Ground-Water Aquifer Sensitivity Assessment and Management Practices Evaluation for Pesticides in the Mesilla Valley of New Mexico

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ABSTRACT

An efficient approach to assessing ground-water aquifer sensitivity is to employ a regional Geographic Information System (GIS) to determine and map the relative sensitivity of aquifers to contamination sources. A pilot study in the Mesilla Valley of Doña Ana County, New Mexico was initiated to develop the most appropriate approach and format. The Mesilla Valley was selected based on the intensity of the area's pesticide applications and the availability of information required for analysis. Experience and added insight were expected to be gained in how to gather, process, and analyze data most efficiently. The DRASTIC model was used to assess aquifer sensitivity by combining data sets that describe the depth-to-ground water, recharge rates, aquifer material, soils composition, land slope, vadose zone materials, and saturated hydraulic conductivity for the Mesilla Valley in Doña Ana County. The study evaluated the data requirements and techniques necessary to employ the DRASTIC model in other regions of New Mexico. GIS layers were developed for each of the DRASTIC parameters and combined into a natural sensitivity coverage for the study area. The resulting natural sensitivity values were grouped into six categories: *very slight* - indicating that the ground-water aquifer is very well protected and risk of contamination from nonpoint sources is very low; *slight* - the ground-water aquifer is reasonably well protected, but because one or more of the hydrologic parameters are conducive to contaminant transport, there is a higher level of risk of nonpoint pollution; *low* - the ground-water aquifer is somewhat protected, but more than one of the parameters are conducive; *moderate* - the ground-water aquifer is susceptible to contamination because few natural protections exist; *severe* - the ground-water aquifer is much more susceptible to contamination due to several hydrologic conditions; and *extreme* - all hydrologic parameters are conducive to the rapid transport of contamination to the ground-water aquifer. Results indicated that of the 2,282 km^2 included in the study area, less than one percent was classified as *extreme*, slightly over 10 percent as *severe*, almost 19 percent as *moderate*, nearly 43 percent as *low*, about 16 percent as *slight*, and over 12 percent as *very slight*.

Possible nonpoint source pollution from agricultural operations necessitates that farming practices be evaluated for their potential impact on water quality. Time and cost constraints favor a modeling approach for the evaluation process, especially in regional-scale studies. The Irrigation Scheduling Model (IRRSCHM) was used to evaluate local farmers' practices and irrigation scheduling management practices for their potential impact on ground-water contamination in the Mesilla Valley. The irrigation management practices included tensiometer-based irrigation scheduling with porous cup position fixed at 30-cm soil depth or moving with the dynamic root zone, and irrigation scheduling at "50 percent plant available water depletion." The objective was to monitor cyanazine (Bladex) and metolachlor (Dual) concentrations at 180-cm below the soil surface during a 30-year cropping period. The main input parameters required by IRRSCHM are field capacity, permanent wilting point, soil profile organic matter, and pesticide half-life value distributions. Because the study was regional in nature, most of the soil series were grouped into appropriate textural classes. Results showed that Bladex and Dual concentrations at the 180-cm depth generally increased with increasing soil sand content. Also, Bladex and Dual concentrations were lowest and insignificant, relative to the corresponding drinking water Health Advisory Level, under farmers' management practices. In contrast, scheduling irrigation with tensiometers based on Natural Resources Conservation Service recommendations, resulted in the higher Bladex and Dual concentrations at the same 180-cm depth. For example, current management practices resulted in the mean maximum Bladex concentrations of 2.42×10^{-6} for sandy soil class and 1.20×10^{-18} for clayey soil class, relative to the 1.30×10^{-2} mg L^{-1} Health Advisory Level. For Dual, the mean maximum concentrations were 1.63×10^{-3} and 4.89×10^{-9} relative to the 5.25×10^{-1} mg L^{-1} Heath Advisory Level, for sandy and clayey soil classes, respectively. Consequently, the study showed that current farmers' management practices do not pose a threat to ground-water quality in the study area.

Key Words: Aquifer Sensitivity, Mesilla Valley, DRASTIC, Simulation, Geographic Information System, Best Management Practices, Water Quality.

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PURPOSE

This document reports on Phase 1 of a 3-phase project. The overall effort was envisioned to consist of an assessment of ground-water aquifer sensitivity in the state of New Mexico to contamination from pesticides. The project was divided into components: Phase 1) pilot-study area aquifer sensitivity assessment, initial Best Management Practices (BMP) evaluation, and preliminary aquifer sensitivity assessment; Phase 2) validation of BMPs, incorporation of ground-water model, final sensitivity assessment for pilot study area, and priority assessment for other areas of the state; and Phase 3) program initiation to extend the system into other priority areas of the state and ultimately to produce ground-water aquifer sensitivity maps and BMP libraries for pesticides statewide. Map information and environmental data for New Mexico were to be compiled and used. Ground-water aquifer sensitivity maps at appropriate scale for use by regulatory programs were planned. These map products and BMPs would provide state and local governments, as well as landowners, a valuable decision-making tool for identifying geographic areas most susceptible to ground-water contamination and report on identified and evaluated BMPs that then could be implemented to minimize the potential for ground-water contamination from agricultural pesticide use. This effort continues the development of a State Management Plan for Pesticides by the New Mexico Department of Agriculture (NMDA). The project was conducted by a project team assembled by the New Mexico Water Resources Research Institute (WRRI).

GOALS

Project goals were to produce: 1) GIS-based pesticide specific ground-water aquifer sensitivity maps for appropriate areas of the state to aid in decision making relative to water-quality management, and 2) a library of BMPs evaluated for effectiveness in preventing ground-water contamination for inclusion in state regulatory/nonregulatory programs.

Phase 1 would identify data sources required for producing the necessary base maps, the methods for spatial and tabular manipulation and preprocessing, and the analytic procedures required for generating the map and attribute products for the pilot study area; incorporate data into a modified DRASTIC model for ground-water aquifer sensitivity assessment; run the process models to evaluate selected BMPs for the pilot study area; and produce preliminary ground-water aquifer sensitivity maps and BMP library for the pilot study area.

Phase 2 would validate the process models by incorporating feedback from a ground-water model, produce final ground-water aquifer sensitivity maps and BMP library for the pilot study area, establish other state priority areas and identify data sources, refine the methods for spatial and tabular manipulation and preprocessing, and identify final analytic procedures required for generating the final map and attribute products for other priority areas of the state.

Phase 3 would extend the system developed in the pilot study to priority areas of the state to provide managers/regulators mapped and corresponding tabular information relating the sensitivity of ground-water aquifers to contamination from pesticide use and BMP libraries necessary to maintain ground-water quality.

INTRODUCTION

PROJECT STRATEGY

Developing statewide pesticide vulnerability assessments and producing ground-water aquifer sensitivity maps for New Mexico are expected to be a long-term effort due to budget and time constraints. Hence, it was necessary to develop, test, and apply the system to a pilot area, and design a priority system that guides available resources to areas of the state where the potential for contamination is greatest and where sufficient information is available.

With the exception of man-made impacts on ground water within relatively localized urban and rural areas, ground water in New Mexico typically is of good quality. A significant part of the state's ground water contains less than 5000 parts per million (ppm) of total dissolved solids (TDS), a common measurement of the relative quality of ground water for domestic, livestock, and agricultural use. Ground-water quality frequently varies locally due to its depth, distance from recharge areas, type of aquifer in which it occurs, and its proximity to mineralized zones and ore bodies.

New Mexico's ground water is used for domestic, municipal, industrial and agricultural purposes. Shallow alluvial aquifers, typically most sensitive to contamination, are extensively utilized for domestic and agricultural purposes. Urban, oil refining and industrial activities have contributed petroleum hydrocarbons, hazardous materials, nitrates, and other toxic pollutants to ground water. Waste-disposal sites have added metals as well as organic and inorganic contaminants to ground water. Irrigated agriculture, weed and pest control activities, mining, oil refining, underground storage tanks, and the disposal of industrial and commercial wastes also have impacted ground-water quality within the state by adding pesticides and nitrates. In localized areas, mineral extraction has increased ground-water salinity and added radionuclides, cyanide, metals, and/or toxic pollutants.

Aquifer susceptibility to influx of these chemicals is dependent upon the character of the overlying soils and sediments, the aquifer's chemical and physical properties, and the configuration of the water table. All these characteristics interact and must be considered holistically to determine the relative natural sensitivity of each aquifer to contamination. Many other factors can affect the vulnerability of ground water to contamination, for example, current and prior land use, irrigation practices, and others.

Ground-water contamination generally exists within fairly localized areas of the state, although all rural and municipal drinking water supplies could be impacted in the future if appropriate contaminant source management practices are not established and implemented. This project did not directly determine where problems exist by sampling and testing ground-water quality, but was an attempt to identify sensitive areas where ground-water contamination currently may be a problem or likely could become a problem in the future.

Ground-water resources within the state's farming areas are susceptible to contamination from applied agricultural chemicals. This is due to some ground-water aquifers being located relatively near the soil surface, farmlands being intensively cultivated, and irrigation acutely practiced. Therefore, leaching of applied agricultural chemicals could be the main route through which ground water is contaminated. This project would develop an assessment of the sensitivity of ground-water aquifers and evaluate current and recommended BMPs for farming operations in protecting these ground-water aquifers.

PILOT STUDY AREA

The majority of agricultural cropland in the pilot area is located in the Mesilla Valley. In this valley, the Rio Grande has a complex meandering and flooding history. As a result, a diverse and intricate pattern of soil types occur. The soils have textures ranging from clay to sand and often have stratified profiles. Thus the pilot area represents one of the more complex areas in the state and was expected to challenge the project methodology.

The USDA and National Cooperative Soil Survey have mapped the Mesilla Valley soils twice. In 1914, a general soil survey of the Mesilla Valley was produced (Nelson and Holmes 1914) at a scale of 1:63,360. In 1980, after the adoption of Soil Taxonomy (USDA 1975), the Doña Ana soils survey was published (Bulloch and Neher 1980). The survey, which produced a detailed soil map of the floodplain, was published at a scale of 1:24,000. This information was made available to the project in digital form. It was considered preliminary, but sufficiently processed for project purposes. In addition, soils surrounding the floodplain of the Mesilla Valley have also been studied extensively as part of the USDA Soil-Geomorphic Desert Project (Hawley 1975; Gile and Grossman 1979, Gile et al. 1981).

Geologic mapping of both bedrock and surficial geology in Doña Ana County has been produced (Dane and Bachman 1965). Hydrogeologic investigations in the area have continued (Hawley and Lozinsky 1992).

Depth-to-water table information had been collected for a number of years in an extensive network of wells by the US Geological Survey in a cooperative state program. This information was available in digital form.

TECHNOLOGICAL SOLUTION

The most efficient approach to assessing ground-water aquifer sensitivity is to employ a regional Geographic Information System (GIS) to determine and map the relative sensitivity of aquifers to contamination sources. The National Water Well Association (Aller et al. 1985) developed the DRASTIC model to assess aquifer sensitivity by combining data sets that describe the depth-to-ground water, recharge rates, aquifer material, soils composition, land slope, vadose zone materials, and saturated hydraulic conductivity. DRASTIC has been the most commonly used aquifer sensitivity assessment method, however, it is not intended to predict the occurrence of ground-water contamination (USEPA 1993). Recent work has further improved upon this method, evolving the method beyond a simple rating of sensitivity, to a descriptive approach identifying areas with similar hydrogeologic characteristics (i.e., hydrologic setting) and assessing individually these areas' ground-water susceptibility to potential contamination (Hearne et al. 1992). This type of analysis is much more useful to local decision makers. An understanding of the hydrogeologic setting which determines the basic processes under which ground-water contamination occurs must be incorporated into the process of designing alternative management strategies. This project incorporated such information and techniques. It also required that data be gathered at appropriate scales and with sufficient map accuracy.

GIS is a technological tool used to integrate and analyze spatial data to assist in decision making. Using computer processing techniques, GIS can integrate a vast array of data, answer "what if" questions, and produce either maps, tables, or diagrams in a form useful to a decision maker. This effort complements the state's current and future endeavors utilizing GIS in identifying and prioritizing ground-water areas which may require additional protection from both urban and rural pollution sources.

DATA MANAGEMENT

The WRRI maintains a Water Resources Data System (WRDS). This system consists of not only hardware, software, and various data files, but also cooperative agreements for access to many state, federal, and other data sources. The State of New Mexico provides WRRI base funding to maintain the WRDS. It is expected that the map coverages and databases developed under this project will be integrated into the WRDS and will be accessible to various local, state and federal agencies.

To ensure map accuracy and position registration, base maps that had known control points from the National Geodetic Survey were utilized. As additional coverages were digitized or otherwise incorporated into the GIS, the control points were identified and verified. This reduced the amount of error generated by map distortion or projection transformation. Additionally, through each step in the map overlay process, map boundaries were inspected to ensure edge matching between base maps.

Utilization of ARC/INFO software ensured accessibility and compatibility of the data system with a variety of other national and state databases.

COOPERATION AND PARTICIPATING AGENCIES

An agreement was established with the USDA Natural Resources Conservation Service (NRCS) to facilitate the timely delivery of the digital soil data needed for the natural sensitivity assessment. The project employed a student intern who was assigned to the Albuquerque Office of the NRCS during part of the summer of 1995 and 1996 to assist in their GIS laboratory section. In addition, the NM Environment Department agreed to conduct pesticide sampling at selected sites in the pilot study area at the request of the project team should there be indications from the modeling effort of detectible pesticide concentrations.

A project advisory committee was established to provide guidance and recommendations to the project team as well as assist with access to information. Meetings generally were held on a monthly basis to inform the committee of project progress and to review procedures and findings.

STUDY OBJECTIVES

Because irrigation is extensively practiced in New Mexico and the pilot study area, it was imperative to assess how current farming practices affect the leaching losses of applied agricultural chemicals and their potential impact on ground-water contamination. Most applied water is given sufficient time to infiltrate the soil. Consequently, leaching of applied agricultural chemicals likely is the main avenue through which ground water is contaminated. Understanding the pollution potential of agricultural chemicals under practices currently used by local farmers would assist in devising Best Management Practices (BMPs) that minimize leaching losses of agricultural chemicals under irrigated conditions. Because the water table in the pilot study area is about 180 cm below the soil surface and irrigation is practiced intensively in the valley, ground water is potentially vulnerable to contamination from agricultural chemical applications. Therefore, agricultural chemicals must be managed effectively to control leaching and reduce the pollution potential of applied chemicals.

Overall study objectives were to assess the sensitivity of Mesilla Valley ground-water aquifers to contamination from pesticide use, to identify and evaluate BMPs for effectively reducing pesticide leaching, and to protect the area's ground-water resources from contamination. The sensitivity assessment would develop and investigate the employment of a modified DRASTIC model in a GIS framework for use in establishing priority areas for nonregulatory and regulatory pesticide programs. To evaluate management practices, the specific objective was to use the IRRSCHM model to assess comparatively the impact that area farmers' management practices and selected irrigation scheduling management practices could have on pesticide leaching and concentrations below the 180-cm soil profile.

SPECIFIC OBJECTIVES

Phase 1 - Pilot Study

Objective 1: Sensitivity Assessment

A pilot study in the Mesilla Valley of Doña Ana County, New Mexico was initiated to develop the most appropriate approach and format. This process could then be undertaken in other potentially vulnerable areas of the state. The Mesilla Valley in Doña Ana County was selected based on the intensity of the county's pesticide applications and the availability of information required for the analysis. Experience and added insight was expected to be gained in how to gather, process, and analyze data most efficiently.

The study would utilize a procedure similar to the DRASTIC (Aller et al. 1985) model and enhancements made to it by EPA and USGS (Hearne et al. 1992), for evaluating ground-water sensitivity. This analytic framework assesses relative sensitivity of land units by integrating mapped information on vadose zone geology, soils, recharge, hydraulic conductivity, slope, aquifer media and depth to water.

Objective 2: Process Modeling and BMP Evaluation

A process model would be utilized to estimate the pesticide concentration going below the root zone, calculated for current farming practices and proposed BMPs. The current practices would be obtained by surveying local farmers. The BMPs to be evaluated would be selected in cooperation with the USDA, Natural Resource Conservation Service (NRCS, formerly SCS) and the New Mexico Cooperative Extension Service (NMCES). Both services are involved in developing and delivering BMPs to the state's agricultural community. The NRCS currently recommends use of tensiometers to schedule irrigation. However, there are many ways to operate the irrigation system based on tensiometer readings and numerous procedures to determine the number and depth of those tensiometers. Each increasingly complicated procedure requires more sophistication and understanding of the water and chemical movement processes.

Project Linkages to Other Programs

The ground-water aquifer sensitivity product—an intermediate product—developed under this project was expected to be useful to other state agencies, local governments, municipalities, and residents as planning tools for protecting ground water. This product could be used to evaluate other known and potential point sources of ground-water contamination, including leaking underground storage tanks, landfills, spill sites, hazardous waste treatment, storage and disposal facilities, and other contamination sources as well as provide useful information for the development, assessment and evaluation of Wellhead Protection Areas and their vulnerability to different sources of contamination. This would enable state and local governments to develop comprehensive management plans for protecting ground water and municipal wells from nonpoint contaminant sources in their areas.

STUDY AREA DESCRIPTION

The Mesilla Valley is located in Doña Ana County, New Mexico and El Paso County, Texas (Fig. 1). The study was restricted to the portion within New Mexico. Agriculture is a major activity, and irrigation is the chief use of water in the area. The Rio Grande is the primary source of irrigation water, which is administered by the Elephant Butte Irrigation District (EBID) in the New Mexico part of the Mesilla Valley. The Rio Grande is the primary surface-water feature. Rio Grande water is stored in Elephant Butte Reservoir, about 75 miles upstream from Leasburg Dam, and in Caballo Reservoir, about 45 miles upstream from Leasburg Dam, and in a number of reservoirs farther upstream. The discharge of the Rio Grande in the Mesilla Valley is regulated by releases from these two reservoirs and diverted into an extensive network of canals. An extensive network of drains carries return flows back to the river. Surface water is supplemented by ground water primarily in years when surface supplies are insufficient for crop requirements. Ground water is used for all domestic water needs both public and private.

CLIMATE

The region's climate is arid, but becomes semiarid in high mountainous areas within the region. The average annual precipitation, mostly in the form of rain, is just over 20 cm. About half the annual rainfall results from thunderstorms during July through September. Figure 2 summarizes the area's precipitation for the period 1960-1992. Temperatures average about 60 degrees Fahrenheit, but often range over a span of 30 degrees Fahrenheit during 24-hour periods in the summer.

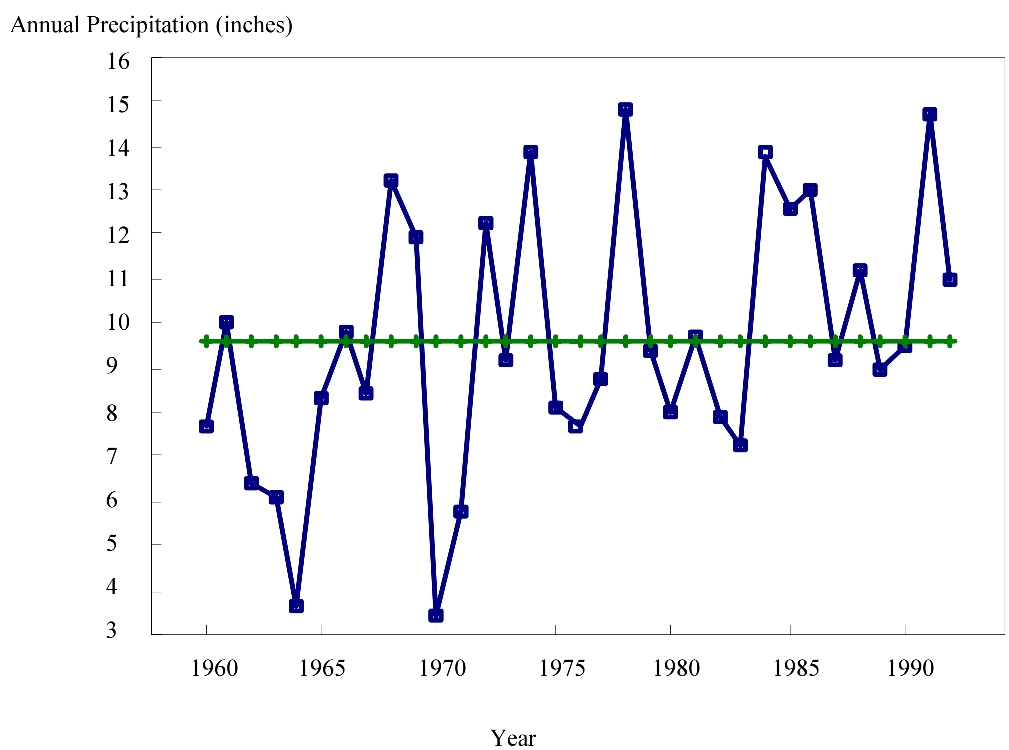
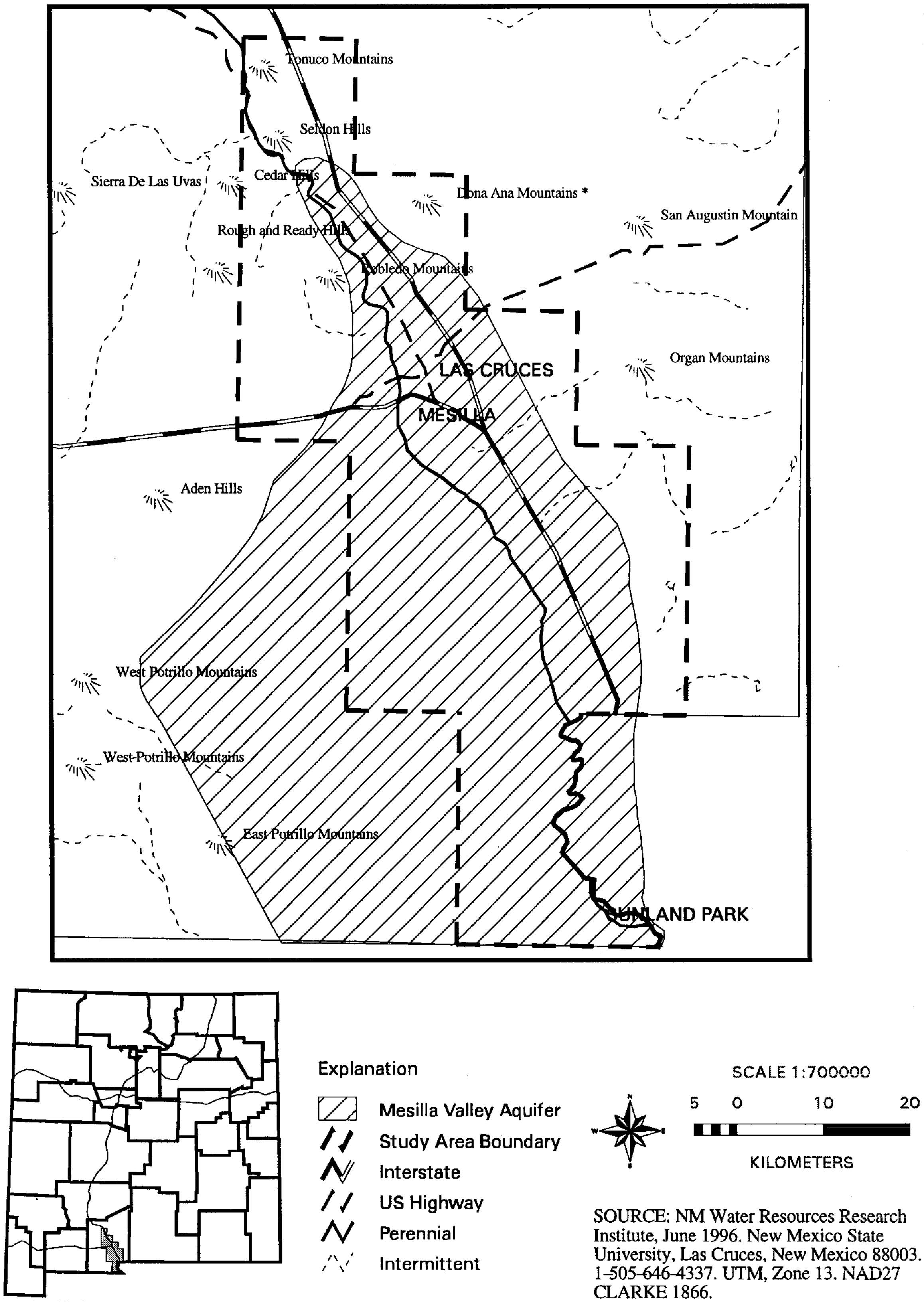


Figure 2. Annual precipitation 1960-1992, New Mexico State University, Las Cruces, New Mexico.

Figure 1. Study Area Location Map



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GEOLOGY

The Mesilla Basin is at the southern end of a north-trending series of structural basins and flanking mountain uplifts that comprise the Rio Grande rift (Chapin and Seager 1975; Seager and Morgan 1979; Chapin 1988). The rift extends through New Mexico from the San Luis Basin of south-central Colorado to the Hueco Bolson and Bolson de los Muertos area of western Texas and northern Chihuahua, Mexico (Hawley 1978).

The area's geology (Fig. 3) includes numerous mountain ranges and outcrops forming impermeable and semi-impermeable boundaries for the intermontane bolsons and the valley of the Rio Grande. For the most part, the mountains in the region consist of fault-block uplifts with a general north-south trend (Kottlowski 1958).

The Mesilla Bolson is encompassed completely by mountains. The Robledo Mountains and the Doña Ana Mountains form the northern boundary; the East and West Potrillo Mountains, the Aden Hills, the Sleeping Lady Hills, and the Rough and Ready Hills form the western boundary; the Sierra de Cristo Rey and the Sierra de Juarez form the southern boundary; and Goat Mountain, Tortugas Mountain, the Organ Mountains, Bishop Cap Mountain, and the Franklin Mountains form the eastern boundary (Fig. 1).

The Robledo Mountains consist of a tilted fault-block uplift that has the form of a wedge-shaped horst. They are bound on the east and west by faults and tilt toward the south. The peaks and high ridges are mostly underlain by thick-bedded carbonate rocks of Paleozoic age. The western portion of the Mesilla Bolson commonly is called the West Mesa. The West Mesa is approximately 300 feet above the present valley floor. The West Potrillo Mountains reflect the primary form of the basaltic volcanic cones and flows that underlie the West Mesa. The Aden Hills, the Sleeping Lady Hills, and the Rough and Ready Hills are comprised of a belt of small peaks, ridges, buttes, and elongated mesas underlain by Tertiary volcanic rocks. The Sierra de Cristo Rey and the Sierra de Juarez are in Mexico. To the east, Goat Mountain is similar in composition to that of San Diego Mountain. Small fault-block uplifts form Tortugas Mountain and Bishop Cap Mountain. Both the Organ Mountains and the Franklin Mountains are similar in composition to the Caballo Mountains (King et al. 1971).

The Mesilla Bolson covers approximately 11,000 square miles. The Rio Grande enters the bolson through Selden Canyon, between the Robledo Mountains and the Doña Ana Mountains, and exits through the El Paso Narrows, between the Franklin Mountains and the Sierra de Cristo Rey. The Mesilla Valley, created by the latest incision of the Rio Grande, extends from Leasburg to northwest El Paso along the eastern portion of the Mesilla Bolson. The altitude of the valley ranges from 3,980 feet at Leasburg Dam to 3,729 feet at the El Paso Narrows. The Mesilla Valley is about 50 miles long and is about 5 miles across at its widest section. The Mesilla Valley covers an area of approximately 110,000 acres (Frenzel and Kaehler 1990).

HYDROGEOLOGY

The bolsons within the study area contain ground-water systems primarily consisting of basin-fill aquifers composed of unconsolidated alluvial deposits. The aquifer system may be divided into two main geologic units: the Rio Grande floodplain alluvium and the Santa Fe Group (King et al. 1971). The Rio Grande floodplain alluvium is the upper aquifer. It was deposited by the latest incision of the Rio Grande from the late Pleistocene to the Holocene age. Beneath the Rio Grande floodplain alluvium is the Santa Fe Group. The Santa Fe Group is an intermontane basin-fill unit composed of alluvial deposits of Miocene to middle Pleistocene age (Wilson et al. 1981). The Santa Fe Group can further be broken down into three facies:

- alluvial-fan facies, composed of various size sediments ranging from gravel to clay, which is formed by the erosion of the nearby hills and mountains;

Figure 3. Geology –Dona Ana County, New Mexico

SOURCE: Dane and Bachman 1965, Geology of New Mexico, 1:500,000 map, USGS in cooperation with New Mexico Tech, New Mexico Bureau of Mines & Mineral Resources, and UNM, Geology Dept., (digital file scanned and georeference corrected by USGS/WRD).

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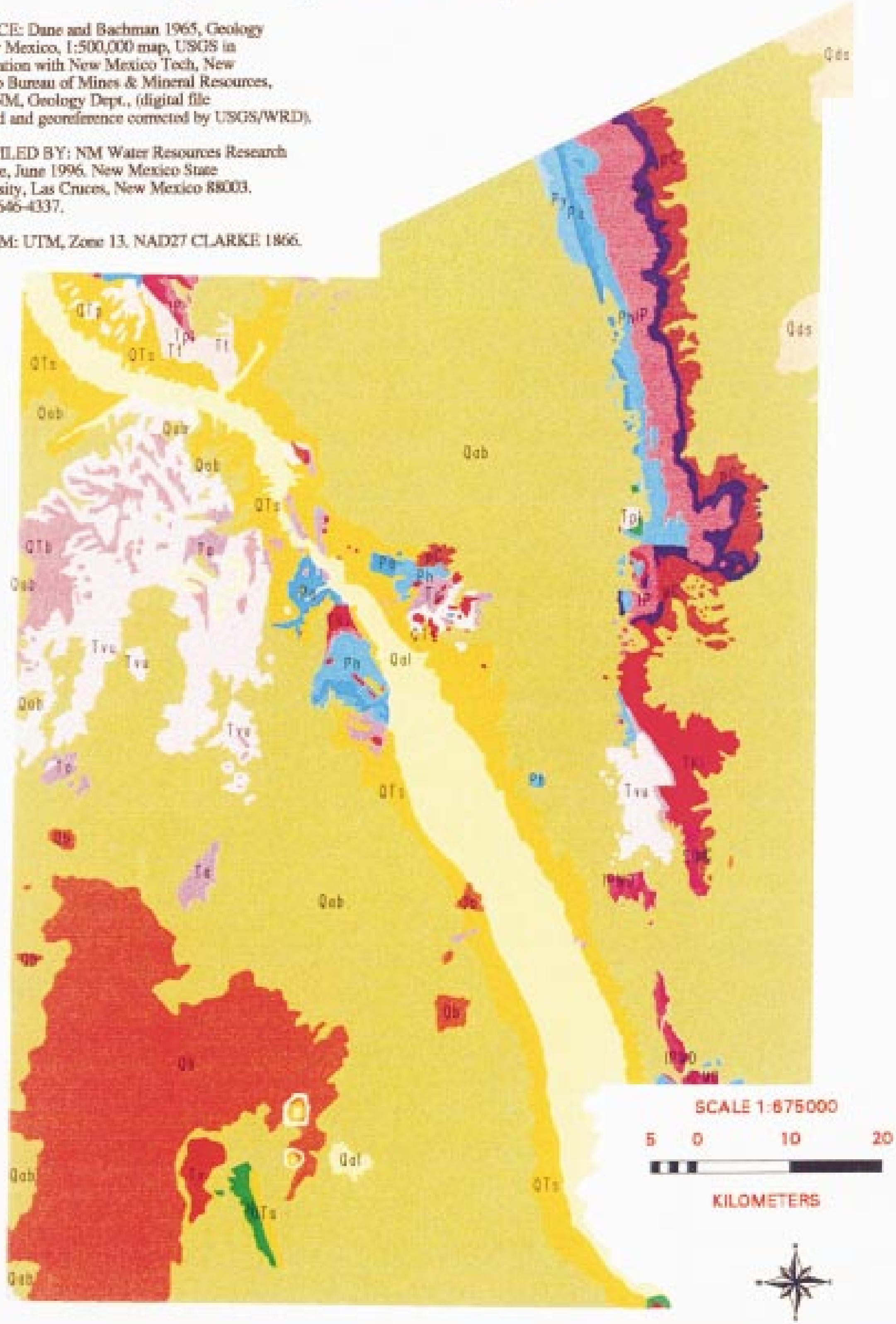
DATUM: UTM, Zone 13, NAD27 CLARKE 1866.



- clay facies, possibly produced by the continued erosion of alluvial-fan facies or by ancient lake and playa deposits; and
- fluvial facies, consisting of well-sorted sand and gravel deposited axially by the Rio Grande and its major arroyos (King et al. 1971). Because the layers were directly deposited by the Rio Grande, the horizontal permeability greatly exceeds the vertical permeability, usually by several orders of magnitude (Wilson et al. 1981).

The Mesilla Bolson contains most of the available water in the region. The floodplain alluvium has a basal gravel layer about 30 to 40 feet thick that is covered by sand, gravel, and clay lenses. Alluvial deposits continue hundreds of feet under the valley slopes, which have been continually building up on the floodplain ever since the Pleistocene age (Wilson et al. 1981). The water table is approximately 10 to 25 feet below the surface. Ground water within this alluvium typically moves southeastward down the valley at an average gradient of about 4 to 6 feet per mile; however, the direction is somewhat influenced by nearby hydraulic structures such as the Rio Grande, drains, canals, well pumpage and heavily irrigated fields (Wilson and White 1984).

Recharge into the floodplain alluvium is due primarily to seepage from the river and canals along with infiltration of irrigation water. An example of this recharge occurred on January 15, 1986, when an abrupt rise in Rio Grande stage due to a scheduled upstream release caused a rapid rise of ground-water levels. This rapid response of ground-water levels to a rise of flow in the Rio Grande indicates a strong hydraulic connection between the river and the floodplain alluvium. Records of mean daily water levels in monitoring wells maintained by the USGS and mean daily river stage clearly indicate that the water levels in the wells in the floodplain alluvium follow the trends of the river stage throughout the year. Recharge from precipitation and interbasin ground-water inflow are considered minor. The net recharge to the aquifer is directly related to Rio Grande streamflow and the volume of river water used for irrigation (Nickerson and Myers 1993). The specific capacities ranged from 10 to 217 gpm/foot drawdown with an average of 69 gpm/foot drawdown. Based on these specific capacities of shallow irrigation wells that perforated the floodplain alluvium south of Las Cruces, the transmissivity was estimated to range from 10,000 ft^2/day to 20,000 ft^2/day (Wilson and White 1984).

Most ground-water discharge from the Mesilla Bolson takes place in the vicinity of the valley-margin and floodplain surfaces (Nickerson and Myers 1993). This discharge occurs in several different ways:

- flow to agricultural drains
- seepage to the Rio Grande in the gaining reaches of the stream
- well discharge
- evapotranspiration
- discharge from interbasin ground-water outflow is considered minor (Wilson et al. 1981)

When the water table in the floodplain alluvium aquifer intersects a drain channel, discharge to the channel occurs. Some drains flow all year, while others flow periodically, varying with water levels in the shallow water table. Much of the irrigation water that infiltrates to the water table is thus returned by drains to the river (Nickerson and Myers 1993).

Discharge to the Rio Grande in the gaining reaches of the river occurs when the potentiometric surface of the aquifer rises above the river stage. Seepage investigations show that the Rio Grande is usually a losing stream through most of the Mesilla Valley. Portions of the river, however, are gaining. Gains have been reported between Leasburg Dam and Las Cruces (Wilson et al. 1981) and immediately upstream from the El Paso Narrows in the southern end of the Mesilla Valley.

The Santa Fe Group is a leaky-confined aquifer. The largest amounts of freshwater can be found in the fluvial facies. This facies varies in depth due to the volcanic activity within the region from 280 feet in the northern part of the bolson, to over 2,000 feet near the center of the bolson. In some areas of the northern West Mesa, the fluvial facies extends to depths close to 2,500 feet below the surface. In the southern section of the bolson, well fields near Cañutillo, Texas withdraw a substantial amount of water from depths up to 1,100 feet below the surface. The southeastern sections of the basin contains a thick clay facies. At the El Paso Narrows, a bedrock high prevents much of the ground water from leaving the valley.

Recharge into the Santa Fe Group comes from the ground water in the floodplain alluvium. The water moves down through layers of sand and around clay layers. Cones of depression also permit the ground water to enter the Santa Fe Group. Based on aquifer tests, the transmissivity ranged from 10,900 ft^2/day to 40,000 ft^2/day throughout the bolson. The average horizontal hydraulic conductivity was 67 ft/day. These tests also provided evidence that the horizontal hydraulic conductivity apparently decreases with depth (Wilson and White 1984). Vertical hydraulic conductivity values were found to range from 0.21 ft/day to 3.0 ft/day for the entire thickness of the confining layer.

The Mesilla Valley is located on the eastern side of the Mesilla Basin and is characterized by a broad erosional surface of low topographic relief produced by the meandering Rio Grande. An extensive remnant of an earlier basin-floor surface, the "West Mesa" of recent water resource publications (Wilson et al. 1981; Myers and Orr 1986), that predates river-valley incision is preserved between the Mesilla Valley and the East Potrillo and Robledo mountain uplifts to the west. The Mesilla Basin (Fig. 1) is defined geologically and hydrologically by structural boundaries. The ground-water basin is bounded by uplifted blocks of bedrock or by relatively impermeable volcanic rocks and is filled with alluvial sediment from surrounding mountains and with fluvial sediment carried in by the ancestral Rio Grande.

SURFACE-WATER SYSTEM

The surface-water system in the Mesilla Valley is part of an intricate connection with the ground-water system. For more detailed discussion of the hydrologic systems of the Mesilla Valley and Mesilla Basin, and the interaction between the two systems see Wilson and others (1981), Peterson and others (1984), Frenzel (1992), and Nickerson and Myers (1993). The Rio Grande is a highly regulated stream with reservoir storage and channel stabilization throughout the area. The regulation of the river is controlled by an irrigation project (Rio Grande Project), interstate compact, and international treaty. Operation of the Rio Grande is based on discharge at upstream index stations and storage in upstream reservoirs (Nickerson and Myers 1993). Streamflow in the river and the amount of water diverted for irrigation may vary greatly from year to year. During the irrigation season, March through September, water is released from the storage reservoirs, diverted from the river by diversion dams, and distributed through numerous canals, laterals, and ditches. Excess diversions and return flow from irrigation is returned through a network of drains. To control water flow, surface water for the area is stored in two large reservoirs, Caballo Reservoir and Elephant Butte Reservoir. Percha Dam, Leasburg Dam, and Mesilla Dam are diversion dams along the Rio Grande that divert water into irrigation canals. Percha Dam diverts water for the Rincon Valley, Leasburg Dam diverts water for the northern portion of the Mesilla Valley, and Mesilla Dam diverts water for the southern portion.

The surface water available for release to the Rio Grande Project from Elephant Butte and Caballo reservoirs has been highly variable over time. This is due to variances in the hydrologic cycle and differing operational parameters. The flow into Elephant Butte Reservoir has averaged about 904,000 acre-feet per year (1895-1985) and past the Elephant Butte gaging station about 872,000 acre-feet per year (1915-1992).

Most of the region's farming activities are restricted to the valley (Fig. 1) where the land surface is fairly level and the mean depth to the water table is about 180 cm. The main field crops grown in the valley are alfalfa, chile, corn, cotton, and onions (New Mexico Department of Agricultural 1993). Crop production is extensively supported by irrigation. Most irrigation is done using furrow irrigation systems, with little or no tail-end water.

Historical irrigation practices have used the ground-water system effectively as a reservoir in a combined stream-aquifer system. During years of sufficient surface water, most of the water needed for irrigation is diverted from the Rio Grande. Blaney and Hanson (1965) estimated that about one-third of applied irrigation water may replenish the ground-water system. Peterson, Khaleel, and Hawley (1984) in their quantification of components of a Mesilla Bolson hydrologic budget reported that the two most important sources of subsurface water in the Mesilla Bolson was applied irrigation water (62.2%) and seepage losses from surface waterways (30.0%). They further qualified their numbers "*the reader is cautioned not to interpret the average annual volume attributed to irrigation sources in Table 1 as being recharge to the water table. Instead, a very large portion of the applied irrigation water is probably lost to evapotranspiration before infiltrating water reaches saturated depths. As a consequence, it is possible that more net recharge to the saturated subsurface regime is actually contributed by stream losses than from irrigation water.*" (Peterson, Khaleel, and Hawley 1984, p 108).

Water levels in shallow observation wells located near the Rio Grande vary with river stage. Water levels in observation wells near the river increase and decline in response to the amount of infiltration of applied irrigation water (Nickerson and Myers 1993). Some ground water seeps into drains that discharge to the Rio Grande. During years of inadequate surface-water supply, ground water is used as a supplemental water supply. This causes abnormally low ground-water levels resulting in less water being discharged to the drains. Ground-water levels generally return to normal after an irrigation season when surface water is plentiful.

WATER QUALITY

Throughout the Mesilla Valley there is a layer or zone of slightly saline ground water near the land surface that occupies the flood-plain alluvium aquifer and the upper part of the Santa Fe Group (Wilson and White 1984). This zone is mostly a result of evapotranspiration and the resulting concentration of salts being flushed down to the water table. Water in this zone may exceed a dissolved-solids concentration of 2,000 milligrams per liter with sulfate being the predominant anion (Wilson and White 1984). Below the slightly saline zone is a much thicker zone of freshwater. There is a thin transition zone of freshwater having a dissolved-solids concentration of 500 to 1,000 milligrams per liter below the slightly saline water zone. Below the transition zone is a zone of freshwater generally less than 500 milligrams per liter dissolved solids that extents to a depth of 1,500 feet, and from this depth to about 2,500 feet, the aquifer contains freshwater having a dissolved-solids concentration of 500 to 1,000 milligrams per liter (Wilson and White 1984).

During 1990 sampling for agricultural chemicals was conducted for 20 wells in Doña Ana County by the New Mexico Environment Department (NMED) and analyzed for volatile organic compounds (VOCs) and carbamate pesticides. Two sites had detectable levels of VOCs but the levels were below state or federal standards. During the summer of 1992 the NMED, Surface Water Quality Bureau, conducted a water quality survey of ground-water wells and surface water drains located in Doña Ana County to analyze the water quality of irrigation wells and surface water drains for organochlorine pesticides, organophosphate pesticides, chlorophenoxy acid herbicides, VOCs, and carbamate pesticides (Richards 1993). Six surface water drains and one ground-water well were sampled. Analysis revealed no detectable levels of any of the constituents.

The U.S. Geological Survey National Water-Quality Assessment Program conducted a two-phase synoptic study of the occurrence and distribution of pesticides and nutrients in the surface water of the Mesilla Valley. Phase one, conducted in April-May 1994 during the high-flow irrigation season, consisted of a 6-week time-series sampling event during which 17 water-column samples were collected at 3 main-stem sites on the Rio Grande and a synoptic irrigation-run sampling event during which 19 water-column samples were collected at

7 main-stem sites, 10 drain sites, and 2 sites at the discharges of wastewater-treatment plants. Phase two, conducted in January 1995 during the low-flow non-irrigation season, consisted of a non-irrigation synoptic sampling event during which 18 water-column samples were collected at seven main-stem sites, nine drain sites, and two sites at the discharges of wastewater-treatment plants (Healy 1996). The 51 water-column samples were analyzed for 78 pesticides and metabolites and 8 nutrients along with other constituents. A total of 100 detections of 17 different pesticides were detected in 44 of the water-column samples. None of the concentrations exceeded U.S. EPA's drinking-water standards or any other federal or state criteria. As many as 38 percent of these detections may be attributed to pesticide use upstream from the valley or to nonagricultural pesticide use within the valley (Healy 1996). The highest concentration of any pesticide was 0.75 microgram per liter (µg/L) of carbofuran.

STUDY PROCEDURES

GROUND-WATER AQUIFER SENSITIVITY ASSESSMENT

Review of Assessment Techniques

The goal in selecting an assessment technique was to select the most sophisticated technique (thereby allowing the incorporation of all relevant information), which could be utilized with existing and readily available data. Future maintenance and updating had to be considered as well as the level of expertise required to use the technique. Specifically, the model should: 1) accommodate regional areas as small as those represented by USGS 7.5 minute topological maps, 2) use readily available data, and 3) allow subsequent updates to be undertaken without high level expertise. In September 1993, the U.S. Environmental Protection Agency (EPA) released *A Review of Methods for Assessing Aquifer Sensitivity and Ground Water Vulnerability to Pesticide Contamination* (USEPA 1993). It provides a comprehensive evaluation of numerous techniques and methods, each method reviewed in terms of information required, expertise level necessary, intended uses, and experiences of applications that had been performed. Based on this evaluation and local and state considerations of available information, technical expertise required, and need for future updating, the DRASTIC method was selected. The method was designed as a true aquifer sensitivity method and allowed for modification.

DRASTIC Model Modification

The DRASTIC model rates relative sensitivity of land units by integrating information on vadose zone geology, soils, recharge, hydraulic conductivity, slope, aquifer media, and depth to ground water in determining a ranking of ground-water sensitivity. It was designed to allow flexibility so that the local hydrogeological setting and its parameters could be weighted appropriately. The hydrogeological setting is defined by the spatial representation of designated mappable units. The mappable units incorporate the major hydrogeological factors which affect and often control ground-water movement. Thus, the modifications to DRASTIC were incorporated in both the selection of and weighting of these factors.

Hydrologic Parameters and Data Acquisition

The hydrogeological factors are depth to the water table (D), net recharge to the aquifer (R), aquifer media (A), soil media (S), topography (T), impact of the vadose zone (I) and hydraulic conductivity of the aquifer (C). These factors, or parameters, comprise the acronym DRASTIC. Each parameter is described as follows.

Depth-to-Water Table (D)
Depth to water refers to the depth from the land surface to the surface of the saturated zone in an unconfined aquifer or to the top of the confined aquifer. The data for the depth to water parameter were derived from the USGS Ground-Water Site Inventory Database (GWSI). The database is maintained by the USGS and contains information for nearly all areas of the state. These ground-water sites (wells) are selected for monitoring that provided an ability to acquire ongoing information, where the well's construction information was known, and that provided a good spatial dispersion. Well monitoring is performed by USGS staff and cooperators assuring quality information. The GWSI database includes local well identification numbers; latitude and longitude locations for each well; well construction information such as depth of well, diameter, casing, date of construction, aquifer code, and others; depth to the water table; and date of each measurement. Most sites are measured annually with selected sites measured more frequently. EBID provides monthly water-level data to GWSI for 41 wells in the Mesilla Valley.

The information was extracted from the state USGS computer site with the assistance of USGS personnel by defining the area desired and the GWSI parameters to be included in the selection. The resulting file was transferred from the USGS computer to the WRRI computer. The file was imported into database file (dbf) format and was further manipulated in this form.

For the depth-to-water table parameter, the latitude and longitude coordinates, and the depths to water for water wells in the Mesilla Valley and surrounding area including northwest El Paso County, Texas were used to create a water depth contour map. This database contained 797 observation sites with 10,204 depth to water table measurements. The measurements' dates spanned the period from the mid-1950s through 1994 with most sites being measured annually and selected sites measured more frequently. To develop a GIS coverage that represented the parameter, a single measurement for each site was selected. A selection was made from the database of sites having measurements within the last five-year period (January 1, 1990-December 31, 1994). This resulted in 242 sites. The most recent measurement was selected from this set. The water depth ranged from less than 5 feet to greater than 300 feet (Wilkins and Garcia 1995).

The site locations (latitude and longitude) were converted to decimal degrees. The database was then imported into ARC/INFO format and reprojected from the Geographic Coordinate System to the Universal Transverse Mercator coordinate system. To ensure sufficient data points throughout the study area, additional information from the Texas well database provided by the Texas Water Development Board was incorporated into the database.

To develop the depth-to-water contour coverage, the geostatistical technique of kriging was used. Kriging is a commonly used statistical technique to estimate the regional distribution of model values based upon scattered data points or measurements (Davis 1986). The gaussian semivariogram kriging model was utilized since it best represented the data. The next step was to create a polygon coverage (latticepoly) that represented areas of water-level depths based on attribute values. The depth-to-water table interval range, and the DRASTIC rating, weight, and resulting index are listed in Table 1.

Table 1. Depth-to-water table parameter rating (Dr), weight (Dw), and index (D)

Range[1] (feet)	Rating[1] (Dr)	Weight[2] (Dw)	Index (D)
0-5	10	5	50
5-10	9	5	45
10-20	8	5	40
20-30	7	5	35
30-50	5	5	25
50-70	3	5	15
70-100	2	5	10
100+	1	5	5

[1] Modified for local conditions from Aller et al, 1985, table 4.
[2] From Aller et al, 1985, table 3.

Net Recharge (R)

The primary source of ground water is precipitation and seepage from losing streams that infiltrate through the unsaturated zone to the water table. Net recharge indicates the amount of water per unit area of land which penetrates the ground surface and reaches the water table. The Mesilla Valley lies within an arid region where evapotranspiration exceeds regional precipitation. Therefore, the only significant potential recharge to the aquifer is through deep percolation resulting from agricultural irrigation, and infiltration from losing-water bodies such as the Rio Grande, irrigation canals and drains.

To depict this recharge parameter, it was necessary to separate agricultural areas from nonagricultural areas. This was accomplished by using two digital land use maps (El Paso and Las Cruces quads of the scale 1:250,000) for the geographic area. These digital land use maps were acquired from the USEPA over the internet. Level 1 land use codes (Anderson et al. 1976) were utilized to classify the maps (Table 2). Potential net recharge for non-irrigated land is considered to be between zero and 2 inches per unit area (Frenzel and

Kaehler 1990). Potential net recharge of irrigated land and water bodies is considered to be in excess of 10 inches per unit area (Frenzel and Kaehler 1990). All agricultural land in the area receives irrigation water for successful crop production. Urban and built-up areas, rangeland, and barren land were assigned a rating of 1. Agricultural areas, water bodies, and wetlands were assigned a rating of 9. This digital map was clipped to match the project study area and to provide the coverage for the net recharge parameter.

Table 2. Net recharge parameter rating (Rr), weight (Rw), and index (R)

Land Use Code[1]	Land Use[1]	Rating (Rr)[2]	Weight (Rw)[3]	Index (R)
1	Urban or Built-Up Land	1	4	4
2	Agricultural Land	9	4	36
3	Rangeland	1	4	4
4	Forest Land	1	4	4
5	Water	9	4	36
6	Wetland	9	4	36
7	Barren Land	1	4	4

[1] USGS land use and land cover classification system for use with remote sensor data (modified from Anderson et al. 1976).

[2] Modified for local conditions from Aller et al, 1985, table 5.

[3] From Aller et al, 1985, table 3.

Aquifer Media (A)

The shallow aquifer system in the Mesilla Valley is made up of the saturated part of the inner-valley fill, and channel sands and gravels in underlying beds of the Camp Rice Formation (Strain 1966) of the Upper Santa Fe Group (Hawley et al. 1969; Seager et al. 1971, 1976, 1982, 1987; Hawley 1975, 1978; Gile et al. 1981; Gustavson 1991) that were deposited by an ancestral Rio Grande during the mid to late Pliocene interval of basin filling.

The Santa Fe Group and the Rio Grande floodplain alluvium constitute the major aquifer for the valley and together are referred to as the “basin-fill deposits” in the USGS Open File Report 88-305 (Frenzel and Kaehler 1990). The stratigraphy, lithology, and geologic history of the Santa Fe Group and younger units were described by Hawley and others (1969), Seager and others (1971), Hawley (1975), Lovejoy and Hawley (1978), and Seager and others (1984). The basin-fill primarily consists of sands and gravels, with intermittent over-bank clay deposits.

To depict the aquifer media parameter, the 1:500,000 scale 1993 surface geology digital map (Dane and Bachman 1965) was clipped to match the project study area and reclassified to differentiate between the unconsolidated alluvium (Qal), basin-fill deposits (Qab), basalt flows (Qb) and cones, the Santa Fe Group (QTs), and the generally consolidated bedrock of the pre-Santa Fe Group. The alluvium is composed primarily of floodplain deposits consisting of channelized sands and gravels, with intermittent over-bank clay deposits. The basin-fill deposits consist of thin discontinuous cover of alluvial sands, gravels, and clays; eolian sands; and lucustrine deposits that overlie the Santa Fe Group. The basalt flows and cones generally postdate the Santa Fe Group and are limited in areal extent. The Santa Fe Group consists of unconsolidated to moderately consolidated sedimentary deposits, minor ash-fall volcaniclastics, and some volcanic rocks. The sedimentary deposits comprise lacustrine deposits of alternating layers of sand and clay; alluvial-fan deposits composed of sand, gravel, silt, and clay; and fluvial-facies composed of sand with lenses of gravel, silt, clay and sandy clay. The fluvial-facies are the most extensive deposits and contain most of the fresh water in the basin. These classes were assigned the DRASTIC ratings and weight listed in Table 3.

Table 3. Aquifer media parameter rating (Ar), weight (Aw) and index (A)

Ptype[1]	Aquifer media[1]	Rating (Ar)[1]	Weight (Aw)[2]	Index (A)
Qab	Sand and gravel w/silt and clay	6	3	18
Qal	Sand and gravel w/silt and clay	6	3	18
Qb	Basalt	9	3	27
QTs	Sand and gravel w/silt and clay	6	3	18
pQTs	pre-Santa Fe Group rocks	4	3	12

[1] Modified for local conditions from Aller et al, 1985, table 6.

[2] From Aller et al, 1985, table 3.

Soil Media (S)

In general, a soil's pollution potential is affected largely by the type and amount of clay present, the shrink/ swell potential (controlling the development of macropores and other secondary permeability features), and the soil's grain size. The DRASTIC index includes soils ratings appropriate for the pollution potential associated with development of secondary permeability.

The data were acquired from the NRCS state office in Digital Line Graph (DLG) format (USGS 1990). The data received included database files that contained information concerning soil characteristics and an individual DLG file for each 1:24,000 (7.5 minute) Quadrangle map for Doña Ana County.

The soil coverage was developed by NRCS using the GRASS mapping system. These files were then imported into ARC/INFO and modified so that the attribute database would contain the Map Unit Symbol and Map Unit Name for each soil series. Based on the soil characteristics of the Map Unit Symbol (soil classification contained in the Soil Survey of Doña Ana County Area, New Mexico 1980), values were assigned as specified by the DRASTIC model (Aller et al. 1985, p. 8-9). The selection of a value for the parameter was based on the most restrictive soil zone that occurred in the profile. The DRASTIC values for the parameter were then attached to the database. Table 4 contains the soil media and DRASTIC rating, weight and resulting index.

Table 4. Soil media parameter rating (Sr), weight (Sw) and index (S)

Soil Media[1]	Rating (Sr)[1]	Weight (Sw)[2]	Index (S)
Basalt	1	5	5
Caliche	1	5	5
Carbonate Hardpan	1	5	5
Carbonate-cemented	1	5	5
Clay	1	5	5
Clay Loam	3	5	15
Dumps	1	5	5
Gravel	10	5	50
Gravel Pit	1	5	5
Lime-coated Basalt	1	5	5
Limestone Bedrock	1	5	5
Loam	5	5	25
Loamy Sand	8	5	40
Rock Outcrop	1	5	5
Sand	9	5	45
Sandy Clay	2	5	10
Sandy Clay Loam	4	5	20
Sandy Loam	7	5	35
Silt	4	5	20
Silty Clay	2	5	10
Silty Loam	5	5	25
Thin or Absent	1	5	5
Water	10	5	50
Outside of Soil Survey	1	5	5

[1] Modified for local conditions from Aller et al, 1985, table 7.

[2] From Aller et al, 1985, table 3.

Topography (T)
The topography coverage was derived from USGS Digital Elevation Model (DEM) files obtained over the Internet. A DEM consists of an array of elevations for ground positions that are usually at regularly spaced intervals. The 1-degree DEM provides coverage in 1- by 1-degree blocks and is available for all of the contiguous United States, Hawaii, and most of Alaska. The basic elevation model is produced by the Defense Mapping Agency (DMA) using cartographic and photographic sources.

The 1-degree DEM consists of a regular array of elevations referenced horizontally on the geographic coordinate (latitude/longitude) system of the World Geodetic System 1984 Datum. Elevation data located on the degree lines (all four sides) correspond to the same profiles on adjoining DEM blocks. Elevations are in meters relative to mean sea level. Spacing of the elevations along and between each profile is at 3 arc-seconds with 1,201 elevations per profile.

The DEMs for the 1:250,000 scale Las Cruces and El Paso quads were acquired and imported into ARC/INFO using the function 'demlattice.' The two lattices were then merged into one large lattice that was then clipped by a coverage of the study area. The lattice coverage was then used to derive a polygon coverage that represented the slope (or topography) for the study area. The latticepoly command used a lookup table to assign codes to the range in slope. This code was then used to attach a DRASTIC parameters database to the coverage. The topography rating, weight, and index are listed in Table 5.

Table 5. Topography parameter rating (Tr), weight (Tw), and index (T)

Range (Percent Slope)	Rating (Tr)	Weight (Tw)[1]	Index (T)
0-2	10	3	30
2-6	9	3	27
6-12	5	3	15
12-18	3	3	9
18+	1	3	3

[1] From Aller et al, 1985, table 3.

Impact of the Vadose Zone Media (I)
The lithology of the vadose zone is made up of the unsaturated part of the inner-valley fill, and channel sands and gravels in underlying beds of the Camp Rice Formation (Strain 1966) of the Upper Santa Fe Group (Hawley et al. 1969; Seager et al. 1971, 1976, 1982, 1987; Hawley 1975, 1978; Gile et al. 1981; Gustavson 1991) that were deposited by an ancestral Rio Grande during the mid to late Pliocene interval of basin filling. The vadose zone media ratings, weights and index are listed in Table 6.

Table 6. Vadose zone media parameter rating (Ir), weight (Iw) and index (I)

Ptype[1]	Vadose Zone Media[1]	Rating (Ir)[1]	Weight (Iw)[2]	Index (I)
Qab	Sand and gravel w/silt and clay	6	4	24
Qal	Sand and gravel w/silt and clay	6	4	24
Qb	Basalt	9	4	36
QTs	Sand and gravel w/silt and clay	6	4	24
pQTs	Pre-Santa Fe group	4	4	16

[1] Modified for local conditions from Aller et al, 1985, table 9.

[2] From Aller et al, 1985, table 3.

Hydraulic Conductivity of the Aquifer (C)
The hydraulic conductivity coverage was derived from work that had been conducted for the City of Las Cruces Wellhead Protection Program (Hanson et al. 1994) and from the ground-water modeling work for the Mesilla Basin (Frenzel and Kaehler 1990). A digital file that contained spatial representation of areas with similar hydraulic conductivity was imported into ARC/INFO and modified.

The first modification of the file included assigning geographic control points so that the coverage could be rotated and projected into the UTM coordinate system. The second involved modifying the "K" values originally assigned to the polygons representing hydraulic conductivity. These values were multiplied by a conversion factor that would match the requirements for the hydraulic conductivity parameter for the DRASTIC model (Aller et al. 1985, p. 8-9). The DRASTIC values for the parameter were then attached to the attribute database for analysis. The original file contained the hydraulic conductivity values in K units. Table 7 below contains the transformed values and the DRASTIC rating, weight, and index.

Table 7. Hydraulic conductivity of the aquifer parameter rating (Cr), weight (Cw), and index (C) (gpd/ft^2) = 7.48 * K (ft/day)

Zone	Hydraulic Conductivity[1] (ft/day)	Hydraulic Conductivity (gpd/ft^2)	Rating (Cr	Weight[2])(Cw)	Index (C)
K1	140.0	1047.20	5	2	10
K2	70.0	523.60	4	2	8
K3	22.0	164.56	2	2	4
K4	18.0	136.64	2	2	4
K5	11.0	82.28	1	2	2
K6	4.5	33.66	1	2	2
K7	0.0	0.00	1	2	2

[1] From Frenzel and Kaehler 1990, Fig. 20, p. 49

[2] From Aller et al, 1985, table 3.

Combining DRASTIC Parameter Coverages

Data tables containing the index values and parameter ranges are joined to the feature attribute table for each parameter coverage based upon the range value classification. To aid in interpreting and evaluating the natural sensitivity assessment, a GIS layer was developed for each parameter.

The seven parameter coverages were combined together by geometric intersection of the polygon coverages. All polygons from the seven coverages were split at their intersections and preserved in the output coverage. The output coverage contained the combined polygons and feature attribute tables of all seven coverages. For each polygon the feature attribute table generated contained a field for each DRASTIC parameter index value and the area of each polygon. To obtain the final (combined) DRASTIC index values, a new field was created in the feature attribute table of the natural sensitivity (NATSEN) coverage. This NATSEN index was calculated by summing the DRASTIC parameters and placing the result in the field. The weights assigned for the purpose of combining the parameters are those recommended for an agricultural application of the model (Aller et al. 1985). Table 8 lists the weights for each of the DRASTIC parameters.

Additional analysis was performed to create a table that contained the combined DRASTIC values, frequency of occurrence, and the summation of the area for each value. Bar graphs of the combined DRASTIC value-frequency and DRASTIC value-area were created in order to assist in grouping the index values into ranges of sensitivities.

Table 8. Assigned weights for combining DRASTIC parameters (from Aller et al. 1985, Table 3)

DRASTIC parameter	Weight
Depth-to-water table	5
Net recharge	4
Aquifer media	3
Soil media	5
Topography	3
Impact of the vadose zone	4
Hydraulic conductivity	2

MANAGEMENT PRACTICES EVALUATION

Nonpoint source pollution from nutrients and pesticides application has the potential to degrade water resources. The pollution threat could be minimized by identifying and adopting Best Management Practices (BMPs) at or near the source areas. Thus, BMPs may have to be developed for locations known to be affected by nonpoint source pollution. Several cultural or management practices could be put together to constitute the various components of BMPs. For example, Izuno et al. (1995) evaluated cultural practices for developing appropriate BMPs intended to reduce phosphorus loading in the Everglades Agricultural Area in southern Florida. While BMPs have the potential to alleviate or minimize the pollution problem, it is imperative to tailor appropriate BMPs for specific problems and areas for optimum results (Watson et al. 1994).

BMPs involve the use of an integrated approach to solving environmental problems or achieving the maximum desired goal. Thus, practices thought to assist in maintaining environmental quality or increasing crop production could be grouped together. For example, soil conservation practices such as conservation tillage, contouring and terracing, use of sedimentation ponds, cover cropping and plant residue use, strip cropping, and laser leveling of field surfaces could be used to control nonpoint pollution (Reay et al. 1992; Hamlett and Epp 1994). These practices could minimize runoff losses by increasing water infiltration and water application uniformity. Additionally, cover crops are sources of plant biomass helpful in restoring or maintaining high levels of soil organic matter and soil biological activity (Bruce et al. 1991), which consequently minimize the bulk of organic pesticides carried in runoff and leached under favorable conditions.

Nutrient management may be included in the BMPs selected to control nonpoint source pollution. Crops require nutrients for optimum growth. However, nutrient use varies within the growing season. Such variation must be taken into consideration when formulating a crop fertilization scheme for an area. Nutrients not used by the crops could be subject to loss through leaching, runoff, or they could be transformed into forms not available to the crops. Nutrient management practices should include proper fertilizer placements (Watson et al. 1994) and nutrient application in suitable amounts, form, and at the appropriate time, making use of most residual nutrients in the soil profile (Hamlett and Epp 1994).

Care is needed when applying pesticides on the field. More important, an appropriate amount of the required pesticide must be applied at the most opportune time for maximum impact on the target pests to minimize repeated applications later in the growing season. If possible, pesticides should be applied at the time the crop is most sensitive to pest infestation. Heavy irrigation following pesticide application could result in runoff losses and leaching into deep soil layers where microbial activity and plant uptake are limited, thereby increasing the pesticides' potential to move toward ground water under high soil moisture conditions. Thus, poor pesticide management can increase the pollution potential of pesticides especially under irrigated conditions.

It is highly likely that applied agricultural chemicals will leach and run off under an irrigated agricultural setting, especially if adequate irrigation management practices are not in place. Adopting good irrigation management practices could minimize nonpoint source pollution from irrigated fields. The main focus of irrigation management is to determine how to use irrigation water most effectively to sustain optimum crop growth and yield as well as to minimize runoff and leaching. The amount of irrigation water applied and time of application are very critical. Best results can be achieved by using climate data or tensiometers to schedule irrigation. Also, the pollution potential of applied pesticides and nutrients could be minimized by avoiding over-irrigation which will curtail leaching and runoff losses. Other sound irrigation management practices include land leveling, installing subsurface and surface drains, recovering tailwater, checking valves for leaks on the water distribution network to ensure efficient delivery of an appropriate amount of water to the field, and using flow measuring devices to record the exact amount of water delivered to the field.

The degree of success in minimizing nonpoint source pollution in irrigated agriculture depends in part on the type of irrigation system being used. Irrigation systems range from basin, furrow through sprinkler, to trickle irrigation systems. Each system commands a different degree of efficiency, overhead cost, maintenance cost, and other associated costs. Even though overhead and maintenance costs dictate the choice of irrigation system, it is imperative that attention is paid to other factors such as the field slope and soil type when selecting an irrigation system to match a particular field condition. Once an appropriate system has been selected within the constraints, it should be well designed and managed effectively to reduce surface runoff and leaching losses of applied pesticides and nutrients. Ranjha and others (1992) used appropriate furrow design to reduce leaching losses of carbofuran and hexazinone in alfalfa fields. Short furrow lengths and a high head inflow rate reduced carbofuran and hexazinone leaching losses. On the other hand, long furrow lengths and a low head inflow rate increased leaching losses, especially in coarse textured soils because of low water storage efficiency and higher infiltration rates (Ranjha et al. 1992). Thus, leaching losses of applied pesticides below the rooting zone under furrow irrigated conditions could be reduced by adopting short furrow lengths with a high head inflow rate to maintain high water storage efficiency.

Cropping sequence or cropping pattern may be altered to break continuous pesticide application over several years. This approach is most applicable when the alternate crops being grown require different types of pesticides. Alternatively, a cover crop could be sandwiched between two or more sequential cropping seasons to break pesticide application events. This crop management practice could limit the frequency and pesticide or fertilizer amounts normally applied, which, consequently, may reduce the pollution potential. Incorporating a cover crop in the cropping sequence may increase soil organic matter, a soil constituent having the ability to retard organic pesticides movement in soils.

Because pest infestation impairs crop growth and decreases yield, the pest eradication method or management program used must be effective and efficient. Pest management involves different approaches, each approach most applicable at different levels of pest infestation. For example, vigilance is required to ensure that no new pest establishes on the farm. If a new pest is identified, it should be eradicated promptly without leaving it room to propagate in the future. Although chemicals are effective in controlling pests, their use should be the last resort. Complete eradication of pests may not result in maximum profit or returns. Schweizer and others (1988) showed that systematic reduction of herbicide use over a four-year period did not result in a significant reduction in crop yield and adjusted gross returns. Thus, it may be appropriate to design pest management practices to achieve less than 100% pest eradication for a minimum yield lost. Such an approach may lead to a significant reduction in the amount of pesticide applied over a time period. Reducing the amount of pesticide used may lessen the quantity of pesticide leached under high soil moisture conditions. Also, an integrated approach that encompasses the use of appropriate cultural practices such as vigilance, crop rotation and mechanical pest control, along with the planting of resistant crop varieties, using biological pest control if available, sparing use of pesticides, and timing of pesticide application are recommended (Swanton and Weise 1991). The integrated approach for pest control is intended to produce the highest pest control results achievable since individual control measures operating alone may not be very effective. The integrated approach could help limit the amount of pesticide needed and even reduce the potential for the target pest to develop resistance to the pesticide. Once a pest develops resistance to a pesticide, large amounts of the pesticide may have to be used to achieve the desired level of pest control. Alternatively, a new chemical may have to be substituted in order to control the pest, thereby continuing the pesticide-use cycle in the environment.

Current Farming Practices

Farmers in Doña Ana County were surveyed to record current management practices used for farming operations. Specific practices recorded were cropping sequence including planting and harvest dates, irrigation scheduling practices indicating the time and amount of water applied for each cropping season, and the type, time, and amount of pesticide applied. Farm locations were recorded and used to identify the soil type in the

Soil Survey Report for the Doña Ana County Area. For each soil type, the field capacity, permanent wilting point, saturated hydraulic conductivity, air entry potential, and the exponential parameter of Campbell's soil water retention model (b-value) were estimated following the procedure described in the section: *Soil Hydraulic Parameters*.

Proposed Best Management Practices

Most farmlands in Doña Ana County are fairly level with the mean depth-to-water table being about 1.8 meters (about 6 feet). Crop production is supported by intense irrigation practices. Under these conditions, ground-water contamination through runoff losses was expected to be minimal. Leaching of applied agricultural chemicals is the most likely route through which ground water could be contaminated. Proposed modifications of farming practices in the county were those intended to control leaching losses of applied chemicals. The proposed BMPs are:

Crop Rotation
Crop rotation is practiced to break the continuous use of one particular chemical over an extended period and thereby preventing pest buildup in the environment.

Irrigation Scheduling
Irrigation scheduling is very critical in controlling leaching because of the intense irrigation practiced in this area. Scheduling irrigation to provide an adequate amount of water to the crops at the right time could limit over-irrigation and thereby reduce leaching losses. A simple approach is to schedule irrigation using tensiometers installed within the root zone. Soils vary with respect to both their water holding capacity and the tension at which different amounts of water are held. For example, NRCS office in Las Cruces, with qualifications, has recommended that crops being grown on sandy loam soils should be irrigated when the tensiometer reading is about 23 KPa (centibars) and about 74 KPa (centibars) for a clayey soil (Appendix A). The NRCS further recommends that the porous cup of the tensiometers be spaced throughout the active root zone, which will vary depending on the crop. Another tensiometer installation scheme allows the position of the porous cup to change with the dynamic crop root zone. Alternatively, an irrigation scheduling model could be used to estimate when and how much water to apply to meet a desired yield and leaching fraction levels. The use of such a model requires local weather data. In the absence of readily available data, the weather data could be generated using the model WGEN (Richardson and Wright 1984) or any available daily weather generating model. The advantage of using irrigation scheduling models lies in their flexibility to experiment with different water management schemes (different time and amount of water applications) before selecting the scheme that gives best results.

First Irrigation after Chemical Application
The time at which the field is irrigated following pesticide application is critical for chemical leaching, especially if the field is irrigated intensively. Management practices may appropriately impose a three to four day delay of irrigation following an agricultural chemical application. This practice may allow some of the applied chemical to degrade or be adsorbed by soil colloidal particles, resulting in less of the chemical being available for leaching under favorable soil moisture conditions.

Changing Irrigation System
Irrigation efficiency varies with the irrigation system. Generally, irrigation efficiency increases from a surface to a drip/trickle irrigation system. High irrigation efficiency results from good control over water application and distribution on the field. Maintaining high irrigation efficiency could minimize the amount of water that moves past the root zone and, consequently, helps control chemical leaching. Thus, changing from a furrow irrigation system to a sprinkler system could result in a substantial reduction in the amount of applied chemical that leaches below the root zone, reducing the potential for ground-water pollution.

Increasing Soil Surface Layer Organic Matter Content
The organic matter content of the soil surface layer may be increased by incorporating organic material (plant materials) into the soil layer. The resultant increases in organic matter leads to an increase in organic chemical adsorption, a process that retards organic chemical movement in soils. Thus, occasionally incorporating organic material into the soil surface layer may restrict pesticides from moving readily with soil water into lower soil depths. Additionally, the carbon constituent of the organic material could serve as an energy source for enhancing microbial degradation of applied pesticides. Because the area's climate is semiarid and adequate soil moisture is maintained through irrigation, rapid decomposition of added organic materials could occur. Therefore, it may be necessary to apply organic materials to the soil surface layer every three to four years.

Integrated Pest Management Practices - Sparing Use of Pesticide
The principle behind integrated pest management practices is the use of several pest control measures concurrently to control pests. For example, mechanical pest control and vigilance could be combined with minimal pesticide use to achieve a thorough pest control on the field. Because each pest control measure reduces infestation by some amount, the combined effects of the different pest control measures could be more promising. By complementing pesticide use with other means of pest control, the amount of applied pesticide could be reduced.

SETTING UP THE IRRSCH MODEL

The IRRSCH model was designed to simulate the scenarios of interest. This entailed providing appropriate input data to drive the model. IRRSCHM requires the following inputs: soil organic matter distribution in the soil profile, pesticide half-life values in the soil profile, cropping sequence for multiyear simulations, irrigation scheduling data for each cropping sequence, planting date, harvest date, and time of pesticide application. Procedures used for acquiring the appropriate input data are as follows:

Soil Hydraulic Parameters

The purpose of this section is to evaluate the different methods for estimating field capacity (FC) and permanent wilting point (PWP) values and to determine the simplest method that gives satisfactory values for different soil types.

Irrigation scheduling models (Shayya et al. 1990, 1991; Shayya and Bralts 1994; Fox et al. 1992), and volume-based water quality models such as PRZM (Carsel et al. 1984, 1985) and CMLS (Nofziger and Hornsby 1985) require either soil information about FC and PWP or information about the soil's available water capacity. The soil's available water capacity is defined as the field capacity minus the permanent wilting point. The soil's available water capacity is used in the models to maintain a tipping bucket approach to flow where the soil profile is divided into discrete layers. Water fills each layer up to FC with the excess moving into the next layer below. Field capacity and permanent wilting point for different soil types are reported as a range of values in the NRCS soil survey for each county in the United States. The water balance models are sensitive to the FC and PWP values used in the input file. Consequently, selecting the maximum, minimum, or mean value from the range can affect the calculated time to irrigate or the amount of pesticide or nitrates that enter the ground water.

Conventional methods used to determine FC and PWP from field or laboratory measurements are costly and time consuming (Mualem 1992). Predictive methods, based on regression analysis in which soil particle size fractions and/or other soil data are correlated with soil hydraulic properties, have been developed by several workers including Campbell (1985), Saxton and others (1986), and Gregson and others (1987). The accuracy of predicted soil hydraulic properties are not known. Even if measured values are available for direct comparison, they may not reflect the physical properties of the soil type because of extensive spacial variability that exists in field soils (Yeh et al. 1986).

The indirect methods develop regression equations for predicting the parameters needed to describe the moisture release curve. Field capacity and permanent wilting point values are then estimated using a moisture release curve model and setting the soil matrix potential at -33 and -1500 KPa, respectively. For light sandy soils, the water content at -10 KPa appears more representative for FC (Donigian and Carsel 1992; Walker and Skogerboe 1987). Jensen and others (1990) stated that FC for coarse textured soils could be estimated at -10 KPa and at -20 KPa for medium to fine textured soils. Ratliff and others (1983) compared field measured and calculated available water (difference between soil moisture estimated at -33 KPa and that estimated at -1500 KPa) and concluded that the estimated water contents at -33 KPa were significantly less than the field measured for sands, sandy loams, and sandy clay loams. In contrast, the calculated soil moisture contents at -33 KPa were significantly more than the field measured values for silty loams, silty clay loams, and silty clays. However, Ratliff and others (1983) defined FC as the water content of a soil after drainage became practically negligible. For some of the clayey soils, the time to reach field capacity was 20 days. Besides, the plots were subject to evaporation losses and rainfall inputs. Consequently, the heavier soils would have a lower FC value than were normally calculated. Plants can take water out from the soil immediately after irrigation. In most irrigation management models, the FC value is the upper limit value for soil water content. The calculated soil water contents at -1500 KPa were significantly less than the field measured permanent wilting point values for sands, silty loams, and sandy clay loams, and significantly more than the field measured values for loams, silty clays, and clays. Consequently, Ratliff and others (1983) recommended that available soil water should be measured in the field instead of using laboratory procedures. An array of choices is listed below:

1. measure in the field, the soil moisture content 48 hours after an irrigation to determine FC and select PWP from the general values for that soil type

2. use a general value for different soil types for both FC and PWP

3. select either the minimum, mean, or maximum value from a range of available FC and PWP values presented in the county NRCS soil survey report

4. estimate the coefficients that describe the moisture release curve based on soil particle size fractions (percent sand, silt, and clay) for the soil type from the center point of the soil textural class in the soil textural triangle; use the soil moisture release curve model to calculate field capacity at soil matric potential taken from a range between -10 and -33 KPa depending on the soil type; then, calculate PWP at -1500 KPa

5. use the indirect method to parameterize the soil moisture release curve model and the saturated hydraulic conductivity, and then solve Richard's Equation for infiltration and redistribution; after 48 hours of redistribution, use the predicted soil moisture content to estimate the field capacity value; then, run the model until the soil matric potential reaches -1500 KPa to determine the soil moisture content at PWP

FC values of six soil types presented by Israelsen and Hansen (1962) were regressed against percent sand, silt, and clay taken from the center point of each soil textural class as shown in the USDA soil textural triangle. The linear coefficients were determined using a multiple regression model. The soil moisture content at FC was estimated using the resultant regression model. The same approach was used to find the regression model PWP values using the data in Israelsen and Hansen (1962).

The data in Israelsen and Hansen (1962), though not referenced, represents the average FC values for the different soil textural classes listed. The approach used to verify that the values given by Israelsen and Hansen (1962) are reasonable or could be improved is to take the percent sand, silt, and clay values from the center of the USDA soil textural triangle for each soil class and use them in the equations presented by Campbell (1985) to estimate the parameters for the soil moisture release curve model. The FC values could be estimated at a soil matric potential value that ranges from -10 to -33 KPa. Likewise, the soil moisture content at PWP could be estimated at a soil matric potential value of -1500 KPa. Parameters were determined for the soil moisture release curve model shown in Equation 1:

$$\psi = \psi_e \; (\theta/\theta_s)^{-B} \tag{1}$$

where ψ is matric potential (KPa), ψ_e is air entry potential (KPa), B is b-value, and θ and θ_s are unsaturated and saturated soil moisture content ($m^3\ m^{-3}$), respectively.

Air entry potential and B were estimated based on Campbell's model (1985), which requires particle size fractions for input. Geometric particle diameter (d_g) and the geometric standard deviation (σ_g) were used to estimate ψ_e and B. d_g and σ_g are calculated as follows:

$$d_g = \exp(a) \tag{2}$$

$$\sigma_g = \exp(b) \tag{3}$$

and

$$a = \Sigma m_i \; \ln(d_i) \tag{4}$$

$$b = \sqrt{[\Sigma m_i \; (\ln \; d_i)^2 - a^2]} \tag{5}$$

respectively.

B is estimated as

$$B = 2\psi_{es} + 0.2\sigma_g \tag{6}$$

and ψ_e (KPa) calculated as

$$\psi_e = \psi_{es}(\rho_b/1.3)^{0.67B} \tag{7}$$

where:

$$\psi_{es} = 0.5(d_g)^{-0.5} \tag{8}$$

and σ_b is soil bulk density in g cm^{-3}.

Along with the equations for estimating the moisture release curve the equation (Eq. 9) given by Campbell (1985) was used to estimate the saturated conductivity (K_s):

$$K_s = C \times \exp(-6.9m_c - 3.7m_s) \tag{9}$$

where m_s and m_c are silt and clay mass fractions and C is a constant. The saturated conductivity and the soil moisture release curve models were used in Campbell's (1985) finite difference solution to Richard's Equation for infiltration and redistribution:

$$\frac{\partial\theta}{\partial t} = \frac{\partial}{\partial z}\left(K(\theta)\frac{\partial H}{\partial z}\right) \pm U(z,t) \tag{10}$$

where θ is volumetric soil moisture content (m^3m^{-3}), H is hydraulic head (m), t is time (s), K is hydraulic conductivity (m/s), z is soil depth (m) and U is source/sink term (s^{-1}).

Water was allowed to infiltrate for two hours and then redistributed in 24-hour and 48-hour periods for field capacity (FC) determination. FC is defined as the soil water content when drainage is negligible. After employing Campbell's (1985) model for infiltration/redistribution, the soil water contents in the top 60 cm of the profile were averaged to represent FC. Permanent wilting point (PWP) was determined by running

Campbell's (1985) infiltration/redistribution model until the soil matric potential, during evapotranspiration events, reached -1500 KPa. The PWP also was calculated based on the -1500 KPa using the soil moisture release curve model.

Soil samples were collected from selected fields of different soil types which varied from sandy to clayey soils 48 hours after the soils had been flood irrigated. Samples were collected at 30 cm increments to a depth of 90 cm. The soil moisture content was determined by drying the sample in an oven for 24 hours at 104°C. The soil sample was then analyzed for percent sand, silt, and clay and then rewetted to PWP, which was measured using a soil psychrometer.

The linear regression relating FC and PWP data given by Israelsen and Hansen (1962) and percent sand (S_a), silt (S_i) and clay (C_l) resulted in a coefficient of variation of 0.99. The equation for FC is :

$$FC = -2.28667 + 0.0331 \times C_l + 0.0321 \times S_i + 0.0296 \times S_a \qquad \textbf{(11)}$$

where FC is expressed as the soil's gravimetric moisture content (g/g) at FC.

The equation for PWP is:

$$PWP = -1.3307 + 0.0156 \times C_l + 0.0148 \times S_i + 0.0137 \times S_a \qquad \textbf{(12)}$$

where PWP is expressed as the soil's gravimetric moisture content (g/g) at PWP.

The FC and PWP values obtained by regressing Israelsen and Hansen (1962) data against percent sand, silt, and clay and values obtained by running Cambell's model for 24- and 48-hour redistribution are shown in Table 9. As shown in Table 9, FC and PWP values generated by the multiple regression equations and by Campbell's model for 24-hour and 48-hour redistribution are very close. Comparing FC values generated by the two procedures yielded correlation coefficients of 0.988 and 0.998 for Campbell's (1985) infiltration/redistribution model simulation with 24- and 48-hour redistribution events, respectively. Thus, the estimated FC using Campbell's (1985) infiltration/redistribution model with 48-hour redistribution correlated better with FC values given by Israelsen and Hansen's (1962) data. Even the moisture content in a sandy soil computed by Cambell's (1985) infiltration/redistribution model with 48-hour redistribution was closer to Israelsen and Hansen's (1962). Comparison results suggest that the 24-hour redistribution is not long enough for all the large pores to drain.

Field capacity (FC) values obtained using the soil moisture release curve model (Eq. 1) must be adjusted depending upon the soil type. Corresponding matric potentials for the adjusted FC values could range from 10 KPa for sandy soils to 50 KPa for the heavy clayey soils.

Permanent wilting point (PWP) values for clayey and silty soils determined by Campbell's (1985) infiltration/redistribution model and by soil moisture release curve model, with soil moisture potential set at -1500 KPa, were high compared to Israelsen and Hansen's (1962) data. However, both procedures gave almost identical PWP values for loamy soil. For sandy soil, PWP values produced by both procedures were lower than Israelsen and Hansen's (1962) values.

Table 9. Comparison of different methods for determining field capacity and permanent wilting point values

USDA Text-ure Class	Average Bulk Density (g/cc)	Israelsen	FC Campbel 24-hrs	48-hrs	FC MRC 10 KPa	20 Kpa	30 KPa	40 KPa	50 KPa	Israelsen	Camp PWP	Camp Psi-value	MRC 1500 KPa
c	1.260	0.351	0.365	0.355	0.405	0.386	0.375	0.368	0.362	0.172	0.316	-1500.190	0.285
cl	1.350	0.264	0.305	0.293	0.305	0.282	0.270	0.261	0.255	0.125	0.179	-1500.090	0.174
l	1.390	0.223	0.263	0.252	0.247	0.221	0.207	0.198	0.191	0.102	0.105	-1500.020	0.111
lsa	1.580	0.116	0.137	0.126	0.090	0.070	0.061	0.055	0.051	0.051	0.019	-163.883	0.015
sa	1.630	0.091	0.103	0.093	0.050	0.036	0.029	0.025	0.023	0.039	0.007	-66.024	0.004
sac	1.440	0.231	0.264	0.255	0.255	0.238	0.229	0.223	0.218	0.113	0.186	-1500.040	0.156
sacl	1.470	0.200	0.236	0.227	0.219	0.199	0.188	0.181	0.176	0.095	0.124	-1500.050	0.111
sal	1.530	0.139	0.184	0.174	0.148	0.126	0.115	0.107	0.102	0.062	0.056	-426.608	0.046
si	1.160	0.332	0.398	0.378	0.442	0.398	0.375	0.359	0.347	0.149	0.167	-1500.220	0.209
sic	1.280	0.312	0.357	0.347	0.391	0.371	0.360	0.352	0.346	0.150	0.295	-1500.320	0.266
sicl	1.240	0.321	0.369	0.356	0.409	0.383	0.368	0.358	0.351	0.151	0.257	-1500.070	0.252
sil	1.280	0.276	0.330	0.315	0.338	0.305	0.288	0.276	0.267	0.125	0.138	-1500.100	0.163

Explanation of columns:

Camp and MRC mean Campbell ET/redistribution model and soil moisture release curve, respectively.

FC and PWP mean field capacity and permanent wilting point, respectively. FC and PWP values are expressed in g/g.

Israelsen: Data were obtained by multiple-linear regression on Israelsen and Hansen's (1962) published averages against percent sand, silt, and clay with the following results:

Intercept	-2.8667	-1.3307
Clay coeff.	0.0331	0.0156
Silt coeff.	0.0321	0.0148
Sand coeff.	0.0296	0.0137
R^2	0.9988	0.9968

Campbell: Data were obtained for field capacity by running Campbell's redistribution model with the root zone set to saturation, and then allowing 24 and 48 hours of redistribution. The resulting root zone water content was taken as field capacity. Data were obtained for permanent wilting point by running Campbell's ET model with initial conditions near saturation, and allowing extraction to continue until the bottom of the root zone reached 1500 KPa, or the soil became too dry for computation to continue. The resulting average root zone water content was taken as the permanent wilting point. The matric potential for the given PWP values are listed in the table.

Moisture release curve values (MRC): Data were obtained by computing the moisture content from the moisture release curve of each soil type at the stated matric potential.

Moisture content at different matric potential was also measured for a sandy soil collected from Farmington, New Mexico. A power function was fit to the data to estimate parameters for the soil moisture release curve model (Eq. 1). PWP was estimated by setting the matric potential at -1500 KPa in the soil moisture release curve model and back calculating the corresponding soil moisture content. The estimated PWP matched the value given by Israelsen and Hansen (1962) for the soil type but failed to match accurately the value obtained when the soil moisture release curve model parameters were estimated using Campbell's (1985) procedure that requires percent sand, silt, and clay as inputs (eqs. 2-8). Similar results were obtained for clay and loamy soils. Additionally, the mean percent sand, silt, and clay for soil types given in the USDA soil textural triangle were used to estimate parameters for the soil moisture release curve model, based on Campbell's (1985) procedure. The estimated PWP values, based on the new set of parameters, were higher than the values given by Israelsen and Hansen (1962) for the soil types. Consequently, Israelsen and Hansen's (1962) method, the multiple regression approach, gives better PWP estimates than the soil moisture release curve model (Eq. 1) at -1500 KPa soil matric potential. Directly measuring the soil moisture content at -1500 KPa soil matric potential produces PWP values close to the values presented in Israelsen and Hansen (1962). However, it is impossible to determine soil moisture release curves for all soils series in New Mexico for FC and PWP estimates due to the high cost of such an undertaking. The solution is to use models to estimate FC and PWP values. The simple empirical relationship developed by regressing FC and PWP data using Israelsen and Hansen's (1962) multiple regression model against soil particle size fractions provides as good a result as the more physically based models that require percent sand, silt and clay as inputs.

FC and PWP values used for IRRSCHM simulations were estimated using the empirical multiple regression model in which particle size fractions were regressed against FC and PWP data presented in Israelsen and Hansen (1962).

FC and PWP values are sensitive to estimation methods. Because direct measurements could be time consuming when dealing with a large number of soils, estimation models are recommended for use. However, an appropriate estimation model is needed to obtain sound values that reflect soil hydraulic properties. In this study, good FC and PWP values for different soil classes were obtained using an empirical regression model in which PC and PWP values given by Israelsen and Hansen (1962) for different soils were regressed against the corresponding soil particle size fractions.

Organic Matter Content

The problem of estimating organic content in soils can be solved by dividing the problem into two parts: 1) estimating the soil surface (top 30cm) organic content and 2) extrapolating that estimate to the lower soil depths.

Soil organic matter contents are often correlated with soil texture (South and Davey 1983). The more clay and silt in the soil, the higher the organic matter content. This is a result of fewer macro pores in a fine textured soil which favors slower decomposition of organic matter. Data from a study of organic matter content for 45 southern nurseries (South and Davey 1983) were used along with data from several fields in the Las Cruces area to obtain a linear relationship between soil texture and organic matter content. The data from the nurseries were compiled into a weighed average organic matter content by soil type. The types specified in the data were composites of basic soil classifications, and an average composition of percent sand, silt, and clay was estimated by taking the averages of the listed soil type compositions. Because the relationship between organic matter content and soil composition is said to increase as both silt and clay content increase (South and Davey 1983), the organic matter content of a soil should decrease as the sand component increases. Regressing organic matter against the percent sand in the soils, the following relationship was developed, with an R^2 value of 0.895:

$$O = -0.007 \times S + 1.581 \qquad \textbf{(13)}$$

where:

O is percent organic matter content in the soil, and
S is percent sand composition of the soil.

Once the surface layer content is known, the remaining problem is to estimate the content of the lower depths for the soil profile. Data for organic matter content by depth for 93 soil series (Gile and Grossman 1979) was normalized for each series and the average relative content for each depth was determined. This provided the following relationship between relative organic matter content and depth, with an R^2 value of 0.67:
where:

$$O_{Relative} = -0.1733 \times \ln(x) + 1.0904 \qquad \textbf{(14)}$$

$O_{Relative}$ is relative organic matter content, and x is depth below the surface in centimeters.

Because the soil series were in nonagricultural areas, the data were not used in the analysis of organic matter by soil type. Equations 13 and 14 were used to estimate the organic matter distribution in a soil profile, in which soil surface organic matter content was first obtained and then scaled to obtained values for lower soil depths.

Pesticide Half-Life Values

In the model assumptions, pesticide half-life estimates for different soils are related to the relative organic content of the soil. The relationship between relative organic matter and chemical half-life was determined by evaluating the relative organic matter and half-life values from studies of Aldicarb (Bowman 1988; Pennell et al. 1990) and Atrazine (Bacci et al. 1989; Ghadiri et al. 1984; Hiltbold and Buchanan 1977; Walker 1978). The relative organic matter from each series of studies was normalized with the average for the corresponding series. Likewise, the associated half-life values for each study were normalized with the corresponding mean values. Analysis of the resulting values gave the following relationship:

$$HL_n = -0.6346 \times \ln(OM_n) + 0.76316 \tag{15}$$

where:

HL_n is the normalized half-life,
OM_n is the normalized relative organic matter content.

This relationship has an R^2 value of 0.725. The data were normalized to obtain a relationship independent of the particular locations from which it was collected, because published values for representative half-lives of various pest control chemicals are average values from multiple studies and sources. To obtain a useful value for any particular location, the representative value must be adjusted.

The actual values for a particular soil's half-life can be obtained by normalizing the relative organic matter content of that soil with respect to the mean value of organic matter for the soils for which studies have been conducted. The normalized value is then used in the relationship given to obtain a normalized half-life value associated with that relative organic matter content. The normalized value is then multiplied by the representative value for the chemical to obtain the actual half-life value for the chemical in the particular soil.

The mean relative organic matter content was determined by taking into account that most areas from which studies of half-life values have been done fall within three soil orders: Aridisols, Mollisols, and Alfisols. The relative organic matter content for each of these soil orders is 1, 4, and 3 percent, respectively (Brady 1990).

The half-life values for each layer in a soil profile are obtained by using the empirical model (Eq. 16), using the relative organic matter in the layer. For example, a hypothetical half-life value of 20 days is given with a known relative organic matter content of 0.75 percent and the half-life value is needed for a soil which has 2 percent relative organic matter. The actual pesticide half-life used is estimated as

$$HL = 20 days \times \left[-0.6346 \times \ln\left(\frac{2.0}{0.75} \right) + 0.76316 \right] = 2.81 days \quad \textbf{(16)}$$

Observe that due to the increased organic matter, the actual half-life is much shorter than the reference value. This fact emphasizes the need to make the adjustment. If the target soil relative organic matter content is not known, an estimate can be obtained using the representative value for the soil order given in Brady (1990).

Cropping Sequence for Multiple-Year Simulations

The main field crops grown in Doña Ana County, based on acreage under cultivation, are alfalfa, chile, cotton, corn, and onions (New Mexico Department of Agriculture 1993). The proportion of each crop acreage relative to the total acreage for the five crops was estimated. A set of 100 crop-units comprising alfalfa, chile, corn, cotton, and onions was formed. The number of each crop in the set was determined based on the relative proportion of acreage cultivated with respect to the total acreage covered by the five crops. The ratio of each crop with respect to the rest in the set is cotton-0.52, alfalfa-0.20, chile-0.14, corn-0.07, and onions-0.07.

In addition to simulating the impact that farming practices may have on pesticides leaching in a single season, a multiyear simulation covering a 30-year period also was planned. This requires that a cropping sequence be generated for a 30-year period. The cropping sequence was generated by randomly selecting one crop every year from a set of 100 crop-units made up of alfalfa, chile, corn, cotton, and onions. Crop selection for each year was done independently of the previous year's selection. Thus, each crop had the same chance of being selected each year as pre-determined by the relative acreage with respect to the total acreage under cultivation.

Irrigation Scheduling Data

Irrigation scheduling data for alfalfa, chile, corn, cotton, and onions grown on clayey, clay loam, loam, sandy loam, and loamy sand soils were obtained from Elephant Butte Irrigation District (EBID). The data covered the five-year period from 1990 to 1994. For multiyear simulations covering a 30-year period under the farmers' management practices, irrigation scheduling data for each crop within the cropping sequence were randomly selected from the irrigation scheduling database and the year dates changed to correspond to the climate years used by IRRSCHM. On the other, a 7.6 cm of water per irrigation was used when irrigation was scheduled at 50 percent plant available water depletion level or when tensiometers were used for scheduling. The 7.6 cm represents an average depth of application. Actual depth of application depends on soil type, field length, and management practices.

Planting and Harvest Dates

The planting date used for each crop was the average date on which local farmers planted the crops (Table

10). However, the harvest date was estimated by calculating the average cumulative heat units, expressed in growing-degree-days, from planting to harvest for each crop. The cumulative heat units at harvest used were 550, 3205, 1379, 2015, and 1775 for alfalfa, chile, corn, cotton, and onions, respectively. The cumulative growing-degree-days (CGDD) are estimated as:

$$CGDD = \sum_{i}^{n} \left(\frac{T_{max} - T_{min}}{2} - T_{base} \right) \quad \textbf{(17)}$$

where T_{max} and T_{min} are the maximum and minimum daily temperature (°C), respectively, T_{base} is assumed to be the threshold temperature below which crop growth ceases, i and n are the planting and harvesting dates, respectively. The base temperature, maximum temperature above which and minimum temperature below which growing-degree-days are not accumulated are shown in Table 11 for each crop.

Table 10. Average farmers' planting date

Crops	Planting Date
Alfalfa	1 January
Chile	27 April
Corn	15 April
Cotton	15 March
Onions	31 January

Table 11. Maximum, minimum, and base temperatures for alfalfa, chile, corn, cotton, and onions growth

Crops	Maximum Temperature (°C)	Minimum Temperature (°C)	Base Temperature (°C)
Alfalfa	NA	NA	5.0
Chile	30.0	5.0	5.0
Corn	30.0	10.0	10.0
Cotton	30.0	12.0	12.0
Onions	25.0	7.0	7.0

Time of Pesticide Application

Pesticide application must be done at the recommended time to achieve effective results. For this study, pesticide application timing was determined based on the cumulative growing-degree-days (heat units) calculated from the planting date to the date on which specific pesticides were applied by local farmers. The growing-degree-days accumulated at Baldex and Dual applications were 341 and 890, respectively.

RESULTS

GROUND-WATER AQUIFER SENSITIVITY ASSESSMENT

The natural sensitivity assessment consisted of developing a GIS layer for each of the seven DRASTIC parameters (depth to water, net recharge, aquifer media, soil media, topography, impact of the vadose zone, and hydraulic conductivity). These layers are described below followed by the combined natural sensitivity (NATSEN) coverage.

DEPTH TO WATER

The depth to water below the land surface in the Mesilla Valley and surrounding area including northwest El Paso County, Texas is presented in Figure 4 (figures are placed together at the end of this section). Table 12 presents the areal extent of the selected depth-to-water table intervals. The depth-to-water table indicates that over 60 percent of the study area had a depth to water greater than 100 feet (Table 12). Areas with depth to water less than 5 feet accounted for 5.3 percent, 5-10 feet 3.1 percent, 10-20 feet 7.3 percent, 20-30 feet 5.2 percent, 30-50 feet 7.2 percent, 50-70 feet 4.8 percent, 70-100 feet 6.4 percent, and over 100 feet 60.7 percent.

Table 12. Areal extent of depth-to-water table by interval, Mesilla Valley

Depth-to-water table interval (ft)	Areal extent (km^2)	Percent
0-5	121.7	5.3
5-10	69.6	3.1
10-20	167.2	7.3
20-30	118.6	5.2
30-50	164.2	7.2
50-70	108.9	4.8
70-100	147.1	6.4
100+	1,385.2	60.7
Total	2282.5	100.0

NET RECHARGE

The net recharge for the Mesilla Valley classified by land use ratings is presented in Figure 5. Table 13 presents the areal extent of each of the land use ratings. About 16 percent of the area was classified as agricultural and about 77 percent was classified as rangeland.

Table 13. Areal extent of net recharge areas, Mesilla Valley

Land use classification	Areal extent (km^2)	Percent
Urban or built-up land	109.0	4.8
Agricultural land	369.1	16.2
Rangeland	1769.2	77.5
Forest land	1.4	0.1
Water bodies	8.4	0.3
Wetland	0.7	< 0.1
Barren land	24.7	1.1
Total	2282.5	100.0

AQUIFER MEDIA

The aquifer media classification for the Mesilla Valley is presented in Figure 6. Table 14 presents the areal extent of each of the aquifer media classifications. About 47.8 percent of the area was classified as basin-fill, 23 percent as alluvium, and about 28.4 percent as Santa Fe or Pre-Santa Fe Group.

Table 14. Areal extent of aquifer media classification, Mesilla Valley

ptype	Aquifer media	Areal extent (km^2)	Percent
Qab	Basin-fill	1092.1	47.8
Qal	Alluvium	524.9	23.0
Qb	Basalt	18.3	0.8
QTs	Santa Fe Group	414.7	18.2
pQTs	Pre-Santa Fe Group	232.5	10.2
Total		2282.5	100.0

SOIL MEDIA

Table 15 presents the areal extent of the soil media classifications for the Mesilla Valley. Figure 7 presents a map of the Mesilla Valley for each of the soil media classes. Loamy sand was the dominant soil type found in the Mesilla Valley with over 46 percent of the study area classificied as such. Sandy loam was next with almost 14 percent.

Table 15. Areal extent of soil media classification, Mesilla Valley

Soil media	Areal extent (km^2)	Percent
Basalt	23.0	1.0
Caliche	0.4	< 0.1
Carbonate hardpan	19.7	0.9
Carbonate-cemented	171.4	7.5
Clay	40.7	1.8
Clay loam	148.2	6.5
Dumps & gravel pits	1.5	0.1
Limestone bedrock	108.8	4.8
Loam	95.2	4.2
Loamy sand	1,067.7	46.8
Rock outcrop	115.1	5.0
Sandy clay loam	53.6	2.3
Sandy loam	317.6	13.9
Silty clay loam	22.3	1.0
Silty loam	89.5	3.9
Water	7.8	0.3
Total	2282.5	100.0

TOPOGRAPHY

Table 16 presents the areal extent of the Mesilla Valley by topography classification. The study area is relatively level with over 60 percent classified with slopes less than 2 percent and more than 28 percent with slopes less than 6 percent. Figure 8 presents a map of the Mesilla Valley topography.

Table 16. Areal extent of the topography for the Mesilla Valley

Topography (percent slope)	Areal extent (km^2)	Percent
0-2	1,383.8	60.6
2-6	643.5	28.2
6-12	146.6	6.4
12-18	39.4	1.7
18+	69.2	3.1
Total	2,282.5	100.0

IMPACT OF VADOSE ZONE MEDIA

Table 17 lists the areal extent of the area classified for impact of the vadose zone. Over 47 percent of the area was classified as basin-fill and 23 percent as alluvium. Over 28 percent was classified as Santa Fe or Pre-Santa Fe Group. A map of the area with the impact of the vadose zone parameter is presented in Figure 9.

Table 17. Areal extent of the vadose zone media, Mesilla Valley

ptype	Impact of vadose zone	Areal extent (km^2)	Percent
Qab	Basin-fill	1,092.0	47.8
Qal	Alluvium	524.9	23.0
Qb	Basalt	18.3	0.8
QTs	Santa Fe Group	414.7	18.2
pQTs	Pre-Santa Fe Group	232.6	10.2
Total		2282.5	100.0

HYDRAULIC CONDUCTIVITY OF THE AQUIFER

Table 18 presents the areal extent of the hydraulic conductivity classes for the aquifer in the Mesilla Valley. Over 36 percent of the ground-water aquifer was classified as K7 and over 32 percent as K3. Figure 10 presents a map of the hydraulic conductivity classes for the Mesilla Valley.

Table 18. Areal extent of the hydraulic conductivity classes in the Mesilla Valley

Hydraulic conductivity class[1]	Areal extent (km^2)	Percent
K1	70.2	3.1
K2	336.5	14.7
K3	737.2	32.3
K4	132.6	5.8
K5	78.5	3.4
K6	97.1	4.3
K7	830.4	36.4
Total	2282.5	100.0

[1] See table 7, pg 21.

NATURAL SENSITIVITY ASSESSMENT

By combining the seven DRASTIC parameters a natural sensitivity index was developed. These values were grouped into six categories *very slight* - indicating the ground-water aquifer is very well protected and contamination risk from nonpoint sources is very low; *slight* - indicating the ground-water aquifer is reasonably well protected, but because one or more of the hydrologic parameters are conducive to contamination, there is a higher level of risk of nonpoint source pollution; *low* - the ground-water aquifer is somewhat protected, but more than one of the parameters are conducive to contamination; *moderate* - the ground-water aquifer is susceptible to contamination because there are few natural protections; *severe* - the ground-water aquifer is much more susceptible to contamination due to a number of hydrologic conditions; and *extreme* - all hydrologic parameters are conducive to the rapid transport of contamination to the ground-water aquifers. Results indicated that of the 2,282 km^2 included in the study area, a very small area (less than one percent) was classified as *extreme*. However, this area as well as the *severe* class deserve special attention, as natural conditions are such that any contaminant is likely to reach the water table quite rapidly. Table 19 presents the aerial extent of each of the six natural sensitivity categories. Plate 1 presents the NATSEN coverage in map form (Plate 1 is contained in the packet on back cover).

Table 19. Areal extent of the natural sensitivity classes in the Mesilla Valley

Natural Sensitivity Class	Areal extent (km^2)	Percent
Very Slight	262.0	11.5
Slight	313.8	13.7
Low	1,159.3	50.8
Moderate	351.0	15.4
Severe	183.5	8.0
Extreme	12.9	0.6
Total	2282.5	100.0

EVALUATION OF BEST MANAGEMENT PRACTICES

The pesticides of interest were metholachlor (Dual) and cyanazine (Bladex), which are used on chile and cotton crops, respectively, in the Mesilla Valley. These chemicals are part of the EPA-listed pesticides requiring monitoring because of their frequent detection in ground water. IRRSCHM runs were made to evaluate local farmers' irrigation and pesticide management practices on Bladex and Dual leaching in different soil classes. Model runs were also made to evaluate alternate management practices for scheduling irrigation. The alternate irrigation scheduling management practices included: tensiometer-based irrigation scheduling at 50 percent plant available water depletion level with the tensiometer porous cup placed at fixed soil depth (30-cm); tensiometer-based irrigation scheduling at 50 percent plant available water depletion level with the tensiometer porous cup moving with the center of the root zone; and tensiometer-based irrigation scheduling with the tensiometer porous cup moving with 75 percent of the dynamic crop root zone over time. For all simulations, a 30-year cropping sequence was used. Bladex and Dual concentrations in the soil water at the 180-cm were scaled using the corresponding Health Advisory Level for each pesticide.

CURRENT FARMERS' MANAGEMENT PRACTICES

According to the survey conducted, farmers use the following practices in their agricultural production:

Irrigation

Fields are irrigated based on when farmers are supplied with water from the irrigation district. EBID establishes an equal allotment of water per acre at the beginning of the growing season. If the allotment is insufficient to satisfy crop demands, farmers supplement the amount of surface water obtained from EBID by use of ground-water irrigation wells. Irrigation timing is based on individual farmer's experience. All the water supplied by EBID is used during the periods that the fields are irrigated. The practice could lead to under irrigation when water requirements exceed supply, in which case, crops could be grown under water stress leading to yield reduction. Alternatively, over irrigation occurs when water supply exceeds requirements, which could lead to leaching of applied agricultural chemicals.

Amount and Time of Chemical Application

Farmers apply chemicals at manufacturers' recommended rates as contained on pesticide labels. Likewise, the chemical is applied according to the recommended time stipulated on the label. Adhering to label recommendations allows farmers to apply safe amounts of chemicals at the most appropriate time to achieve optimum pest control results. Also, the practice may reduce the pollution potential of chemicals in the environment. When the time of pesticide application is not specified on the label, the chemical application time is based on farmers' experience.

Crop Rotation

Most farmers in the area practice crop rotation by growing a different crop the following year. The rotation practice offers the opportunity to break from continuous use of a specific chemical for a long period of time, thus minimizing the build up of applied chemicals in the soil system or the environment.

Land Surface Leveling
Local farmers normally laser-level the surface of farm lands periodically. The practice is commonly accompanied by a basin irrigation system. Land surface leveling improves the uniformity of water distribution on the field.

Cover Crops
Farmers do not grow leguminous crops during fallow periods. Growing leguminous crops could increase soil organic matter content, a soil constituent having the ability to retard organic pesticide's downward movement through the soil profile. Some farmers, however, do grow sudan grass and sorghum during the fallow periods and then disk them to build up surface soil layer organic matter content.

The model IRRSCHM was used to predict the impact farmers' management practices and alternate irrigation scheduling management practices may have on crop yield, leaching fraction, and pesticide leaching. Besides soil physical properties (field capacity, permanent wilting point, and bulk density), IRRSCHM requires organic matter and pesticide half-life distribution in the soil profile, planting and harvest dates. IRRSCHM was modified to simulate crop growth characteristics, soil moisture and pesticide dynamics in the soil profile in multiple-year time periods. The modification allowed for the eventual assessment of continuous cropping (same crop or different crops) on the movement of pesticide applied in at least one cropping year in a multiyear time sequence.

Specific characteristics for each soil type, Las Cruces climate data covering the entire simulation period, farmers' management practices and the proposed BMPs, and planting and harvest dates were used to drive IRRSCHM. The operation sequence, including batch files, for generating all the input files to drive IRRSCHM is presented in Appendix A. For each simulation, crop yield, leaching fraction, and pesticide concentration in soil solution at 180 cm below the soil surface were recorded and used for comparing and contrasting the impact of different management practices on pesticide leaching.

For each soil class, the relative maximum Bladex concentration at the 180-cm soil depth (Fig. 11) varied reflecting textural and organic matter content distribution differences in lower soil layers for individual soil series of soil classes. For example, maximum Bladex concentrations for loamy sand soil class ranged from 7.19×10^{-10} to 3.25×10^{-8} mg L^{-1} during a 30-year simulation period. The corresponding maximum Bladex concentrations for clayey soil class ranged from 2.36×10^{-21} to 2.89×10^{-20} mg L^{-1}. Based on the mean concentrations, the relative Bladex concentration was 6.37×10^{-7} for loamy sand and 1.20×10^{-18} for clayey soils (Fig. 12). These concentrations were 6 orders of magnitude less than the 1.3×10^{-2} mg L^{-1} Bladex Health Advisory Level. Generally, the mean relative Bladex concentrations at the 180-cm soil depth increased with increasing soil sand content (Fig. 12). Differences in relative concentrations among all the soil classes reflect differences in saturated hydraulic conductivity, organic matter content, and pesticide half-life values distribution in the soil profiles for the different soil classes.

The trend in Dual concentrations at 180-cm soil depth for the different soil classes (figs. 13 and 14) was similar to that observed for Bladex. However, Dual concentrations at 180-cm soil depth were comparatively higher than those of Bladex. Similarly, Dual concentrations relative to the 5.25×10^{-1} mg L^{-1} Health Advisory Level were higher compared to Bladex (Fig. 15). For example, the mean relative Dual concentration for the sandy soil class was about 3 orders of magnitude less than the 5.25×10^{-1} mg L^{-1} Dual Health Advisory Level whereas that of Bladex was about 6 orders of magnitude less than the 1.3×10^{-2} mg L^{-1} Bladex Health Advisory Level. Bladex and Dual concentrations were negligible compared to the Health Advisory Levels. However, the results showed that 1) less Bladex reached the bottom of the root zone compared to Dual because of the relatively short maximum Bladex half-life value of 14 days, 2) the area ground water is much more susceptible to Dual pollution than to Bladex, and 3) that Dual health threat is much higher than that of Bladex under current farmers' management practices.

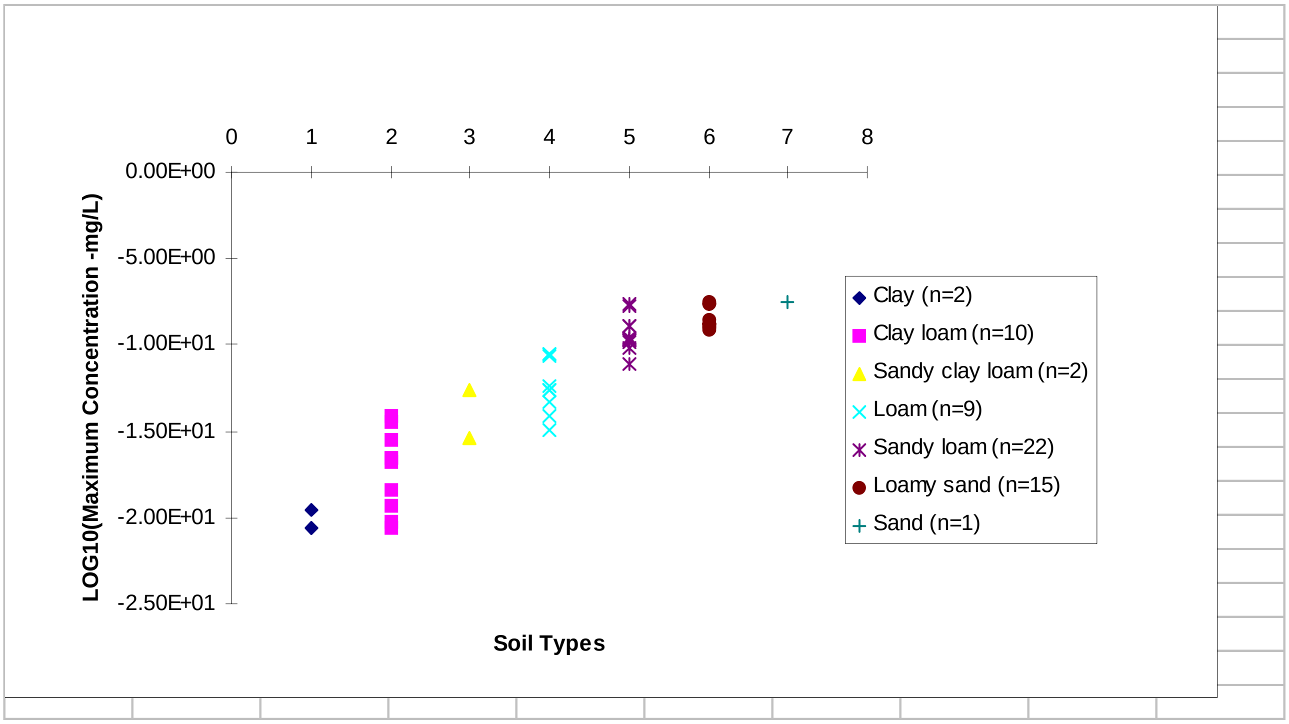


Figure 11. Maximum Bladex concentrations at 180-cm soil depth under the farmers' management practices.

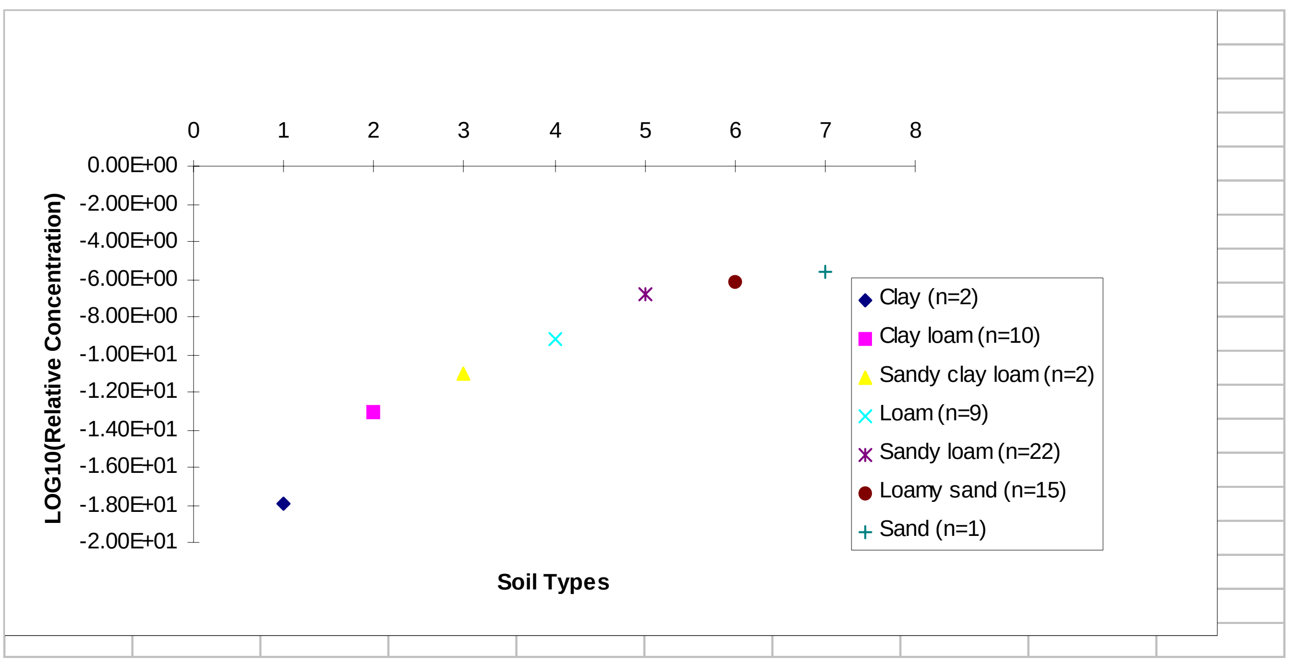


Figure 12. Relative maximum Bladex concentrations at 180-cm soil depth under the farmers' management practices: mean value for each soil type.

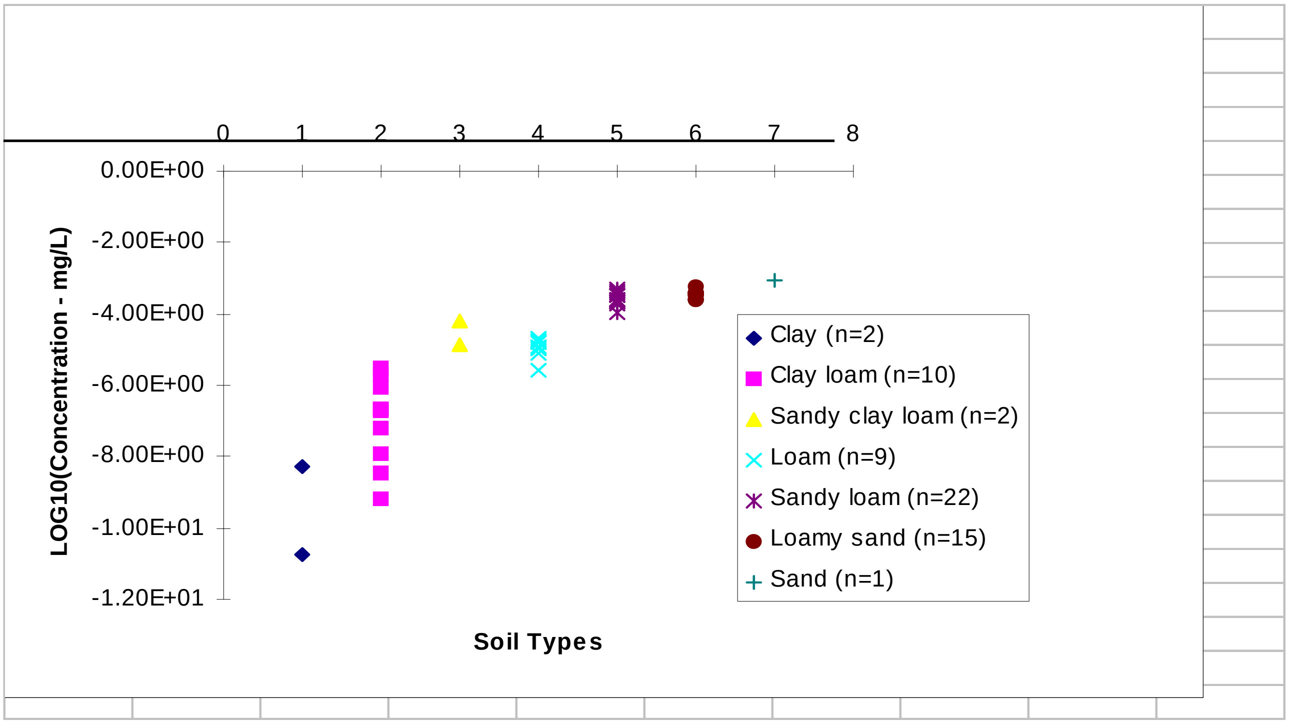


Figure 13. Maximum Dual concentrations at 180-cm soil depth under the farmers' management practices.

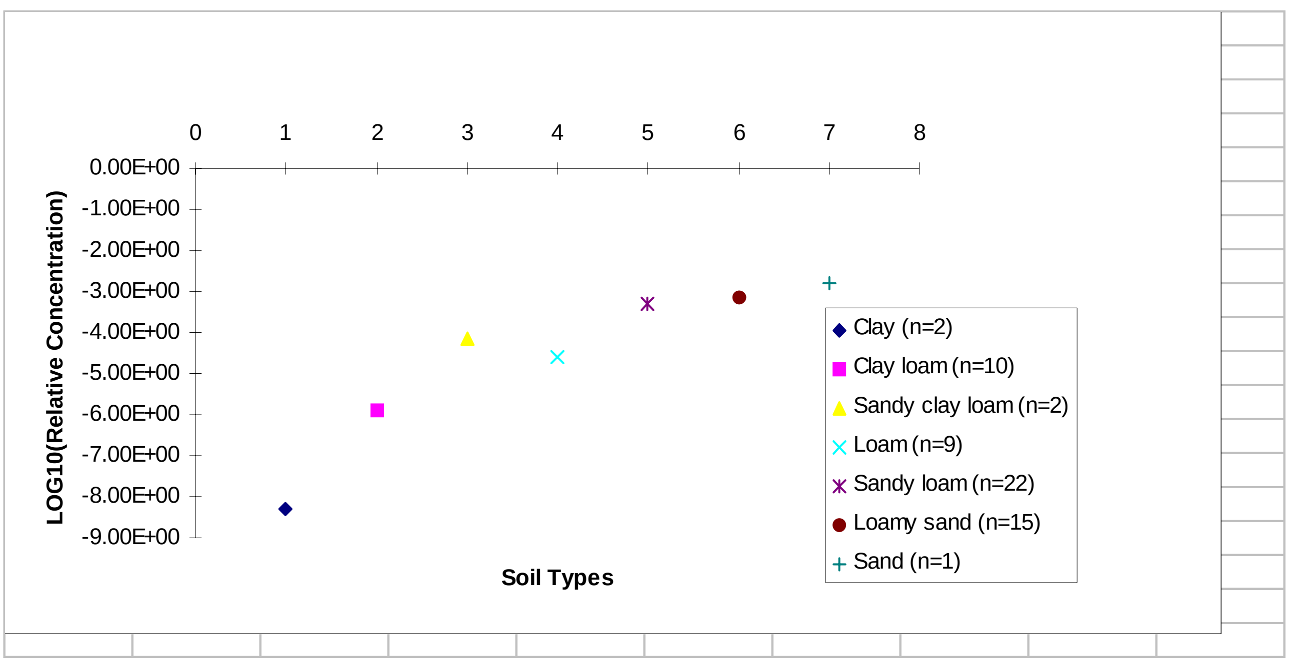


Figure 14. Relative maximum Dual concentrations at 180-cm soil depth under the farmers' management practices: mean value for each soil type.

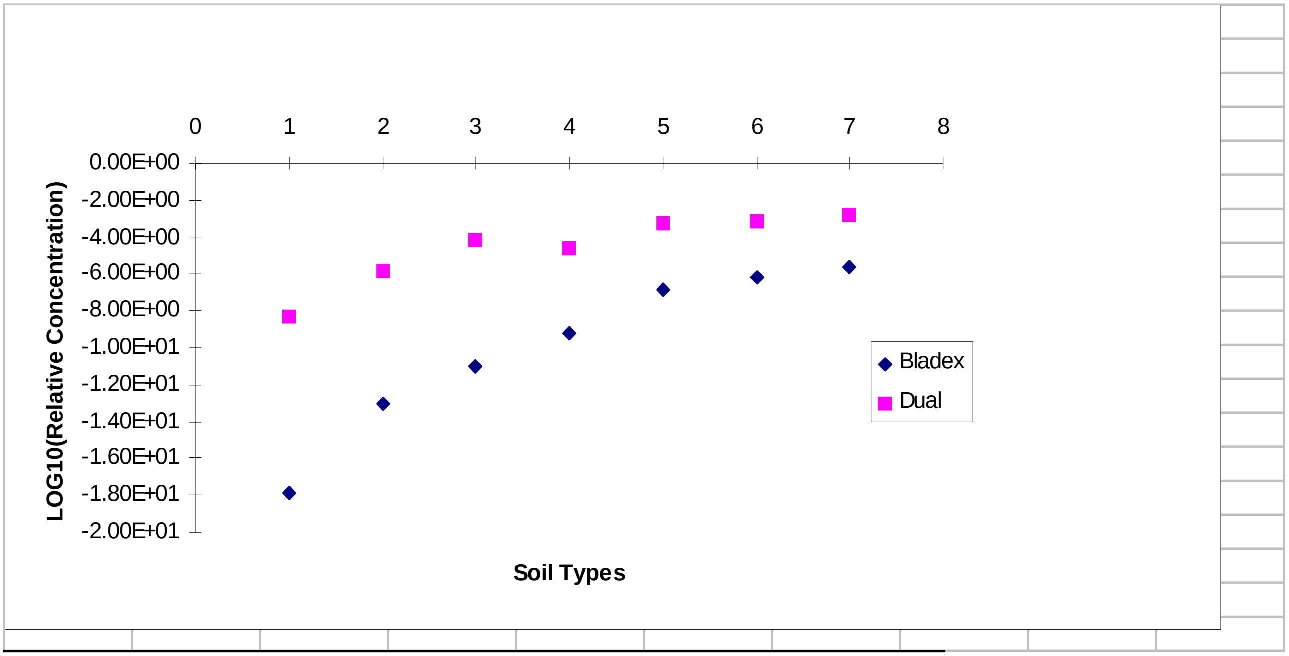


Figure 15. Relative maximum Bladex and Dual concentrations at 180-cm soil depth under the farmers' management practices: mean value for each soil type.

IRRIGATION SCHEDULING WITH TENSIOMETERS

Three irrigation scheduling practices based on tensiometers were evaluated: 1) 30-cm fixed depth for the tensiometer porous cup, 2) moving the tensiometer porous cup with the center of dynamic crop root zone, and 3) moving the tensiometer porous cup with 75 percent of the dynamic root zone. Irrigation water was applied immediately when tensiometer threshold values were observed. The threshold values for tensiometer readings at which irrigation was triggered in different soil types were based on NRCS recommendations The fixed tensiometer at 30 cm resulted in large and unrealistic calculations of water applications. The tensiometer at the center of the dynamic root zone resulted in the model applying the correct amount water on the sand and sandy loam fields but over watered on the clay and clay loam field. When the tensiometer was placed with 75 percent of the dynamic root zone on these fields the correct amount of water was applied (Fig 16). For each irrigation management practice, Bladex concentrations were much less than Dual concentrations, following the same trend observed under farmers' management practices. However, Bladex concentrations with the tensiometer placed with 75 percent of the dynamic root zone were less than the concentrations of Bladex when the tensiometer was placed at 50percent of the dynamic root zone (Table 20). Similar results were observed for Dual (Table 21). This occurred because the irrigation scheduling model put less water on the fields when irrigations were scheduled using tensiometers placed with 75 percent of the dynamic root zone.

Table 20. Mean maximum Bladex concentrations at 180-cm soil depth resulting from tensiometer-based irrigation scheduling

Soil Class ID Number	Soil Class	Moving Tensiometer (mg/L) 0.5 depth	Stationary Tensiometer (mg/L) 0.75 depth
1	Clay	7.9E-07	2.3E-09
2	Clay loam	1.2E-04	3.5E-06
4	Loam	2.50E-05	2.9E-07
5	Sandy loam	1.50E-05	4.8E-07
7	Sand	1.6E-04	6.3E-06

Table 21. Mean maximum Dual concentrations at 180-cm soil depth resulting from tensiometer-based irrigation scheduling

Soil Class ID Number	Soil Class	Moving Tensiometer (mg/L)	Stationary Tensiometer (mg/L)
1	Clay	1.8E-04	1.4E-05
2	Clay loam	4.4E-04	1.7E-04
4	Loam	3.0E-04	3.1E-05
5	Sandy loam	2.5E-04	4.8E-05
7	Sand	1.6E-04	1.3E-04

Tensiometer-based irrigation scheduling resulted in Bladex and Dual concentrations greater than those obtained under farmers' management practices. For example, with a tensiometer placed at 50 percent of the dynamic root zone, the mean Dual concentration at the 180-cm soil depth of sandy soils was 20 times less than the Health Advisory Level compared to 625 times less under the farmers' management practices.

IRRIGATION SCHEDULING AT 50 PERCENT PLANT AVAILABLE WATER DEPLETION

Scheduling irrigation at 50 percent plant available water depletion is a normally recommended management practice used to ensure adequate crop growth and minimal leaching. Bladex and Dual concentrations at 180-cm soil depth under this practice followed the trend of increasing concentrations with sandy soils observed under the farmers' management practices. The difference, however, is that comparatively higher Bladex and Dual concentrations reached the 180-cm soil depth when irrigation scheduling was at 50 percent plant available water depletion. For example, the mean Bladex and Dual concentrations in sandy soil class were 232 and 20 times less, respectively, than their corresponding Health Advisory Level. In contrast, Bladex and Dual concentrations under the farmers' management practices were 416,666 and 625 times less, respectively, than the corresponding Health Advisory Level. Thus, higher levels of Bladex and Dual concentrations reached the 180-cm soil depth when irrigation was scheduled at 50 percent plant available water depletion compared to the resultant concentrations under farmers' management practices. Because of system constraints, farmers put on less water than they would if they scheduled irrigation to prevent crop stress.

COMPARISON OF BLADEX AND DUAL CONCENTRATIONS

Bladex and Dual concentrations were highest in all soil classes under tensiometer-based irrigation scheduling management practices compared to concentrations under other management practices. In contrast, the lowest concentrations occurred under current practices. Additionally, Bladex and Dual concentrations under irrigation management that schedules irrigation at 50 percent plant available water depletion fall between the highest and the lowest concentrations observed under management practices discussed earlier. Tables 22A-D present mean Bladex and Dual relative concentrations for each soil class under different management practices. The relative concentrations are modeled concentrations/Health Advisory Level.

Table 22. Mean relative maximum Bladex and Dual concentrations under different management practices (Relative concentration is concentration/Health Advisory Level)

A. Management Practice: Farmers' Management Practices

Soil Class ID Number	Soil Class	Relative Concentration Bladex	Relative Concentration Dual
1	Clay	1.20E-18	4.80E-09
2	Clay loam	8.44E-14	1.30E-06
3	Sandy clay loamß	9.96E-12	7.45E-05
4	Loam	6.84E-10	2.49E-05
5	Sandy loam	1.55E-07	5.11E-04
6	Loamy sand	6.37E-07	6.85E-04
7	Sand	2.42E-06	1.63E-03

B. Management Practice: Irrigation Schedule at 50 Percent Plant Available Water Depletion

Soil Class ID Number	Soil Class	Relative Concentration Bladex	Relative Concentration Dual
1	Clay	3.22E-12	1.67E-04
2	Clay loam	2.28E-07	1.17E-03
3	Sandy clay loamß	1.95E-06	4.08E-03
4	Loam	8.92E-07	3.01E-03
5	Sandy loam	9.46E-06	1.27E-02
6	Loamy sand	4.18E-05	2.39E-02
7	Sand	4.29E-04	5.35E-02

C. Management Practice: Moving Tensiometer at 50% of the dynamic root zone

Soil Class ID Number	Soil Class	Relative Concentration Bladex	Relative Concentration Dual
1	Clay	1.50E-06	1.40E-02
2	Clay loam	2.20E-04	3.40E-02
4	Loam	4.70E-05	2.30E-02
5	Sandy loam	3.00E-05	1.90E-02
7	Sand	3.20E-05	5.10E-02

D. Management Practice: Moving Tensiometer at 75% of the dynamic root zone

Soil Class ID Number	Soil Class	Relative Concentration Bladex	Relative Concentration Dual
1	Clay	4.50E-09	1.10E-03
2	Clay loam	6.70E-06	1.30E-02
4	Loam	5.50E-07	2.40E-03
5	Sandy loam	9.20E-07	3.70E-03
7	Sand	1.20E-05	1.00E-03

Farmers' requests for water are usually not met immediately by EBID, a situation that results in water stress periods between two consecutive irrigations. The delay in water delivery allows some pesticides to degrade before water is eventually delivered onto the farmers' fields. Additionally, leaching is reduced if the delivered water is not enough to replenish the root zone. These conditions likely accounted for the least Bladex and Dual concentrations at the 180-cm soil depth under farmers' management practices. Farmers suffer for their management practices by having decreased crop evapotranspiration and yield. Study results showed that Bladex and Dual concentrations at the 180-cm soil depth were insignificant compared to the Health Advisory Level for each pesticide, and practically no ground-water contamination by Bladex and Dual leaching resulting from the current farmers' management practices in the Mesilla Valley. Thus, current farmers' management practices do not pose a threat to area ground-water quality.

The local NRCS office recommendations for the tensiometer-based irrigation scheduling suggest that crops grown on sandy, sandy loam, loam, and clay loam soils be irrigated at about 6, 23, 44, and 74 KPa tensiometer readings, respectively (Appendix B), which correspond to 49, 35, 23, and 14 percent plant available water depletion levels in the same order (Irrigation scheduled for sandy soil using tensiometers have a larger percent of the available water depleted before an irrigation compared to the depletion level of available water at irrigation for a clay soil.) The plant available water values were estimated using Campbell's (1985) soil moisture release curve model with FC and PWP values for each soil class taken from the data given by Israelsen and Hansen (1962). The 80 KPa tensiometer reading recommended by NRCS for clayey soils resulted in an extremely low plant available water depletion level. Instead, the 210 KPa value was used to obtained a 19 percent available water depletion level in clayey soils. The irrigation scheduling management practices based on the NRCS recommendations resulted in frequent irrigations and unrealistic seasonal irrigation amounts if the tensiometer was placed at 50 percent of the dynamic root zone, for crops grown on fine textured soils, creating high soil moisture conditions that enhanced pesticide leaching. For example, the mean seasonal irrigation amount and leaching fraction for clay loam soil were about 97.0 cm and 0.21, respectively, under the farmers management practices, 160 cm and 0.35 under irrigation scheduling at 50% plant available water depletion, and 400.0 cm and 0.68 under the tensiometer-based irrigation scheduling when the tensiometer was placed at 50 percent of the dynamic root zone depth. When the tensiometer was placed at 75 percent of the dynamic root zone, the water applied decreased to 225 cm (Fig. 16) and the leaching fraction was only 50 percent. The graphs showing the mean seasonal leaching fractions, and relative evapotranspirations (relative yields) resulting from the different management practices tested are presented in Appendix C. The study results showed that irrigating the fields soon after the threshold tensiometer readings were observed was an appropriate management practice only if the tensiometer was placed in the proper position of the root zone based on the soil type. Tensiometers should be place to the 50 percent depth of the root zone in sand and sandy loam soils but must be placed at the 75 percent dept of the root zone in heaver clay and clay loam soils. Thus, the relatively high Bladex and Dual concentrations at the 180-cm soil depth under the tensiometer-based irrigation management practices were the result of more frequent irrigations during crop growth periods. Leaching under the tensiometer-based irrigation management practices could be minimized by increasing the values of the tensiometer threshold readings at which irrigations are triggered or by delaying 3-7 days before irrigation when the recommended tensiometer threshold readings are observed. Preliminary field studies by EBID showed that irrigating the fields 3 days after tensiometer threshold readings were observed resulted in less applied water compared to the amount of water used under the farmers practices.

SUMMARY

The DRASTIC model was used to assess aquifer sensitivity by combining data sets that describe the depth-to-ground water, recharge rates, aquifer material, soils composition, land slope, vadose zone materials, and saturated hydraulic conductivity for the Mesilla Valley in Doña Ana County. The data requirements and techniques necessary to employ the DRASTIC model in other regions of New Mexico was evaluated. GIS coverages were developed for each of the DRASTIC parameters and combined into a natural sensitivity coverage. The resulting natural sensitivity values were grouped into six categories: *very slight* - indicating that the ground-water aquifer is very well protected and risk of contamination from nonpoint sources is very low; *slight* - the ground-water aquifer is reasonably well protected, but because one or more of the hydrologic parameters are conducive to contaminant transport, there is a higher level of risk of nonpoint pollution; *low* - the ground-water aquifer is somewhat protected, but more than one of the parameters are conducive; *moderate* - the ground-water aquifer is susceptible to contamination because few natural protections exist; *severe* - the ground-water aquifer is much more susceptible to contamination due to several hydrologic conditions; and *extreme* - all hydrologic parameters are conducive to the rapid transport of contamination to the ground-water aquifer. Results indicated that of the 2,282 km^2 included in the study area, less than one percent was classified as *extreme*, slightly over 10 percent as *severe*, almost 19 percent as *moderate*, nearly 43 percent as *low*, about 16 percent as *slight*, and over 12 percent as *very slight*.

The model IRRSCHM was used to assess local farmers' management practices and three irrigation scheduling practices for their potential impact on Bladex and Dual leaching into ground water in a 30-year cropping sequence. Study area soils were grouped into appropriate classes based on texture so that study results could be categorized by soil class for each management practice. Field capacity, permanent wilting point, organic matter content, and pesticide half-life distribution in each soil class profile were estimated and used to drive IRRSCHM.

Bladex and Dual concentrations at the 180-cm soil depth generally increased with increasing soil sand content. Bladex and Dual concentrations reaching the 180-cm soil depth were at most two and three orders less, respectively, than the corresponding Health Advisory Level for all the management practices considered in the study. However, Bladex and Dual concentrations at the 180-cm soil depth were least, being at most six and two orders less than the Health Advisory Level for each pesticide compared to concentrations observed under different management practices. This suggests that the current farmers' management practices do not adversely impact the ground-water resources in the Mesilla Valley. This may be due to deficit irrigation conditions imposed by late water deliveries to farmers' fields. The model indicated that tensiometer-based irrigation scheduling, in which water is applied immediately when tensiometer threshold readings are observed, was the least appropriate management practice for controlling pesticide leaching when the tensiometer was placed in the correct depth in the dynamic root zone. The tensiometer-based irrigation scheduling could be improved by increasing the values of the threshold readings at which irrigation is triggered. Because EBID has observed a reduction in the amount of water normally used by farmers when irrigation is done 3-7 days after the tensiometer threshold readings are observed, it is recommended that future studies should assess how different tensiometer threshold readings and depth of placement affect the level of seasonal irrigation levels, leaching fractions, and relative evapotranspirations (relative yields). The study results could assist in selecting the appropriate tensiometer threshold readings and placement depth for different soil classes that will result in minimal pesticide leaching and yield reductions. The methodology developed in the study to assess farming practices impact on pesticide leaching in the Mesilla Valley could be used in other locations for preliminary regional studies to identify farming practices capable of impacting ground water or identify areas prone to pesticide leaching.

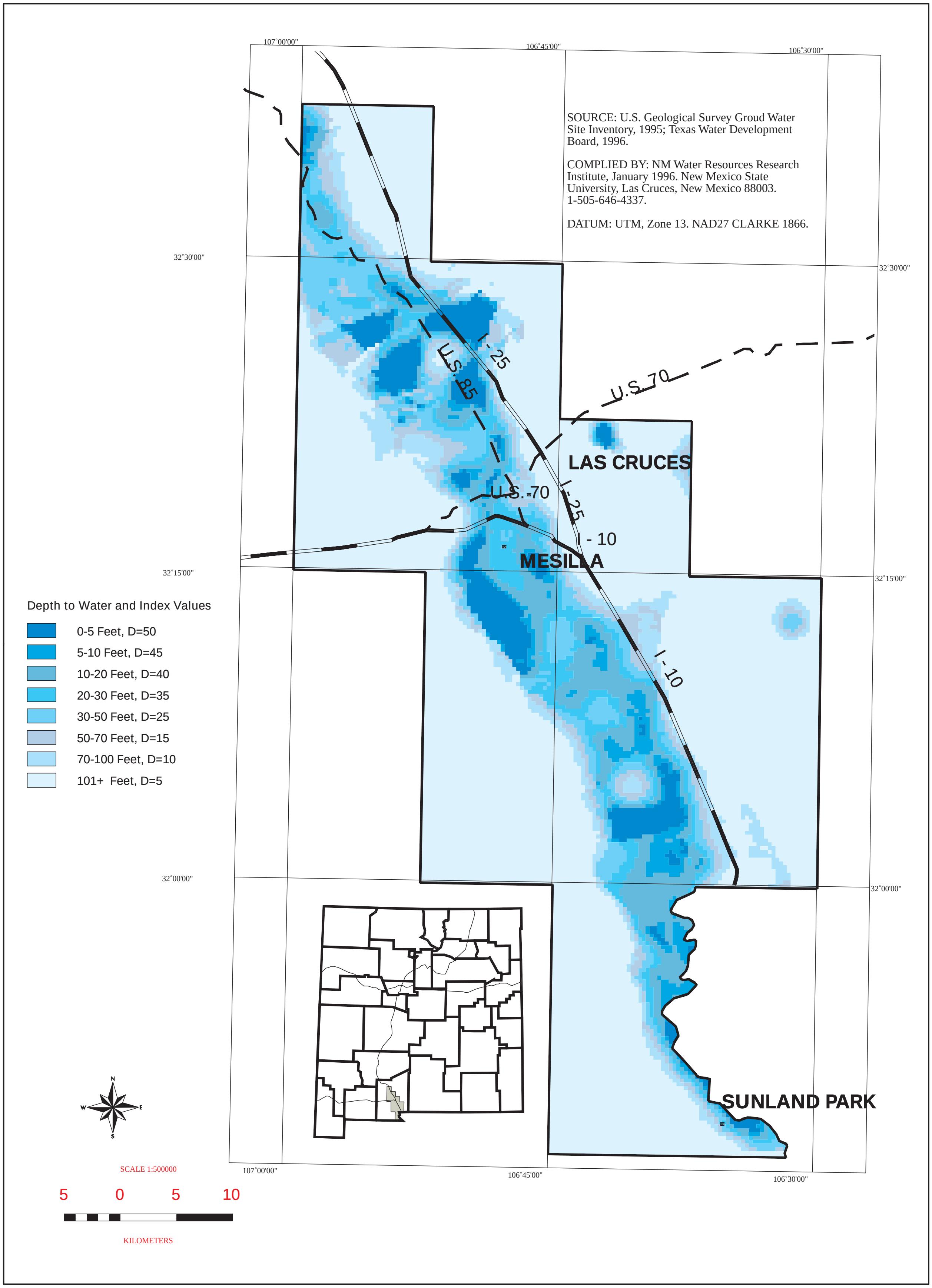
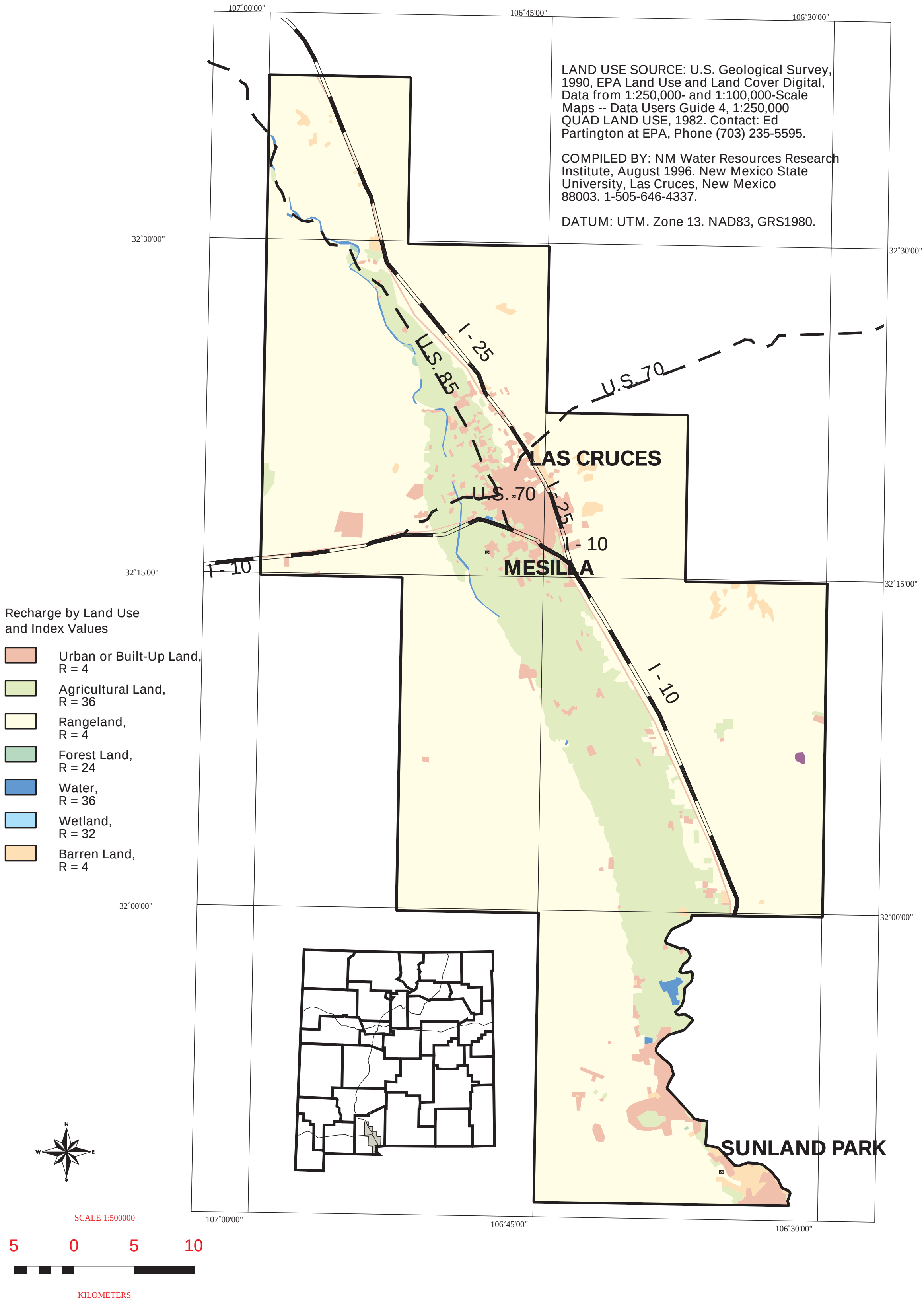
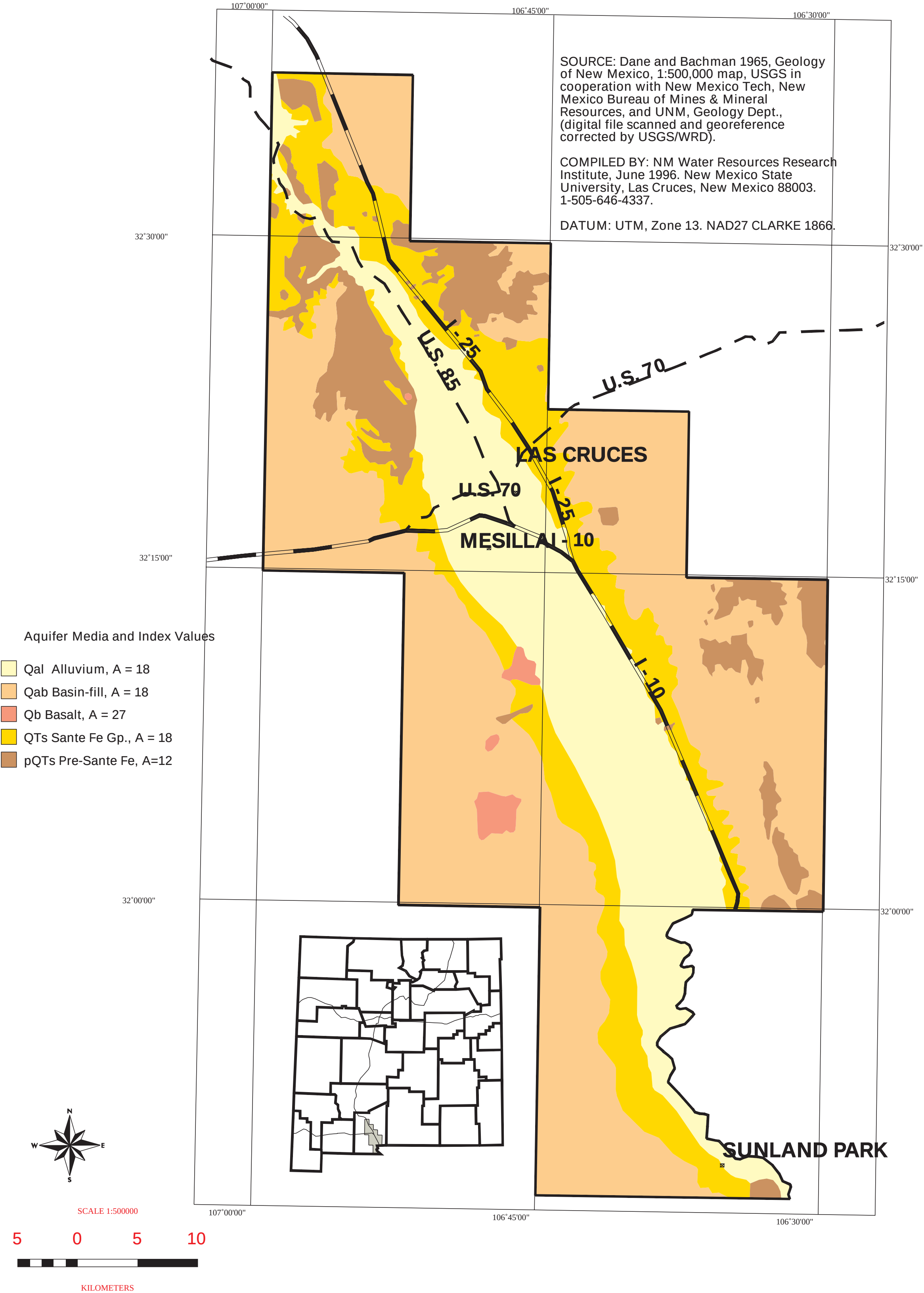


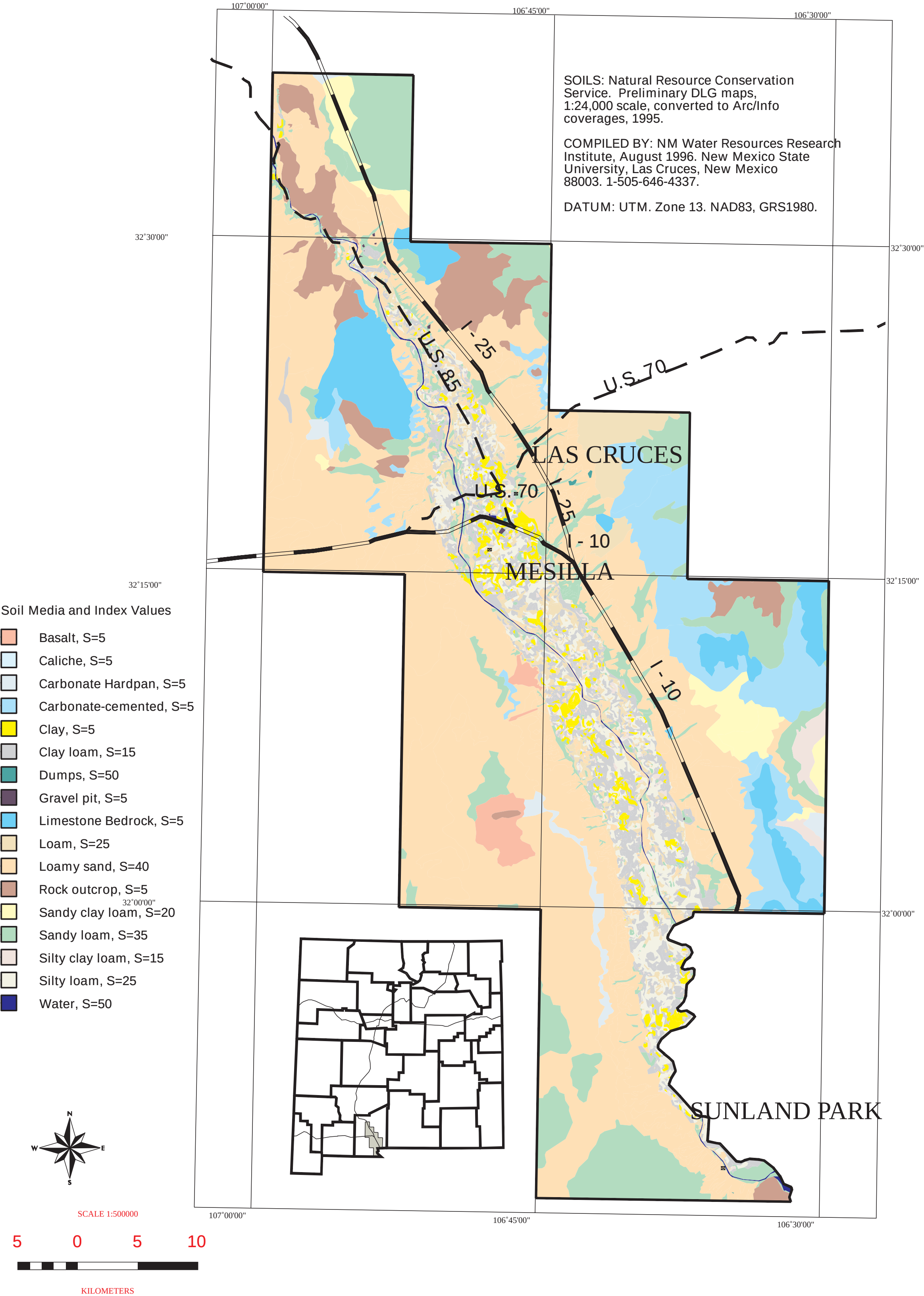
Figure 4. Depth to Water - Mesilla Valley, New Mexico.



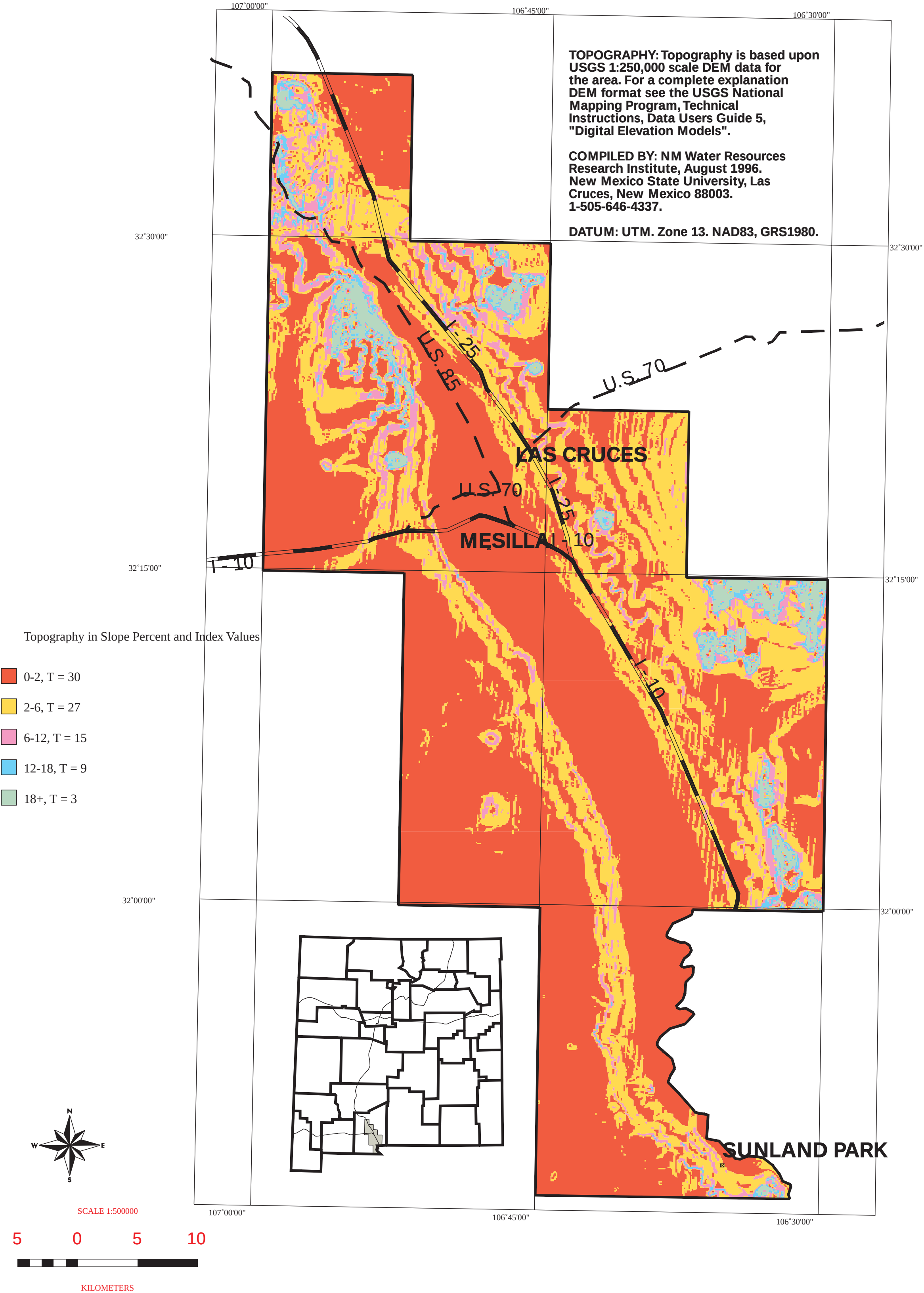
107°00'00"
106°45'00"
106°30'00"
32°30'00"
32°15'00"
32°00'00"
LAND USE SOURCE: U.S. Geological Survey, 1990, EPA Land Use and Land Cover Digital, Data from 1:250,000- and 1:100,000-Scale Maps -- Data Users Guide 4, 1:250,000 QUAD LAND USE, 1982. Contact: Ed Partington at EPA, Phone (703) 235-5595.
COMPILED BY: NM Water Resources Research Institute, August 1996. New Mexico State University, Las Cruces, New Mexico 88003. 1-505-646-4337.
DATUM: UTM. Zone 13. NAD83, GRS1980.
I - 25
U.S. 85
U.S. 70
LAS CRUCES
I - 10
MESILLA
SUNLAND PARK
Recharge by Land Use and Index Values
Urban or Built-Up Land, R = 4
Agricultural Land, R = 36
Rangeland, R = 4
Forest Land, R = 24
Water, R = 36
Wetland, R = 32
Barren Land, R = 4
N
W
E
S
SCALE 1:500000
5 0 5 10
KILOMETERS



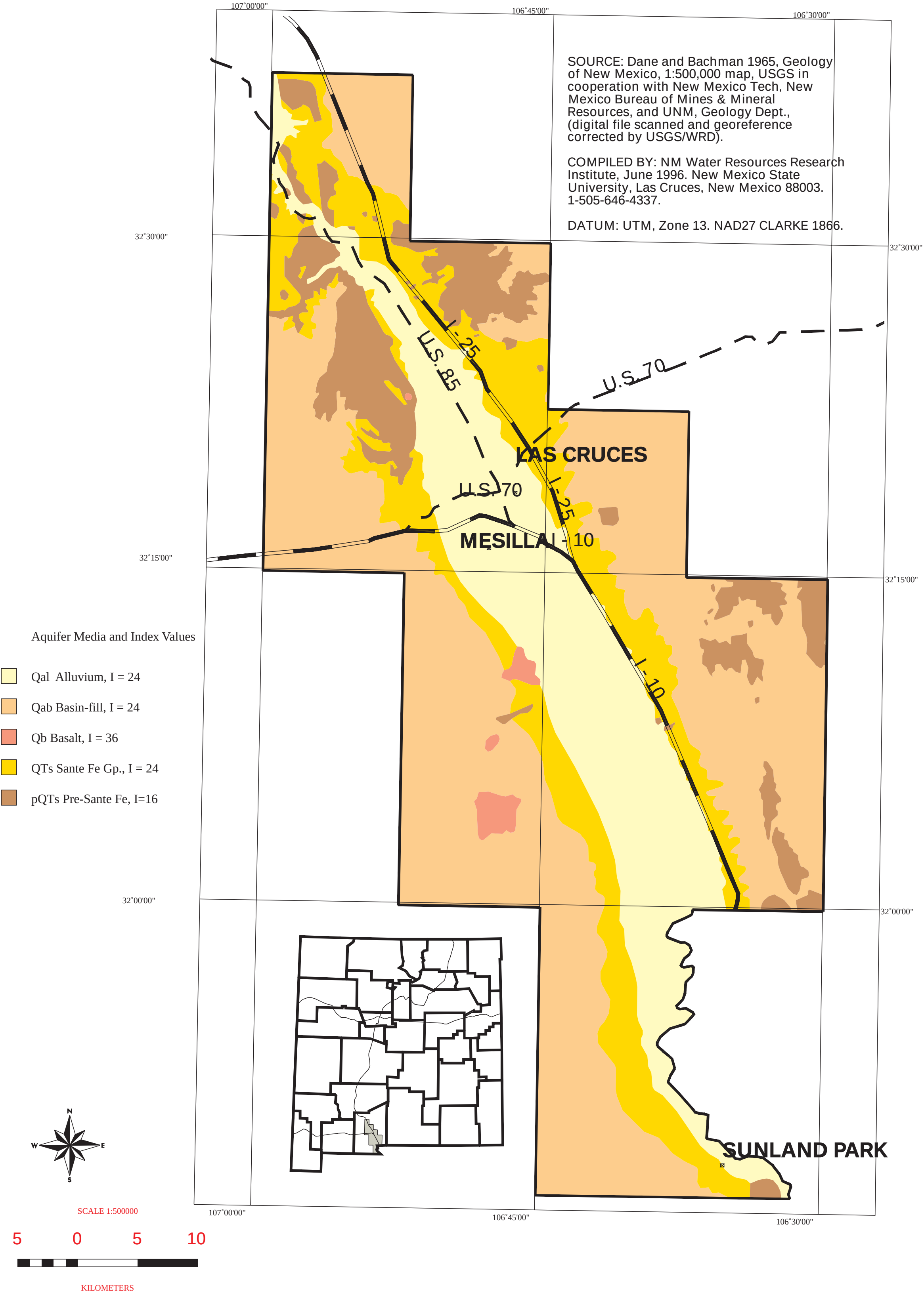
107°00'00"
106°45'00"
106°30'00"
32°30'00"
32°15'00"
32°00'00"
SOURCE: Dane and Bachman 1965, Geology of New Mexico, 1:500,000 map, USGS in cooperation with New Mexico Tech, New Mexico Bureau of Mines & Mineral Resources, and UNM, Geology Dept., (digital file scanned and georeference corrected by USGS/WRD).
COMPILED BY: NM Water Resources Research Institute, June 1996. New Mexico State University, Las Cruces, New Mexico 88003. 1-505-646-4337.
DATUM: UTM, Zone 13. NAD27 CLARKE 1866.
I - 25
U.S. 85
U.S.70
LAS CRUCES
U.S. 70
MESILLA
I - 10
SUNLAND PARK
Aquifer Media and Index Values
Qal Alluvium, A = 18
Qab Basin-fill, A = 18
Qb Basalt, A = 27
QTs Sante Fe Gp., A = 18
pQTs Pre-Sante Fe, A=12
N
W
E
S
SCALE 1:500000
5
0
5
10
KILOMETERS

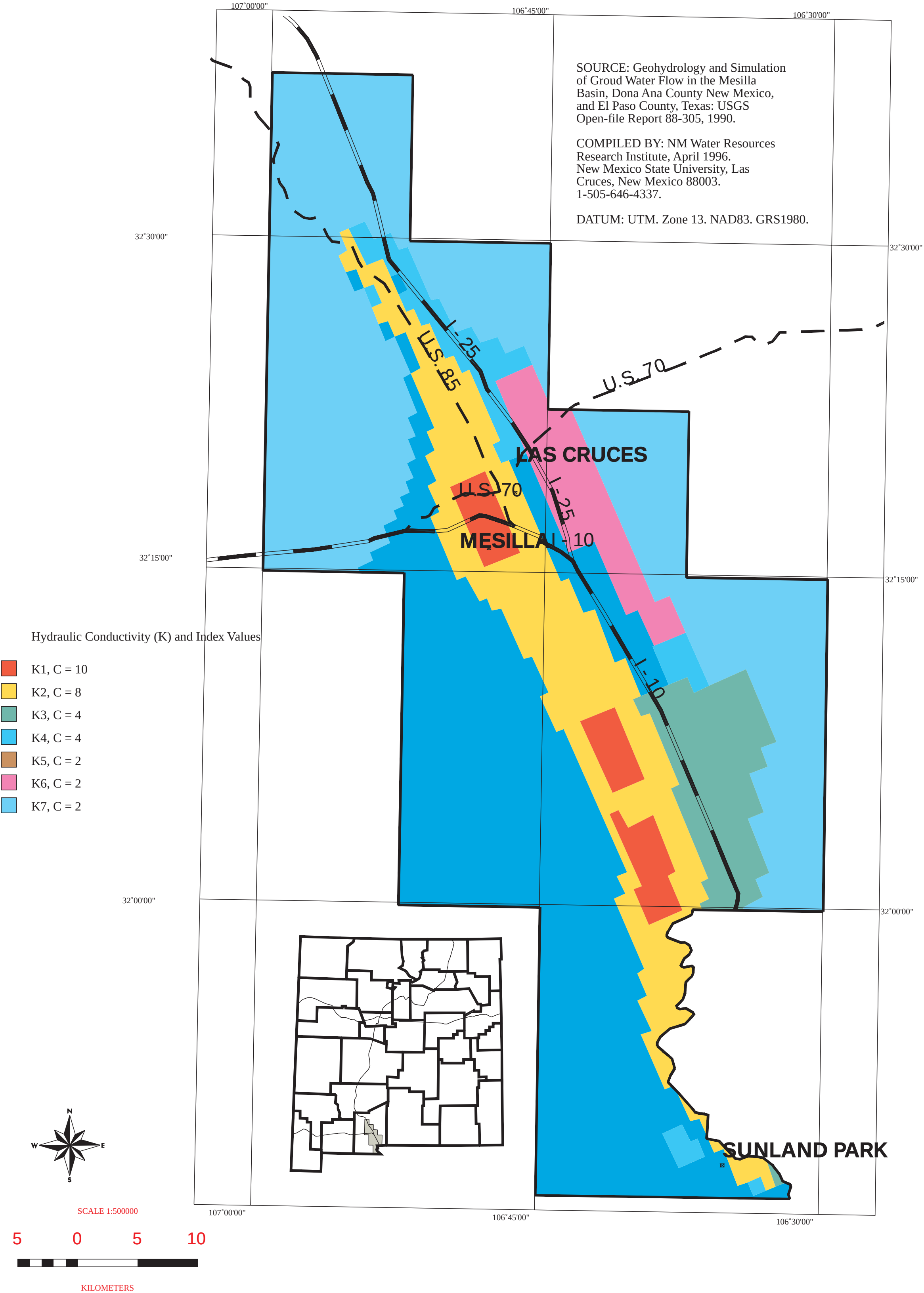


SOILS: Natural Resource Conservation Service. Preliminary DLG maps, 1:24,000 scale, converted to Arc/Info coverages, 1995.
COMPILED BY: NM Water Resources Research Institute, August 1996. New Mexico State University, Las Cruces, New Mexico 88003. 1-505-646-4337.
DATUM: UTM. Zone 13. NAD83, GRS1980.
107°00'00"
106°45'00"
106°30'00"
32°30'00"
32°15'00"
32°00'00"
I - 25
U.S. 85
U.S. 70
LAS CRUCES
I - 10
MESILLA
SUNLAND PARK
Soil Media and Index Values
Basalt, S=5
Caliche, S=5
Carbonate Hardpan, S=5
Carbonate-cemented, S=5
Clay, S=5
Clay loam, S=15
Dumps, S=50
Gravel pit, S=5
Limestone Bedrock, S=5
Loam, S=25
Loamy sand, S=40
Rock outcrop, S=5
Sandy clay loam, S=20
Sandy loam, S=35
Silty clay loam, S=15
Silty loam, S=25
Water, S=50
N
W
E
S
SCALE 1:500000
5
0
5
10
KILOMETERS

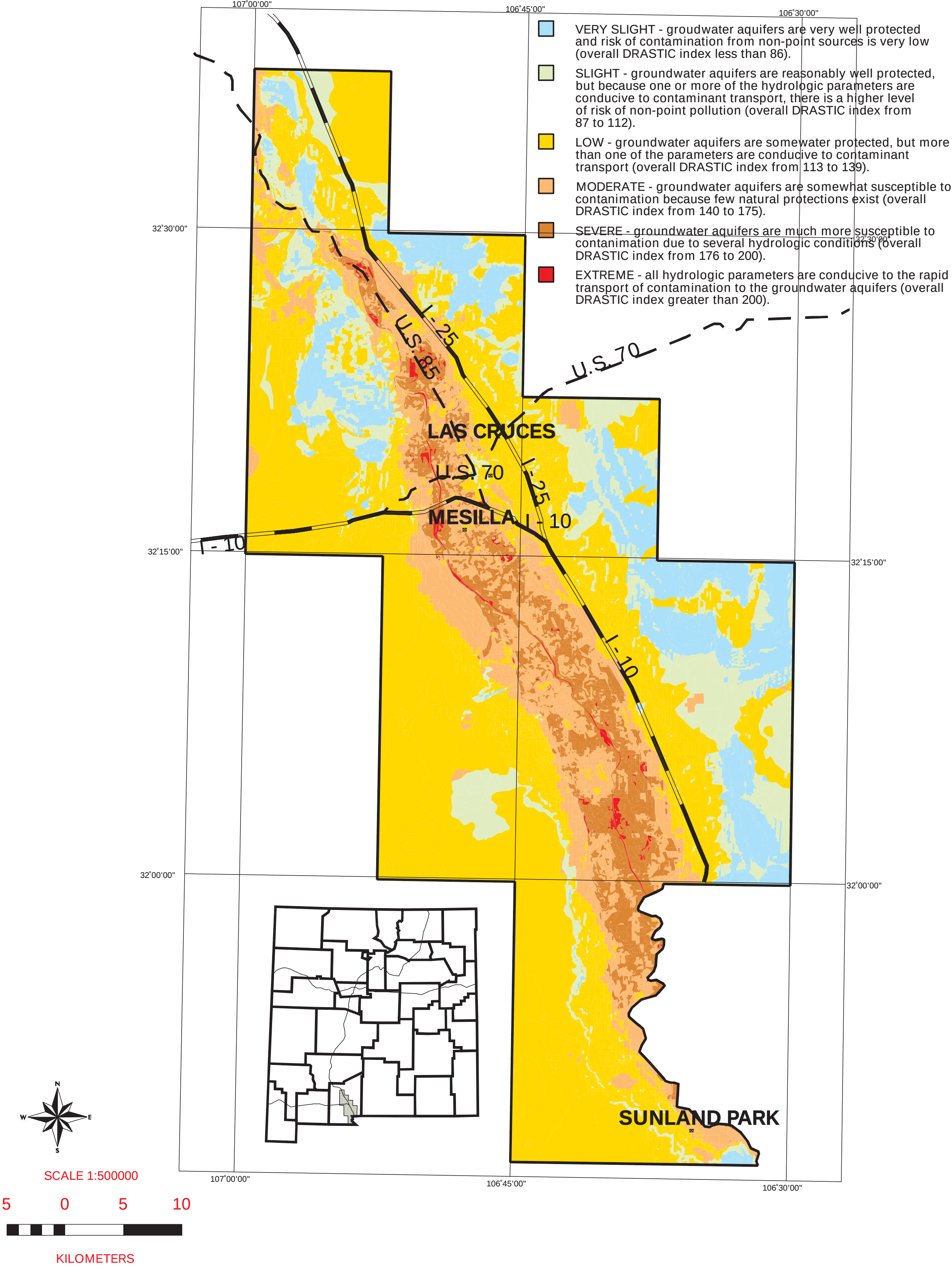


TOPOGRAPHY: Topography is based upon USGS 1:250,000 scale DEM data for the area. For a complete explanation DEM format see the USGS National Mapping Program, Technical Instructions, Data Users Guide 5, "Digital Elevation Models".
COMPILED BY: NM Water Resources Research Institute, August 1996. New Mexico State University, Las Cruces, New Mexico 88003. 1-505-646-4337.
DATUM: UTM. Zone 13. NAD83, GRS1980.
107°00'00"
106°45'00"
106°30'00"
32°30'00"
32°15'00"
32°00'00"
I - 25
U.S. 85
U.S. 70
LAS CRUCES
MESILLA
I - 10
SUNLAND PARK
Topography in Slope Percent and Index Values
0-2, T = 30
2-6, T = 27
6-12, T = 15
12-18, T = 9
18+, T = 3
N
W
E
S
SCALE 1:500000
5
0
5
10
KILOMETERS


SOURCE: Dane and Bachman 1965, Geology of New Mexico, 1:500,000 map, USGS in cooperation with New Mexico Tech, New Mexico Bureau of Mines & Mineral Resources, and UNM, Geology Dept., (digital file scanned and georeference corrected by USGS/WRD).
COMPILED BY: NM Water Resources Research Institute, June 1996. New Mexico State University, Las Cruces, New Mexico 88003. 1-505-646-4337.
DATUM: UTM, Zone 13. NAD27 CLARKE 1866.
107°00'00"
106°45'00"
106°30'00"
32°30'00"
32°15'00"
32°00'00"
LAS CRUCES
MESILLA
SUNLAND PARK
I - 25
I - 10
U.S. 85
U.S. 70
Aquifer Media and Index Values
Qal Alluvium, I = 24
Qab Basin-fill, I = 24
Qb Basalt, I = 36
QTs Sante Fe Gp., I = 24
pQTs Pre-Sante Fe, I=16
N
S
E
W
SCALE 1:500000
5
0
5
10
KILOMETERS



SOURCE: Geohydrology and Simulation of Groud Water Flow in the Mesilla Basin, Dona Ana County New Mexico, and El Paso County, Texas: USGS Open-file Report 88-305, 1990.
COMPILED BY: NM Water Resources Research Institute, April 1996. New Mexico State University, Las Cruces, New Mexico 88003. 1-505-646-4337.
DATUM: UTM. Zone 13. NAD83. GRS1980.
107°00'00"
106°45'00"
106°30'00"
32°30'00"
32°15'00"
32°00'00"
I - 25
U.S. 85
U.S. 70
LAS CRUCES
MESILLA
I - 10
SUNLAND PARK
Hydraulic Conductivity (K) and Index Values
K1, C = 10
K2, C = 8
K3, C = 4
K4, C = 4
K5, C = 2
K6, C = 2
K7, C = 2
N
S
E
W
SCALE 1:500000
5
0
5
10
KILOMETERS


107°00'00"
106°45'00"
106°30'00"
32°30'00"
32°15'00"
32°00'00"
VERY SLIGHT - groudwater aquifers are very well protected and risk of contamination from non-point sources is very low (overall DRASTIC index less than 86).
SLIGHT - groundwater aquifers are reasonably well protected, but because one or more of the hydrologic parameters are conducive to contaminant transport, there is a higher level of risk of non-point pollution (overall DRASTIC index from 87 to 112).
LOW - groundwater aquifers are somewater protected, but more than one of the parameters are conducive to contaminant transport (overall DRASTIC index from 113 to 139).
MODERATE - groundwater aquifers are somewhat susceptible to contanimation because few natural protections exist (overall DRASTIC index from 140 to 175).
SEVERE - groundwater aquifers are much more susceptible to contanimation due to several hydrologic conditions (overall DRASTIC index from 176 to 200).
EXTREME - all hydrologic parameters are conducive to the rapid transport of contamination to the groundwater aquifers (overall DRASTIC index greater than 200).
I - 25
U.S. 85
U.S. 70
LAS CRUCES
MESILLA
I - 10
SUNLAND PARK
N
S
E
W
SCALE 1:500000
5
0
5
10
KILOMETERS

REFERENCES

Aller, L., T. Bennett, J.H. Lehr, and R.J. Petty. 1985. *DRASTIC: A Standardized System for Evaluating Ground Water Pollution Potential Using Hydrogeologic Settings*. USEPA, Office of Research and Development, Robert S. Kerr Environmental Research Laboratory, Ada, OK, 163 pp.

Anderson J.R., E.E. Hardy, J.T. Roach, and R.E. Witmer. 1976. A Land Use and Land Cover Classification System for Use with Remote Sensor Data. U.S. Geological Survey, Prof. Paper 964, Reston, VA, pp. 28.

Bacci, E., A. Renzoni, C. Gaggi, D. Calamari, A. Franchi, M. Vighi, and A. Severi. 1989. Models, field studies, laboratory: An integrated approach to evaluate the environmental fate of atrazine (s-Triazine herbicide). *Agriculture, Ecosystems and Environment*, 27:513-522.

Blaney, H.F. and E.G. Hanson. 1965. *Consumptive Use and Water Requirements in New Mexico*. New Mexico State Engineer Office Technical Report 32.

Bowman, B.T. 1988. Mobility and persistence of metolachlor and aldicarb in field lysimeters. *J. Environ. Qual.* 17:689-694.

Brady, N.C. 1990. *The Nature and Properties of Soils*. Tenth edition, Macmillan Publishing Company, NY, 621 pp.

Bruce, R.R., P.F. Hendrix, and G.W. Langdale. 1991. Role of cover crops in recovery and maintenance of soil productivity. Pp. 109-115. In *Cover Crops for Clean Water*. W.L. Hargrove (ed.), Soil and Water Conserv. Soc., Ankeny, IA.

Bulloch Jr., E.H. and R.E. Neher. 1980. *Soil Survey of Doña Ana County Area New Mexico*. U.S. Department of Agriculture, Soil Conservation Service.

Campbell, G.S. 1985. *Soil Physics with BASIC*. Elsevier, NY.

Carsel, F., L.A. Mulky, M.N. Lorber, and L.B. Baskin. 1985. The Pesticide Root Zone Model (PRZM): A procedure for evaluating pesticide leaching threats to groundwater. *Ecol. Model*, 30:49-69.

Carsel, R.R., C.N. Smith, L.A. Julkey, J.D. Dean and P. Jowise. 1984. *Users Manual for the Pestcide Root Zone Model (PRZM): Release 1*. U. S. Environmental Protection Agency, Athens, GA. EPA-600/3-84-109.

Chapin, C.E. and W.R. Seager. 1975. Evolution of the Rio Grande rift in the Socorro and Las Cruces areas: New Mexico Geological Society, Guidebook 26, pp. 297-321.

Chapin, C.E. 1988. Axial basins of the northern and central Rio Grande rifts. *Sedimentary cover—North American Craton (U.S.)*. Geological Society of America, Geology of North America, L.L. Sloss (ed.). D-2:165-170.

Dane, C.H. and G.O. Bachman. 1965. *Geology of New Mexico*. 1:500,000 map, USGS in cooperation with NM Inst. of Mining & Tech., NM Bur. of Mines & Mineral Res., Univ. of NM, Geology Dept., (digital file scanned and georeference corrected by USGS/WRD).

Davis, J.C., 1986, *Statistics and Data Analysis in Geology*, Second edition: John Wiley & Sons, New York, NY, 646 p.

Donigian, A.S. Jr and R.F. Carsel. 1992. Developing computer simulation models for estimating risks of pesticide use: research vs. user needs. Weed Technology, *J of American Weed Science Society*, Champaign, Ill, July/Sept v.6(3) p. 677-682.

Fox Jr., F., A.T. Scherer, D.C. Slack, and L.J. Clark. 1992. *Arizona irrigation Scheduling User's Manual Vol. 1.01*. Agricultural and Biosystems Engineering, University of Arizona, Tuscon, AZ.

Frenzel, P.F. 1992. *Listings of Model-Input Values for the Simulation of Geowater Flow in the Mesilla Basin, Doña Ana County, New Mexico and El Paso County, Texas*. U.S. Geological Survey, Open-File Report 91-455.

Frenzel, P.F. and C.A. Kaehler. 1990. *Geohydrology and Simulation of Ground-Water Flow in the Mesilla Basin, Doña Ana County, New Mexico and El Paso County, Texas*. U.S. Geological Survey, Open-File Report 88-305.

Ghadiri, H., P.J. Shea, G.A. Wicks, and L.C. Haderlie. 1984. Atrazine dissipation in conventional-till and no-till sorghum. *J. Environ. Qual.*, 13:549-552.

Gile, L.H. and R.B. Grossman. 1979. *Soils and Landscapes of a Desert Region Astride the Rio Grande Valley Near Las Cruces, New Mexico*. The Desert Project Soil Monograph, USDA Soil Conservation Service, October 1979, pp. 759-959.

Gile, L.H., J.W. Hawley, and R.B. Grossman. 1981. *Soils and Geomorphology in a Basin and Range Area of Southern New Mexico—Guidebook to the Desert Project*. Memoir 39, NM Bureau of Mines and Mineral Resources, Socorro, NM, 222 pp.

Gregson, K., D.J. Hector, and M. McGowan. 1987. A one-parameter model for the soil water characteristic. *J. Soil Science*, 38:483-486.

Gustavson, T.C. 1991. *Arid Basin Depositional Systems and Paleosols: Fort Hancock and Camp Rice Formations (Pliocene-Pleistocene) Hueco Bolson, West Texas and Adjacent Mexico*. University of Texas at Austin, Bureau of Economic Geology, Report of Investigations No. 198, 49 pp.

Hamlett, J.M. and D.L. Epp. 1994. Water quality impacts of conservation and nutrient management practices in Pennsylvania. *J. Soil and Water Conserv.* 49:1:59-66.

Hanson, A., Z. Samani, and B. Avalos. 1994. *Final Report, City of Las Cruces Wellhead Protection Program: Phase I (Part A) Groundwater Modeling, Delineation of Zone of Contribution, Geographical Information System.* Civil, Agricultural, and Geological Engineering Department, New Mexico State University, Las Cruces, NM. 1994. 211 pp.

Hawley, J.W., F.E. Kottlowski, W.R. Seager, W.E. King, W.S. Strain, and D.V. LeMone. 1969. *The Santa Fe Group in South-Central New Mexico Border Region*. NM Bureau of Mines and Mineral Resources, Circular 104, pp. 235-274.

Hawley, J.W. 1975. Quaternary history of Doña Ana County region, south-central New Mexico, New Mexico Geological Society, Guidebook 26th field conference, pp. 139-150.

Hawley, J.W. (Complier). 1978. *Guidebook to the Rio Grande Rift in New Mexico and Colorado*. NM Bureau of Mines and Mineral Resources, Circular 163, 241 pp.

Hawley, J.W. and R.P. Lozinsky. 1992. *Hydrogeologic Framework of the Mesilla Basin in New Mexico and Western Texas*. NM Bureau of Mines and Mineral Resources, Open-File Report 323, Socorro, NM.

Healy, D. 1996. *Water-quality Assessment of the Rio Grande Valley, Colorado, New Mexico, and Texas—Occurrence and Distribution of Selected Pesticides and Nutrients at Selected Surface-water Sites in the Mesilla Valley*, 1994-95; Water Resources Investigations Report; U.S. Geological Survey, Albuquerque, NM. 1996. 92 pp.

Hearne, G., M. Wireman, A. Campbell, S. Turner, and G.P. Ingersall. 1992. *Vulnerability of the Uppermost Ground Water to Contamination in the Greater Denver Area, Colorado*. USGS Water-Resources Investigations Report 92-4143, 241 pp.

Hiltbold, A.E. and G.A. Buchanan. 1977. Influence of soil pH on persistence of atrazine in the field. *Weed Science*, 25:515-520.

Israelsen, O.W. and V.E. Hansen. 1962. *Irrigation principles and Practices*, John Willey and Sons, Inc. New York, pp.1-447.

Izuno, F.T., A.B. Bottcher, F.J. Coale, C.A. Sanchez, and D.B. Jones. 1995. Agricultural BMPs for phosphorus reduction in south Florida. *ASAE*, 38:3:735-744.

Jensen , M.E., R.D. Burman and R.G. Allen (eds). 1990. Evapotranspiration and irrigation water requirements. ASCE Manuals and Reports on Engineering Practice No. 70, published by ASCE, New York.

King, W.E., J.W. Hawley, A.M. Taylor, and R.P. Wilson. 1971. *Geology and Ground-Water Resources of Central and Western Doña Ana County, New Mexico*. New Mexico Institute of Mining and Mineral Resources, Hydrologic Report 1.

Kottlowski, F.E. 1958. Geologic history of the Rio Grande near El Paso. *Guidebook of Franklin and Hueco Mountains, Texas*. West Texas Geological Society, Guidebook, Field Trip, pp. 46-64.

Lovejoy, E.M.P. and J.W. Hawley. 1978. Road log, El Paso to New Mexico-Texas state line. *Guidebook to the Rio Grande Rift*. NM Bureau of Mines and Mineral Resources, Circular 163, J.W. Hawley (ed.), pp. 57-68.

Mualem, Y. 1992. Modeling the hydraulic conductivity of unsaturated porous media. *Proceedings International Workshop on Indirect Methods for Estimating the Hydraulic Properties of Unsaturated Soils.* Univ. California, Riverside, CA, M.Th. van Genuchten, F.J. Leij, and L.J. Lund (eds), pp. 15-36.

Myers, R.G. and B.R. Orr. 1986. *Geohydrology of the Aquifer in the Sante Fe Group, Northern West Mesa of the Mesilla Basin near Las Cruces, New Mexico*. U.S. Geological Survey, Water-resources Investigations Report 84-4190, 37 pp.

Nelson, J.W. and L.C. Holmes. 1914. *Soil Survey of Mesilla Valley, New Mexico-Texas.* Government Printing Office, Washington, D.C.

New Mexico Department of Agriculture. 1993. *New Mexico Agricultural Statistics*, pp. 71.

Nickerson, E.L. and R.G. Myers. 1993. *Geohydrology of the Mesilla Ground-water Basin, Doña Ana County, New Mexico, and El Paso County, Texas*. U.S. Geological Survey, Water-Resources Investigation Report 92-4156.

Nofziger, D.L. and A.G. Hornsby. 1985. *Chemical Movement in Layered Soils: User's Guide*. Florida Cooperative Extension Service, Gainesville, Circular 780, pp. 1-44.

Pennell, K.D., A.G. Hornsby, R.E. Jessup, and P.S.C. Rao. 1990. Evaluation of five simulation models for predicting aldicarb and bromide behavior under field conditions. *Water Resources Research*, 26:11:2679-2693.

Peterson, D.M., R. Khaleel, and J.W. Hawley, 1984. *Quasi-Three Dimensional Modeling of Groundwater Flow in the Mesilla Bolson*. New Mexico and Texas Technical Compeletion Report Project No. 1-3-45645.

Ranjha, A.Y., R.C. Peralta, A.M. Requena, H.M. Deer, M. Ehteshami, R.W. Hill, and W.R. Walker. 1992. Best management of pesticide-furrow irration systems. *Irrigation Science*, 13:9-14.

Ratliff, L.F., J.T. Ritchie, and D.K. Cassel. 1983. Field measured limits of soil water availability as related to laboratory-measured properties. *Soil Science Society American Journal*, 47:770-775.

Reay, W.G., D.L. Gallagher, and G.M. Simmons, Jr. 1992. Groundwater discharge and its impact on surface water quality in a Chesapeake Bay inlet. *Water Resources Bulletin*, 28:6:1121-1131.

Richards, K.M. 1993. *Water Quality Survey for Agricultural Chemicals in Ground Water Wells and Surface Water Drains, Federal Fiscal Year 1993.* Evaluation and Planning Sect, Surface Water Quality Bureau, NM Environment Department, Santa Fe, NM, 15 pp.

Richardson, C.W. and D.A. Wright. 1984. *WGEN: A model for generating daily weather variables*. U.S. Dept. of Agriculture, ARS-8, pp. 83.

Saxton, K.E., W.J. Rawls, J.S. Romberger, and R.I. Papendick. 1986. Estimating generalized soil-water characteristics from texture. *Soil Science Soc. Am. J.*, 50:1031-1036.

Schweizer, E.E., D.W. Lybecker, and R.L. Zimdahl. 1988. Systems approach to weed management in irrigated crops. *Weed Science*, 36:840-845.

Seager, W.R., R.E. Clemons, J.W.Hawley, and R.E. Kelley. 1971. *Geology of San Diego Moutain Area, Doña Ana County, New Mexico*. NM Bureau of Mines and Mineral Resources, Bulletin 97, 38 pp.

Seager, W.R., F.E. Kottlowski, and J.W. Hawley. 1976. *Geology of Doña Ana Mountains, New Mexico*. NM Bureau of Mines and Mineral Resources, Circular 147, 36 pp.

Seager, W.R. and P. Morgan. 1979. Rio Grande rift in southern New Mexico, west Texas and northern Chihuahua. *Rio Grande Rift, Tectonics and Magmatism*. American Geophysical Union, Washington, DC, R.E. Riecker (ed.), pp. 87-106.

Seager, W.R., R.E. Clemons, J.W. Hawley, and R.E. Kelley. 1982. Geology of Northwest Part of Las Cruces 1 x 2 sheet. NM Bureau of Mines and Mineral Resources, Geologic map 53, scale 1:125,000, 3 sheets.

Seager, W.R., M. Shafiqullah, J.W. Hawley, and R.F. Marvin. 1984. New K-Ar dates from basalts and evolution of the southern Rio Grande Rift. *Geological Society of America Bulletin*, 95:87-99.

Seager, W.R., J.W. Hawley, F.E. Kottlowski, and S.A. Kelley. 1987. Geology of east half of Las Cruces and northeast El Paso 1x2 sheets. New Mexico Geologic Map 57, NM Bureau of Mines and Mineral Resources, Socorro, NM.

Shayya, W.H., V.F. Bralts, and T.R. Olmsted. 1990. A general irrigation scheduling package for microcomputers. *Computers and Electronics in Agriculture*. Elsevier Scientific Publishing Company, Amsterday, The Netherlands, 5:197-121.

Shayya, W.H., V.F. Bralts, T.R. Olmsted, and T. Loudon. 1991. *Irrigation Scheduling Based on Growing Degree Days*. ASAE Paper 91-2643 presented at ASAE meeting, Chicago, IL, December 17-20, 1991.

Shayya, W.H. and V.F. Bralts. 1994. *Guide to SCS-Microcomputer Irrigation Scheduling Package SCS-Scheduler Version 3*. Department of Agricultural Engineering, Michigan State University, East Lansing, MI.

South, D.B. and C.B. Davey. 1983. The southern forest nursery soil testing program. Alabama Agricultural Experiment Station, Circular 265:17-19.

Strain, W.S. 1966. *Blancan Mammalian Fauna and Pleistocene Formations, Hudspeth County, Texas*. Texas Memorial Museum, Bulletin 10, 55 pp.

Swanton, C.J. and S.F. Weise. 1991. Integrated weed management: the rational approach: *Weed Technol*., 5:663-667.

U.S. Department of Agriculture, Soil Conservation Service. 1975. *Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys.* USDA Handbook No. 436, Government Printing Office, Washington, DC.

US Geological Survey, 1990, National Mapping Program Technical Instuctions, Data Users Guide 5, Digital Line Graphs from 1:24,000-Scale Maps: U.S. Geological Survey, Reston, VA.

USEPA, Office of Water. 1993. *A Review of Methods for Assessing Aquifer Sensitivity and Ground Water Vulnerability to Pesticide Contamination*. Report 813-R-93-002.

Walker, A. 1978. Simulation of the persistence of eight soil-applied herbicides. *Weed Research*, 18:305-313.

Walker, W.R. and G.V. Skogerboe. 1987. *Surface Irrigation Theory and Practice*, Prentice Hall Inc. New Jersey, pp. 1-386.

Watson, J.E. Hassinger, K. Reffruschinni, M. Sheedy, and B. Anthony. 1994. Best management practices meeting water quality goals. *J. Soil and Water Conserv*., 49:2:39-43.

Wilkins, D.W. and B.M. Garcia. 1995. Ground-water Hydrographs and 5-year Ground-Water-Level Changes, 1984-93, for Selected Areas In and Adjacent to New Mexico. U.S. Geological Survey Open-File Report 95-434, Albuquerque, NM.

Wilson, C.A., R.R. White, B.R. Orr, and R.G. Roybal. 1981. *Water Resources of the Rincon and Mesilla Valleys and Adjacent Areas, New Mexico*. NM State Engineer Office, Technical Report 43.

Wilson, C.A. and R.R. White. 1984. *Geohydrology of the Central Mesilla Valley, Doña Ana County, New Mexico*. U.S. Geological Survey, Water-Resources Investigation Report 82-555.

Yeh, J.T.C., L.W. Gelhar and P.J. Wierenga. 1986 Observations of spatial variability of soil-water pressure in a field soil. Soil Sci. 142(1):7-11.

APPENDIX A
IRRSCHM Model Setup

Setup of IRRSCHM model runs for evaluating BMPs is accomplished by performing the following tasks:

Defining soil profiles
Defining irrigation schedules
Developing a cropping sequence
Creating driver files based on defined profiles, schedules, and sequencing
Executing the program to process the runs

In describing each of these tasks, program and file names are given with a complete relative path within the project directory. It is generally assumed that a program should be run while in the directory containing the program.

Defining Soil Profiles

Each soil profile definition begins with obtaining a description of the profile. In this case, the Doña Ana Soil Survey was used as the source for profile descriptions. Enter each soil profile description into a spreadsheet using the following format:

	A	B	C	D	E	F	G	H
1	Map	Series	Depth (cm)	Depth (cm)	Texture	USDA	Numeric	Organic Matter
2	ID	Name	Top	Bottom	Code	Texture	Soil ID	%
3	AA	A Soil	0	5	CL	Clay Loam	2	1.34
4			5	15	SA	Sand	5	1.12

Note that the first two rows contain header information identifying the contents of each column, and that the Map ID and Series Name appear only on the first line for that series. Each layer is usually distinguished by changing horizons and/or soil classification.

The spreadsheet is then saved as a TAB delimited ASCII file in IRRSCH\PDF for processing by the IRRSCH\PDF\XL2PDF.BAT program. This program reads the above data from the ASCII file and uses it to create a base-line PDF file for each soil series found. The program is executed with the name of the input file list on the command-line (wildcards allowed) as follows:

d:\...\irrsch\pdf> XL2PDF <name.ext> [<name.ext>...]

Note that you may use multiple files as input for this program.

The IRRSCH\PDF\FIXALL.BAT program is then executed to form adjusted copies of each base PDF file in the appropriate directory in the FIELDS directory tree. Execute the program with no arguments:
d:...\irrsch\pdf> FIXALL

IRRSCH\PDF\FIXALL.BAT calls the program IRRSCH\PDF\FIXPDF.BAT to make the appropriate adjustments to the cell sizes for a 2.54cm dispersion length, and Retardation coefficients and Half-Life values for DUAL and BLADEX. When IRRSCH\PDF\FIXALL.BAT is done, there are two new copies of each base PDF; one for DUAL, the other for BLADEX.

IRRSCH\PDF\FIXPDF.BAT also can be run as a stand-alone program. It prompts for each input value and the output file name when run. It takes the name of the input PDF file as a command-line parameter:

d:...\irrsch\pdf> FIXPDF <name.ext>

Do NOT use wildcards in the file specification on the command-line when using this program as it generates only one output file and will not distinguish between multiple input files.

The subdirectories and files in the IRRSCH\FIELDS directory tree are organized according to surface soil type and Map ID. Contained within the IRRSCH\FIELDS directory are the subdirectories for each Soil Type, named according to the Type ID Number. Each soil type directory contains subdirectories for each PDF which has that soil type for the top layer. These subdirectories have the same name as the corresponding PDF file, without the PDF extension. Each of these contain the two actual PDF files for DUAL and BLADEX, named DUAL90.PDF and BLDX14.PDF, respectively. The path to each PDF file is of the form:

IRRSCH\FIELDS\<Surface_Soil_ID_#>\<Soil_Type_ID_CODE>\DUAL90.PDF
IRRSCH\FIELDS\<Surface_Soil_ID_#>\<Soil_Type_ID_CODE>\BLDX14.PDF

Where:

Surface_Soil_ID_# is the two-digit ID number of the top layer, and
Soil_Type_ID_CODE is the two-letter Map Unit ID for the soil type.

The Surface Soil ID is determined by calling the IRRSCH\PDF\TYPESET.BAT program. This program matches the Map Unit ID to a Soil Type ID. It is called as follows:

d:...\irrsch\pdf> TYPESET <MUID>

Where:

MUID is the Map Unit ID code (usually two letters).

Defining Irrigation Schedules

Irrigation schedules are defined by entering the crop name, field ID, year, and irrigation dates in a spreadsheet in the following format:

	A	B	C	D
1	Crop: <name>			
2	No. <field_#>			
3	Year: <year>			
4		Date		Irrigation (inches)
5		<m/d/y>		<amount>
.				
.				
.				
	No. <field_#>			
	Year: <year>			
		Date		Irrigation (inches)
		<m/d/y>		<amount>
.				
.				
.				
	CROP: <name>			
	No. <field_#>			
	Year: <year>			
.				
.				

In short, the file can contain as many different crops and fields as needed for the given soil type. When all schedules are entered into a spreadsheet, the file should be exported as a TAB delimited ASCII file in the SRC directory.

This file is then processed by running SRC\ISF.BAT which will create a directory of the same name as the input file, and create separate ISF (irrigation schedule files) files for each crop, field, and year as specified in the data. Execute the program with the input file list on the command line (wildcards allowed) as follows:

d:...\src> ISF <name.ext> [<name.ext>...]

The completed schedule files are then copied into the IRRSCH directory structure by the SRC\COPYISF.BAT program. Execute the program as follows:
d:..\src> COPYISF

This program copies the ISF files from a list of subdirectories (c cl l lsa sal), according to crop types in the list (alf chi cor cot oni) corresponding to the five crop types used in the runs. This program does not require any command-line parameters, and expects its input to be in the set of directories listed. It will leave un-touched any files in any other directories, so schedule spreadsheet files should be converted to ASCII files with appropriate names.

The copied files are organized by soil type, and crop ID under the RRSCH\ISF directory, so the path to each file is of the form:

IRRSCH\ISF\<SoilType#>\<CROPID#>___<F#><YR>.ISF

where:

F# is the field ID number (two digits) from the input file, and YR is the year (two digits) of the Schedule.

Developing a Cropping Sequence

The cropping sequence is a function of the relative area within the region which is devoted to each crop being evaluated. The frequency of each crop within the sequence is directly proportional to the ratio of the crop with respect to all crops in the set for evaluation. The sequence input file IRRSCH\ROTATION.CRP is generated by picking random items from a collection with a uniform distribution based on the proportionality of each crop. For example, if corn, alfalfa, cotton, chile and onions have respectively the percentages 2, 5, 75, 15, and 3, the collection would have 100 items with the proportions for each crop equal to that crop's percentage. Random selection from that collection, for a large sample set, gives the sequence for the IRRSCH\ROTATION.CRP file. This file is then used to generate individual crop sequences for each soil type group by randomly selecting a starting point in the file and sequencing through it.

Create Driver Files Based on Defined Profiles, Schedules, and Sequencing

The IRRSCH program requires several input files, including data for climate information, irrigation schedules, crop descriptions, and soil profiles. The soil profile generation is fully described in *Defining Soil Profiles*. The other files required must still be put together using the components created as described in *Defining Irrigation Schedules* and *Developing a Cropping Sequence*.

The IRRSCH\IRRSCHMK.BAT program does most of the remaining work to process the input data files. Execute the program with no command-line arguments as follows:

d:..\irrsch> IRRSCHMK

This program reads the IRRSCH\ROTATION.CRP file and generates two 30-year crop sequences for each soil type directory in the IRRSCH\FIELDS\ directory, one starting with Chile, and one starting with Cotton. As it steps through each sequence, it reads the description for the next crop in line from IRRSCH\CDF\<crop_ID>.CDF and copies it to the IRRSCH\FIELDS\<soil_type>\<Start_Crop>.CDF file, where Start_Crop is the first two letters of the initial crop in the sequence, and soil_type is the two digit ID number of the soil type. The program then chooses an irrigation schedule from the IRRSCH\ISF\<soil_type>\<crop_ID>\ directory, and a corresponding Climate file, based on the year of the chosen irrigation schedule, from the IRRSCH\CLM\ directory. The information from these two files is then copied to IRRSCH\FIELDS\<Start_Crop>.ISF and IRRSCH\FIELDS\<Start_Crop>.CLM after adjusting the year information in each to match the sequence position. The program then adds the chemical information to the irrigation schedule if the crop is the correct type for the chemical in question. The chemical applications are based on Heat Units computed from the Climate data.

When IRRSCH\IRRSCHMK.BAT is finished the current practice data files are completed. To create the input files for the tensiometer based management practices, the program IRRSCH\FIELDS\MKTNSM.BAT is run to reprocess each of the previously created data sets. This program uses the PERL scripts IRRSCH\FIELDS\FIXCR_?.PL (where ? is one of {M,S,T}) to adjust the tensiometer settings in each crop driver file (CDF) to create three new versions, one for each of the tensiometer-based BMPs; NRCS recommendation with moving tensiometer, NRCS recommendation with stationary tensiometer, and 50 percent depletion. The adjusted CDFs are named by prepending the original file name with 'M', 'S', or 'T' for Moving, Stationary, and 50 percent Tensiometer readings, respectively. The IRRSCH\MKTNSM.BAT program also creates a new irrigation schedule using the PERL script IRRSCH\FIELDS\FIXSCHED.PL to eliminate all applications except those used to add chemicals from the original schedules. The new schedule is named by prepending the original name with 'NW'.

The data file sets are completely generated when both of these programs are finished. The final preparation step for running the model is the set marker files for IRRSCH\FIELDS\RUNALL.BAT to identify which files are associated with each PDF file. These marker files are created by running the IRRSCH\FIELDS\SETRUNS.BAT program. This program sets marker files for each directory so that all runs will be made.

After IRRSCH\FIELDS\SETRUNS.BAT has been run, you may disable particular runs, or sets of runs by doing one of the following:

To Disable:	Do:
All runs for a SOIL NUMBER	create NO_RUN in the SOIL NUMBER dir.
One runs for a PDF Set	create NO_RUN in the PDF's dir.
One Start Crop Series	delete all marker files with the Series ID in the PDF dir.
One run for a Crop Series	delete the appropriate marker file with the Series ID in the PDF dir.

Marker files are files with the same name as the associated PDF file with an extension containing the Crop Series ID. The Series ID is the first two letters of the Crop Series name (e.g. CO for cotton) and is preceeded by an optional one-letter-code for the BMP (one of {M,S,T}).

Execute the Program to Process the Runs

The final step is to run the model for each data set and process the output to determine peak and average concentrations and to generate a data file which can be used to plot the concentrations over time. This is done by the IRRSCH\FIELDS\RUNALL.BAT program. Execute the program with no command-line arguments as follows:

d:...\irrsch\fields> RUNALL

This program calls two other batch files to process Farmers practices and tensiometer-based BMP runs, IRRSCH\FIELDS\RUNFMSCH.BAT and IRRSCH\FIELDS\RUNTNSM.BAT, respectively. Each of these may be run individually:

d:...\irrsch\fields> RUNFMSCH

OR

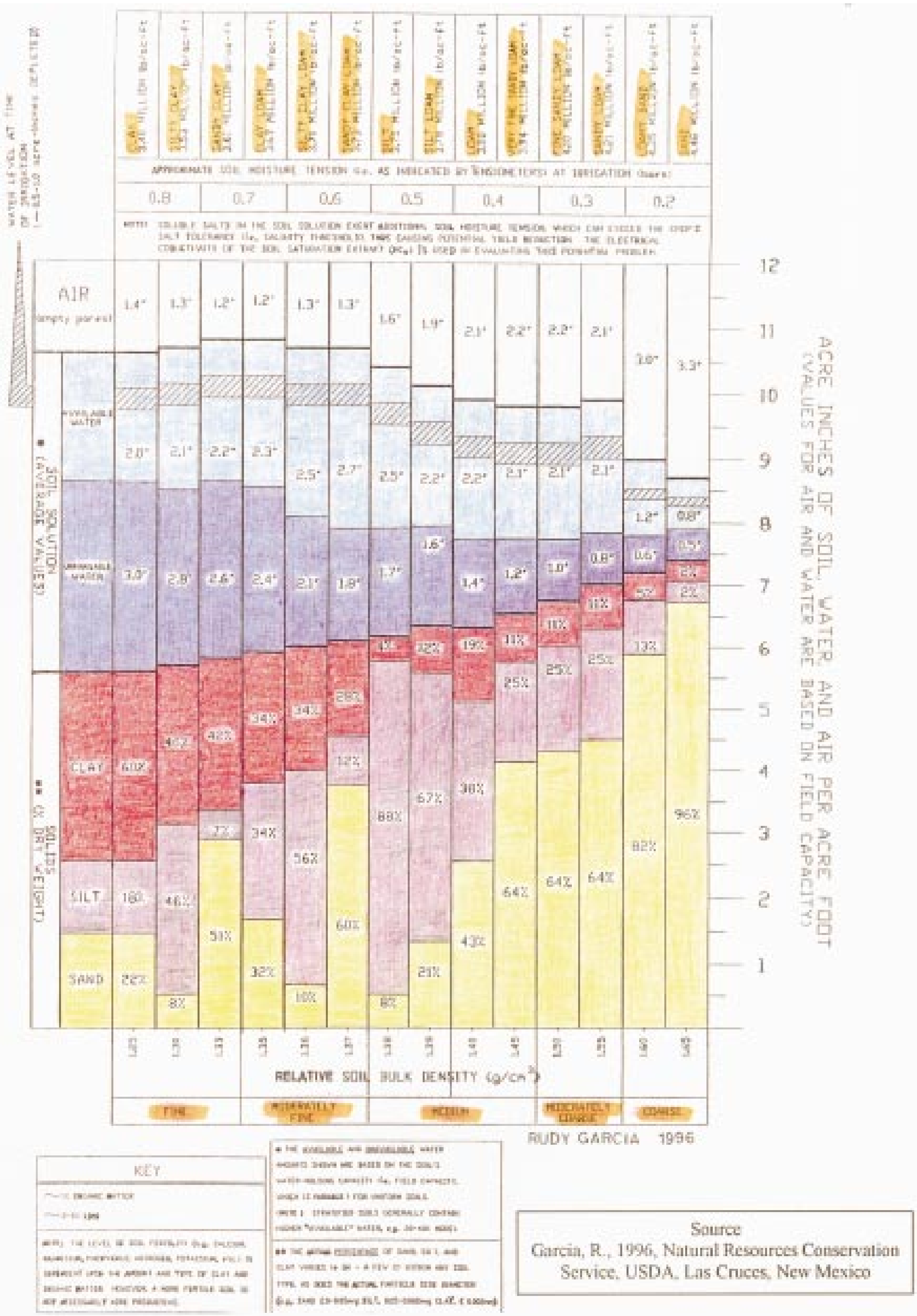
d:...\irrsch\fields> RUNTNSM

These programs call the IRRSCHMR.EXE program, which should be in the current PATH statement in the DOS environment. When IRRSCHMR.EXE has completed, IRRSCH\FIELDS\PROC_CNC.BAT is called to generate the processed output files IRRSCH\FIELDS\<soil_type>\<soil_id>\<file_set>.AVG and IRRSCH\FIELDS\<soil_type>\<soil_id>\<file_set>.DAT, where file_set is the name of the set of crop, schedule and climate files being used.

When the processing is complete, the raw output file (OUT) is deleted to conserve disk space.

APPENDIX B

General Guide for Calcareous Soils



Source:Garcia, R., 1996, Natural Resources Conservation Service, USDA, Las Cruces, New Mexico.

APPENDIX C

Seasonal Leaching Fraction and Relative ET Plots

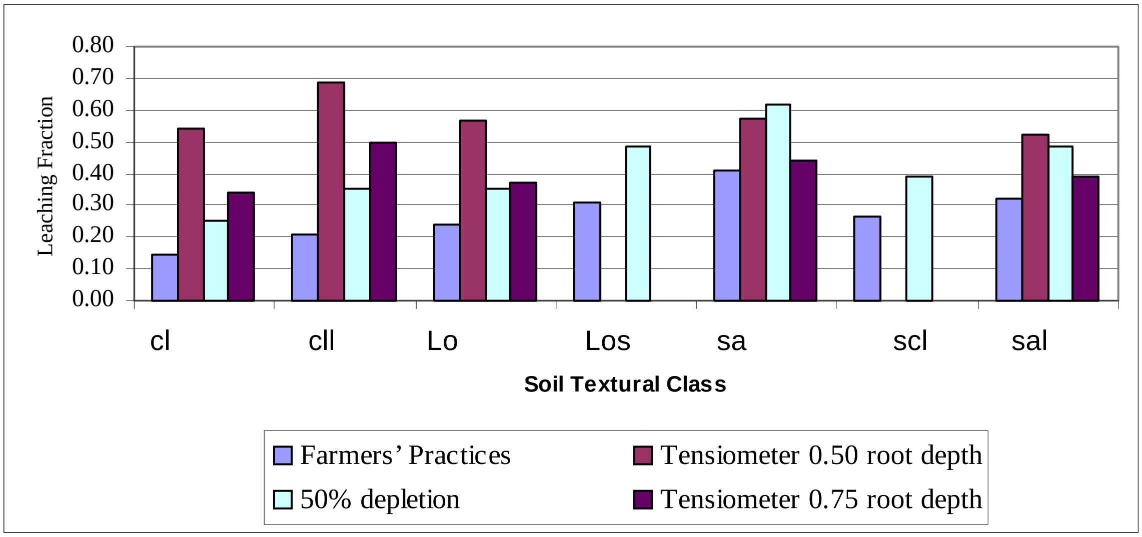


Figure C1. Mean seasonal leaching fraction occuring in each soil type under different irrigation scheduling practices. (Soil Texture Classes: cl=clay, cll=clay loam ,Lo=loam, Los=loamy sand, sa=sand, scl=sandy clay, sal=sandy loam)

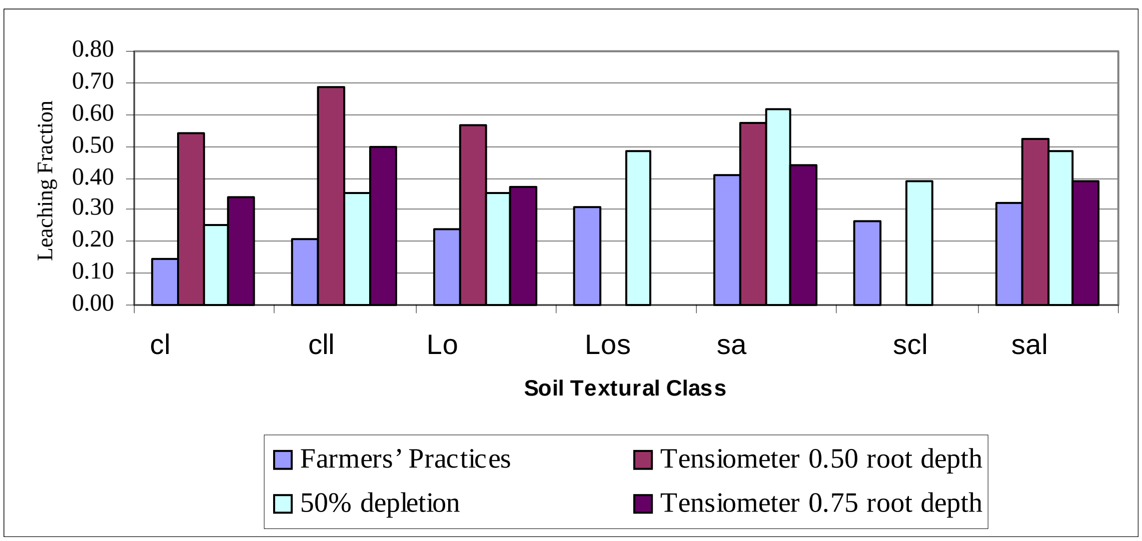


Figure C2. Mean seasonal relative evapotranspiration under different irrigation scheduling practices. (Soil Texture Classes: cl=clay, cll=clay loam ,Lo=loam, Los=loamy sand, sa=sand, scl=sandy clay, sal=sandy loam)