 30%_Drain 100m	4.98%	4.28%	6.65%	3.41%	2.65%	4.31%
Rech 50%_Drain 50m	5.36%	5.26%	8.28%	3.68%	3.29%	5.44%
Rech 80%_Drain 50m	5.06%	4.22%	6.74%	3.51%	2.70%	4.61%
Seep 50%_Drain 100m	4.40%	1.53%	1.48%	3.03%	0.79%	0.75%
Seep 90%_Drain 50m	4.82%	2.02%	2.63%	3.32%	1.05%	1.47%
Rech 30%_Seep 50%_Drain 100m	5.22%	4.62%	7.06%	3.58%	2.85%	4.56%
Rech 50%_Seep 90%_Drain 50m	5.54%	5.83%	9.60%	3.81%	3.60%	6.28%
Rech 80%_Seep 90%_Drain 50m	5.20%	4.28%	7.63%	3.62%	2.71%	5.18%

Soil Salinity

Scenario	*Reduction in Soil Salinity (%) - Irrigated Area*			*Reduction in Soil Salinity (%) - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline	-	-	-	-	-	-
Rech 30%_Seep 50%	8.53%	10.58%	16.19%	7.19%	8.59%	13.44%
Rech 50%_Seep 90%	10.48%	14.90%	23.70%	9.05%	12.17%	20.07%
Rech 80%_Seep 90%	9.19%	9.21%	18.57%	8.42%	8.61%	16.70%
Rech 30%_Drain 100m	9.65%	9.57%	14.93%	8.11%	7.60%	12.27%
Rech 50%_Drain 50m	11.36%	13.16%	19.81%	9.57%	10.66%	16.51%
Rech 80%_Drain 50m	9.65%	8.42%	15.60%	8.64%	7.71%	13.79%
Seep 50%_Drain 100m	5.95%	-1.06%	0.81%	5.11%	-1.42%	0.11%
Seep 90%_Drain 50m	7.61%	0.87%	4.35%	6.58%	-0.23%	2.80%
Rech 30%_Seep 50%_Drain 100m	10.52%	10.92%	16.66%	8.84%	8.70%	13.70%
Rech 50%_Seep 90%_Drain 50m	12.32%	16.01%	24.58%	10.53%	12.62%	20.54%
Rech 80%_Seep 90%_Drain 50m	10.30%	9.45%	19.18%	9.36%	8.45%	16.90%

GW Salinity

Scenario	*Reduction in GW Salinity (%) - Irrigated Area*			*Reduction in GW Salinity (%) - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline	-	-	-	-	-	-
Rech 30%_Seep 50%	-1.85%	-5.41%	-6.57%	-1.63%	-4.88%	-6.37%
Rech 50%_Seep 90%	-3.78%	-14.80%	-21.83%	-3.30%	-13.36%	-20.07%
Rech 80%_Seep 90%	-4.90%	-21.04%	-34.85%	-4.02%	-17.84%	-29.87%
Rech 30%_Drain 100m	0.17%	1.54%	2.55%	0.23%	1.39%	1.98%
Rech 50%_Drain 50m	-0.24%	0.45%	1.01%	0.01%	0.58%	0.75%
Rech 80%_Drain 50m	-0.95%	-2.53%	-4.33%	-0.42%	-1.56%	-3.35%
Seep 50%_Drain 100m	-0.42%	-1.55%	-3.09%	-0.56%	-1.77%	-3.24%
Seep 90%_Drain 50m	-1.48%	-7.11%	-12.11%	-1.62%	-7.16%	-11.65%
Rech 30%_Seep 50%_Drain 100m	-1.21%	-3.00%	-3.89%	-1.11%	-3.00%	-4.01%
Rech 50%_Seep 90%_Drain 50m	-3.10%	-12.73%	-19.54%	-2.73%	-11.65%	-18.08%
Rech 80%_Seep 90%_Drain 50m	-4.38%	-19.82%	-34.02%	-3.56%	-16.90%	-28.91%

WT Depth

Scenario	*Change in WT Depth (%) - Irrigated Area*			*Change in WT Depth (%) - Total Area*		
	1999	2000	2001	1999	2000	2001
Baseline	-	-	-	-	-	-
Rech 30%_Seep 50%	12.37%	15.70%	15.62%	10.34%	12.78%	13.12%
Rech 50%_Seep 90%	21.86%	29.10%	30.69%	18.42%	23.52%	25.46%
Rech 80%_Seep 90%	29.11%	37.53%	40.35%	24.29%	30.40%	33.11%
Rech 30%_Drain 100m	10.94%	8.94%	7.64%	8.78%	7.10%	6.25%
Rech 50%_Drain 50m	16.30%	12.78%	11.18%	12.90%	10.20%	8.91%
Rech 80%_Drain 50m	21.81%	18.67%	17.66%	17.69%	14.71%	14.20%
Seep 50%_Drain 100m	10.30%	11.87%	11.29%	8.98%	10.15%	9.97%
Seep 90%_Drain 50m	16.45%	19.71%	20.48%	14.30%	16.53%	17.47%
Rech 30%_Seep 50%_Drain 100m	16.10%	17.18%	16.62%	13.35%	13.79%	13.72%
Rech 50%_Seep 90%_Drain 50m	26.30%	30.54%	31.58%	22.14%	24.83%	26.33%
Rech 80%_Seep 90%_Drain 50m	32.75%	38.73%	40.83%	27.38%	31.38%	33.64%

Figure L-1. Baseline Scenario: Average Water Table Depth (m) over Irrigation Season 1999

Figure L-2. Baseline Scenario: Average Water Table Depth (m) over Irrigation Season 2000

Figure L-3. Baseline Scenario: Average Water Table Depth (m) over Irrigation Season 2001

Figure L-4. Baseline Scenario: Average Soil Water Salinity (mg/L) over Irrigation Season 1999

Figure L-5. Baseline Scenario: Average Soil Water Salinity (mg/L) over Irrigation Season 2000

Figure L-6. Baseline Scenario: Average Soil Water Salinity (mg/L) over Irrigation Season 2001

Figure L-7. Baseline Scenario: Average Relative Yield (Scale of 1.0) over Irrigation Season 1999

Figure L-8. Baseline Scenario: Average Relative Yield (Scale of 1.0) over Irrigation Season 2000

Figure L-9. Baseline Scenario: Average Relative Yield (Scale of 1.0) over Irrigation Season 2001

Figure L-10. 50% Recharge Reduction Scenario: Increase in Water Table Depth over Irrigation Season 1999

Figure L-11. 50% Recharge Reduction Scenario: Increase in Water Table Depth over Irrigation Season 2000

Figure L-12. 50% Recharge Reduction Scenario: Increase in Water Table Depth over Irrigation Season 2001

Figure L-13. 50% Recharge Reduction Scenario: Decrease in Soil Water Salinity over Irrigation Season 1999

Figure L-14. 50% Recharge Reduction Scenario: Decrease in Soil Water Salinity over Irrigation Season 2000

Figure L-15. 50% Recharge Reduction Scenario: Decrease in Soil Water Salinity over Irrigation Season 2001

Figure L-16. 90% Seepage Reduction Scenario: Increase in Water Table Depth over Irrigation Season 1999

Figure L-17. 90% Seepage Reduction Scenario: Increase in Water Table Depth over Irrigation Season 2000

Figure L-18. 90% Seepage Reduction Scenario: Increase in Water Table Depth over Irrigation Season 2001

Figure L-19. 90% Seepage Reduction Scenario: Decrease in Soil Water Salinity over Irrigation Season 1999

Figure L-20. 90% Seepage Reduction Scenario: Decrease in Soil Water Salinity over Irrigation Season 2000

Figure L-21. 90% Seepage Reduction Scenario: Decrease in Soil Water Salinity over Irrigation Season 2001

Figure L-22. Subsurface Drainage (50-m Spacing) Scenario: Increase in Water Table Depth over Irrigation Season 1999

Figure L-23. Subsurface Drainage (50-m Spacing) Scenario: Increase in Water Table Depth over Irrigation Season 2000

Figure L-24. Subsurface Drainage (50-m Spacing) Scenario: Increase in Water Table Depth over Irrigation Season 2001

Figure L-25. Subsurface Drainage (50-m Spacing) Scenario: Decrease in Soil Water Salinity over Irrigation Season 1999

Figure L-26. Subsurface Drainage (50-m Spacing) Scenario: Decrease in Soil Water Salinity over Irrigation Season 2000

Figure L-27. Subsurface Drainage (50-m Spacing) Scenario: Decrease in Soil Water Salinity over Irrigation Season 2001

Figure L-28. 200% Pumping Volume Increase Scenario: Increase in Water Table Depth over Irrigation Season 1999

Figure L-29. 200% Pumping Volume Increase Scenario: Increase in Water Table Depth over Irrigation Season 2000

Figure L-30. 200% Pumping Volume Increase Scenario: Increase in Water Table Depth over Irrigation Season 2001

Figure L-31. 200% Pumping Volume Increase Scenario: Decrease in Soil Water Salinity over Irrigation Season 1999

Figure L-32. 200% Pumping Volume Increase Scenario: Decrease in Soil Water Salinity over Irrigation Season 2000

Figure L-33. 200% Pumping Volume Increase Scenario: Decrease in Soil Water Salinity over Irrigation Season 2001

Figure L-34. 50% Recharge Reduction-90% Seepage Reduction-Subsurface Drainage Installation (50-m Spacing) Combination Scenario: Increase in Water Table Depth over Irrigation Season 1999

Figure L-35. 50% Recharge Reduction-90% Seepage Reduction-Subsurface Drainage Installation (50-m Spacing) Combination Scenario: Increase in Water Table Depth over Irrigation Season 2000

Figure L-36. 50% Recharge Reduction-90% Seepage Reduction-Subsurface Drainage Installation (50-m Spacing) Combination Scenario: Increase in Water Table Depth over Irrigation Season 2001

Figure L-37. 50% Recharge Reduction-90% Seepage Reduction-Subsurface Drainage Installation (50-m Spacing) Combination Scenario: Decrease in Soil Water Salinity over Irrigation Season 1999

Figure L-38. 50% Recharge Reduction-90% Seepage Reduction-Subsurface Drainage Installation (50-m Spacing) Combination Scenario: Decrease in Soil Water Salinity over Irrigation Season 2000

Figure L-39. 50% Recharge Reduction-90% Seepage Reduction-Subsurface Drainage Installation (50-m Spacing) Combination Scenario: Decrease in Soil Water Salinity over Irrigation Season 2001

Figure L-40. 30% Recharge Reduction-50% Seepage Reduction-Subsurface Drainage Installation (100-m Spacing) Combination Scenario: Increase in Water Table Depth over Irrigation Season 1999

Figure L-41. 30% Recharge Reduction-50% Seepage Reduction-Subsurface Drainage Installation (100-m Spacing) Combination Scenario: Increase in Water Table Depth over Irrigation Season 2000

Figure L-42. 30% Recharge Reduction-50% Seepage Reduction-Subsurface Drainage Installation (100-m Spacing) Combination Scenario: Increase in Water Table Depth over Irrigation Season 2001

Figure L-43. 30% Recharge Reduction-50% Seepage Reduction-Subsurface Drainage Installation (100-m Spacing) Combination Scenario: Decrease in Soil Water Salinity over Irrigation Season 1999

Figure L-44. 30% Recharge Reduction-50% Seepage Reduction-Subsurface Drainage Installation (100-m Spacing) Combination Scenario: Decrease in Soil Water Salinity over Irrigation Season 2000

Figure L-45. 30% Recharge Reduction-50% Seepage Reduction-Subsurface Drainage Installation (100-m Spacing) Combination Scenario: Decrease in Soil Water Salinity over Irrigation Season 2001

Figure L-46. 50% Recharge Reduction-90% Seepage Reduction Combination Scenario: Increase in Water Table Depth over Irrigation Season 1999

Figure L-47. 50% Recharge Reduction-90% Seepage Reduction Combination Scenario: Increase in Water Table Depth over Irrigation Season 2000

Figure L-48. 50% Recharge Reduction-90% Seepage Reduction Combination Scenario: Increase in Water Table Depth over Irrigation Season 2001

Figure L-49. 50% Recharge Reduction-90% Seepage Reduction Combination Scenario: Decrease in Soil Water Salinity over Irrigation Season 1999

Figure L-50. 50% Recharge Reduction-90% Seepage Reduction Combination Scenario: Decrease in Soil Water Salinity over Irrigation Season 2000

Figure L-51. 50% Recharge Reduction-90% Seepage Reduction Combination Scenario: Decrease in Soil Water Salinity over Irrigation Season 2001

APPENDIX M: ADDITIONAL ANALYSIS – TRIAL STOCHASTIC MODELING EXERCISE

The primary sources of uncertainty in groundwater flow and salinity transport modeling include the natural variability of aquifer and system parameters and the limited amount and limited accuracy of available data upon which models must be based. Uncertainty always exists to some degree in groundwater models simply due to the fact that you cannot have data available at every modeled location. Regions must be discretized into homogenous areas represented by singular values, and, therefore, the smaller-scale variability of aquifer parameters is not represented and inaccuracies are introduced. Also, uncertainty is present in modeling because time-variant parameters must be simplified to represent average conditions over discrete time steps (i.e. stress periods).

In addition to the inability to exactly capture the true natural variability of the modeled system, there are many other sources of uncertainty. Some parameters are not easily measurable or there are inaccuracies inherent in measurement techniques. Values of these types of parameters must be approximated based on the modeler's judgment and evidence from outside studies or references. There may also exist undetected data measurement errors that might have occurred in the field. These could be due to instrument malfunctions or technician mistakes. Uncertainty may also arise because the model algorithms are not completely accurate representations of the natural system behavior. There may be model formulation errors such as unidentified or misidentified boundary conditions. General conceptual model errors may exist. Truncation errors resulting from the simplification of analytical functions in numerical approximations may contribute to overall model uncertainty as well. Also, unidentified phenomena or processes affecting the modeled system might exist and, therefore, increase uncertainty.

Jay R. Lund, a professor of civil engineering at the University of California, Davis, identifies four sources of uncertainty contained in the results of mathematical models (1991):

1. Uncertainties in the values of parameters and constants in the model's equations.
2. Uncertainties in the true values of input data to the model.
3. Errors introduced by the numerical method that solves the model's equations.
4. Errors or uncertainties in the form of those equations that constitute the structure of the mathematical model.

All of these undoubtedly play some role in the overall vagueness and ambiguity that one faces in predicting groundwater flow and transport; however, it is impossible to always accurately identify and quantify every contributing source of uncertainty.

Uncertainty in modeling is an important issue because, if not adequately addressed, it can lead to solution alternatives that are based on potentially biased information and are, therefore, poorly designed and ineffective. Conversely, some solution alternatives are unnecessarily over-designed to compensate for uncertainty. In some cases, the nature of existing problems or problem areas might be misidentified because the uncertainty of the modeling results was not considered. In general, there may exist a lack of confidence in modeling results, and models might be discarded from the decision-making process based on a poor understanding of uncertainty. Finally, when the reliability and confidence associated with model predictions is not quantified in some way, it is difficult for decision-makers to properly or adequately interpret modeling results.

Trial Stochastic Modeling Analysis

The purpose of the trial analysis presented here is to demonstrate how one could investigate model sensitivity to stochastically-generated realizations of model parameters and, thereby, gain insight into model uncertainty quantification. Future work of the investigators will include application of these methods to achieve a much better estimate of model output uncertainty and a better understanding of potential impacts to modeled solution alternatives.

To perform the trial analysis, a geostatistical modeling package know as Isatis (version 4.0.1) (Geovariances 2001) was employed. Based on a preliminary sensitivity analysis of model parameters, the deep layer hydraulic conductivity was chosen for analysis. Only 29 data points were available for this data set within the study region; therefore, the degree of uncertainty in values at unobserved locations is high.

The conducted trial stochastic modeling exercise was based on the Monte Carlo approach. Due to limited available time and resources, the number of trials was limited to ten. Typically, within a Monte Carlo framework, the number of trials is much larger. If such an approach were adopted for this study, the number of trials would need to be great enough to ensure that the resultant output statistics are stabilized. This number would likely vary significantly depending upon which model parameter(s) was being modeled stochastically. The purpose of this trial analysis is simply to demonstrate the steps that would need to be taken to incorporate a stochastic approach and to show the feasibility of such an approach using currently available tools.

The steps taken using the Isatis software package are listed below. Screenshots are provided showing interface menus for critical steps.

1. The available deep hydraulic conductivity data were imported into Isatis in ASCII format (*File* menu – *Import* command).
2. The data were converted into a Gaussian distribution for use in conditional simulation (*Statistics* menu – *Raw<-->Gaussian Transformation* command).
3. An experimental variogram was determined from the imported data (*Statistics* menu – *Exploratory Analysis* command).
4. A variogram model was fitted to the experimental variogram (*Statistics* menu – *Variogram fitting* command). Both the experimental variogram and the best-fit variogram model are shown in Figure M-1. The specified variogram model parameters are shown in the screenshot of the Isatis *Model Definition* window given in Figure M-2. The resultant best fit was a spherical-type curve with a

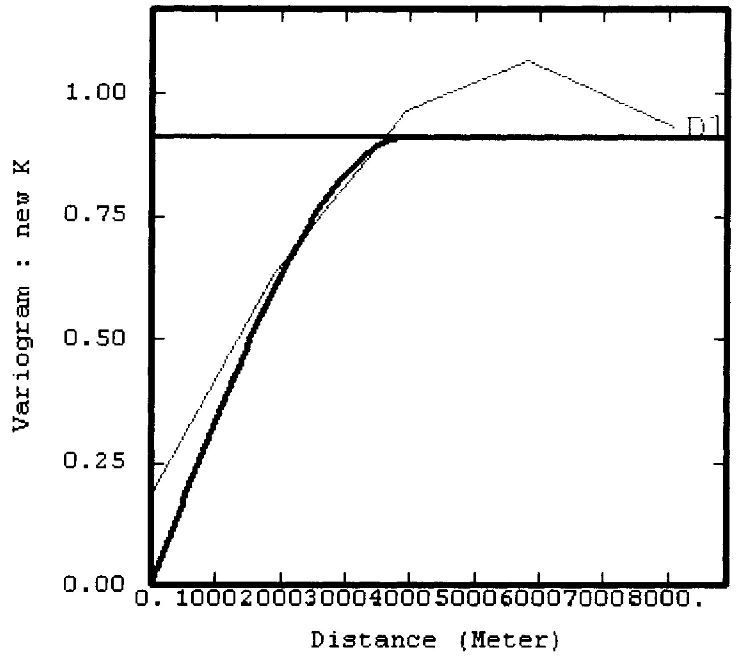
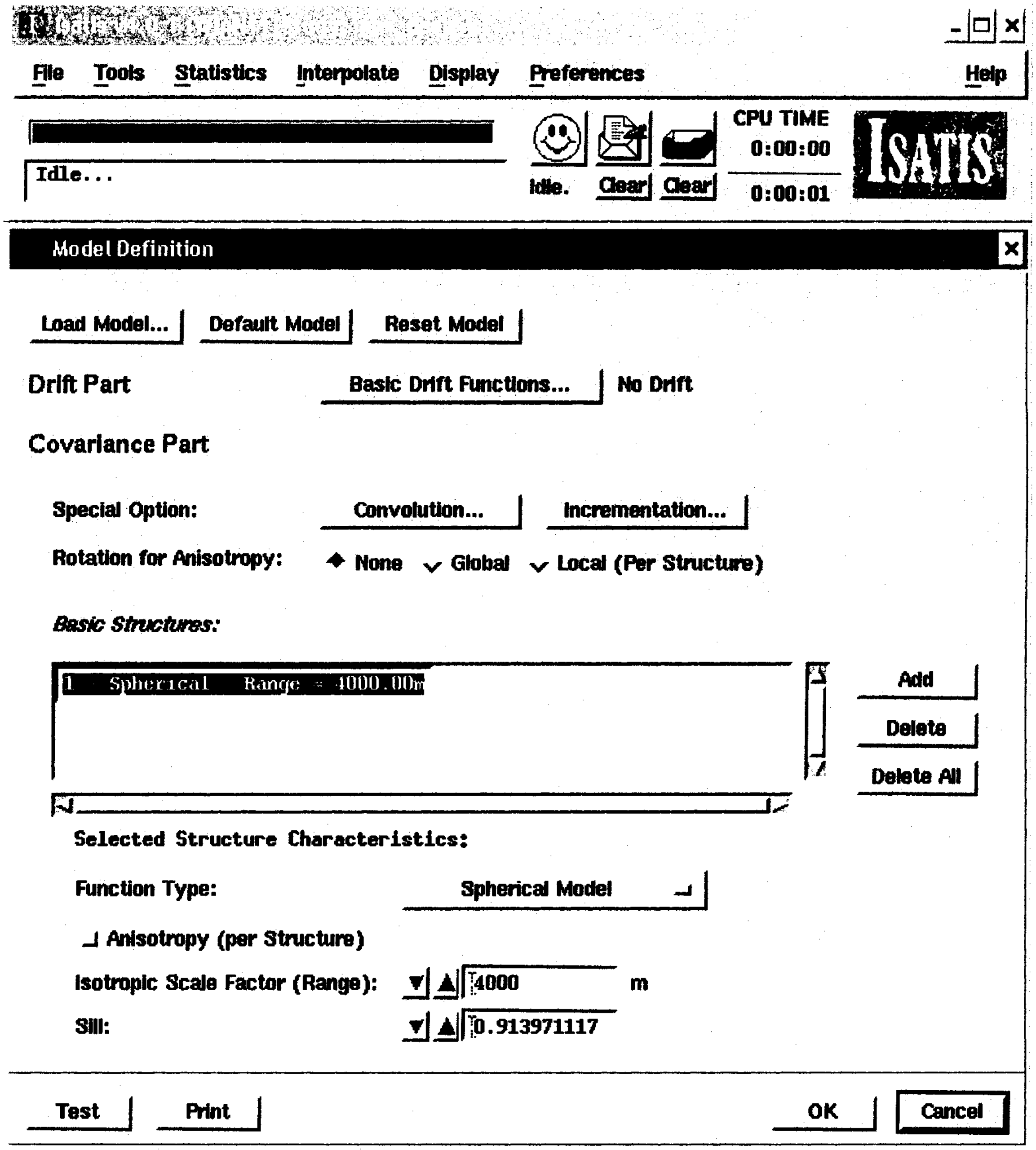


Figure M-1. Experimental Variogram and Fitted Variogram Model

range of 4000 m. This range defines the maximum correlation length between spatial locations where data are evaluated.

5. The fitted variogram model was then utilized with the Sequential Gaussian Simulation (SGS) method (*Interpolate* menu – *Conditional Simulations* submenu – *Sequential Gaussian...* command) to produce a set of conditional grid realizations, i.e. a set of grids containing statistically possible values where the original data point values are preserved. The SGS method uses a random path to scan grid cells and fill the target cell based on a defined search neighborhood. The target cell value is simulated from a Gaussian distribution accounting for correlation of surrounding cells within the search neighborhood by means of the

specified variogram (Geovariances 2001). A screenshot of Isatis showing the SGS window is given in Figure M-3. In total, ten realizations were generated. One of the generated grids is shown (as displayed in Isatis) in Figure M-4.



Idle...

CPU TIME
0:00:00
0:00:01

Drift Part No Drift

Covariance Part

Special Option:

Rotation for Anisotropy: ◆ None ✓ Global ✓ Local (Per Structure)

Basic Structures:

1 Spherical Range = 4000.00m

Selected Structure Characteristics:

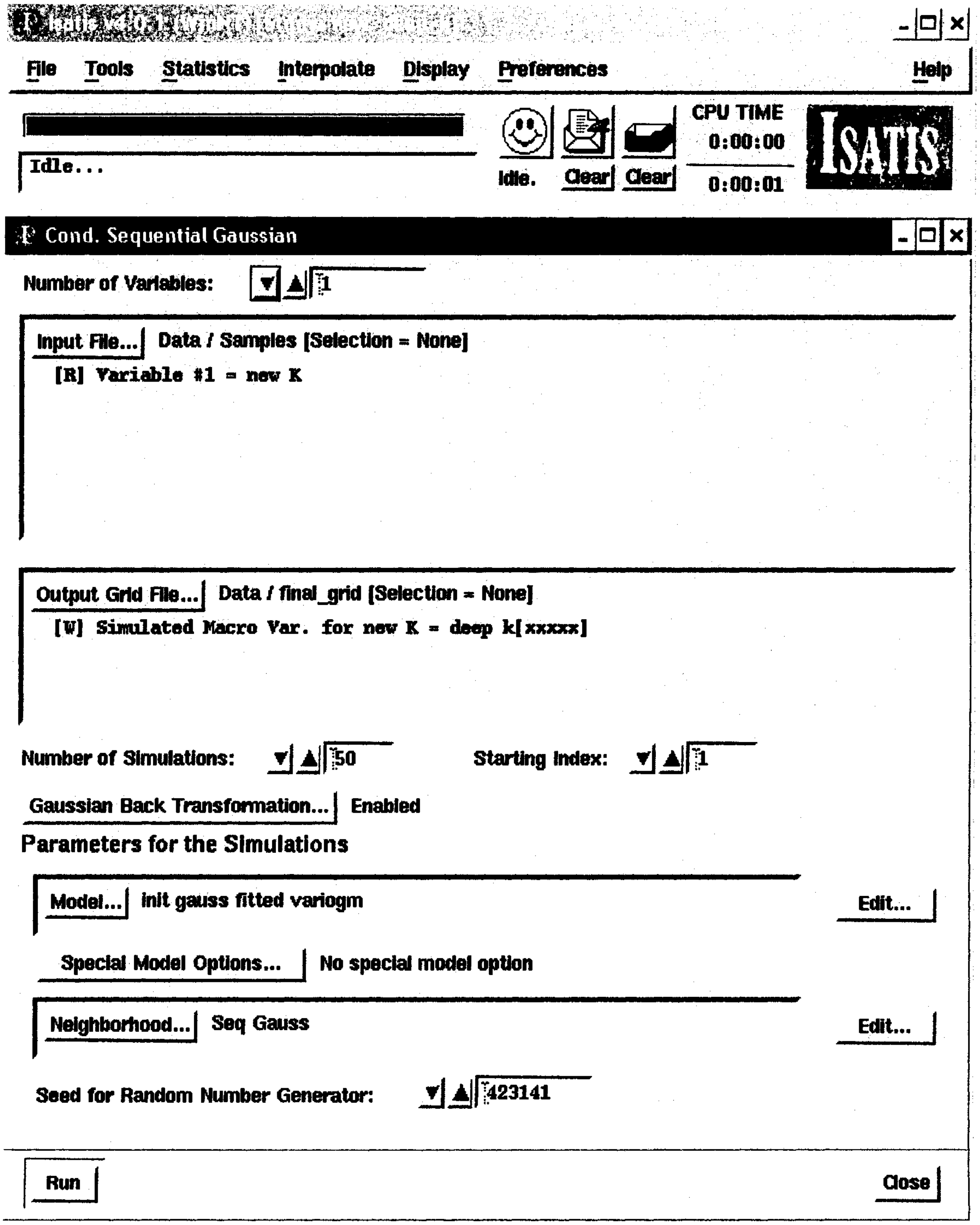
Function Type: Spherical Model

☐ Anisotropy (per Structure)

Isotropic Scale Factor (Range): 4000 m

Sill: 0.913971117

Figure M-2. Isatis Screenshot Showing *Model Definition* Window



Number of Variables: 1

Input File... Data / Samples [Selection = None]

[R] Variable #1 = new K

Output Grid File... Data / final_grid [Selection = None]

[W] Simulated Macro Var. for new K = deep k[xxxxx]

Number of Simulations: 50

Starting Index: 1

Gaussian Back Transformation... Enabled

Model... init gauss fitted variogm

Special Model Options... No special model option

Neighborhood... Seq Gauss

Seed for Random Number Generator: 423141

Figure M-3. Isatis Screenshot Showing *Conditional SGS* Modeling Window

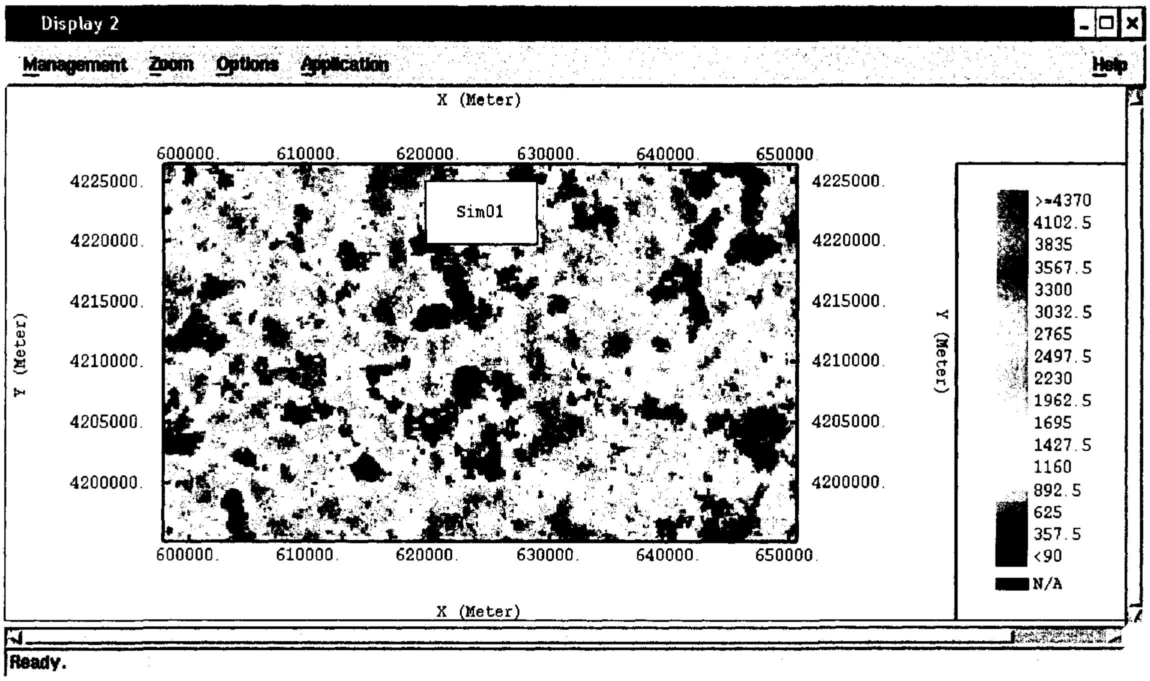


Figure M-4. Generated K Grid (Realization No. 10 of 10)

6. Generated realizations were analyzed statistically to verify that the characteristics of the observed data were preserved.
7. The ten realizations of deep hydraulic conductivity produced were applied in the flow and salinity models.
8. Two model outputs, time-averaged water table depth and time-averaged soil salinity, were processed from each model run for further examination.

Trial Stochastic Modeling Results

The results that are presented represent output from a preliminary version of the transient groundwater flow and salinity models. This version did not incorporate adjustments to the evapotranspiration rates based on soil conditions; therefore, the results for the baseline models are different than those for the final version. Results of the test runs of the deterministic baseline models used in this analysis and the model results from the 10 deep K realizations being applied within the models are shown in Table M-1.

As can be seen from this table, there are significant differences in the overall spatial means of both water table depth and soil salinity for the different realizations of the deep K data set. The minimum mean time-averaged water table depth of 5.500 m was predicted in simulation number six. The maximum time-averaged water table depth of 5.709 m was a result of simulation number four. Simulation number eight yielded the lowest predicted average soil salinity (3,302 mg/L), and the highest predicted average soil salinity (3,447 mg/L) occurred as a result of the deterministic baseline model. The spatial coefficient of variation (CV) values show that for both water table depth and soil salinity, the deterministic baseline model predicts the least spatial variability. This is likely a reflection of the manual calibration of the deterministic models and the restriction of the local variability (spatial) around the calibration target locations.

Results from the stochastic model runs were averaged and compared spatially to the calibrated deterministic baseline model results. A map of the differences in predicted water table depth is shown in Figure M-5. Differences in some locations of +/- 4 m are present. In particular, the area in the western/southwestern portions (near the town of Rocky Ford) of the study area yielded different results. This area corresponds to areas where significant adjustments to aquifer parameters (including deep K) were required to achieve a reasonable deterministic model calibration.

Table M-1. Summary of Stochastic Modeling Results

	Time-Averaged WT Depth (Irrigation Season Only)		**Time-Averaged Soil Salinity (Irrigation Season Only)**	
Simulation	*Mean (m)*	*CV*	*Mean (mg/L)*	*CV*
Baseline	5.553	0.838	3477	0.408
Sim 1	5.577	0.888	3388	0.427
Sim 2	5.627	0.900	3362	0.422
Sim 3	5.558	0.852	3356	0.414
Sim 4	5.709	0.924	3415	0.429
Sim 5	5.675	0.908	3359	0.427
Sim 6	5.500	0.900	3378	0.425
Sim 7	5.617	0.908	3386	0.411
Sim 8	5.658	0.869	3302	0.427
Sim 9	5.579	0.964	3359	0.425
Sim 10	5.670	0.928	3396	0.421
Cumulative (Sim 1 – 10)	5.617	0.905	3370	0.423

Figure M-5. Difference in Predicted Water Table Depth (m) – Baseline vs. Stochastic Results

In addition to mapping the differences between the deterministic and stochastic results, a detailed examination of the distribution of the predicted values under each modeling approach was conducted. Of particular interest is whether the predicted values yielded from the stochastic modeling were similar in overall distribution shape to the predicted deterministic output. The mapped differences indicate that this may not be the case; however, as was shown in Table M-1, the CV values were relatively similar (within 10%).

For water table depth, the predicted distribution of the temporally averaged values is given in Figure M-6. For both the deterministic and stochastic cases, the best-fit distribution is a Pearson 5. As can be seen on the histograms, and as can be inferred from the previously mentioned CV values, the stochastic results show a wider range of variability. The values of the 5% and 95% ordinates for the deterministic baseline model are 0.97 m and 14.92 m, respectively. For the stochastic model, this range expands to 0.67 m and 16.06 m. Again, this is likely a reflection of the calibration adjustments to deep K which occurred away from the data points upon which the generated deep K realizations were conditioned.

For the predicted average soil salinity, it was found that the best-fit distribution types were slightly different for the deterministic and stochastic cases. As shown in Figure M-7, the best-fit distribution for the deterministic model output is an Inverse Gaussian, whereas the best-fit distribution for the stochastic (cumulative averaged) model output is

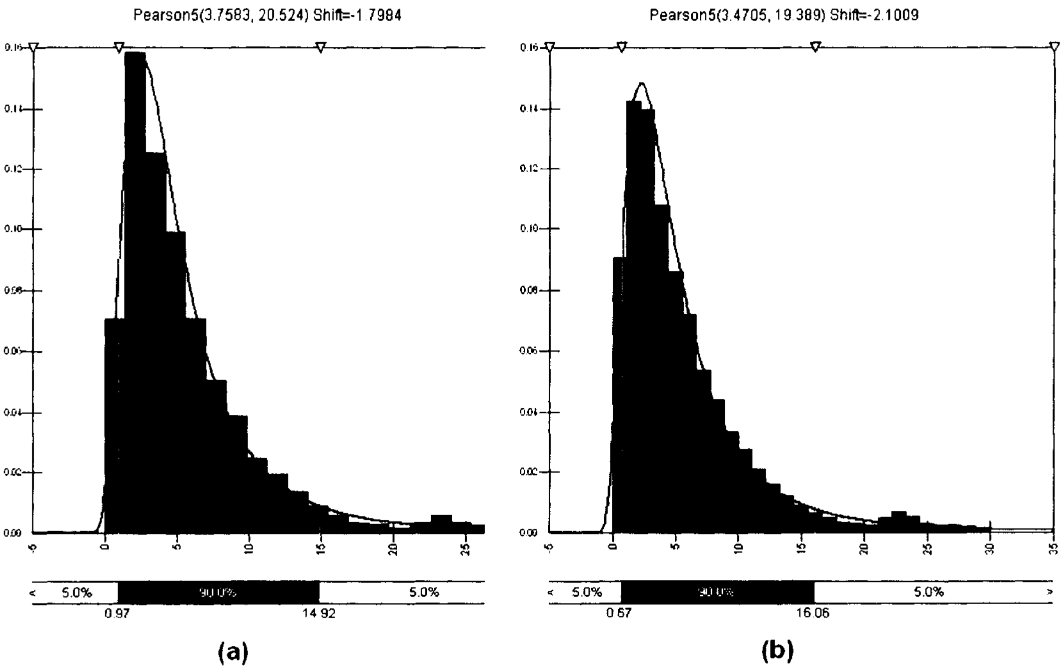


Figure M-6. Distribution of Predicted Time-Averaged Water Table Depth for (a) The Deterministic Baseline Model (b) The Stochastic Modeling Approach

a Weibull type. As can be seen, these distribution types are similar in shape; however, the Inverse Gaussian is notably more peaked. Again, the stochastic results show greater variability, with the predicted values of the 5% and 95% ordinates being 1,279 mg/L and 5,936 mg/L as opposed to values of 1,419 mg/L and 6,011 mg/L for the deterministic baseline model. The shift in mean downward by approximately 100 mg/L in the stochastic approach is significant and likely a reflection of the deterministic model calibration adjustments.

Although not too much should be read into the results of this analysis, considering that only 10 realizations were produced, this exercise does demonstrate that significant

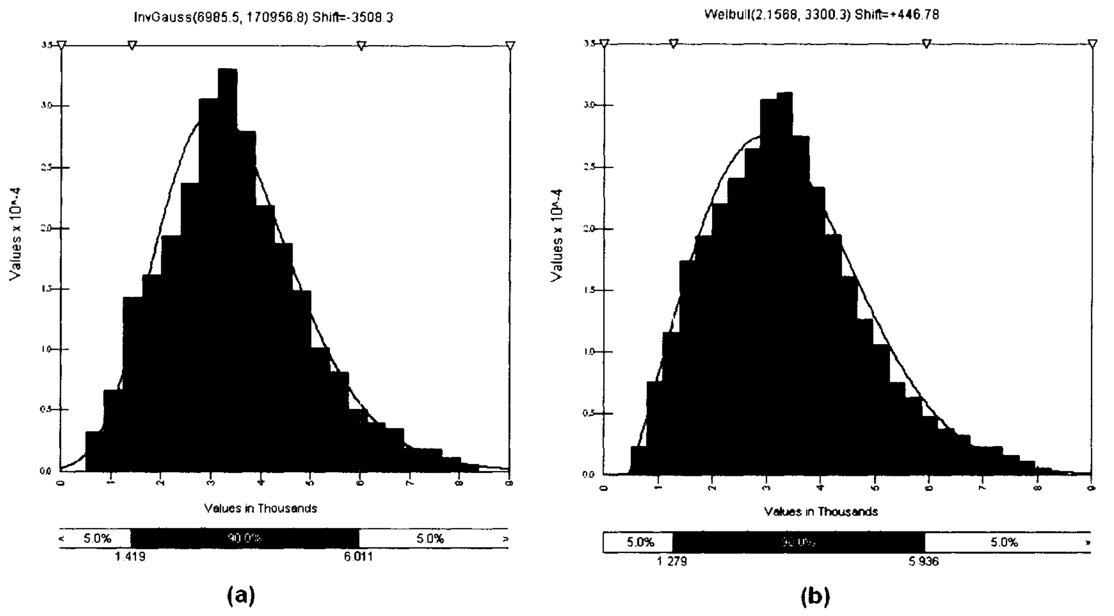


Figure M-7. Distribution of Predicted Average Soil Salinity for (a) The Deterministic Baseline Model (b) The Stochastic Modeling Approach

differences can exist in model prediction when uncertainty is addressed in a stochastic modeling framework. An additional beneficial output of the stochastic approach will be the ability to estimate confidence limits of outputs at a specific location. This type of output is not given here due to the limited number of realizations that were modeled; however, this type of output would be extremely useful in assessing the potential effectiveness of proposed solution alternatives in the study region.

Theoretically, any number of model parameters can be examined individually (as demonstrated) or simultaneously (as in mult-variate analysis) using this method to improve model predictions and quantify uncertainty. A limitation of this method, however, is that some information gleaned during a deterministic calibration effort could potentially be lost. Unless stochastic realizations of parameters are also conditioned on points in areas where a very limited range of parameter values can produce a target result, it is likely that a stochastically-produced calibration will yield inferior results in comparison with a manual deterministic calibration. However, if realizations are conditioned in a fashion that effectively meets calibration targets, the stochastic modeling approach presented could yield valuable additional information. The presented exercise demonstrates that stochastic modeling is a feasible approach with available computational tools. However, it is recommended that the specific modeling improvements detailed within Chapter 7 be adopted before attempting a thorough stochastic modeling effort. The increase in efficiency gained by such improvements would reduce the computational burden of stochastic techniques substantially.

APPENDIX M REFERENCES

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Lund, J. R. 1991. "Random Variables Versus Uncertain Values: Stochastic Modeling and Design." *Journal of Water Resources Planning and Management*, Vol. 117, No. 2, 179-194.