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Nitrate Concentrations, 1936-99, and Pesticide Concentrations, 1990-99, in the Unconfined Aquifer in the San Luis Valley, Colorado

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 01-4131

National Water-Quality Assessment Program

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Nitrate Concentrations, 1936-99, and Pesticide Concentrations, 1990-99, in the Unconfined Aquifer in the San Luis Valley, Colorado

By Robert W. Stogner, Sr.

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Albuquerque, New Mexico
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U.S. DEPARTMENT OF THE INTERIOR
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FOREWORD

The U.S. Geological Survey (USGS) is committed to serve the Nation with accurate and timely scientific information that helps enhance and protect the overall quality of life, and facilitates effective management of water, biological, energy, and mineral resources. Information on the quality of the Nation's water resources is of critical interest to the USGS because it is so integrally linked to the long-term availability of water that is clean and safe for drinking and recreation and that is suitable for industry, irrigation, and habitat for fish and wildlife. Escalating population growth and increasing demands for the multiple water uses make water availability, now measured in terms of quantity *and* quality, even more critical to the long-term sustainability of our communities and ecosystems.

The USGS implemented the National Water-Quality Assessment (NAWQA) Program to support national, regional, and local information needs and decisions related to water-quality management and policy. Shaped by and coordinated with ongoing efforts of other Federal, State, and local agencies, the NAWQA Program is designed to answer: What is the condition of our Nation's streams and ground water? How are the conditions changing over time? How do natural features and human activities affect the quality of streams and ground water, and where are those effects most pronounced? By combining information on water chemistry, physical characteristics, stream habitat, and aquatic life, the NAWQA Program aims to provide science-based insights for current and emerging water issues. NAWQA results can contribute to informed decisions that result in practical and effective water-resource management and strategies that protect and restore water quality.

Since 1991, the NAWQA Program has implemented interdisciplinary assessments in more than 50 of the Nation's most important river basins and aquifers, referred to as Study Units. Collectively, these Study Units account for more than 60 percent of the overall water use and population served by public water supply, and are representative of the Nation's major hydrologic landscapes, priority ecological resources, and agricultural, urban, and natural sources of contamination.

Each assessment is guided by a nationally consistent study design and methods of sampling and analysis. The assessments thereby build local knowledge about water-quality issues and trends in a particular stream or aquifer while providing an understanding of how and why water quality varies regionally and nationally. The consistent, multi-scale approach helps to determine if certain types of water-quality issues are isolated or pervasive, and allows direct comparisons of how human activities and natural processes affect water quality and ecological health in the Nation's diverse geographic and environmental settings. Comprehensive assessments on pesticides, nutrients, volatile organic compounds, trace metals, and aquatic ecology are developed at the national scale through comparative analysis of the Study-Unit findings.

The USGS places high value on the communication and dissemination of credible, timely, and relevant science so that the most recent and available knowledge about water resources can be applied in management and policy decisions. We hope this NAWQA publication will provide you the needed insights and information to meet your needs, and thereby foster increased awareness and involvement in the protection and restoration of our Nation's waters.

The NAWQA Program recognizes that a national assessment by a single program cannot address all water-resource issues of interest. External coordination at all levels is critical for a fully integrated understanding of watersheds and for cost-effective management, regulation, and conservation of our Nation's water resources. The Program, therefore, depends extensively on the advice, cooperation, and information from other Federal, State, interstate, Tribal, and local agencies, non-government organizations, industry, academia, and other stakeholder groups. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch
Associate Director for Water

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CONVERSION FACTORS, VERTICAL DATUM, AND ACRONYMS

Multiply	By	To obtain
acre	0.4047	hectare
acre-foot	1,233.4818	cubic meter
acre-inch	102.7903	cubic meter
foot	0.3048	meter
inch	2.54	centimeter
mile	1.609	kilometer
pound avoirdupois	0.4536	kilogram
square mile	2.590	square kilometer
ton	0.9072	megagram

Abbreviated water-quality units in this report: Chemical concentrations are in metric units. Chemical concentrations are in milligrams per liter (mg/L) and micrograms per liter (µg/L). Milligrams per liter expresses the concentration of chemical constituents in solution as weight (milligrams) or solute per unit volume (liter) of water. Micrograms per liter expresses the concentration of chemical constituents in solution as weight (micrograms) or solute per unit volume (liter) of water. For concentrations less than 7,000 mg/L, the numerical value of milligrams per liter is the same as for concentrations in part per million.

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

ACRONYMS

CDPHE	Colorado Department of Public Health and Environment
CSCD	Center Soil Conservation District
CSU	Colorado State University
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act of 1947
FQPA	Food Quality Protection Act of 1996
MCL	Maximum contaminant level
mg/L	Milligrams per liter
µg/L	Micrograms per liter
NAWQA	National Water Quality Assessment Program
NRCS	Natural Resources Conservation Service
RGWCD	Rio Grande Water Conservation District
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WWII	World War II

Nitrate Concentrations, 1936-99, and Pesticide Concentrations, 1990-99, in the Unconfined Aquifer in the San Luis Valley, Colorado

By **Robert W. Stogner, Sr.**

ABSTRACT

The first documented analysis of nitrate concentrations for ground water in the unconfined aquifer was done in 1936.This valleywide investigation indicated that nitrate concentrations were 0.3 milligram per liter or less in water-quality samples from 38 wells completed in the unconfined aquifer. A valleywide study conducted in the late 1940's documented the first occurrences of nitrate concentrations greater than 3 mg/L. Up to this time, soil fertility was maintained primarily through the use of cattle and (or) sheep manure and crop rotation. Subsequent valleywide studies have documented several occurrences of elevated nitrate concentrations in the unconfined aquifer in a localized, intensively cultivated area north of the Rio Grande. The nitrate concentrations in water appear to have changed in response to increasing use of commercial inorganic fertilizers after the mid-1940's.

A 1993 valleywide study evaluated the potential health risk associated with elevated nitrate concentrations in domestic water supplies. Water-quality samples from 14 percent of the wells sampled contained nitrate concentrations greater than 10 milligrams per liter. Most of the samples that contained concentrations greater than 10 milligrams per liter were collected from wells located in the intensively cultivated area north of the Rio Grande.

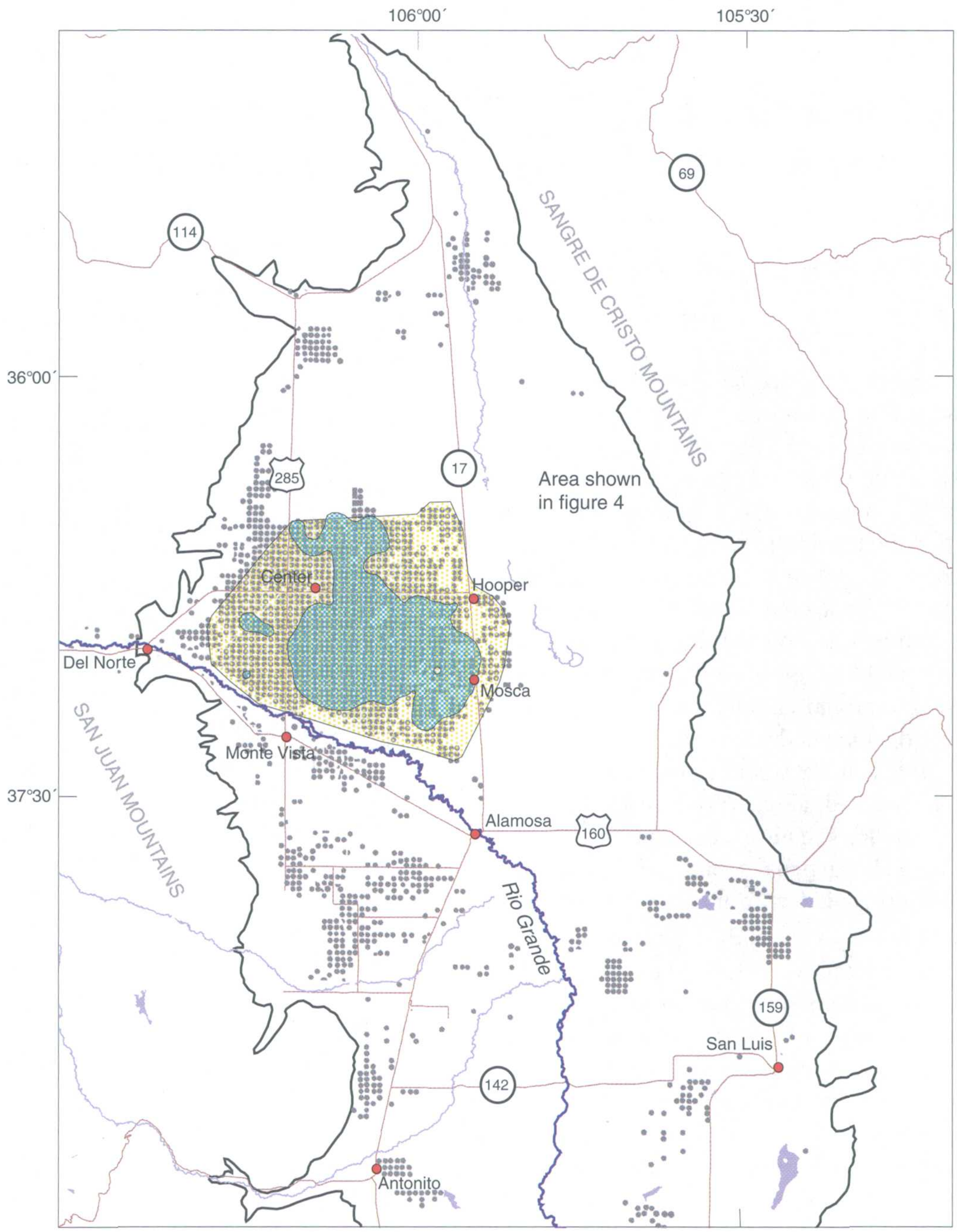
During the 1990's, several local, small-scale, and field-scale investigations were conducted in the intensively cultivated area north of the Rio Grande. These studies identified spatial and temporal variations in nitrate concentration and evaluated the effectiveness of using shallow monitoring wells to determine nitrate leaching. Variations in nitrate concentration were attributed, in part, to seasonal recharge of the aquifer by surface water with low nitrate concentrations. Shallow monitoring wells were effective for determining the amount of nitrate leached, but because of the amount of residual nitrate in the soil from previous seasons, were ineffective in evaluating variations in the amount of nitrate leaching associated with differences in application rates. It was concluded that irrigation practices have the greatest effect on leaching of nitrate to the aquifer. Management tools, such as irrigation scheduling, center-pivot sprinkler systems, soil and ground-water nitrogen credits, and cultivation of cover and winter crops, are being used to help maintain crop quality and yields while minimizing the potential of leaching and reducing residual nitrogen left in the soil.

Review of available data from previous studies indicates that most of the sampled wells with elevated nitrate concentrations are located in the intensively cultivated area north of the Rio Grande. This area represents about 10 percent of the San Luis Valley and approximately 35 percent of the crop and pasture land in the valley. The area where nitrate concentrations exceed the U.S. Environmental Protection Agency drinking water maximum contaminant level represents about 150 square miles or 5 percent of the valley.

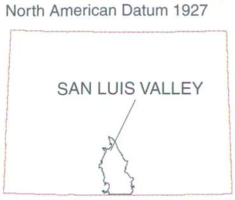
Aquifer vulnerability to and contamination by pesticides was not evaluated until the 1990's. Risk analyses indicated that selected pesticides can pose a contamination threat to an unconfined aquifer in areas consisting primarily of sandy loam soil; sandy loam soils are common in the San Luis Valley. Water-quality samples collected from some wells during 1990 and 1993 indicated trace- to low-level pesticide contamination. The occurrence of pesticides was infrequent and isolated.

INTRODUCTION

The San Luis Valley, which lies within the Rio Grande Basin, is a high, arid valley in south-central Colorado (fig. 1) bounded by the Sangre de Cristo Mountains to the east and the San Juan Mountains to the west. The valley has an average altitude of about



Base modified by Denver Water, 1998.
From U.S. Geological Survey Digital Line Graphs 100,000, 1982.
Roads and cities from Colorado Department of Transportation, 1998.
Universal Transverse Mercator, Zone 13, units feet.
North American Datum 1927



COLORADO

EXPLANATION

- SPRINKLER-IRRIGATED AGRICULTURE
- NITRATE CONCENTRATION--Shows approximate area of nitrate concentration greater than 3 milligrams per liter as nitrogen
- NITRATE CONCENTRATION--Shows approximate area of nitrate concentration greater than 10 milligrams per liter as nitrogen
- — BOUNDARY OF SAN LUIS VALLEY

Figure 1.--Location of San Luis Valley, irrigated land, and identified area of elevated nitrate concentrations in the San Luis Valley.

7,700 feet and an approximate area of 3,200 square miles. Land use in the valley is predominantly rangeland (about 60 percent) and agriculture (about 30 percent). Irrigated agriculture has been used since at least the 1630's when Spanish settlers arrived (Hearne and Dewey, 1988). Agriculture in the valley relies heavily on surface-water diversion and the unconfined aquifer to supply water for irrigation. Several studies evaluating the quality of water in the unconfined aquifer (Scofield, 1938; Powell, 1958; Emery and others, 1973; Edelmann and Buckles, 1984) have identified areas where the water quality in the unconfined aquifer has changed. The San Luis Valley is the northern part of the Rio Grande study unit of the U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) Program.

This report summarizes nitrate concentrations during 1936-99 and pesticide concentrations during 1990-99 in the unconfined aquifer of the San Luis Valley. In addition, the report provides a brief summary of water development and agricultural practices in the valley and describes possible improvements to agricultural practices.

Hydrologic Setting

Surface-water runoff from the surrounding mountains and ground water are important sources of water in the San Luis Valley. The primary aquifers in the valley are composed of several thousand feet of interbedded clay, silt, sand, gravel, and volcanic rock (Hearne and Dewey, 1988). The two main aquifers, the confined and unconfined aquifers, are separated by a confining layer. This confining layer, which underlies a large part of the center of the valley, consists of a series of discontinuous clay beds and volcanic rocks. The top of the confining layer varies from 50 to 120 feet below land surface. Recharge to the underlying confined aquifer occurs along the margins of the San Luis Valley from infiltration of runoff and inflow of ground water from the adjacent mountains. Water in the confined aquifer is used primarily for domestic and municipal water supplies. Recharge to the overlying unconfined aquifer is from infiltration of precipitation, surface water from streams and irrigation canals, and irrigation water applied to crops; inflow of ground water from adjacent mountains; and upward leakage of ground water from the confined aquifer. Water in the shallow, unconfined aquifer is used primarily for agriculture.

Water Development and Agricultural Practices

Irrigated acreage remained small until the 1880's when the present network of large canals and irrigation structures that divert water from the Rio Grande was constructed (Sarason, 1998). The demand for water was so great that by the 1890's all available natural flow of the Rio Grande and its tributaries was diverted for irrigation (Sarason, 1998). By 1900, approximately 1,800 miles of canals and ditches existed (U.S. Department of Agriculture Soil Conservation Service, 1969). Since 1900, most development of canals and ditches has been limited to improvements in existing structures (U.S. Department of Agriculture Soil Conservation Service, 1969).

Historically, crops were irrigated by flood irrigation, which diverts water from ditches into the furrows or field. The water moves along the furrows or across the field and infiltrates the ground. The porous nature of the soil in the San Luis Valley made conveyance of water across fields difficult and resulted in high rates of water loss and uneven rates of irrigation. Because of the porous nature of the soil, however, irrigators found they could store water in the subsoil for use during drier periods of the year.

The large amounts of infiltration from flood irrigation resulted in a higher water table in the unconfined aquifer compared to preirrigation levels. Prior to irrigation, the water table of the unconfined aquifer beneath the Rio Grande alluvial fan was reportedly 50 to 100 feet below land surface (Powell, 1958). The Rio Grande fan extends from near Del Norte southeast to near Alamosa, east to near Mosca and Hooper, and to the northeast north of Hooper. Infiltration of irrigation water brought the water table to within 1 to 3 feet of land surface and within reach of crops (Siebenthal, 1910; Sarason, 1998). Subirrigation or maintaining the water table 1 to 3 feet below land surface became a common method of irrigating crops.

The first irrigation well to pump water from the unconfined aquifer was reportedly installed in 1903 (Powell, 1958). For the purpose of this report, wells completed in the unconfined aquifer above the confining unit are hereafter referred to as shallow wells. Few, if any, additional shallow irrigation wells were installed in the valley until the severe droughts of the 1930's and 1950's forced farmers to augment surface-water supplies with ground water from the shallow unconfined aquifer (Powell, 1958; Sarason, 1998). For the next 50 years, the number of irrigation wells increased dramatically: 176 by 1936; 1,300 by 1952; and more than 2,300 by 1980 (fig. 2) (Powell, 1958; Ralph Curtis, Rio Grande Water Conservation District, written commun., 1999). As the number of pumped wells increased, maintaining high water levels in the unconfined aquifer became increasingly difficult and, by the late 1960's, subirrigation was no longer viable. A moratorium was placed on the installation of new high-capacity wells in the unconfined aquifer by the Colorado State Engineer in 1981 (Ralph Curtis, Rio Grande Water Conservation District, oral commun., 1999). The first center-pivot sprinkler system was installed in the early 1960's (Ralph Curtis, oral commun., 1999) (fig. 2). The center-pivot sprinklers permitted farmers to better manage the application of irrigation water. By 1990, almost 2,000 sprinkler systems were in operation (fig. 2).

The methods used by farmers to manage and maintain soil fertility and field production began to change around the end of World War II (WWII). Prior to and shortly after WWII, most farms were family farms of 160 acres or less. Soil fertility and field productivity were managed through 40-acre crop rotations and the use of cattle and (or) sheep manure as a soil amendment. For example, potatoes were usually grown for two consecutive seasons on 40 of the 160 acres, followed by a small grain crop. The stubble of the small grain would not be tilled into the soil after harvest, providing cover to establish sweet clover or alfalfa, which was grown for 2 to 6 years. Cattle and, more commonly, sheep grazed on the parcel during these extended periods. As one 40-acre parcel was removed from crop production, another was returned. These practices allowed farmers to maintain sizable cattle and (or) sheep herds and field productivity without the widespread use of commercial inorganic fertilizers (Jim Sharkoff, U.S. Department of Agriculture, San Luis Valley Demonstration Project, written commun., 1997; Ralph Curtis, oral commun., 1999). After WWII, farmers began using commercial inorganic nitrogen fertilizer (Alexander and Smith, 1990) (fig. 3) and the size of the average farm also began to increase. The use of commercial inorganic nitrogen fertilizer steadily increased between 1955 and the early 1960's. Beginning in the mid-1960's the annual use of inorganic nitrogen fertilizer increased dramatically.

Acknowledgments

Special thanks are extended to Ralph Curtis (Rio Grande Water Conservation District), Maya terKuile (AGRO Engineering, Inc.), and Kirk Thompson (AGRO Engineering, Inc.) for assistance during the research and preparation of this report. Their insight and historical accounts were most helpful.

NITRATE CONCENTRATIONS, 1936-99

In this report, nitrate concentrations refer to dissolved nitrate as nitrogen. Elevated nitrate concentrations are defined as those greater than a background concentration of 3 milligrams per liter (mg/L). The 3-mg/L value was determined on the basis of early water-quality data collected by Scofield (1938) and Powell (1958) and precipitation chemistry data (National Atmospheric Deposition Program/National Trends Network, accessed June 22, 2000) and agrees with the background concentration defined by Madison and Brunett (1985). Elevated nitrate concentrations indicate areas where the water quality may have been altered as a result of human activities.

The first documented analyses of water-quality samples for nitrate were provided by Scofield (1938) as part of the Rio Grande Joint Investigation. During this investigation, water-quality samples were collected from 38 shallow wells with depths ranging from 6 to 110 feet below land surface, averaging about 30 feet below land surface. Nitrate concentrations were 0.3 mg/L or less. Scofield's investigation was conducted during a period when soil fertility was maintained by the use of legumes and livestock manure and prior to the use of commercial fertilizers.

The water quality in the unconfined aquifer appears to change in response to increasing use of commercial inorganic fertilizers. During 1940-50, Powell (1958) collected water-quality samples from 111 shallow wells with total depths ranging from 3.5 to 110 feet below land surface, averaging about 19 feet below land surface. During April 1946, the first documented occurrence of elevated nitrate, 3.2 mg/L, occurred in a water-quality sample collected from the unconfined aquifer. From 1946 through 1950, Powell collected water-quality samples from six wells (5 percent) containing nitrate concentrations that ranged from 3.2 to 27 mg/L. These wells were dispersed and represented isolated occurrences of elevated nitrate concentrations in water from the unconfined aquifer; wells containing water with nitrate concentrations less than 3 mg/L were located between the wells containing water with nitrate concentrations greater than 3 mg/L.

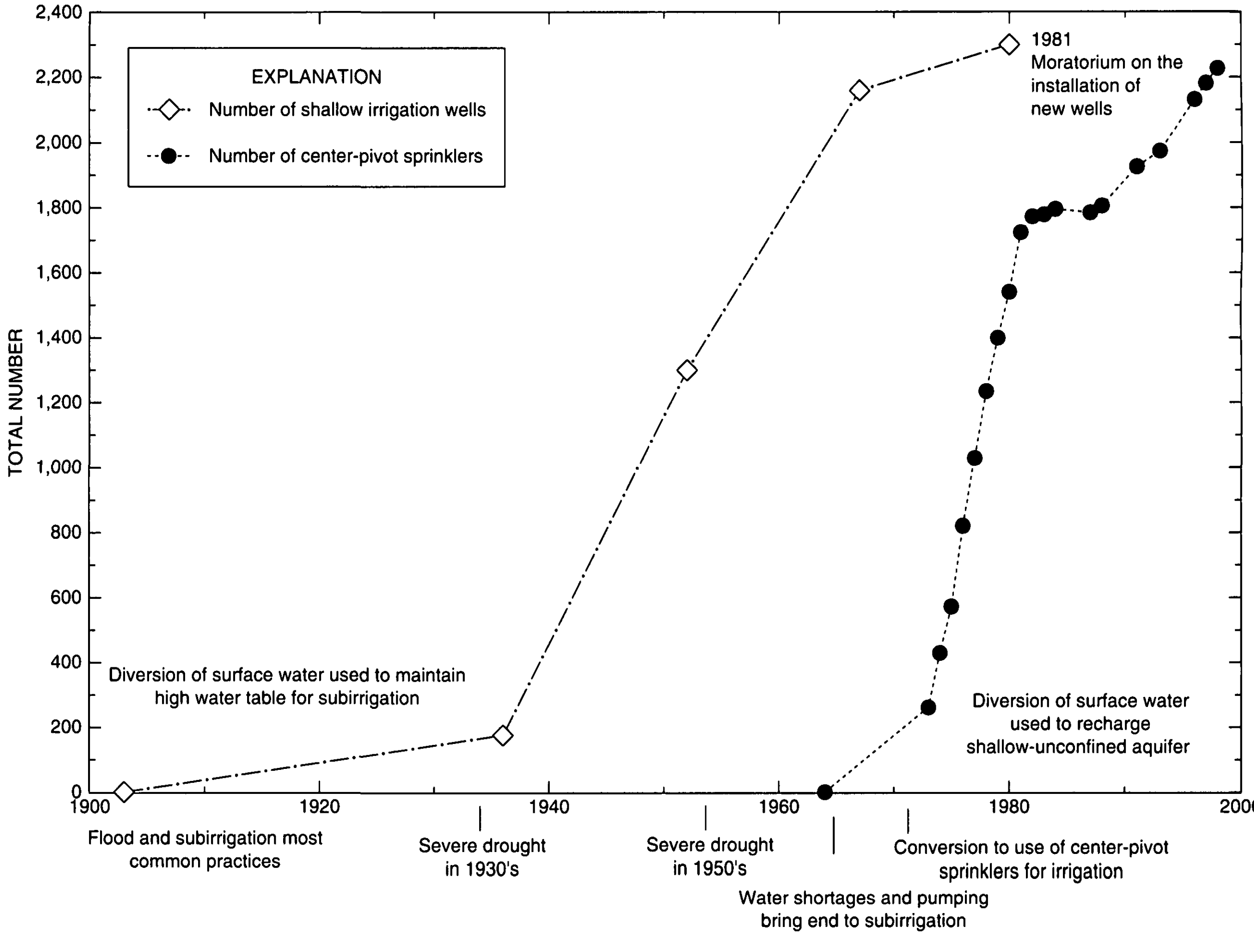


Figure 2.--Timeline of changes in irrigation practices in the San Luis Valley.

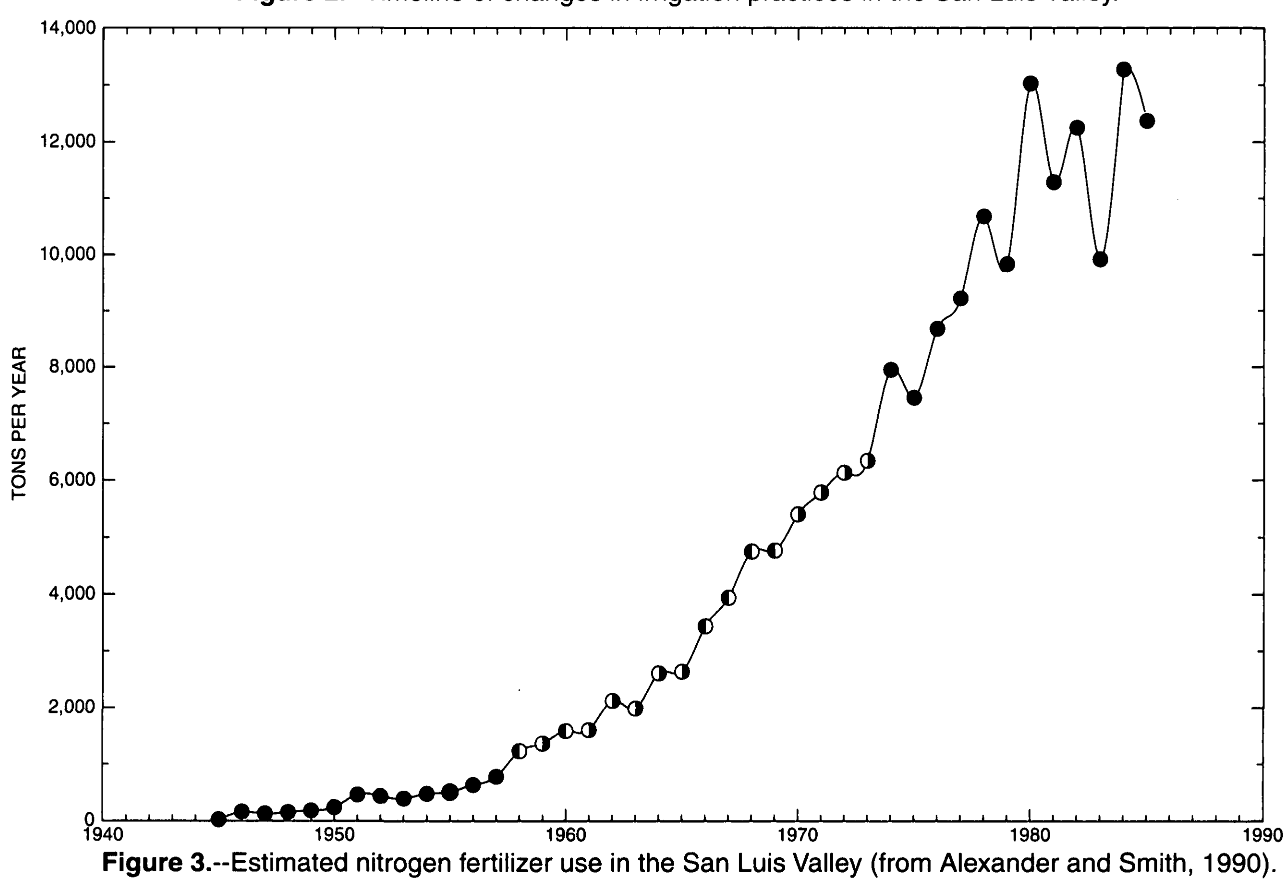


Figure 3.--Estimated nitrogen fertilizer use in the San Luis Valley (from Alexander and Smith, 1990).

The occurrence and magnitude of elevated nitrate concentrations in the unconfined aquifer increased between 1950 and 1968-69 when Emery and others (1972) collected water-quality samples from 207 shallow wells. Samples from 52 wells (25 percent) contained nitrate concentrations ranging from 3.2 to 31 mg/L. This was the first investigation to identify a localized area north of the Rio Grande with elevated nitrate concentrations in the unconfined aquifer. Edelmann and Buckles (1984) observed a similar nitrate distribution in the unconfined aquifer north of the Rio Grande. In 1981, 23 of 57 water-quality samples (40 percent) collected from shallow wells contained nitrate concentrations ranging from 3.6 to 46 mg/L.

The increase in frequency and magnitude of elevated nitrate concentrations in ground-water samples collected from wells completed in the unconfined aquifer from 1946 to 1981 and the lack of information concerning pesticide contamination led to a series of water-quality studies in the 1990's. These studies were conducted by local, State, and Federal agencies and (or) various combinations of the agencies. With the exception of a few studies (Austin, 1993; Anderholm, 1996), the focus of studies in the 1990's changed from large-scale, valleywide studies to small-scale, local, and field-scale studies.

The types of wells used in the studies also began to change as shallow observation wells completed in the upper few feet of the unconfined aquifer were replaced by domestic wells and high-capacity production wells used for center-pivot sprinkler systems. Sampling larger and deeper wells allowed investigators to assess potential health risks associated with drinking water from the unconfined aquifer as a whole and to evaluate the ground-water chemistry of a large part of the unconfined aquifer instead of the upper few feet.

The Colorado Department of Health and Environment (CDPHE) (Austin, 1993) collected water-quality samples from 93 domestic wells completed in the unconfined aquifer throughout the valley to evaluate the potential human health risk associated with elevated nitrate concentrations in domestic water supplies. Nitrate concentrations greater than 3 mg/L were detected in water-quality samples from 32 of the 93 wells (34 percent). Water-quality samples from 13 wells (14 percent) had nitrate concentrations that exceeded the U.S Environmental Protection Agency (USEPA) drinking water maximum contaminant level (MCL) of 10 mg/L (U.S. Environmental Protection Agency, 1996). Most of the water-quality samples that contained concentrations exceeding the MCL were collected from wells in the intensively cultivated area north of the Rio Grande. These results indicate that some rural domestic water supplies may present a potential human health risk associated with the elevated nitrate concentrations.

During the summer of 1993, the USGS collected water-quality samples for nitrate analysis from 35 shallow water-quality monitoring wells completed near the top of the water table. Samples collected from 17 of the wells (49 percent) contained nitrate concentrations ranging from 3.0 to 58 mg/L; water-quality samples from 11 of these 17 wells had nitrate concentrations greater than the 10-mg/L USEPA drinking water MCL. Most of the elevated nitrate concentrations were in samples collected in the intensively cultivated area north of the Rio Grande.

Eddy-Miller (1993) evaluated shallow monitoring wells as a means of detecting leaching of nitrate to the unconfined aquifer. Monitoring wells screened at the water table were installed in seven adjacent agricultural tracts. Fertilizer applications varied from 0 to 85 pounds of nitrate as nitrogen per acre in the different tracts. In addition to the fertilizer, approximately 49 pounds of nitrate as nitrogen per acre were applied as a result of the application of irrigation water. Water-quality samples were collected weekly for nitrate analysis, and soil samples were collected at the beginning and end of the agricultural season. Nitrate concentration in the weekly water-quality samples ranged from 12 to 75 mg/L. Nitrate in the soil ranged from 10 to 20 pounds of nitrate as nitrogen at the beginning of the season per acre, but ranged from 2 to 8 pounds of nitrate as nitrogen per acre at the end of the season. Initial soil nitrate concentrations were determined to have the greatest effect on ground-water nitrate concentrations during the study period. Shallow monitoring wells were considered effective for determining the amount of nitrate leached, but because of the amount of nitrate in the system, nitrate data collected from shallow monitoring wells were ineffective in evaluating differences between fertilizer application rates.

Spatial and seasonal variations in nitrate concentration were evaluated by Thompson (1993), Thompson and Loftis (1995), and Stogner (1997). Nitrate concentrations were highly variable from well to well and within individual wells from one sampling period to another. Variations were attributed, in part, to seasonal recharge of the aquifer by surface water with low nitrate concentrations. Thompson and Loftis (1995) concluded that irrigation practices have the greatest effect on leaching of nitrate to the aquifer.

Nitrate sources were evaluated during August 1994 and August 1995 (Stogner, 1997). Samples were collected from 16 shallow water-quality monitoring wells and analyzed for nitrogen isotopes. Evaluation of nitrate sources indicates that commercial inorganic fertilizers and not organic nitrogen sources (for example, animal waste) likely are the primary source of nitrate in the shallow aquifer in the agricultural area north of the Rio Grande.

In 1997 the USGS began a long-term study, in cooperation with the Rio Grande Water Conservation District (RGWCD) and the Center Soil Conservation District (CSCD). The study focused on the 450-square-mile intensively cultivated area north of the Rio Grande (fig. 1). Farmers in the area rely almost exclusively on ground water for irrigation of potatoes, barley, and other grains, alfalfa, and vegetables.

During June 1997, water-quality samples were collected from 64 irrigation wells. Nitrate concentrations ranged from 0.2 to 34 mg/L. Samples from 54 wells contained nitrate concentrations greater than 3 mg/L, and samples from 27 wells exceeded the USEPA drinking water MCL of 10 mg/L.

The network was expanded to 114 wells in 1998 and to 123 wells in 1999. Nitrate concentrations ranged from 0.2 to 51 mg/L during June 1998 and ranged from the detection level of 0.05 to 55 mg/L during June 1999. Of the 114 wells sampled during June 1998, samples collected from 90 wells contained nitrate concentrations greater than 3 mg/L and samples from 54 wells exceeded the USEPA drinking water MCL. Of the 123 wells sampled during June 1999, samples collected from 95 wells contained nitrate concentrations greater than 3 mg/L and samples from 59 of these wells exceeded the USEPA drinking water MCL.

Review of available data from previous studies indicates that most of the sampled wells with elevated nitrate concentrations are located in the intensively cultivated area north of the Rio Grande (fig. 1). This area represents about 10 percent of the San Luis Valley and approximately 35 percent of the crop and pasture land in the valley. The area where nitrate concentrations exceed the USEPA drinking water MCL represents about 150 square miles or 5 percent of the valley.

PESTICIDE CONCENTRATIONS, 1990-99

Pesticides are defined as chemicals used to kill or control insect, plant, rodent, fungi, bacteria, or other pests (Turner, 1996). Environmental characteristics such as soil characteristics, precipitation, and temperature; pesticide handling and management; accidental spillage or improper disposal; chemical properties such as water solubility and adsorption to soil particles; and irrigation rate may influence pesticide transport to the unconfined aquifer and the degree of ground-water contamination.

The occurrence of pesticides in water from the unconfined aquifer in the San Luis Valley was not evaluated until 1990. In 1990, Colorado State University (CSU), in cooperation with the CDPHE, began a study to evaluate regional pesticide contamination of the unconfined aquifer and assess the vulnerability of the unconfined aquifer to pesticide contamination (Durnford and others, 1990). Thirty-four irrigation wells were selected for sampling, and 30 of the wells were located in the intensively cultivated area north of the Rio Grande (fig. 1). Water-quality samples were collected in June and August and analyzed for 16 pesticides. Trace- to low-level concentrations of one or more pesticides (Bravo; Sencor; Eptam; 2,4-D) were detected in five wells (15 percent) sampled during June and 10 wells (29 percent) sampled during August. The detections were believed to represent either isolated contamination of the unconfined aquifer or sample contamination, not a widespread degradation of water quality in the unconfined aquifer (Durnford and others, 1990).

In 1991, CSU conducted field-scale studies to evaluate transport of pesticides through the soil (Ellerbroek and others, 1992). Pesticides were applied to two actively farmed fields in early June, and soil and ground-water samples were collected during July, August, and September. Pesticides were not detected in soil samples deeper than 9 inches below ground surface, and concentrations decreased during the season in soil samples collected from depths less than 9 inches below ground surface. However, pesticides were detected in water-quality samples collected from wells located in one field. This detection indicates macropore flow, which is flow within large open spaces in the soil (Steila and Pond, 1989). Pesticides were not detected in water-quality samples collected 3 months after their application.

Depending on the depth of the well, placement of the screened interval, well construction, and proximity to and characteristics of potential contaminants, domestic wells can vary in their potential risk of contamination from surface sources. The first study to specifically address potential health risks related to consumption of water from the unconfined aquifer was conducted by the CDPHE (Austin, 1993). Between May and August 1993, the CDPHE collected water-quality samples from 93 domestic wells in the San Luis Valley. Of these, samples from three wells had detectable pesticide concentrations of either 2,4-D or hexazinone, both herbicides, or lindane, an insecticide. The 2,4-D and hexazinone concentrations were less than quantifiable detection levels and estimated to be about 0.2 microgram per liter (µg/L). The concentration of lindane (0.29 µg/L) was greater than the USEPA drinking water MCL of 0.2 µg/L (U.S. Environmental Protection Agency, 1996).

In 1993, the USGS, as part of its NAWQA Program, installed 35 shallow, water-quality monitoring wells throughout the San Luis Valley (Anderholm, 1996). These wells were screened at the water table, and samples collected from them should reflect water quality of recent recharge to the aquifer. Analysis of water-quality samples collected from these wells during the summer of 1993 indicated that four wells had trace amounts of selected pesticides. More specifically, samples from three wells had metribuzin with estimated concentrations ranging from 0.005 to 0.017 µg/L; a sample from one well had a prometon concentration of 0.01 µg/L; and a sample from one well had a metolachlor concentration of 0.072 µg/L. These four wells were located in the intensively irrigated area north of the Rio Grande. A water-quality sample from one well, located in the southern part of the valley near Antonito, contained a trace amount of the pesticide p,p'-DDE, with an estimated concentration of 0.002 µg/L.

Although the USEPA has not established MCL's for any of the four pesticides detected in ground water in the valley, lifetime health advisory concentrations of 100 µg/L have been established for metribuzin, prometon, and metolachlor (U.S. Environmental Protection Agency, 1996). Metribuzin, prometon, and metolachlor concentrations detected in water-quality samples collected from the unconfined aquifer are significantly lower than lifetime health advisory concentrations, and there was no spatial consistency in the occurrence of the pesticides.

POSSIBLE IMPROVEMENTS TO AGRICULTURAL PRACTICES

Organizations such as the San Luis Valley Water Quality Demonstration Project (San Luis Valley Demonstration Project, 1996a,b); U.S. Department of Agriculture Natural Resources Conservation Service (formerly the Soil Conservation Service); Colorado State University Cooperative Extension (1994); private organizations such as AGRO Engineering, Inc.; advisory groups composed of local producers, ranchers, industry consultants, agrichemical field men, and San Luis Valley Demonstration Project personnel (Ristau, 1996); and local ranchers, farmers, and producers have been instrumental in the development, testing, and promotion of water and agrichemical management strategies and tools applicable in the San Luis Valley. Periodic conferences, seminars, and field demonstrations have been held to disseminate information on improved agricultural practices to local farmers and producers.

Pesticides are federally regulated. Legislation such as the Insecticide Act of 1910; the Federal Insecticide, Fungicide, and Rodenticide Act of 1947 (FIFRA); the Federal Environmental Pesticide Act of 1972; as well as others cover registration, sale, transport, and use of pesticides. Recent regulations such as the Food Quality Protection Act of 1996 (FQPA) have been adopted to update and resolve inconsistencies in previous legislation. In the San Luis Valley, the agricultural community has been working with universities and pesticide producers to develop and test products that meet pesticide regulations and address local pest control concerns. Management strategies include seed selection, field monitoring to identify and quantify insect and (or) weed infestations, soil microbe analysis, and appropriate pesticide application (San Luis Valley Demonstration Project, 1996a,b).

Overapplication of irrigation water can result in leaching of agrichemicals below the root zone and to the water table. Center-pivot sprinkler systems and associated wells that are completed in the shallow, unconfined aquifer are the predominant form of irrigation. This system of irrigation provides a more uniform and efficient means of irrigation than surface systems, minimizing overapplication and maximizing net return (Cardon, 1998). Tools, such as computer support software (Dillon, 1999), and management bulletins (Colorado State University Cooperative Extension, 1994) have been developed to help farmers and ranchers manage and protect water resources while maximizing crop production. Irrigation scheduling is probably the most important management tool available to maintain crop quality and yields while minimizing the potential for leaching of agrichemicals to the unconfined aquifer (Cardon, 1998; Thompson, 1998).

Nitrogen management tools and strategies developed and promoted include use of computer support software, use of soil and ground-water nitrogen credits (Sharkoff and Riggenbach, 1997), and use of cover and winter crops (Colorado State University Cooperative Extension, 1994). Computer support software can be used to evaluate nitrogen management practices on nitrate leaching (Jim Sharkoff, National Resources Conservation Service, written commun., 1995). Nitrogen crediting accounts for the nitrogen available in ground water used for irrigation and in the soil when determining the annual nitrogen budget for a particular crop. Cultivation of cover and winter crops protects the soil during early spring crop development or during the winter off-season and can be a means of utilizing and reducing residual nitrogen left in the soil after the preceding agricultural season.

Information from the USGS study that began in 1997 can be used to estimate nitrogen credits from ground water (eq. 1). On the basis of analysis of water-quality samples collected during 1999 and incorporation of the nitrogen in ground water (nitrogen credit) as a component of nitrogen management, farmers can theoretically decrease nitrate fertilizer applications in some areas by as much as 9 pounds per acre-inch of applied irrigation water (fig. 4). By incorporating the nitrogen credits for irrigation water, farmers can theoretically reduce fertilizer applications by 50 to 70 pounds per acre per year depending on crop type and irrigation-water requirements.

$$C = N \times 0.2266 \quad (1)$$

where C = nitrogen credit, in pounds per acre-inch of applied irrigation water,

N = nitrate concentration, in milligrams per liter, and

0.2266 = factor for converting milligrams per liter to pounds per acre-inch.

Advancements in technology such as Geographic Information Systems and Global Positioning Systems have been important and integral components of change in agricultural practices during the 1990's. This technology allows researchers to properly locate and map variations in environmental variables such as quantity and quality of water and soil characteristics. Farmers can accurately locate and map variations in soil and crop characteristics at individual farms, then vary application rates of seed, fertilizer, water, and agrichemicals (Austin, 1993; Jones, 1997).

SUMMARY

Irrigated agriculture has been an integral component of life in the San Luis Valley since the 1630's. The two main aquifers, the confined and unconfined aquifers, are separated by a confining layer. Water in the shallow, unconfined aquifer is used primarily for agriculture. With the increase in the population of the valley beginning in the mid- to late 1800's came increasing demands for water. Flood irrigation and subirrigation were common methods of irrigating crops. Few irrigation wells were developed in the valley until the severe droughts of the 1930's and 1950's forced farmers to augment surface-water supplies with ground water from shallow irrigation wells. The number of these shallow pumped wells increased to more than 2,300 by 1980. Surface-water shortages in the late 1960's initiated a conversion to center-pivot sprinkler systems during the 1970's. Center-pivot sprinklers permit farmers to better manage the application of irrigation water.

The use of commercial inorganic fertilizers rapidly increased between 1955 and the mid-1960's. A 1936 study provided background nitrate concentrations in the unconfined aquifer. Nitrate concentrations greater than 3 mg/L were first documented in 1946 as part of a study conducted between 1946 and 1950 that documented six spatially isolated occurrences of elevated nitrate concentrations. Subsequent studies documented several occurrences of elevated nitrate concentrations in the unconfined aquifer in a localized area north of the Rio Grande in the San Luis Valley. The water quality appears to have changed in response to increasing use of commercial fertilizers.

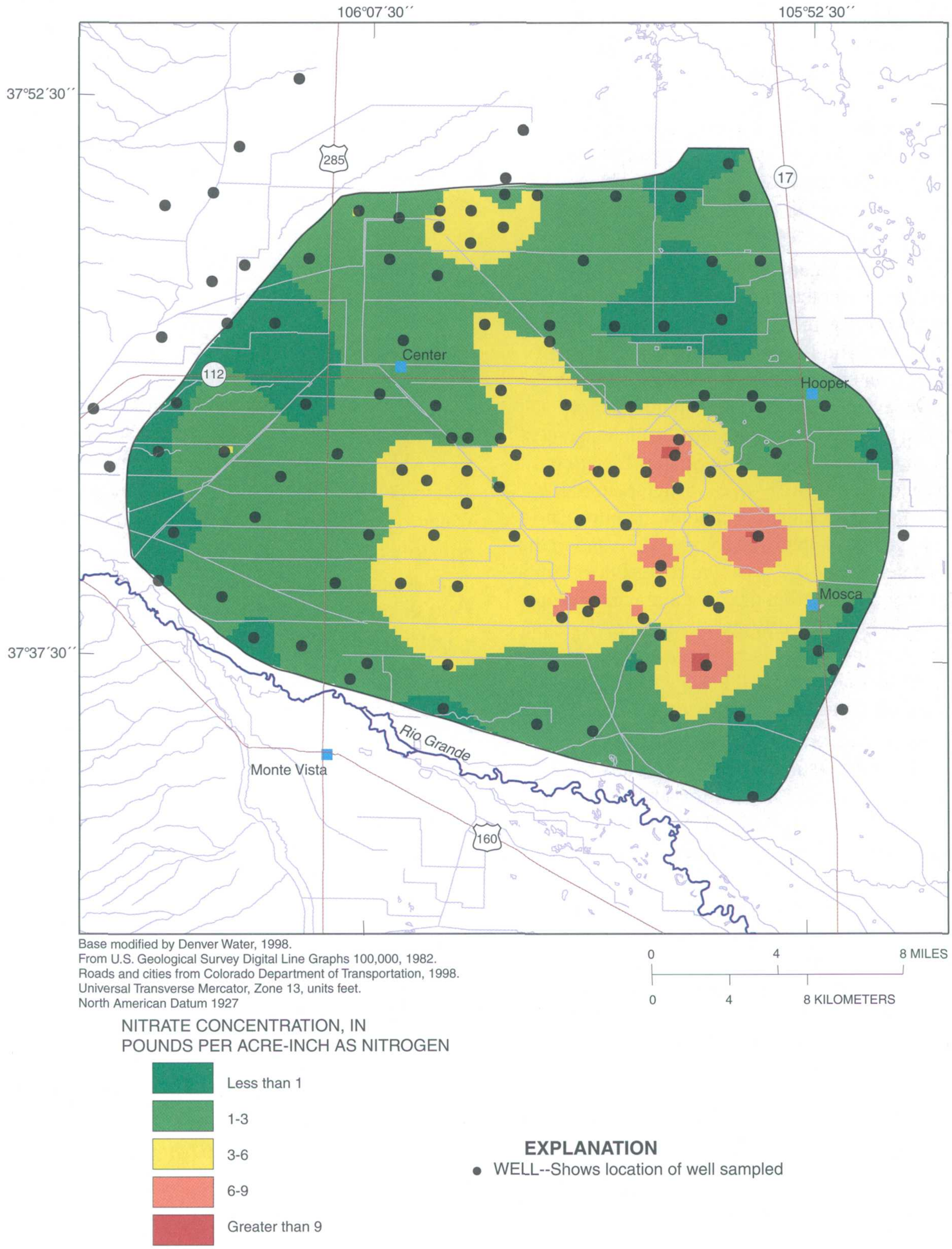


Figure 4.--Approximate distribution of dissolved nitrate, in pounds per acre-inch as nitrogen, in the unconfined aquifer in the intensively irrigated area north of the Rio Grande in the San Luis Valley, June 1999.

During 1993, a regional assessment of the potential health risk associated with elevated nitrate concentrations in domestic water supplies indicated that about 14 percent of the wells sampled had nitrate concentrations that exceeded the USEPA drinking water MCL. Most of the samples that contained concentrations exceeding the MCL were collected from wells located in the intensively cultivated area north of the Rio Grande.

During the 1990's, local, small-scale, and field-scale investigations in the intensively cultivated area north of the Rio Grande identified spatial and temporal variations in nitrate concentrations and the primary source of nitrate in the unconfined aquifer and assessed the effectiveness of shallow monitoring wells to evaluate the amount of nitrate leached under different application rates. Variations were attributed, in part, to seasonal recharge of the aquifer by surface water with low nitrate concentrations. Isotopic analysis of water-quality samples indicated that commercial inorganic fertilizers are the primary source of nitrate in the unconfined aquifer. Shallow monitoring wells were effective for determining the amount of nitrate leached, but ineffective in evaluating variations in the amount of nitrate leached associated with differences in application rates. Irrigation practices were considered to have the greatest effect on leaching of nitrate to the aquifer.

Review of available data from previous studies indicates that most of the sampled wells with elevated nitrate concentrations are located in the intensively cultivated area north of the Rio Grande. This area represents about 10 percent of the San Luis Valley and approximately 35 percent of the crop and pasture land in the valley. The area where nitrate concentrations exceed the USEPA drinking water MCL represents about 150 square miles or 5 percent of the valley.

Aquifer vulnerability to and contamination by pesticides was not evaluated until the 1990's. Analysis of soil samples collected during July, August, and September indicated that pesticides were not detected deeper than 9 inches below ground surface, and concentrations decreased during the season in soil samples collected from depths less than 9 inches below ground surface. Risk analyses indicated that selected pesticides can pose a contamination threat to an unconfined aquifer in areas consisting primarily of sandy loam soils. Water-quality samples collected from some wells during 1990 indicated trace- to low-level pesticide contamination. The occurrence of pesticides was infrequent and isolated.

Management tools, such as computer support software, irrigation scheduling, center-pivot sprinkler systems, soil and ground-water nitrogen credits, and cultivation of cover and winter crops, are being used to help maintain crop quality and yields while minimizing the potential of leaching and reducing residual nitrogen left in the soil.

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