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Ground-Water Hydrology and Water Quality of the Southern High Plains Aquifer, Melrose Air Force Range, Cannon Air Force Base, Curry and Roosevelt Counties, New Mexico, 2002-03

Scientific Investigations Report 2004-5158

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

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

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Suggested citation:
Langman, J.B., Gebhardt, F.E., and Falk, S.E., 2004, Ground-water hydrology and water quality of the Southern High Plains aquifer, Melrose Air Force Range, Cannon Air Force Base, Curry and Roosevelt Counties, New Mexico, 2002-03: U.S. Geological Survey Scientific Investigations Report 2004-5158, 42 p.

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Abbreviations

AOC	area of concern
Cannon AFB	Cannon Air Force Base
CFC's	chlorofluorocarbons
D	deuterium
δ (delta)	isotope ratio (heavy/light isotope) compared to the Vienna Standard Mean Ocean Water minus one unit ($\delta = (R_{sample}/R_{standard}) - 1$) is presented in thousands and is normalized
EOD	explosive ordnance detonation
MDL	method detection limit
MWL	Melrose Air Force Range water-level well
MWQ	Melrose Air Force Range water-quality well
µg/L	micrograms per liter
mg/L	milligrams per liter
µS/cm	microsiemens per centimeter at 25 degrees Celsius
^{18}O	oxygen-18 isotope
‰ (per mil)	thousandths
Range	Melrose Air Force Range
RCRA	Resource Conservation and Recovery Act
SWMU	solid waste management unit
USGS	U.S. Geological Survey
VSMOW	Vienna Standard Mean Ocean Water

Conversion Factors and Datum

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
in (in.)	2.54	centimeter (cm)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
	Flow rate	
gallon per minute (gal/min)	0.06309	liter per second (L/s)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32$$

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Ground-Water Hydrology and Water Quality of the Southern High Plains Aquifer, Melrose Air Force Range, Cannon Air Force Base, Curry and Roosevelt Counties, New Mexico, 2002-03

By Jeff B. Langman, Fredrick E. Gebhardt, and Sarah E. Falk

Abstract

In cooperation with the U.S. Air Force, the U.S. Geological Survey characterized the ground-water hydrology and water quality at Melrose Air Force Range in east-central New Mexico. The purpose of the study was to provide baseline data to Cannon Air Force Base resource managers to make informed decisions concerning actions that may affect the ground-water system. Five periods of water-level measurements and four periods of water-quality sample collection were completed at Melrose Air Force Range during 2002 and 2003. The water-level measurements and water-quality samples were collected from a 29-well monitoring network that included wells in the Impact Area and leased lands of Melrose Air Force Range managed by Cannon Air Force Base personnel. The purpose of this report is to provide a broad overview of ground-water flow and ground-water quality in the Southern High Plains aquifer in the Ogallala Formation at Melrose Air Force Range.

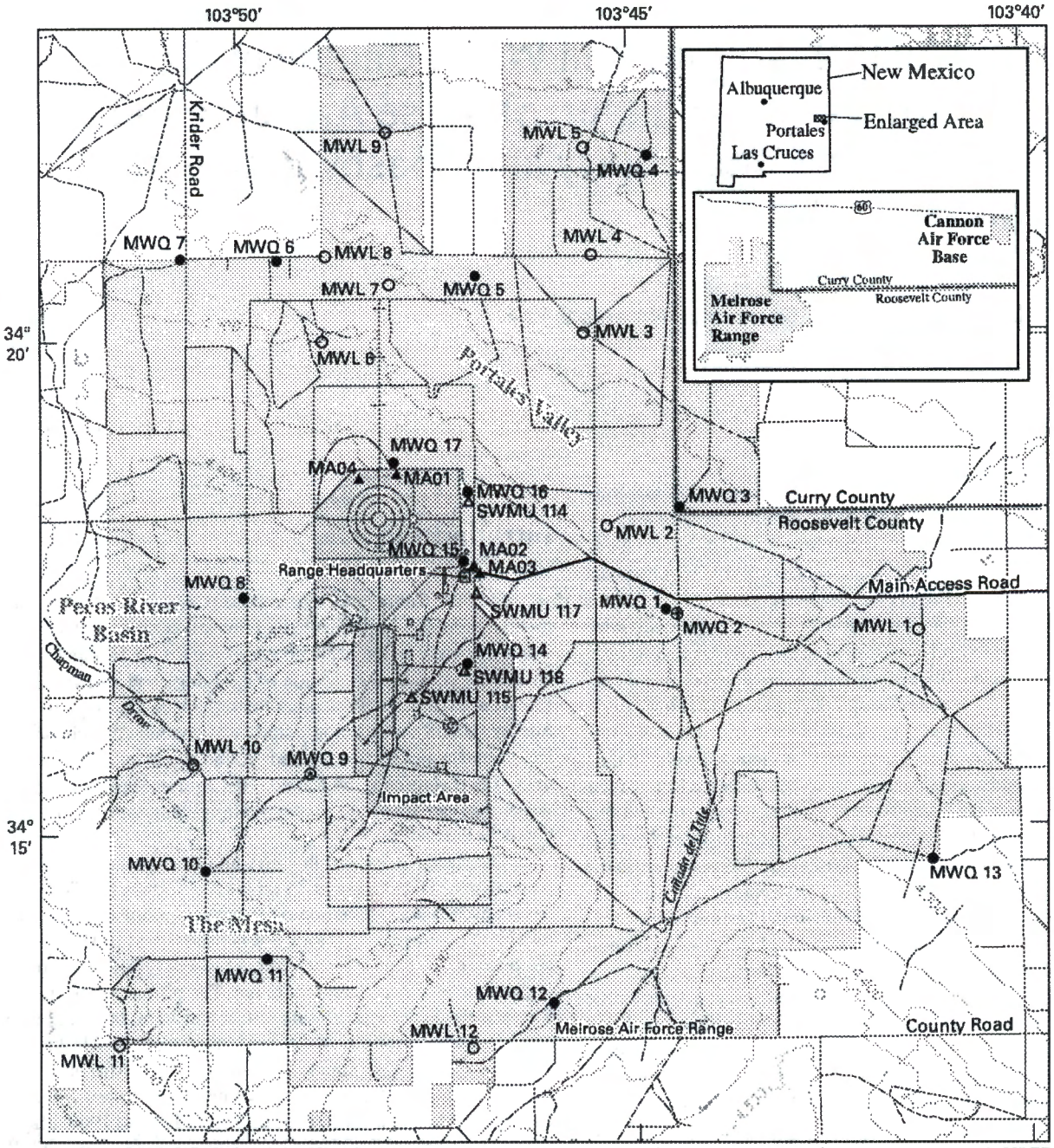
Results of the ground-water characterization of the Southern High Plains aquifer indicated a local flow system in the unconfined aquifer flowing northeastward from a topographic high, the Mesa (located in the southwestern part of the Range), toward a regional flow system in the unconfined aquifer that flows southeastward through the Portales Valley. Ground water was less than 55 years old across the Range; ground water was younger (less than 25 years) near the Mesa and ephemeral channels and older (25 years to 55 years) in the Portales Valley. Results of water-quality analysis indicated three areas of different water types: near the Mesa and ephemeral channels, in the Impact Area of the Range, and in the Portales Valley. Within the Southern High Plains aquifer, a sodium/chloride-dominated ground water was found in the center of the Impact Area of the Range with water-quality characteristics similar to ground water from the underlying Chinle Formation. This sodium/chloride-dominated ground water of the unconfined aquifer in the Impact Area indicates a likely connection with the deeper water-producing zone. No pesticides, explosives, volatile organic compounds, semivolatile organic compounds, organic halogens, or perchlorate were found in water samples from the Southern High Plains aquifer at the Range.

Introduction

In 2001, Cannon Air Force Base (Cannon AFB) environmental managers implemented an investigation to protect the water resources at the Melrose Air Force Range (Range) to ensure the continued operation of the Range and all current (2004) activities. In cooperation with the U.S. Geological Survey (USGS), a hydrologic study was conducted to characterize ground-water hydrology and ground-water quality of the unconfined aquifer at the Range. This aquifer is part of the western extension of the Southern High Plains aquifer in the Ogallala Formation.

The Range is located in Curry and Roosevelt Counties, New Mexico (fig. 1), about 25 mi west of Cannon AFB, and covers 87,925 acres (Cannon AFB owned, public domain, and restricted easement). The Range was established in 1952 and has been in use from its inception to present (2004) as a bombing and air-to-ground gunnery range. The primary user of the Range is the 27th Fighter Wing of Cannon AFB, but the Range provides support training for aircraft from bases in Alaska, Arizona, Arkansas, Colorado, Idaho, Louisiana, Missouri, North Dakota, and Texas as well as other bases in New Mexico. Live ordnance was used at the Range from 1952 to 1969, affecting an area of about 7,000 acres (Cannon Air Force Base, 2002).

The Impact Area of the Range (inner area of Range used for aircraft target practice), northeast of the landform known as "the Mesa," consists of grasslands with a grid of access roads and bombing targets (vehicles, aircraft, and artificial targets) and is defined by a historical boundary that previously delineated the extent of the entire Range (fig. 1). In 1990-91, the boundary of the Range was expanded through the acquisition of agricultural and range land parcels on all sides. These parcels (leased lands) are currently part of Range property but are leased to the prior owners for continued use as agricultural and range land. Leaseholders use the unconfined aquifer for irrigation and stock watering.



Base derived from U.S. Geological National Elevation Dataset
County line derived from U.S. Bureau of the Census

EXPLANATION

Topographic contour—Contour interval 50 feet. Vertical coordinate information is referenced to NAVD 88

MWQ 1 ●	**Water-quality and water-level well and well number**
MWL 1 ○	**Water-level well and well number**
MWQ 2 ⊗	**Well completed in Chinle Formation and well number**
MWQ 9 ⊙	**Hand-dug well with open wall construction, completed in Ogallala Formation and well number**
MA01 ▲	**Area of concern and site number**
SWMU 114 △	**Solid waste management unit and site number**

Figure 1. Location of Melrose Air Force Range, Impact Area, and monitoring wells.

The Range includes eight historical land-use sites that are under investigation as part of the Cannon AFB Environmental Restoration Program. All eight sites are no longer in use and include four solid waste management units (SWMU's) and four areas of concern (AOC's) (fig. 1). The SWMU's include three areas of solid waste burial (SWMU 114, 115, and 117) and an explosive ordnance detonation (EOD) pit (SWMU 118) that was created for treatment of unusable munitions but was never used (Cannon Air Force Base, 2002). The AOC's include a cantonment (temporary housing quarters) burial site (MA01), a helicopter pad that likely included the storage of petroleum products (MA02), a domestic waste burial site (MA03), and a munitions burial site (MA04). Range Headquarters (fig. 1) consists of various buildings and storage yards for Range operation.

Purpose and Scope

This report describes the ground-water hydrology and water quality in the Southern High Plains aquifer at the Range. The purpose is to provide Cannon AFB resource managers with reliable ground-water data and a broad overview of the ground-water system for future planning efforts to protect the aquifer and ensure continued operation of the Range and all its current (2004) activities.

A 29-well monitoring network covering the Impact Area and leased lands of the Range was used from 2002 to 2003 for water-level measurements and water-quality sample collection. All ground-water samples were analyzed for specific conductance, dissolved oxygen, turbidity, temperature, pH, dissolved solids, alkalinity, cyanide, sulfide, major ions, nutrients, organic carbon, and trace elements. Additionally, a single ground-water sample from each well was analyzed for organochlorine and organophosphorous pesticides, nitroaromatic and nitramine explosives, perchlorate, chlorofluorocarbons (CFC's), hydrogen and oxygen stable isotopes, and dissolved gases. One sample from each well in the Impact Area was analyzed for volatile organic compounds, semivolatile organic compounds, and total organic halogens. All constituents are discussed relative to their spatial and temporal distribution at the Range and not to regulatory standards. All samples were collected as "whole" water (unfiltered) samples because of the use of unfiltered water on the Range for agriculture and stock-tank supply.

Description of the Study Area

The Range is located in the Southern High Plains physiographic region (Fenneman and Johnson, 1946) and lies atop a large plateau known as the Llano Estacado that slopes gently to the east-southeast from eastern New Mexico into west Texas (Fahlquist, 2003). Range topography (excluding the Mesa) is open and mostly flat and gently slopes to the northeast. The Mesa dominates the southwest part of the Range, is a topographic high for the Range, and is part of the Western Caprock Escarpment that defines the western boundary of the Southern High Plains aquifer (Nativ, 1988). The Mesa has a plateau area of about 7,775 acres ranging in altitude from 4,600 to 4,700 ft and forms the surface basin boundary between the Pecos River Basin to the west and the Portales Valley to the east (fig. 1). No surface-water bodies are located within the Range except minor ephemeral channels including the Chapman Draw and the Cañada del Tule, which originate at the Mesa (fig. 1). The Range is located in the Plains-Mesa Grassland vegetation unit (Dick-Peddie, 1993), and vegetation consists of grasses and shrubs.

The Range is located within a semiarid region (Tuan and others, 1969). The Range area receives an average of 16.30 in. of precipitation a year; average minimum and maximum temperatures are 42.1 and 72.6 degrees Fahrenheit (Western Regional Climate Center, 2001). Most precipitation at the Range falls during the summer months (Western Regional Climate Center, 2001), and most of the precipitation is likely lost to evaporation. Annual pan evaporation at a weather station in Clovis (about 30 mi east of the Range) averages 86.64 in.; evaporation is largest from May through August (Western Regional Climate Center, 2000).

Water use at the Range is limited to stock tanks, three irrigation wells, and two domestic wells that supply the Range Headquarters. Cannon AFB personnel installed submersible pumps in wells around the Range to provide water for a system of stock tanks located on the leased lands. Pumpage is not monitored, and pumps operate according to pressure in intermediary holding tanks determined by stock-tank water levels. Pumpage is largest during the summer months when cattle require more water and higher evaporation reduces water levels in stock tanks (Kerry Hubbell, Cannon Air Force Base, oral commun., 2002). Water pumped for the stock-tank system is not treated and is fed directly into the distribution system. Two of the irrigation wells are in the northern part of the Range and the third irrigation well is in the eastern part. Two wells at Range Headquarters supply water for fire suppression and non-potable domestic supply. Water usage is not monitored but is likely small because of infrequent fire activity and a total Range personnel of about 20 people. The Range is located in an undeclared ground-water basin of the Southern High Plains aquifer in New Mexico (New Mexico Office of the State Engineer, 2004).

The geologic structure of the Southern High Plains aquifer at the Range includes the Chinle[1], Ogallala, and Blackwater Draw Formations. The Chinle Formation of Triassic age forms the base of the unconfined Southern High Plains aquifer at the Range, consists mostly of clay with some intermixed sand and silt, and ranges in thickness from 0 to 400 ft for eastern New

[1]The Chinle Formation has various accepted names: Chinle Formation, Chinle Formation of the Dockum Group, and Chinle Group (U.S. Geological Survey, 2002). All three names have been used for geologic description of areas in east-central New Mexico with usage dependent on locally identified units. Given a lack of identified units in the Range area, although this upper unit is possibly the Redonda Formation of the Chinle Group (Hester and Lucas, 2001), "Chinle Formation" is used in this report. Locally, this formation is known as the "red beds."

Mexico (McGowen and others, 1977). The Ogallala Formation of Tertiary age is the uppermost formation for the central and southern parts of the Range and lies unconformably atop the upper unit of the eastward-dipping Chinle Formation (Dutton and others, 2001). The Ogallala Formation consists of eolian sand and silt and fluvial and lacustrine sand, silt, clay, and gravel (McLemore, 2001), and can range in thickness from 30 to 600 ft in eastern New Mexico and west Texas (Gustavson, 1996).

The Blackwater Draw Formation of Quarternary age overlies the Ogallala Formation in the northern part of the Range, consists mostly of eolian sand deposits, and can range in thickness from 0 to 80 ft for eastern New Mexico (McLemore, 2001). A caliche layer is typically present in the unsaturated zone of the Blackwater or Ogallala Formations in New Mexico (Hart and McAda, 1985), buts its characteristics at the Range are unknown. Gustavson (1996) indicated that the caliche forming the Western Caprock Escarpment was pedogenic carbonate that accumulated locally during the Tertiary and Quarternary Periods and that other buried caliche layers in the Ogallala Formation are not well known. Drilling at the Range and Cannon AFB has indicated that caliche is discontinuous, of variable thickness, and typically found within 30 ft of the surface (Fredrick Gebhardt, U.S. Geological Survey, oral commun., 2004).

The surface deposits of the Range consist of sand and gravel facies and playa deposits of the Blackwater Draw, Ogallala, and Chinle Formations (fig. 2). Eolian deposits of thin sand with interbeds of caliche of the Blackwater Draw Formation compose the Mesa surface. The northern part of the Range occupies the upper reach of the Portales Valley (fig. 1), and is composed of reworked material from the Blackwater Draw and Ogallala Formations (McLemore, 2001). Eolian deposits of the Blackwater Draw Formation are present in the northern part of the Range as sand deposits and dunes, and the Chinle Formation is exposed in the southwestern portion of the Range near the Mesa.

The saturated Ogallala Formation deposits at the Range are within the western boundary of the Southern High Plains aquifer (Hart and McAda, 1985). In New Mexico, the Southern High Plains aquifer is part of a larger aquifer system extending from South Dakota to Texas and is commonly referred to as the Ogallala aquifer. The part of the Southern High Plains aquifer in New Mexico is composed of hydraulically connected geologic units of late Tertiary or Quaternary age and is underlain by rocks of Triassic, Jurassic, and Cretaceous age (Hart and McAda, 1985). The unconfined Southern High Plains aquifer is composed primarily of the Ogallala Formation (McLemore, 2001).

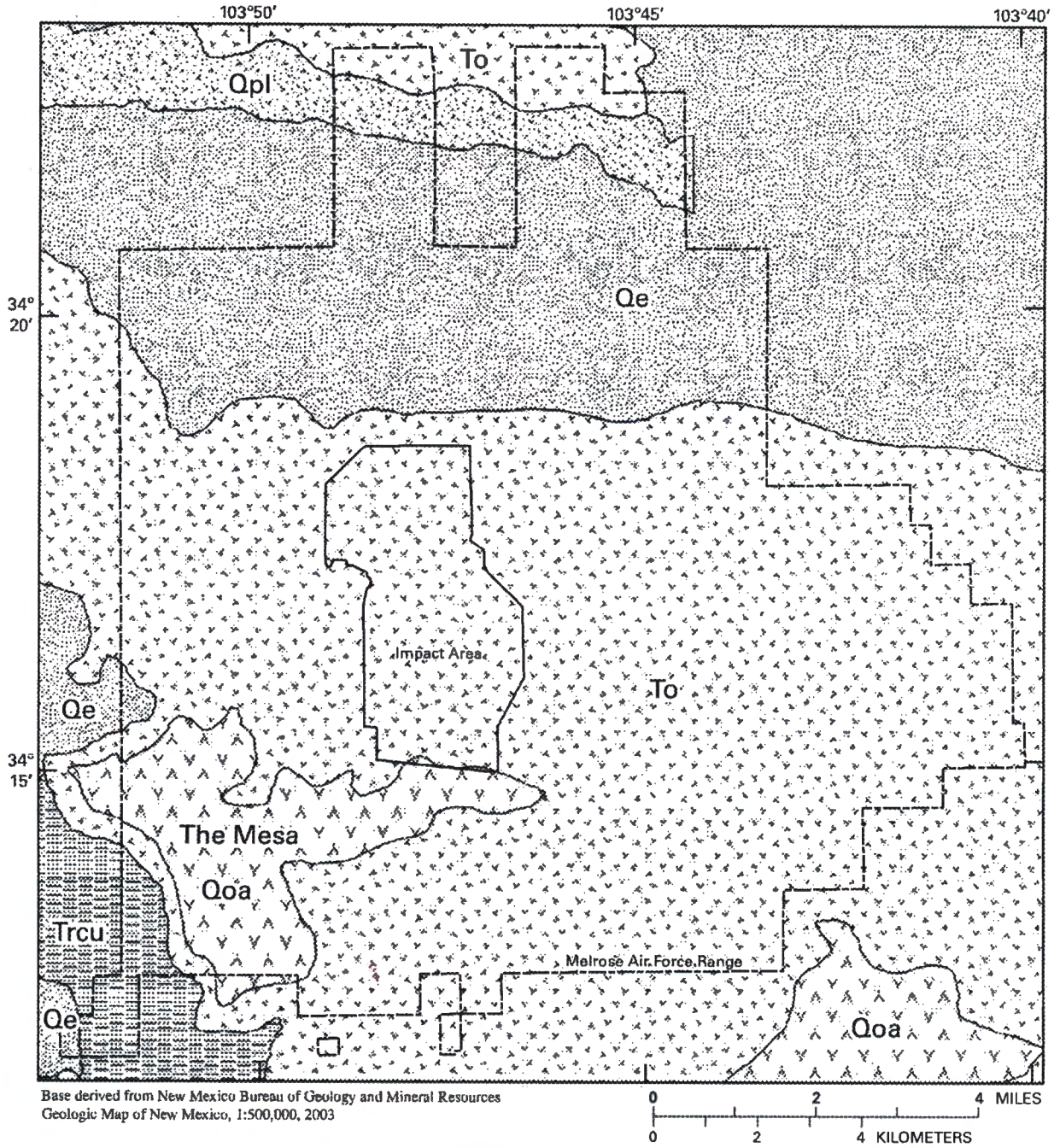
The Chinle Formation has informally been divided into upper and lower units (McGowen and others, 1977; Dutton and Simpkins, 1986). The upper unit is mud-rich with discontinuous sand deposits (Dutton and Simpkins, 1986), and contains a confined aquifer that typically produces only 1-2 gal/min of water (Trauger, 1972). The erosional surface of the upper unit of the Chinle Formation creates an uneven contact with the Ogallala Formation. The Tertiary deposits filled the valleys, uplands, and fluvial channels of the eroded Triassic deposits (Gustavson, 1996). Coarser material was deposited in the paleochannels and finer sediments in the interchannel areas (Fahlquist, 2003). Sand and clay layers are known to overlie the Chinle Formation in eastern New Mexico and west Texas, thereby creating variable permeabilities across the contact with the overlying formation (Nativ and Gutierrez, 1988).

The unconformity and variable deposition of sediments between the Ogallala and Chinle Formations created discontinuous zones of horizontal lithology that produced highly variable spatial porosity and permeability. The variable spatial porosity and permeability produced a discontinuous aquifer in the Ogallala Formation near the Western Caprock Escarpment. Using water levels, Hart and McAda (1985) mapped areas of this discontinuous aquifer at the Range and surrounding area and determined that the discontinuity extends from the Western Caprock Escarpment to areas east of the Range within Roosevelt County. The unconformity at the contact of the Ogallala and Chinle Formations also creates variable vertical permeabilities. Nativ (1988) found permeable and low permeable sequences of the Ogallala-Chinle contact in Roosevelt County southeast of the Range, and found differences in water quality in the Southern High Plains aquifer along the Western Caprock Escarpment that indicated an upward leakage of Chinle Formation water into the Southern High Plains aquifer.

Diffuse areal recharge to the Southern High Plains aquifer has been estimated to range from 0.01 in. per year (Stone and McGurk, 1985) to 1.71 in. per year (Mantei and others, 1966-67) with most estimates less than 1 in. per year (Musharrafieh and Logan, 1999). Ground water in the New Mexico part of the Southern High Plains aquifer is generally suitable for domestic, municipal, and irrigation uses. The water typically contains large concentrations of calcium, magnesium, and bicarbonate and potentially objectionable concentrations of chloride and fluoride for domestic use (Hart and McAda, 1985). Water from older formations, such as the Chinle, is known to be of poorer quality (Nativ, 1988).

Farmers began using the Southern High Plains aquifer in the 1940's for irrigation, and about 94 percent of the water pumped from the entire High Plains aquifer was used for irrigation in 1995 (McGuire and others, 2003). Because of substantial annual pumpage from the aquifer (approximately 17 million gal in 1995), water levels have been declining in the High Plains aquifer since development first began. In New Mexico, water levels in the Southern High Plains aquifer have declined less than the substantial declines recorded in other States (greater than 150 ft in parts of west Texas), but in New Mexico, the saturated thickness of the Southern High Plains aquifer is generally less than 100 ft.

Within New Mexico, ground water in the Southern High Plains aquifer generally flows eastward (Hart and McAda, 1985), which is considered the overall direction of regional flow in the unconfined aquifer. Using 1978 water-level data, Hart and McAda (1985) estimated the depth to water to be about 100 ft below land surface throughout the Range. In 1987 and 1992, the USGS measured depth to water ranging from about



EXPLANATION

	Qe	**Eolian deposits, including Blackwater Draw Formation**—Quaternary
	Qpl	**Lacustrine and playa deposits, including Blackwater Draw Formation**—Quaternary
	Qoa	**Eolian deposits, including Blackwater Draw Formation**—Quaternary
	To	**Alluvial and eolian deposits, including Ogallala Formation**—Tertiary
	Trcu	**Chinle Formation, undivided**—Triassic

Figure 2. Surface geology of Melrose Air Force Range. Modified from New Mexico Bureau of Geology and Mineral Resources, 2003.

40 to 125 ft across the Range. In 2000, water levels measured in the center of the Range by a private contractor ranged from 50 to 150 ft below land surface (Dennis Timmons, Cannon Air Force Base, written commun., 2002).

Previous Studies

Although no published hydrologic studies have been conducted at the Range, water-level and water-quality data are available. Water levels in 13 of the 29 wells used in this study have been measured on multiple occasions since 1962 as part of a USGS statewide program. Additionally, water levels in wells near the SWMU's and AOC's have been measured on three occasions by either private contractors or the USGS at the request of Cannon AFB as part of their Pollution Prevention Program (Dennis Timmons, Cannon Air Force Base, oral commun., 2002). Wells at the SWMU's and AOC's were installed in 1995 for Cannon AFB by the U.S. Army Corps of Engineers for pollution prevention monitoring. A declining water table has resulted in multiple dry monitoring wells since installation.

In 1996 and 2000, a private contractor collected water-quality samples from selected SWMU and AOC monitoring wells. In 1996, the private contractor collected ground-water samples from all four wells at SWMU 114 (fig. 1) for analysis of major ions and trace elements (Foster Wheeler, Environmental Corporation, written commun., 1996). In 2000, the contractor collected samples from all four wells at SWMU 114, all four wells at MA01, and one well at MA02 (fig. 1) for analysis of cyanide, major ions, nitrate, trace elements, nitrogen-based explosives, and volatile organic compounds. In 2001, the USGS collected water-quality samples from eight of the nine monitoring wells sampled by the contractor in 2000 (Fredrick Gebhardt, U.S. Geological Survey, oral commun., 2002). These samples were analyzed for concentrations of the same constituents as in 2000 with the addition of perchlorate. The results of all contractor and USGS ground-water analyses were not published but were submitted to Cannon AFB as informal data submissions as part of Cannon AFB's Pollution Prevention Program. No explosives or volatile organic compounds larger than laboratory method reporting limits were detected.

In 1993, the USGS conducted an investigation of SWMU 118 as part of Cannon AFB's Resource Conservation and Recovery Act (RCRA) application for permitting the EOD pit (Cannon Air Force Base, 1993). Soil and core samples were analyzed for trace elements and explosives. No explosives were detected in soil or core samples, and only concentrations of beryllium in soil were larger than RCRA action levels (Cannon Air Force Base, 1993).

Study Methods

The study design implemented methods described by Lapham and others (1997), and ground-water sample collection followed guidelines established by Wilde and others (1998).

Well Sites

Potential monitoring network wells were examined in the field with Cannon AFB personnel, and 27 wells were selected to be included in the network (fig. 1 and table 1). Twelve wells (non-working windmills) were selected only for water-level measurements (MWL designator), and 15 wells were selected for water-quality sampling and water-level measurements (MWQ designator). Seven of the 15 wells had submersible pumps previously installed as part of the stock-tank system. The remaining eight water-quality wells were previously used as windmills, irrigation wells, or monitoring wells. Former windmills and irrigation wells no longer contain installed pumps. All 27 wells had a single screen set in the unconfined aquifer in the Ogallala Formation.

In June 2002, two additional monitoring wells (MWQ 1 and MWQ 2; fig. 1 and table 1) were installed by the USGS in an area devoid of wells. Well MWQ 1 was completed in the Ogallala Formation, and well MWQ 2 was completed in the upper unit of the Chinle Formation. MWQ 1 initially yielded small quantities of water during well development but provided insufficient water for sampling. MWQ 1 was possibly screened in a discontinuous aquifer zone.

Ground-Water Sample Collection and Analysis

Water levels were measured below a known, fixed altitude from March 2002 to March 2003 using either an electric tape or steel tape. Water-quality samples were collected from June 2002 to March 2003 using one of two methods depending on well configuration. Samples from the seven wells with submersible pumps were collected from spigots located between the well and holding tanks. Samples from the remaining wells were collected using a portable environmental-submersible pump.

Water-quality samples were collected and analyzed as whole water for selected constituents depending on the sample period (table 2). Whole water was collected because wells at the Range provide untreated water for stock tanks throughout the Range and for irrigation in the northern and eastern parts of the Range.

Standard field measurements of specific conductance, dissolved oxygen, turbidity, pH, and temperature were collected at each site during each sample period using portable field meters and a flow-through chamber to reduce atmospheric influences. Stable field measurements were used to determine sufficient purge amounts for sampling formation water.

Median concentrations and ranges were used to evaluate spatial and temporal variability. Standard field measurements and concentrations of dissolved solids, alkalinity, cyanide, sulfide, major ions, nutrients, organic carbon, and trace elements reported in the text are median values. Concentrations of CFC's, stable isotopes, dissolved gases, pesticides, explosives, volatile organic compounds, semivolatile organic compounds, total organic halogens, and perchlorate are individual sample concentrations.

Table 1. Melrose Air Force Range study area monitoring-well information.

[All wells, except MWQ 2, were completed in the Ogallala Formation. MWQ 2 was completed in the Chinle Formation. USGS, U.S. Geological Survey; Cannon AFB, Cannon Air Force Base; NAVD 88, North American Vertical Datum of 1988; ft bls, feet below land surface; MWQ, Melrose Air Force Range water-level and water-quality well; MWL, Melrose Air Force Range water-level well; NA, not available; -----, not applicable]

Well number (fig. 1)	USGS well site identification number	Cannon AFB common name	Land-surface altitude (ft above NAVD 88)	Well depth (ft bls)	Casing material	Dedicated pump
Wells used for water-quality sampling and water-level measurements						
MWQ 1	341714103442501	-----	4,288.80	134	PVC	No
MWQ 2	341714103442502	-----	4,288.80	240	PVC	No
MWQ 3	341820103442601	Ashley pump	4,266.30	163	Steel	Yes
MWQ 4	342152103444201	Solar pump	4,200.12	NA	PVC	Yes
MWQ 5	342031103464701	Telephone pole	4,229.80	101	Steel	Yes
MWQ 6	342048103492701	Homestead	4,268.68	NA	Steel	Yes
MWQ 7	342046103503501	Grider at gate	4,258.18	99	Steel	Yes
MWQ 8	341720103494701	Below golf ball	4,466.57	113	Steel	No
MWQ 9	341533103485801	Hand dug	4,488.30	42	None	No
MWQ 10	341954103503101	Luce jog	4,637.69	58	Steel	Yes
MWQ 11	341345103494301	Parker house	4,661.96	NA	Steel	Yes
MWQ 12	341828103460001	Eroded tank	4,403.45	63	Steel	No
MWQ 13	341440103411101	Hidden mill	4,277.38	177	Steel	No
MWQ 14	341640103470501	EOD pit	4,378.68	120	PVC	No
MWQ 15	341743103470801	MA02MW001D	4,354.29	183	PVC	No
MWQ 16	341825103470301	SWMU114MW004	4,321.25	181	PVC	No
MWQ 17	341845103475801	MA01MW003	4,341.30	161	PVC	No
Wells used for water-level measurements						
MWL 1	341658103411901	Mini-mute east	4,237.38	120	Steel	No
MWL 2	341758103450401	NE100 mill	4,289.45	139	Steel	No
MWL 3	341956103452201	Luce NW	4,222.34	74	Steel	No
MWL 4	342044103451401	Firebreak fence	4,215.80	57	Steel	No
MWL 5	342155103453101	Glass jog pvc	4,192.67	34	PVC	No
MWL 6	341958103485401	Brackish mill	4,301.08	NA	Steel	No
MWL 7	342026103475101	Fence line dip	4,253.91	110	Steel	No
MWL 8	342050103485101	Davis trap mill	4,257.51	114	Steel	No
MWL 9	342200103475501	Northern end	4,238.52	49	Steel	No
MWL 10	341542103502901	Three mills	4,574.99	51	Steel	No
MWL 11	341254103513501	Luce 480 mill	4,576.70	73	Steel	No
MWL 12	341249103470601	County road	4,444.62	58	Steel	No

Table 2. Water-quality constituents and laboratory analysis methods.

[USEPA, U.S. Environmental Protection Agency; sample periods: June 2002, September 2002, December 2002, and March 2003; °C, degrees Celsius; CFC, chlorofluorocarbon; -----, not applicable]

Analysis constituent or group	Description	Wells	USEPA Method[1]	Sample periods
Dissolved solids	Filterable residue	All	MCAWW 160.1[2]	June, September, December, March
Alkalinity	Alkalinity as calcium carbonate	All	MCAWW 310.1	June, September, December, March
Cyanide		All	SW846 9012A[3]	June, September, December, March
Sulfide		All	SW846 9030B	June, September, December, March
Major ions	Ca, Mg, Na, K, HCO_3, SO_4, Cl, F, Br	All	MCAWW 300.0A	June, September, December, March
Nutrients	Nitrate plus nitrite, ammonia, phosphorus	All	MCAWW 300.0A	June, September, December, March
Organic carbon		All	SW846 9060	June, September, December, March
Trace elements	Ag, Al, As, Ba, Be, Cd, Co, Cr, Cu, Fe, Mn, Mo, Ni, Pb, Sb, Se, Tl, V, Zn	All	SW846 7470A, SW846 6010B	June, September, December, March
Organochlorine pesticides	21 chlorine-based pesticides	All	SW846 8081A	June
Organophosphorous pesticides	27 phosphorous-based pesticides	All	SW846 8141A	June
Nitroaromatic and nitramine explosives	14 nitrogen-based explosive compounds	All	SW846 8330	June
Volatile organic compounds	66 organic compounds with low boiling points (less than 200 °C)	MWQ 14 - 17	SW846 8260B	March
Semivolatile organic compounds	107 neutral, basic, and acidic organic compounds that are soluble in methylene chloride	MWQ 14 - 17	SW846 8270C	March
Total organic halogens	All halogenated carbon compounds	MWQ 14 - 17	SW846 9020B	March
Perchlorate		All	EPA 314.0	June, March (wells MWQ 14-17)
Chlorofluorocarbons	CFC-11, 12, and 113	All except MWQ 9	----	December
Hydrogen isotopes	$^2H/^1H$ ratio	All except MWQ 9	----	December
Oxygen isotopes	$^{18}O/^{16}O$ ratio	All except MWQ 9	----	December
Dissolved gases	N_2, CO_2, CH_4, Ar	All except MWQ 9	----	December

[1]All water-quality constituents except CFC's, stable isotopes, and dissolved gases were analyzed by the U.S. Geological Survey (USGS) contract laboratory-Severn Trent Laboratories in Arvada, Colorado. CFC's, stable isotopes, and dissolved gases were analyzed by the USGS CFC/Dissolved Gas/Isotope Laboratories in Reston, Virginia.

[2]U.S. Environmental Protection Agency, 1983.

[3]U.S. Environmental Protection Agency, 1986.

Small concentrations are discussed relative to method reporting limits and method detection limits. Method reporting limits are the smallest concentrations at which measurements become quantitatively meaningful (quantitation limit) (U.S. Environmental Protection Agency, 2000). Method reporting limits are typically about three times the method detection limit. Method detection limits are defined as the statistically calculated minimum concentration that can be measured with 99 percent confidence that the reported value is greater than zero, and are determined from replicate analyses of small concentration standards in a typical representative matrix (U.S. Environmental Protection Agency, 2000).

Chlorofluorocarbon, Stable Isotope, and Dissolved Gas Analysis

CFC, stable isotope, and dissolved-gas concentrations were used to evaluate the age of ground water and associated information about recharge, source waters, and chemical and (or) biological influences. Ground-water CFC concentrations (CFC-11, CFC-12, CFC-113) were compared to known CFC atmospheric concentrations during the past 60 years to estimate when the water entered the ground-water system as recharge (Plummer and Busenberg, 2000). The stable isotopic ratios for hydrogen and oxygen plus the concentrations of dissolved oxygen, carbon dioxide, methane, and argon were used to evaluate any potential biochemical influences on CFC concentrations during storage. Additionally, isotopic differences were used to differentiate potential source waters, and dissolved-gas concentrations were used to examine chemical and (or) biological influences on water quality.

Because of fractionation processes (such as evaporation, isotopic exchange, and microbial activity), water and solutes often develop unique isotopic compositions (ratios of heavy to light isotopes) that may be indicative of their source or of the processes that formed them (Kendall and Caldwell, 1998). Delta (δ) refers to the ratio (R) of heavy to light isotopes divided by the Vienna Standard Mean Ocean Water (VSMOW) minus one unit ($\delta = (R_{sample}/R_{standard}) - 1$). The isotopic ratio is presented in thousandths (per mil, ‰) and is normalized to the per mil scale (Gonfiantini, 1984; Hut, 1987; Coplen, 1988 and 1994).

Dissolved-gas concentrations in ground water can change according to gas inputs from atmospheric and chemical sources and reduction/oxidation conditions (Plummer and Busenberg, 2000). Large nitrogen-gas concentrations can be attributed to contamination, denitrification, or fluctuating water levels and the absorption of entrapped gas within the vadose zone. Methane can indicate reduction of organic compounds, and carbon dioxide can indicate biodegradation. As a conservative gas, argon can be used to view changes to nitrogen when dissolved nitrogen compounds are undergoing reduction or oxidation. Oxygen in the atmosphere and in the unsaturated zone is dissolved in precipitation and recharge water and can be consumed by oxidizable material, principally organic matter and reduced inorganic minerals encountered along the flow path.

Contaminant Monitoring

Because of current (2004) and historical military, grazing, and agricultural land uses at the Range, ground water was analyzed for pesticides, explosives, volatile organic compounds, semivolatile organic compounds, total organic halogens, and perchlorate (table 2). Because the historical use of pesticides is undocumented, water from all wells was analyzed for 21 organochlorine and 27 organophosphorous pesticides. Water from all wells was analyzed for nitrogen-based explosives because of the use of live ordnance at the Range from 1952 to 1969. Water from wells in the Impact Area was analyzed for volatile organic compounds, semivolatile organic compounds, and total organic halogens because of past activities at the SWMU's and AOC's. Because of the recent detection of perchlorate, an oxidizing agent in rocket fuel, at military installations across the Nation, one sample from each well was analyzed for this compound.

Quality Assurance and Quality Control

Quality-assurance procedures were used for water-level measurements and for collection and field processing of water-quality samples to ensure the accuracy of the data and to assist in interpretation of the data. Water levels in wells with dedicated submersible pumps were measured repeatedly to ensure that water levels were stable and not recovering from recent pumping. The portable submersible pump used to collect water-quality samples was decontaminated prior to use in each well. For all wells except the 4-foot diameter, hand-dug well (MWQ 9), a minimum of one well volume was pumped prior to sample collection. During purging, field values of specific conductance, pH, dissolved oxygen, turbidity, and water temperature were monitored and allowed to stabilize prior to sample collection. All open casing wells pumped dry following one well volume extraction. Wells with dedicated pumps were purged for three well volumes because of the availability of water in the surrounding formation. MWQ 9 could not be purged a full well volume because of the well's large diameter; all results for MWQ 9 are qualified for possible non-representation of ground water in the surrounding formation.

Four types of quality-control samples were collected in the field as part of this study: replicates, field-equipment blanks, matrix spikes, and trip blanks. In addition to field quality-control samples, Severn Trent Laboratories used internal quality-assurance practices to provide quality control of analytical procedures. These practices included laboratory-control sample analysis and method-blank sample analysis. For comparison of quality-control sample results, data-quality objectives defined by Severn Trent Laboratory were used to evaluate the quality of the laboratory results (supplemental information located in the back of the report). All water-quality concentrations determined to have quality-control issues are qualified in the results tables in the "Ground-Water Quality" section.

Water-quality data were examined for concentration bias because suspended particulates in water samples may have produced outlier concentrations in the well data sets (supplemental information). With unfiltered samples, there is a potential for suspended particulates in well water to bias valid samples of formation water because of accumulated concentrations on particles and (or) matrix interference. Regular pumping of the dedicated pumps for the stock-tank system provided those wells with sufficient purging to keep the water clear of particulates. Samples collected with the portable submersible pump had the potential to include particulates without sufficient purging. By examining data-set outliers and turbidity, samples that were likely influenced by particulates were identified and qualified accordingly.

Acknowledgments

The cooperation of many individuals and organizations was essential for completion of this study. The authors acknowledge the support and help of the Pollution Prevention and Natural Resource Units of the Cannon AFB Engineering Department. Dennis Timmons, Don White, Peter Zamie, and Rick Crow of Cannon AFB initiated this study and provided useful insight for completion of the study goals. The efforts of Kerry Hubbell and Rick Chandler in providing guidance and escorts across the Range and Dan Cass for his help in surveying and mapping the study area monitoring wells are appreciated. The authors also acknowledge the support of Gary Warren of Range Operations for access to the Impact Area and Sara Caldwell of the USGS for her participation in sample collection and data analysis.

Ground-Water Hydrology

During installation of wells MWQ 1 and 2, drill cuttings indicated a thin soil layer underlain by a thin caliche layer followed by various layers of sand and silt (fig. 3). A saturated gravel layer was encountered between 125 and 130 ft below land surface and is underlain by a thin layer of sand, likely the base of the Ogallala Formation. The altitude of the gravel layer is consistent with the altitude of total depths in most windmills, stock wells, and monitoring wells that were installed in and around the Range to pump water from the unconfined aquifer. Underlying the gravel and thin sand layer is a clay layer about 50 ft thick, which grades into clay with various percentages of sand and silt with some sand stringers. A 2-ft-thick water-yielding zone was present in the clay, sand, and silt deposits of the Chinle Formation at about 235 ft below land surface.

Drilling logs on file with the New Mexico Office of the State Engineer indicate a similar lithology in other areas of the Range not dominated by the Mesa. The top of the unconfined aquifer is typically between 80 and 150 ft below land surface, aquifer thickness ranges from 5 to 40 ft, and the aquifer is typically underlain by a clay layer. Drilling at most sites did not proceed into this clay layer. This clay layer defines the base of the Ogallala Formation at the Range, which represents the base of the unconfined aquifer (fig. 4).

Ground-Water Age

Ground-water ages, as determined by CFC age-dating analysis, ranged from 10 to 55 years across the Range. Younger ground water (less than 25 years) generally was found near the Mesa and in the Impact Area, whereas older ground water (generally 40 to 55 years) was typically found in the Portales Valley (fig. 5). Water from MWQ 11, atop the Mesa, was slightly older (30 years) than water from nearby MWQ 10 (20 years), and water from MWQ 4, in the northern part of the study area, was younger (20 years) than nearby wells (45 to 55 years) in the Portales Valley. MWQ 4 is located in the sand deposits of the Blackwater Draw Formation, which may have aided local recharge.

Local CFC inputs may have elevated CFC concentrations (concentrations of one or two of the three CFC compounds were larger than those found in the atmosphere during the history of CFC production) in ground water in the Impact Area, indicating that CFC concentrations were possibly a mixture of atmospheric sources and local sources from Range activities. Elevated CFC concentrations reduced the validity of ground-water ages for samples from wells MWQ 8 and 14-17. Age determinations in these wells were based on one or two CFC compounds instead of the three compounds. Elevated CFC concentrations may indicate that prior land uses affected water quality in the Impact Area.

The young age (25 years) of ground water in well MWQ 2 in the Chinle Formation is unusual because of similar ground-water ages in the unconfined aquifer in the Impact Area and the older water from the regional flow system in the Portales Valley. Deeper ground water is typically older because it is farther from recharge areas than younger ground water that is recharged in shallower deposits. Analysis of water from MWQ 2 did not indicate elevated CFC concentrations but did indicate possible mixing of different ground waters. This possible mixing suggests a connection between the unconfined aquifer in the Ogallala Formation and the deeper, confined aquifer in the Chinle Formation or similar recharge areas.

Ground-Water Levels

Water levels in the unconfined aquifer declined from 1962 to 2003 at the Range. This decrease corresponds with declining water levels found across the Southern High Plains aquifer (McGuire and others, 2003). Wells shown in figure 6 are representative of the data available for water-level declines at the Range during this period. Ground-water levels in wells with available data (13 wells) declined from about 1 ft (MWQ 12) to 18 ft (MWQ 3) during varying periods of record from 1962 to 2003. The water level in well MWQ 12 fluctuated about 2 ft and declined about 1 ft from 1975 to 2003 (fig. 6). Well MWQ 12 is located adjacent to and may be influenced by channel recharge from an ephemeral tributary of the Cañada del Tule.

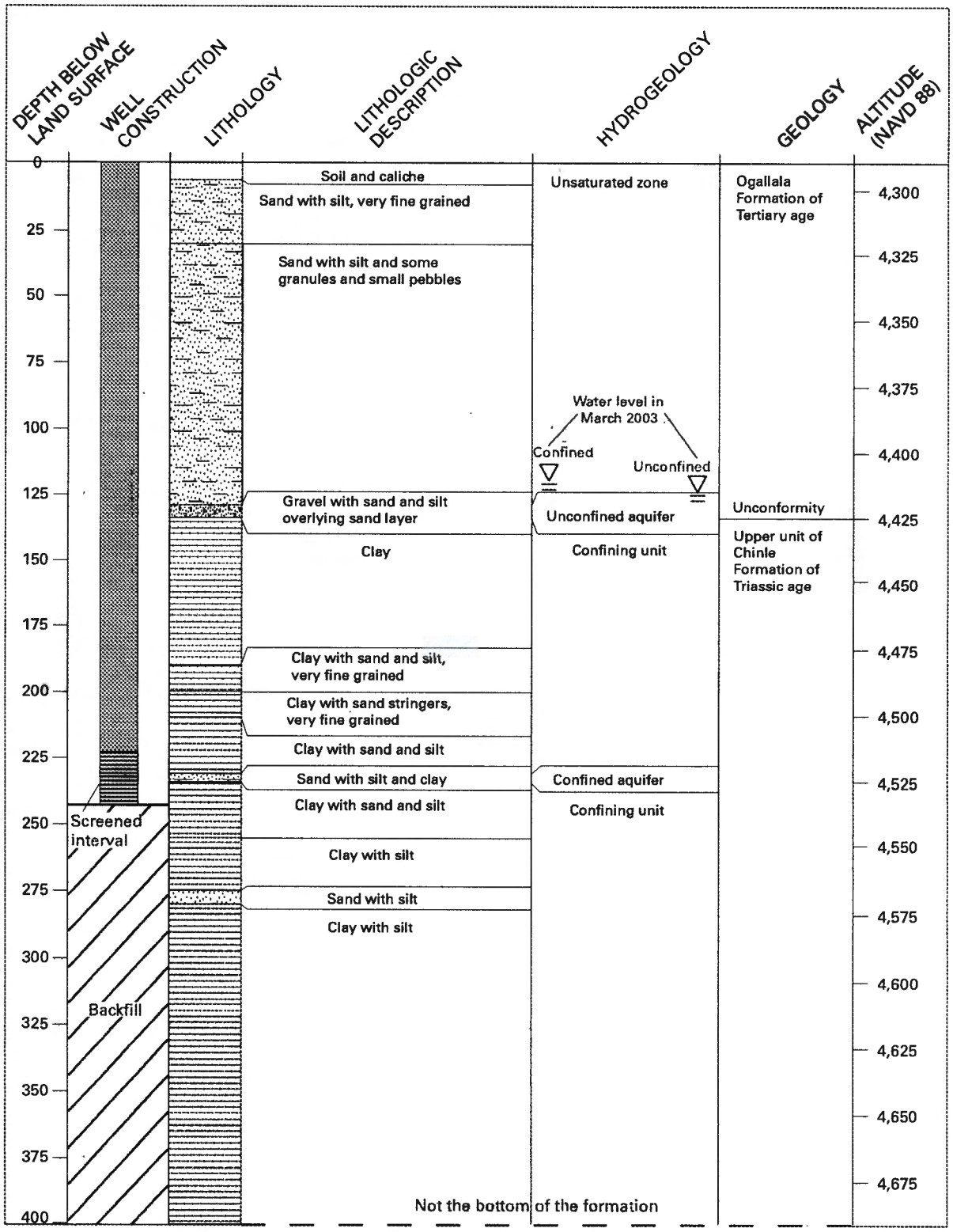
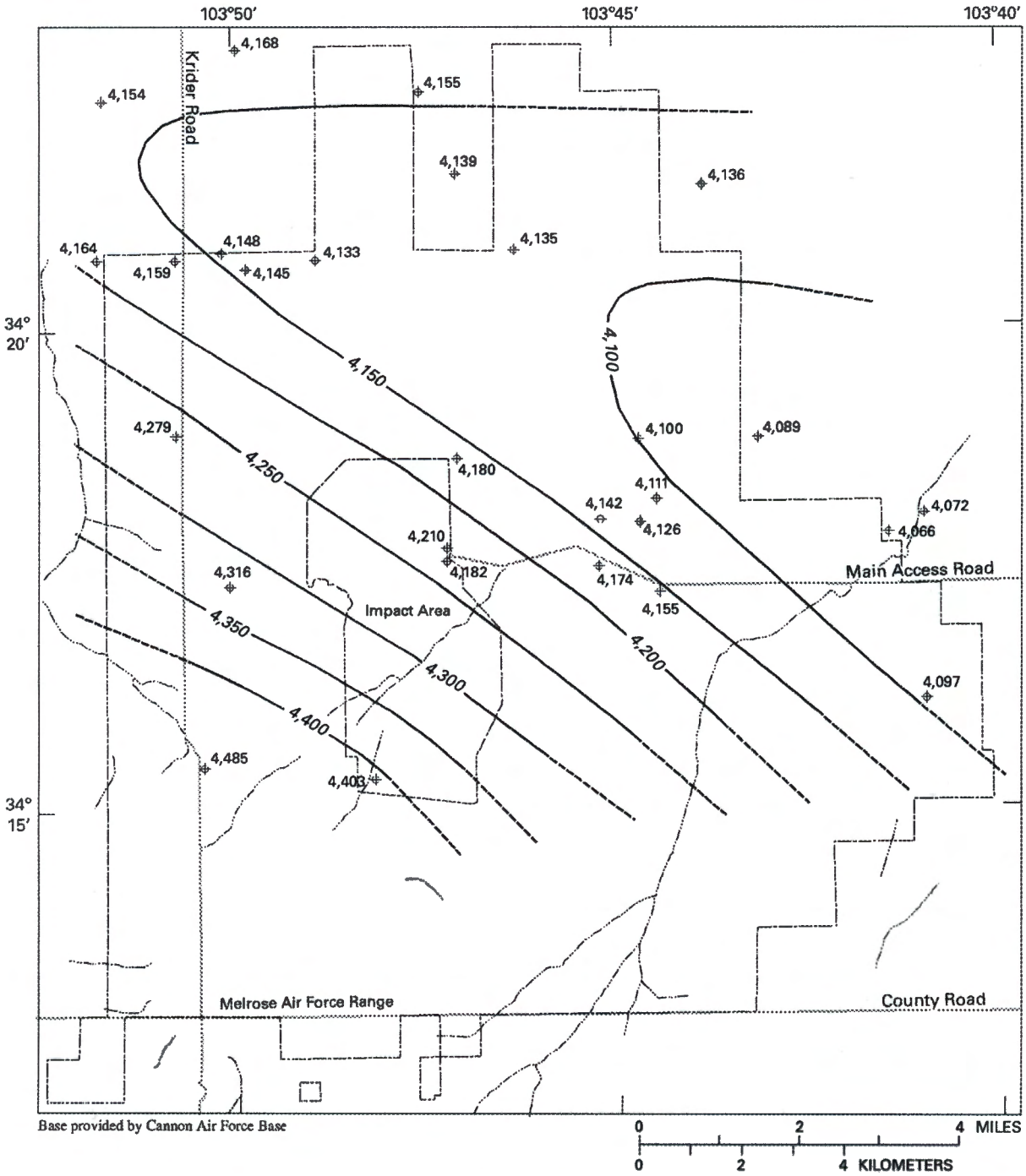


Figure 3. Lithology and hydrogeology of Ogallala and Chinle Formations at well MWQ 2, Melrose Air Force Range.

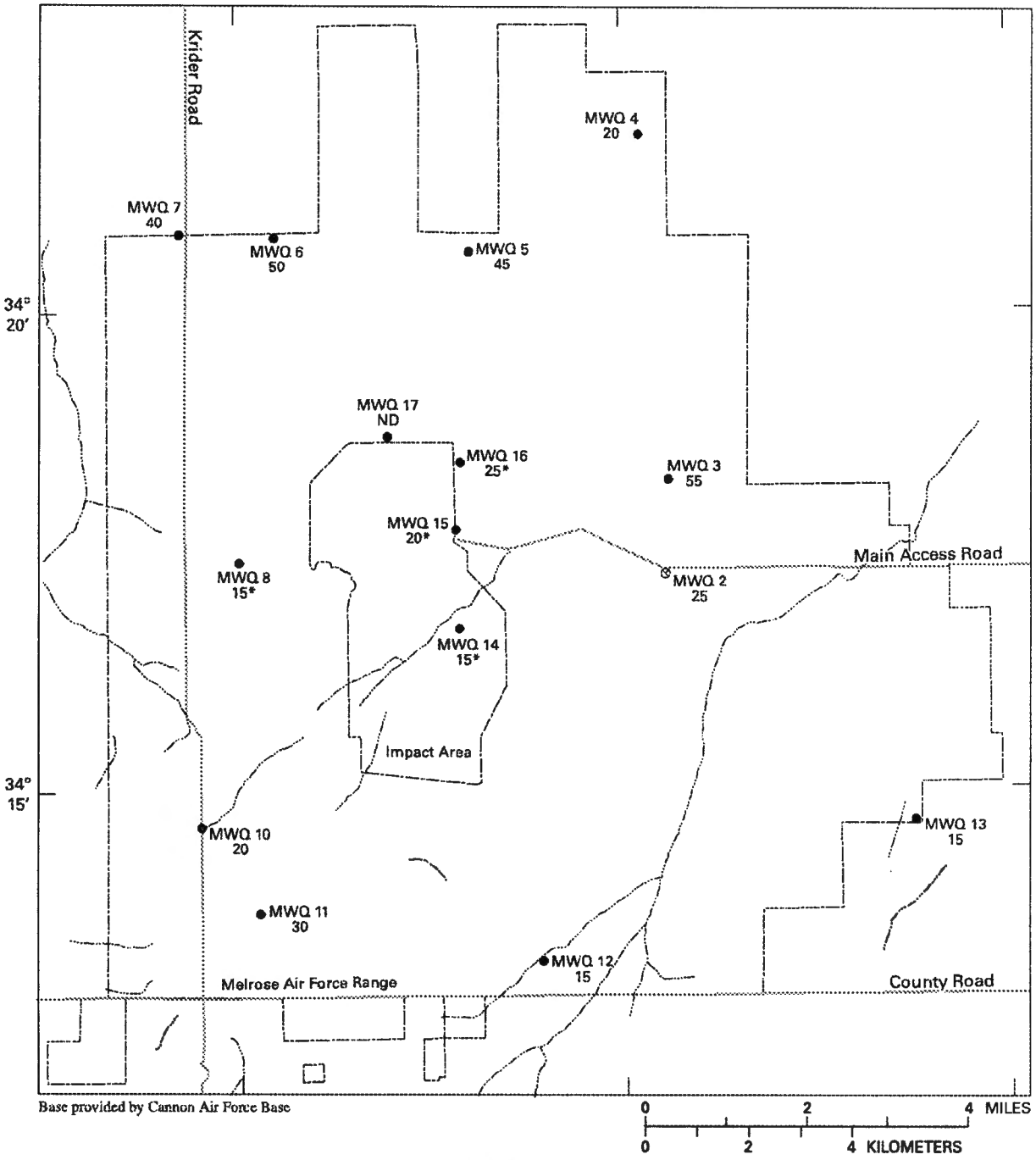


EXPLANATION

— 4,400 — **Line of equal depth of base of the Ogallala Formation**—Dashed where approximate. Interval is 50 feet. Vertical coordinate information is referenced to NAVD 88

4,403 **Well with geologic log on record with New Mexico Office of the State Engineer**—Altitude of the base of the Ogallala Formation. Vertical coordinate information is referenced to NAVD 88

Figure 4. Altitude of the base of the Ogallala Formation at Melrose Air Force Range.



EXPLANATION

MWQ 11 30 ● **Well completed in the Ogallala Formation**—Top characters are well number; bottom number is median ground-water age, in years

MWQ 2 25 ⊗ **Well completed in the Chinle Formation**—Top characters are well number; bottom number is median ground-water age, in years

* **Elevated chlorofluorocarbon concentration for one or two chlorofluorocarbon compounds**

ND **Age not determined**—Chlorofluorocarbon concentration elevated for all three chlorofluorocarbon compounds

Figure 5. Age of ground water at Melrose Air Force Range, December 2002.

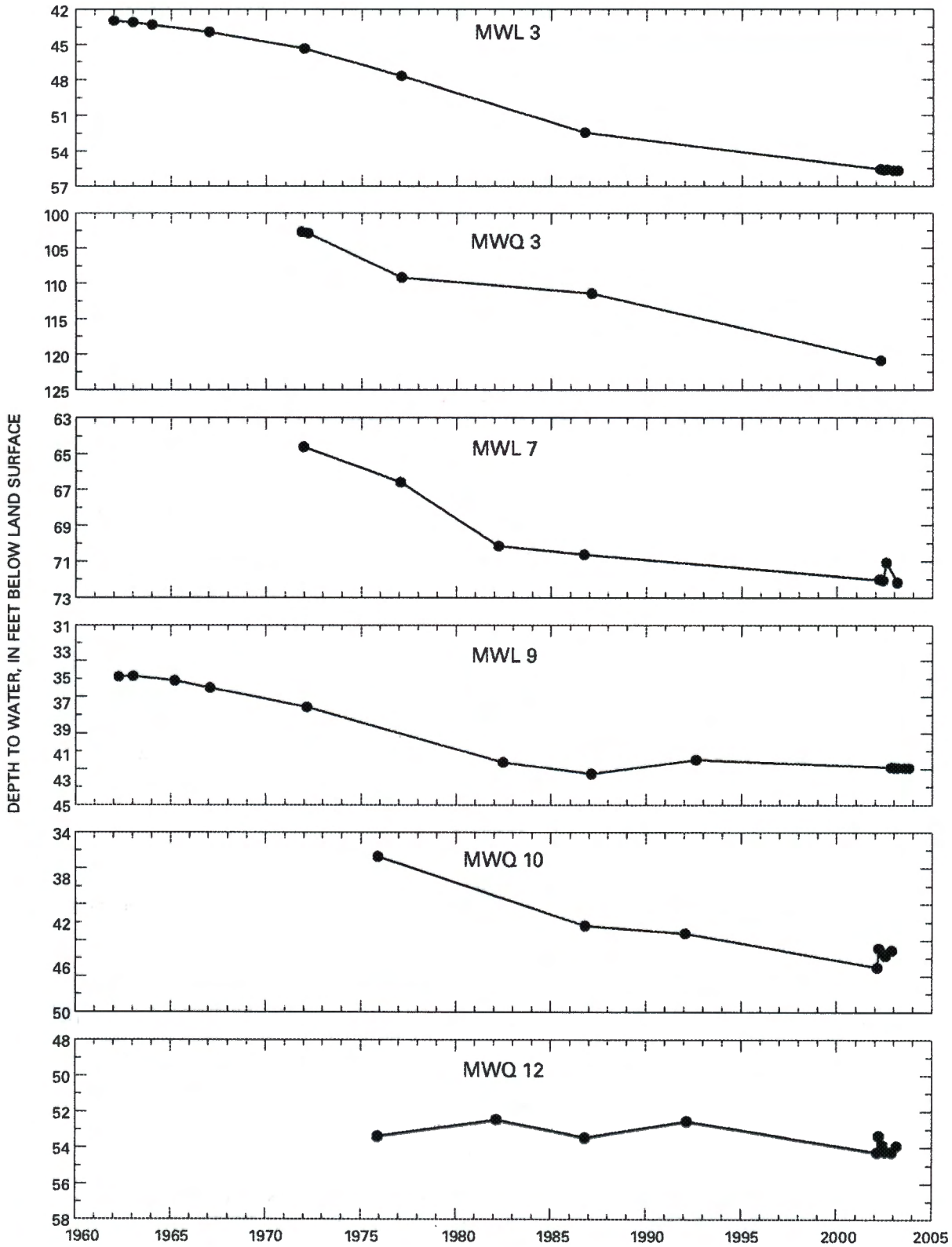


Figure 6. Depth to water from land surface in selected wells at Melrose Air Force Range, 1962-2003.

During the study period, water levels varied less than 1 ft from minimum to maximum depth to water in 21 of the 28 wells. Examples of water-level variations during the study period are shown in figure 7. Water levels in wells MWQ 4, 10, and 11 and MWL 1, 5, 7, and 10 ranged from 1.11 (MWL 7) to 5.27 ft (MWQ 11). The water level in MWQ 11 may have been influenced by pumping, and a slow recovery was not detected during a water-level measurement.

Potentiometric Surfaces

The median potentiometric surface of ground water in the Chinle Formation at well MWQ 2 was about 4,171 ft above NAVD 88 and was higher than the potentiometric surface of wells in the unconfined aquifer in the immediate area. Upward leakage of water from the Chinle Formation to the Ogallala Formation is inhibited at well MWQ 2 because the potentiometric surface in MWQ 1 was about 10 ft lower than the potentiometric surface of MWQ 2.

Locally, the confined aquifer of the Chinle Formation reflects geologic structure (bed dips to the northeast) as indicated by similar zones found in deep boreholes drilled for oil and gas exploration in the Impact Area (New Mexico Office of the State Engineer, written commun., 2003). If the potentiometric surface of the deeper, confined aquifer of the Chinle Formation parallels the dip of the bed, the potentiometric surface of the confined aquifer is likely higher to the southwest, which could facilitate upward leakage over a larger area of the Range if the clay layer separating the aquifers is discontinuous or permeable (fig. 3). In parts of Roosevelt County, the potentiometric surface of the confined aquifer of the Chinle Formation is higher than the potentiometric surface of the Southern High Plains aquifer; thus, it is assumed that upward leakage to the unconfined aquifer is occurring (Nativ, 1988).

Ground-Water Flow

Water-level contours for the unconfined aquifer indicate ground water flowing predominantly northeast from the Mesa to the Portales Valley (fig. 8) in the Southern High Plains aquifer. The change in flow direction in the unconfined aquifer in the Portales Valley indicates two flow systems—local and regional. The local flow system is the ground water in the southwest part of the Range that flows northeast from the Mesa, and the regional flow system is in the Portales Valley where ground water flows east to southeast across the northern part of the Range.

Ground-water flow is southeast and east in the Portales Valley, which corresponds with previously mapped ground-water flow (Hart and McAda, 1985). Direction of ground-water flow is a reflection of the contact between the Ogallala and Chinle Formations. This contact determines ground-water gradient and saturated thickness of the unconfined aquifer in the Ogallala Formation. The local flow-system gradient is about 1.3 percent, and the regional flow-system gradient is about 0.1 percent. Saturated thickness of the aquifer increases as the local flow system merges with the regional flow system.

Ground-Water Quality

Prior to this study, water-quality sampling at the Range had been conducted only at the SWMU's and AOC's. Because of the age of ground water in the unconfined aquifer (15 to 55 years), water quality was not expected to substantially vary during the study period. Analysis of the water-quality data indicated some temporal variation, but because of the whole-water sampling and potential errors in field and laboratory processes, the temporal variation was not considered significant for most constituents.

General Physical and Chemical Properties

Median specific conductance and concentrations of dissolved solids in ground water at the Range varied widely (table 3 and fig. 9) and can be separated into three distinct groups. The first group includes wells in the regional flow system (MWQ 3–7), which yielded ground water with the smallest median specific-conductance values, ranging from 564 to 792 µS/cm, and the smallest median concentrations of dissolved solids, ranging from 370 to 525 mg/L. Water from well MWQ 10, located atop the Mesa, had a median specific conductance of 635 µS/cm and a median concentration of dissolved solids of 380 mg/L, which is similar to the regional flow system (MWQ 3-7). In the second group, samples collected from wells MWQ 9 and 11 near the Mesa and from wells MWQ 12 and 13 near ephemeral streams in the southern part of the Range had larger specific-conductance values (1,100 to 1,436 µS/cm) and larger concentrations of dissolved solids (548 to 860 mg/L). Samples from a third group of wells with similar water quality included wells near and in the Impact Area (MWQ 14-17) and a well located west of the Impact Area (MWQ 8). Water from this group of wells had the largest median specific-conductance values, ranging from 2,575 to 10,665 µS/cm, and the largest median concentrations of dissolved solids, ranging from 1,700 to 6,200 mg/L.

The median concentration of dissolved solids (6,300 mg/L) in water from the Chinle Formation (MWQ 2) was comparable to the median concentrations in water from wells in the unconfined aquifer in the Impact Area, particularly well MWQ 16. Concentrations of dissolved solids varied substantially during the study period in water from wells MWQ 2 (5,260 to 7,700 mg/L) and MWQ 16 (1,870 to 7,400 mg/L) (table 3).

Water in the confined aquifer (MWQ 2) was the warmest (27.2 °C) followed by water in well MWQ 16 in the unconfined aquifer (22.7 °C). Water temperatures in wells near and in the Impact Area generally were higher than water temperatures in wells near the Mesa and in the regional flow system. Similar water temperatures and concentrations of dissolved solids in water from the unconfined aquifer and the deeper, confined aquifer in the Impact Area indicate a possible connection between the Chinle Formation and the Ogallala Formation. This possible connection may be allowing upward leakage from the deeper, confined aquifer to the unconfined aquifer in the local flow system.

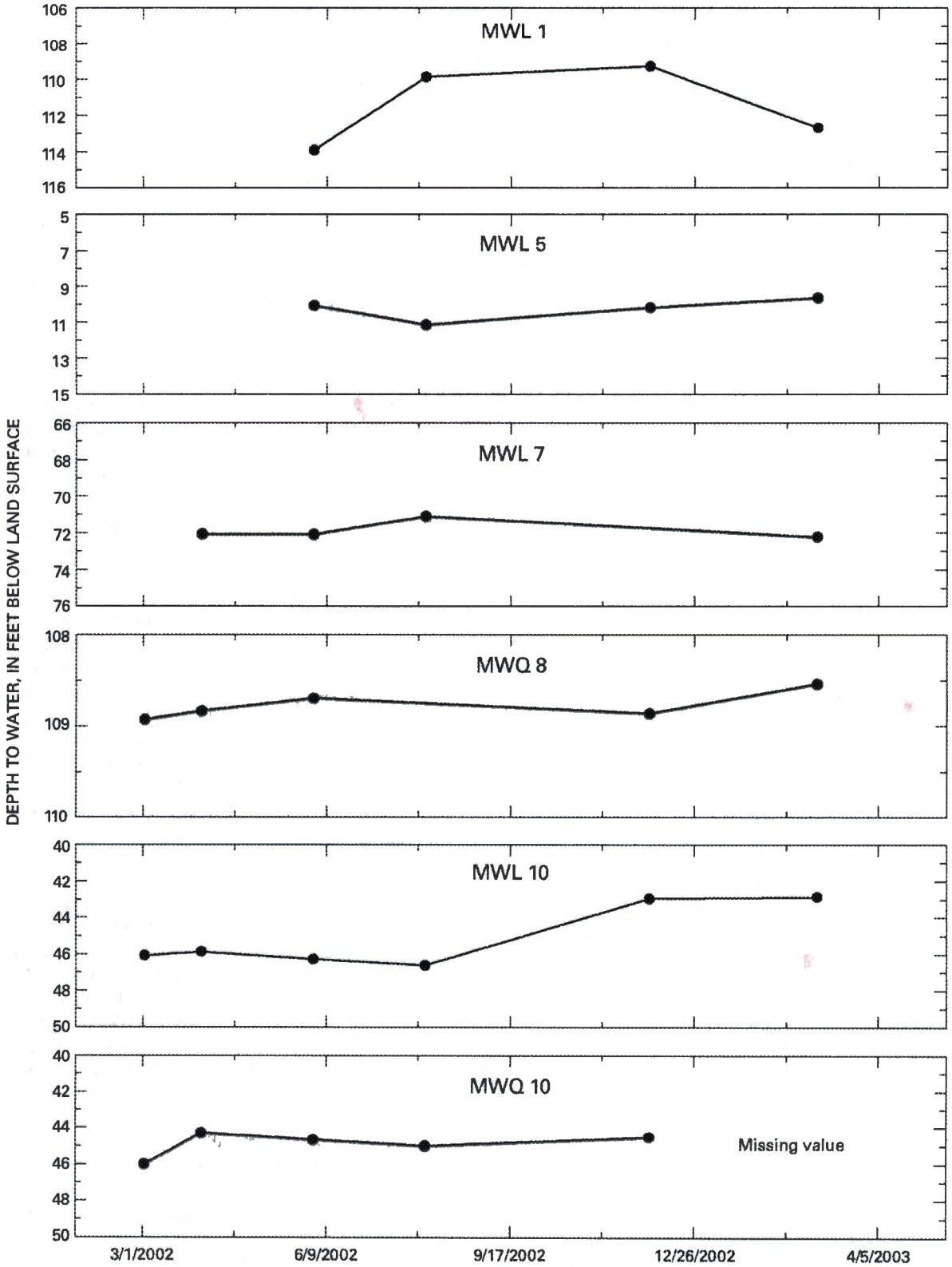
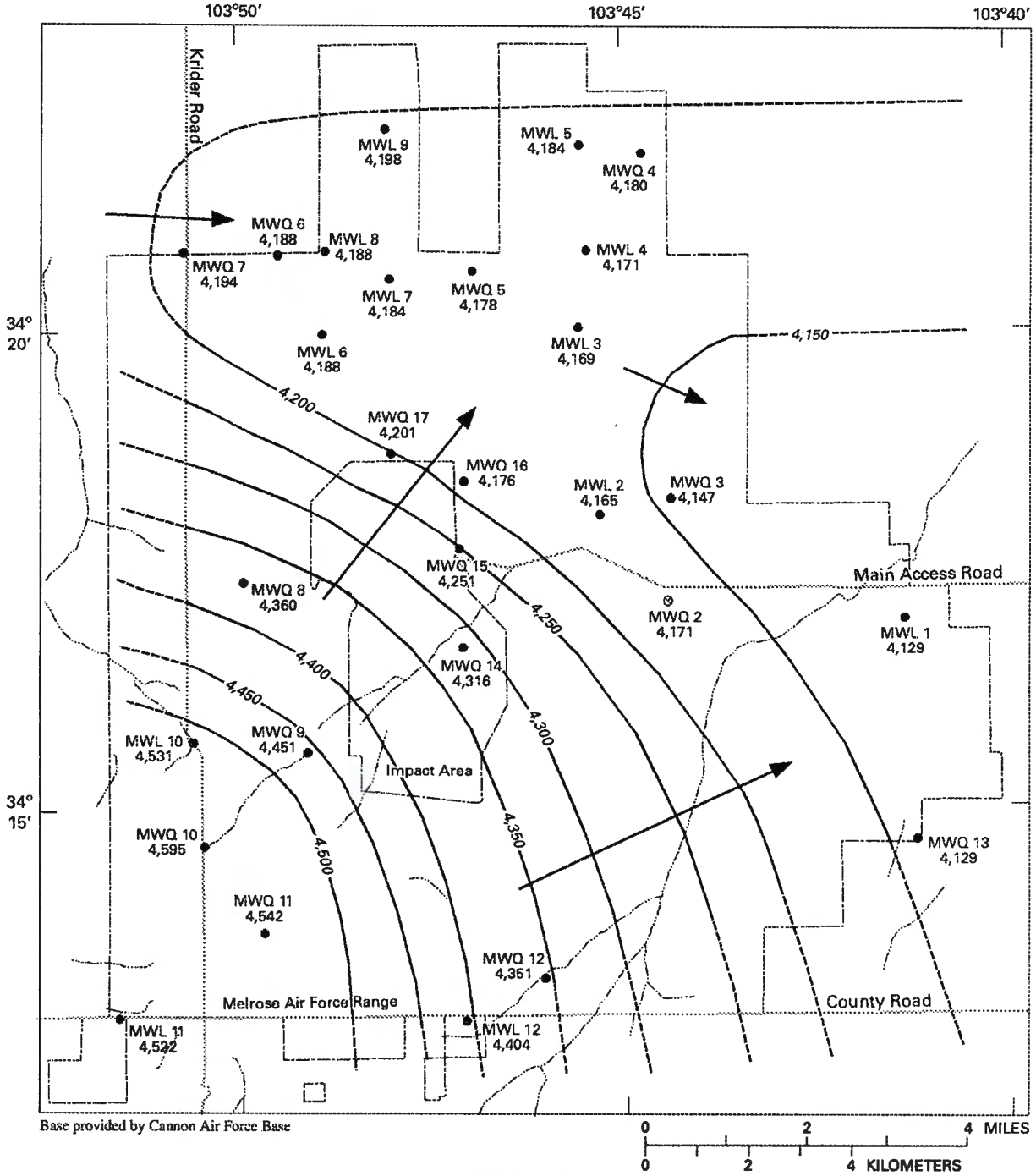


Figure 7. Depth to water from land surface in selected wells at Melrose Air Force Range, 2002-03.



EXPLANATION

Generalized direction of ground-water flow

4,500 **Southern High Plains aquifer water-level contour**—Shows median altitude of water table, 2002-03. Dashed where approximate. Interval is 50 feet. Vertical coordinate information is referenced to NAVD 88

MWL 12 4,404 **Well completed in the Ogallala Formation**—Top characters are well number; bottom number is altitude of water level, in feet above NAVD 88

MWQ 2 4,171 **Well completed in the Chinle Formation**—Top characters are well number; bottom number is altitude of water level, in feet above NAVD 88

Figure 8. Median ground-water altitudes at Melrose Air Force Range, 2002-03.

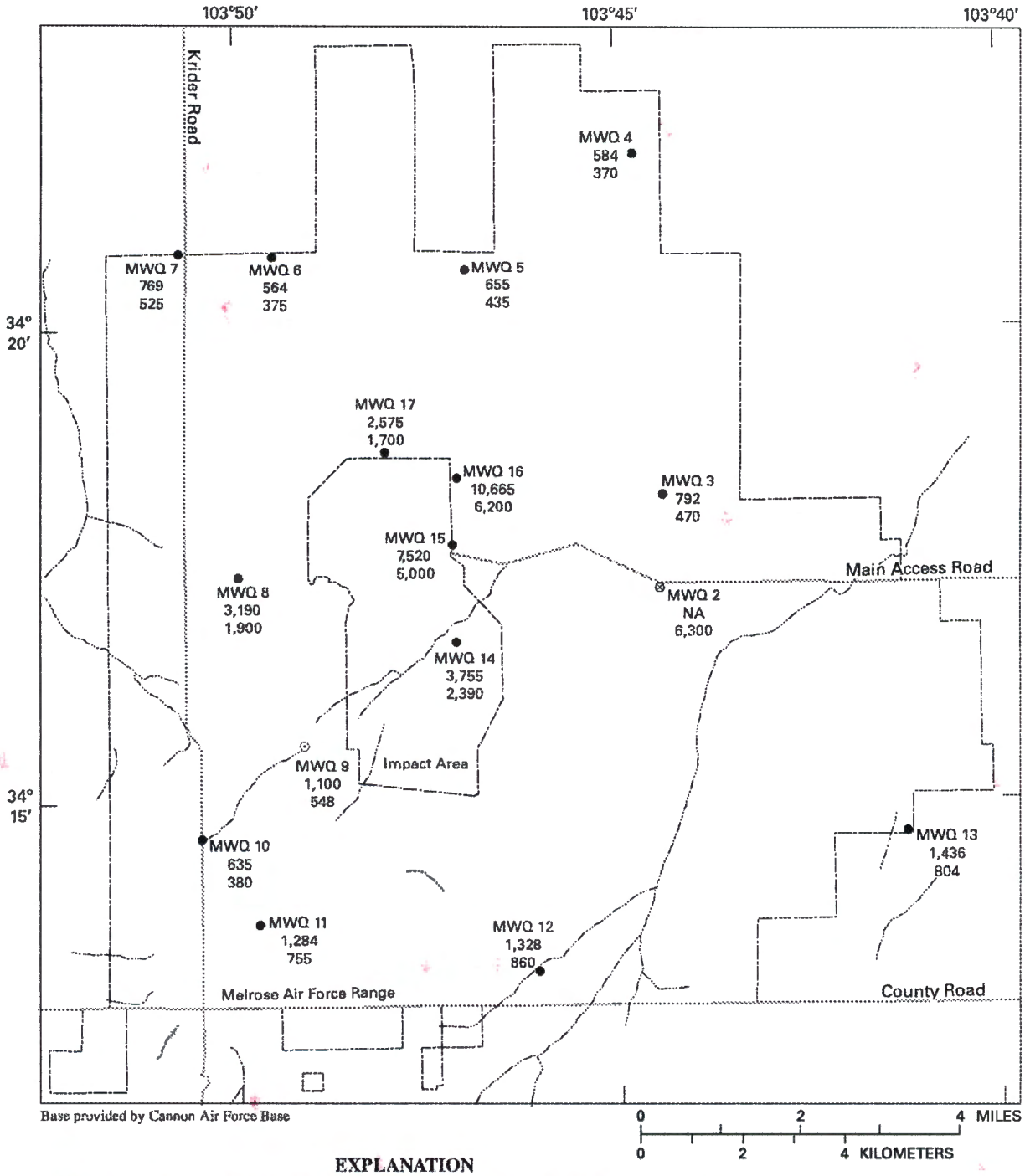
Table 3. Median concentrations and ranges of general physical and chemical properties for ground-water samples collected at Melrose Air Force Range, June 2002 to March 2003.

[All wells, except MWQ 2, completed in the Ogallala Formation; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; NA, not available; NR, concentration is potentially non-representative of the concentration in the surrounding formation because of well construction; V, concentrations lack validity because of potential contamination during sample collection and (or) laboratory analysis; O, outlier(s) removed from data set prior to statistical analysis; <, less than]

Well number (fig. 1)	Specific conductance (µS/cm)		pH (standard units)		Oxygen, dissolved (mg/L)		Temperature (degrees Celsius)	
	Median	Range	Median	Range	Median	Range	Median	Range
[1]MWQ 2	NA	NA	7.8	7.6-7.9	0.6	0.4-1.3	27.2	23.0-31.4
MWQ 3	792	782-803	7.8	7.6-8.2	6.7	2.9-7.1	18.9	17.4-19.2
MWQ 4	584	568-599	7.4	7.3-7.6	7.2	5.5-8.1	15.7	15.1-16.9
MWQ 5	655	631-674	7.5	7.3-7.5	5.1	2.4-7.7	17.9	17.0-18.0
MWQ 6	564	556-577	7.5	6.9-7.6	5.5	4.4-8.1	18.5	17.5-17.5
MWQ 7	769	756-850	7.5	7.3-7.9	5.2	0.0-7.6	18.2	17.4-18.8
MWQ 8	3,190	3,130-3,380	7.6	7.4-7.6	2.5	2.3-3.2	18.2	16.9-20.3
MWQ 9	1,100 NR	1,033-1,173	7.7 NR	7.1-8.2	0.3 NR	0.2-0.9	15.7 NR	14.5-17.3
MWQ 10	635	602-658	7.2	7.1-7.7	7.6	4.4-8.8	17.7	15.0-19.6
MWQ 11	1,284	949-1,623	7.6	7.4-7.9	4.4	2.3-5.3	18.8	17.7-19.7
MWQ 12	1,328	1,210-1,380	7.4	7.4-7.7	6.0	4.0-8.5	18.1	16.1-19.9
MWQ 13	1,436	1,400-1,480	7.8	7.8-8.0	5.3	3.3-7.6	20.5	19.7-21.9
MWQ 14	3,755	3,680-3,880	7.8	7.6-8.0	3.5	1.5-6.3	18.7	16.5-20.5
MWQ 15	7,520	7,270-8,700	7.6	6.9-7.7	1.1	0.2-1.7	20.4	19.6-22.8
MWQ 16	10,665	8,670-13,800	7.5	6.9-7.6	5.6	3.5-6.8	22.7	19.3-23.5
MWQ 17	2,575	1,900-2,740	7.6	7.1-7.8	6.2	4.5-7.8	19.9	17.8-22.0

Well number (fig. 1)	Solids, residue at 180 deg C, dissolved (mg/L)		Alkalinity, lab (mg/L as $CaCO_3$)		Cyanide, total (mg/L)		Sulfide, total (mg/L)	
	Median	Range	Median	Range	Median	Range	Median	Range
[1]MWQ 2	6,300	5,260-7,700	83 V	69-91	0.0043	0.0009-0.0050	<0.97	<0.97
MWQ 3	470	460-502	153	150-160	0.0037	0.0025-0.0075	<0.97	<0.97
MWQ 4	370	360-371	190	180-190	0.0042	0.0012-0.0049	<0.97	<0.97
MWQ 5	435	430-452	170	170-174	0.0045	0.0011-0.0058	<0.97	<0.97
MWQ 6	375	370-390	160	159-160	0.0046	0.0012-0.0067	<0.97	<0.97
MWQ 7	525	480-550	150	150-152	0.0024	0.0010-0.0040	<0.97	<0.97
MWQ 8	1,900	1,560-2,000	235 V	192-240	0.0034	0.0009-0.0038	<0.97	<0.97
MWQ 9	548 NR	540-570	536 NR, V	530-550	0.0032 NR	0.0010-0.0094	<0.97 NR	<0.97-4.5
MWQ 10	380	378-390	229	220-250	0.0024	0.0009-0.0040	<0.97	<0.97
MWQ 11	755	545-960	185	170-218	0.0023	0.0010-0.0036	<0.97	<0.97
MWQ 12	860	797-880	280 V	280-282	0.0022	0.0004-0.0027	<0.97	<0.97
MWQ 13	804	780-830	208 V	200-210	0.0027	0.0008-0.0035	<0.97	<0.97
MWQ 14	2,390	2,300-2,500	142 V	130-150	0.0021	0.0010-0.0044	<0.97	<0.97
MWQ 15	5,000	4,700-5,000	140 V	132-150	0.0024	0.0014-0.0050	<0.97	<0.97
MWQ 16	6,200	1,870-7,400	49 V	40-60	0.0034	0.0010-0.0054	<0.97	<0.97
MWQ 17	1,700 O	1,100-1,800	145 V	100-158	0.0030	0.0015-0.0057	<0.97	<0.97

[1]Well MWQ 2 completed in the Chinle Formation.



EXPLANATION

MWQ 11 ○ **Well**—Top characters are well number; middle number is the median specific conductance, in microsiemens per centimeter at 25 degrees Celsius; and bottom number is the median dissolved-solids concentration, in milligrams per liter
1,284 SC
755 TDS

● **Well completed in the Ogallala Formation**

⊗ **Well completed in the Chinle Formation**

⊙ **Hand-dug well with open-wall construction, completed in the Ogallala Formation**

NA **Not available**

Figure 9. Median specific-conductance values and dissolved-solids concentrations in ground water at Melrose Air Force Range, 2002-03.

Major Ions

As with specific conductance and dissolved solids, water from wells across the Range can be grouped into areas of similar major ion composition (table 4 and fig. 10). Using Back's (1961) classification diagram, water from wells MWQ 9 and 10 (near and on the Mesa) and water from wells MWQ 4-6 in the regional flow system was a mixed cation-bicarbonate type. Water from wells MWQ 11 and 13 along the southern boundary of the Range was a sodium-mixed anion type, and water from wells in and near the Impact Area (MWQ 8 and 14-17 and the deeper well MWQ 2) was a sodium-chloride type. Water from the deeper, confined aquifer in well MWQ 2 had similar ion characteristics as water in the unconfined aquifer at well MWQ 16 (fig. 10). Water from wells MWQ 3, 7, and 12 was of no distinct type.

A mixing pattern of source waters in the direction of ground-water flow can be demonstrated by ion concentrations in water from a line of wells (MWQ 10, 9, 14-17, and 3) that extends northeastward from the Mesa (predominant flow direction of the local flow system) (table 4). Mixed cation-bicarbonate water with small ion concentrations flows from the Mesa near MWQ 9 and 10 through the Impact Area at wells MWQ 14-17, where another source of ground water increases ion concentrations and the water changes to a sodium-chloride type. As water in the local flow system enters the regional flow system near well MWQ 3, the water is of no distinct type and ion concentrations decrease.

Median sodium and chloride concentrations in ground water at the Range can be separated into the same groups as observed with specific conductance and dissolved solids (fig. 11). Concentrations in water from well MWQ 10 were the smallest followed by concentrations in the regional flow system (MWQ 4-7). Concentrations increased at wells MWQ 11-13 at the southern boundary of the Range. Concentrations further increased in water from wells MWQ 8, 14, and 17, followed by the largest concentrations in water from wells MWQ 15, 16, and 2. This increase in sodium and chloride concentrations is likely indicative of ground water mixing with another source of water that increases ion concentrations as water flows from the Mesa through the Impact Area.

Nutrients, Organic Carbon, and Dissolved Gases

The spatial pattern observed with other constituents was not evident with nutrients and organic carbon concentrations (table 5). All median nitrogen as ammonia concentrations were less than 0.40 mg/L except for well MWQ 9 (25.0 mg/L), which was potentially not representative of the surrounding formation because of the well's open-wall construction. Median nitrogen as nitrate-nitrite concentrations ranged from 0.01 mg/L (MWQ 9) to 11.2 mg/L (MWQ 10). Orthophosphate concentrations were less than the method detection limit in all samples except for MWQ 9 (2.0 mg/L). Median phosphorous concentrations ranged from 0.01 mg/L (MWQ 16) to 2.9 mg/L (MWQ 9). All median organic carbon concentrations were less than 2.00 mg/L except for wells MWQ 9 (12 mg/L) and MWQ 15 (6.5 mg/L). Water from well MWQ 15 may have been influenced by past land use (MA02).

Ground-water samples were analyzed for dissolved gases to examine changes across the Range according to gas inputs from the atmosphere, chemical sources, and reduction/oxidation conditions. Methane was detected in water from wells MWQ 2, 6, 12, and 14-16 (table 6). The presence of methane likely indicates methane reduction in ground water in the Chinle Formation (MWQ 2) and in ground water in the Ogallala Formation in an agricultural area (MWQ 6), in an area influenced by cattle (MWQ 12), and in the Impact Area (MWQ 14-16).

Carbon dioxide, nitrogen, and oxygen gas concentrations varied across the Range (fig. 12). Concentrations of carbon dioxide, nitrogen, and oxygen were similar in samples from wells in the regional flow system (MWQ 3-7), ranging from 4.487 to 8.746 mg/L for carbon dioxide, 15.867 to 18.983 mg/L for nitrogen, and 5.819 to 7.004 mg/L for oxygen. Nitrogen concentrations in water from wells MWQ 11-13 in the southern part of the Range were similar, ranging from 13.915 to 14.569 mg/L. Oxygen concentrations were similar in water from wells MWQ 2 (1.535 mg/L), MWQ 8 (1.981 mg/L), and MWQ 15 (1.634 mg/L). Nitrogen concentrations were largest in water from MWQ 14 (22.829 mg/L) and MWQ 15 (23.442 mg/L). Small oxygen and large nitrogen concentrations in water from well MWQ 15 may be indicative of reduction.

Trace Elements

Trace element analysis indicated limited variability across the Range except for aluminum, barium, chromium, manganese, molybdenum, selenium, vanadium, and zinc (table 7). Aluminum, chromium, and zinc likely were influenced by field and laboratory procedures, as indicated by associated qualifiers and large range of values at each site.

Median barium concentrations ranged from 15 to 135 µg/L; the largest concentrations were in water from wells MWQ 9 (135 µg/L) and MWQ 10 (125 µg/L). Barium in water from well MWQ 2 was large (81 µg/L) relative to the remaining 13 wells (table 7), but the large range of values (32-130 µg/L) in water from MWQ 2 indicates a likely influence from field and laboratory procedures or possibly a mixing of source waters.

The large range of manganese concentrations across the Range may have been a result of dissolved-oxygen concentrations and oxidation/reduction processes. The largest concentrations of manganese (table 7) were found in water with the smallest dissolved-oxygen concentrations (MWQ 2 and 9, tables 3 and 6). Manganese is a predominant participant in reduction/oxidation processes, and manganese oxides are typically solids or colloids (insoluble) that may release soluble manganese to water under anaerobic conditions (Stumm and Morgan, 1981). Additionally, the smallest median concentrations of nitrogen as nitrate-nitrite were in water from wells MWQ 2 (0.02 mg/L) and MWQ 9 (0.01 mg/L), and the largest median concentrations of nitrogen as ammonia were in water from MWQ 2 (0.335 mg/L) and MWQ 9 (25 mg/L) (table 5). The small nitrogen as nitrate-nitrite concentrations and large nitrogen as ammonia concentrations also are indicative of reduction and anaerobic conditions.

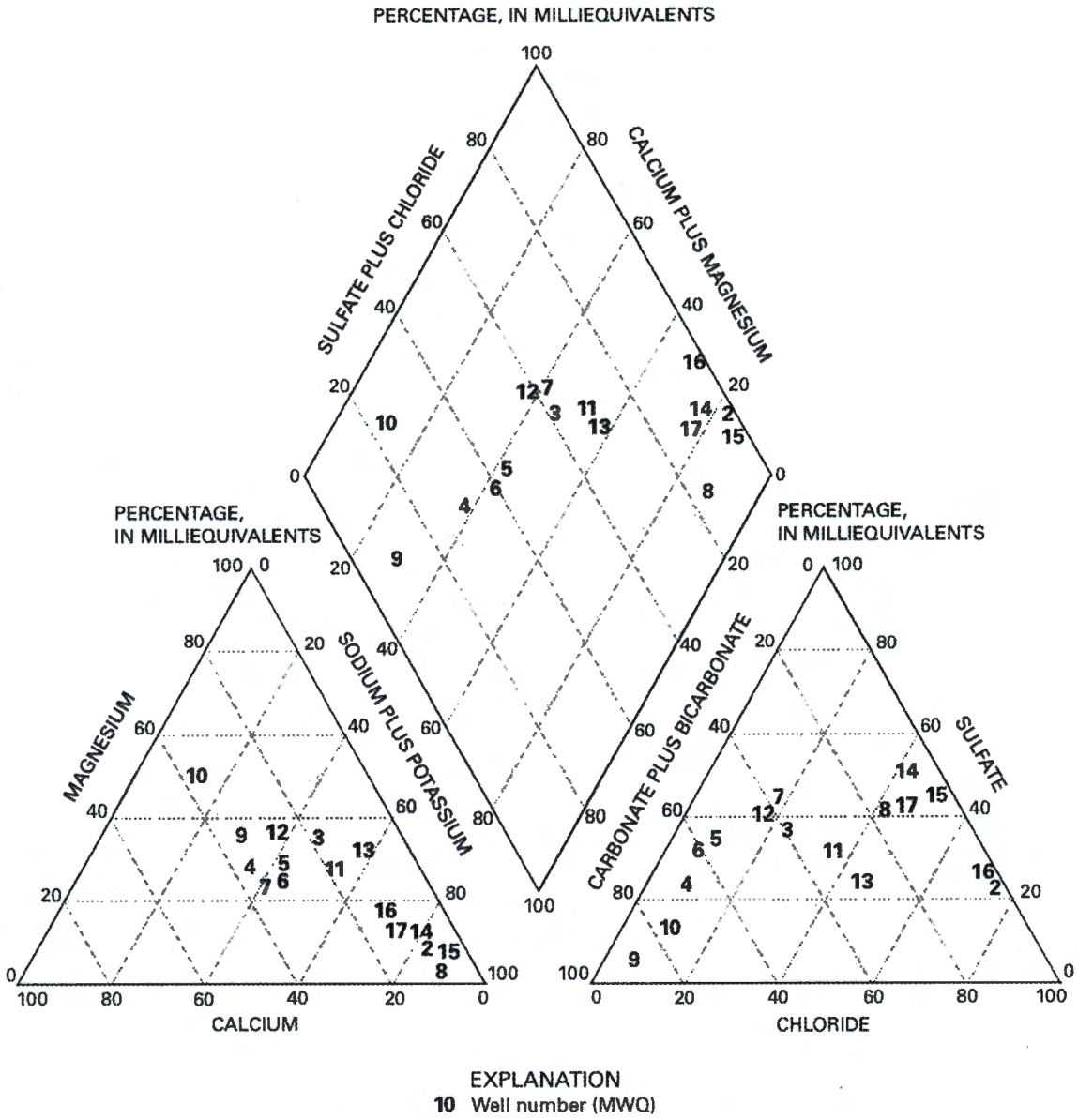
Table 4. Medians and ranges of major ion concentrations for ground-water samples collected at Melrose Air Force Range, June 2002 to March 2003.

[All wells, except MWQ 2, completed in the Ogallala Formation; mg/L, milligrams per liter; V, concentrations lack validity because of potential contamination during sample collection and (or) laboratory analysis; NR, concentration is potentially non-representative of the concentration in the surrounding formation because of well construction]

Well number (fig. 1)	Calcium, total (mg/L as Ca)		Magnesium, total (mg/L as Mg)		Sodium, total (mg/L as Na)		Potassium, total (mg/L as K)	
	Median	Range	Median	Range	Median	Range	Median	Range
[1]MWQ 2	175 V	151-190	115	101-120	2,100	1,900-2,200	8.99	8.20-12.00
MWQ 3	28.5	27.7-33.0	32.0	30.8-34.0	80.8	78.0-87.0	5.35	4.70-6.50
MWQ 4	44.2	42.0-45.0	20.3	19.0-22.0	53.3	51.0-59.0	3.17	2.70-3.30
MWQ 5	42.2	41.0-44.0	22.8	22.0-25.0	65.7	63.0-70.0	2.72	2.40-3.20
MWQ 6	38.1	37.0-40.0	18.9	18.0-20.0	57.0	54.3-64.0	2.35	1.97-2.70
MWQ 7	58.5	53.7-62.0	25.5	23.6-27.0	74.0	68.4-77.0	2.53	2.10-2.70
MWQ 8	51.0 V	44.0-69.3	21.0	18.0-23.3	662	620-680	4.10	2.90-4.81
MWQ 9	72.0 V, NR	71.0-74.0	46.2 NR	45.0-48.0	67.5 NR	63.7-80.0	10.00 NR	9.01-10.00
MWQ 10	52.3	52.0-54.0	40.5	36.9-42.0	16.5	15.2-18	5.18	5.00-5.60
MWQ 11	50.5	24.4-73.0	43.5	21.0-61.0	155	14.9-160	7.95	5.57-9.30
MWQ 12	77.0 V	70.5-82.0	66.5	60.7-71.0	130	120-140	5.25	5.18-5.90
MWQ 13	30.0 V	29.0-32.0	55.0	51.9-59.0	185	177-200	10.40	9.7-11.00
MWQ 14	65.0 V	61.6-87.0	60.5	56.9-77.0	687	660-720	11.25	9.20-13.00
MWQ 15	111 V	100-120	69.5	55.6-83.0	1,650	1,400-1,720	8.27	7.50-8.90
MWQ 16	300 V	260-339	275	240-327	2,050	1,800-2,360	15.90	12.00-17.00
MWQ 17	57.9 V	41.0-65.0	49.9	39.0-58.0	539	320-560	7.20	4.40-8.20

Well number (fig. 1)	Bicarbonate, field, total (mg/L as HCO_3)		Sulfate, total (mg/L as SO_4)		Chloride, total (mg/L as Cl)		Fluoride, total (mg/L as F)		Bromide, total (mg/L as Br)	
	Median	Range	Median	Range	Median	Range	Median	Range	Median	Range
[1]MWQ 2	100	95-104	1,150	1,050-1,200	2,900	2,550-3,300	0.54	0.07-1.10	8.05	7.20-14.0
MWQ 3	181	181-181	136	130-140	59.9	56.0-61.0	1.95	1.90-2.00	0.48	0.44-0.50
MWQ 4	233	222-244	57.0	55.7-59.0	18.5	18.0-19.7	1.80	1.80-1.90	0.26	0.22-0.40
MWQ 5	209	203-214	98.5	92.0-102	22.0	21.0-23.0	2.40	2.40-2.50	0.26	0.16-0.3
MWQ 6	191	184-197	81.0	75.0-87.0	15.5	13.0-16.9	2.65	2.60-2.90	0.34	0.16-0.50
MWQ 7	190	184-195	165	149-170	52.3	48.0-69.0	1.80	1.60-1.90	0.43	0.35-0.79
MWQ 8	285	277-292	600	492-720	445	403-560	2.50	1.60-3.30	3.25	2.4-4.00
MWQ 9	634 NR	592-675	19.6 NR	7.6-28.0	29.0 NR	23.8-33.0	4.25 NR	4.00-4.70	0.39 NR	0.25-0.44
MWQ 10	274	262-285	39.0	35.2-48.0	20.5	14.4-24.0	0.90	0.80-0.94	0.26	0.17-0.35
MWQ 11	245	242-248	190	105-230	160	70.5-220	2.00	1.50-2.40	1.08	0.50-1.40
MWQ 12	338	334-342	275	252-310	90.6	87.0-100	3.85	3.40-4.00	0.65	0.59-0.72
MWQ 13	250	244-255	158	140-160	222	210-230	4.05	3.80-4.50	1.30	1.10-1.50
MWQ 14	182	176-187	905	882-980	560	543-610	2.65	2.20-3.70	4.55	4.30-5.30
MWQ 15	149	143-154	1,795	1,600-1,800	1,500	1,300-1,520	1.85	0.08-2.60	10.10	8.80-11.1
MWQ 16	66	61-70	1,600	1,300-2,020	3,100	2,500-3,630	1.45	0.08-1.70	8.25	6.70-10.7
MWQ 17	212	197-226	587	350-640	465	290-560	2.20	1.40-2.50	1.95	1.30-2.40

[1]Well MWQ 2 completed in the Chinle Formation.



Note: Well MWQ 2 completed in the Chinle Formation. All other wells completed in the Ogallala Formation.

Figure 10. Ground-water composition at Melrose Air Force Range, 2002-03.

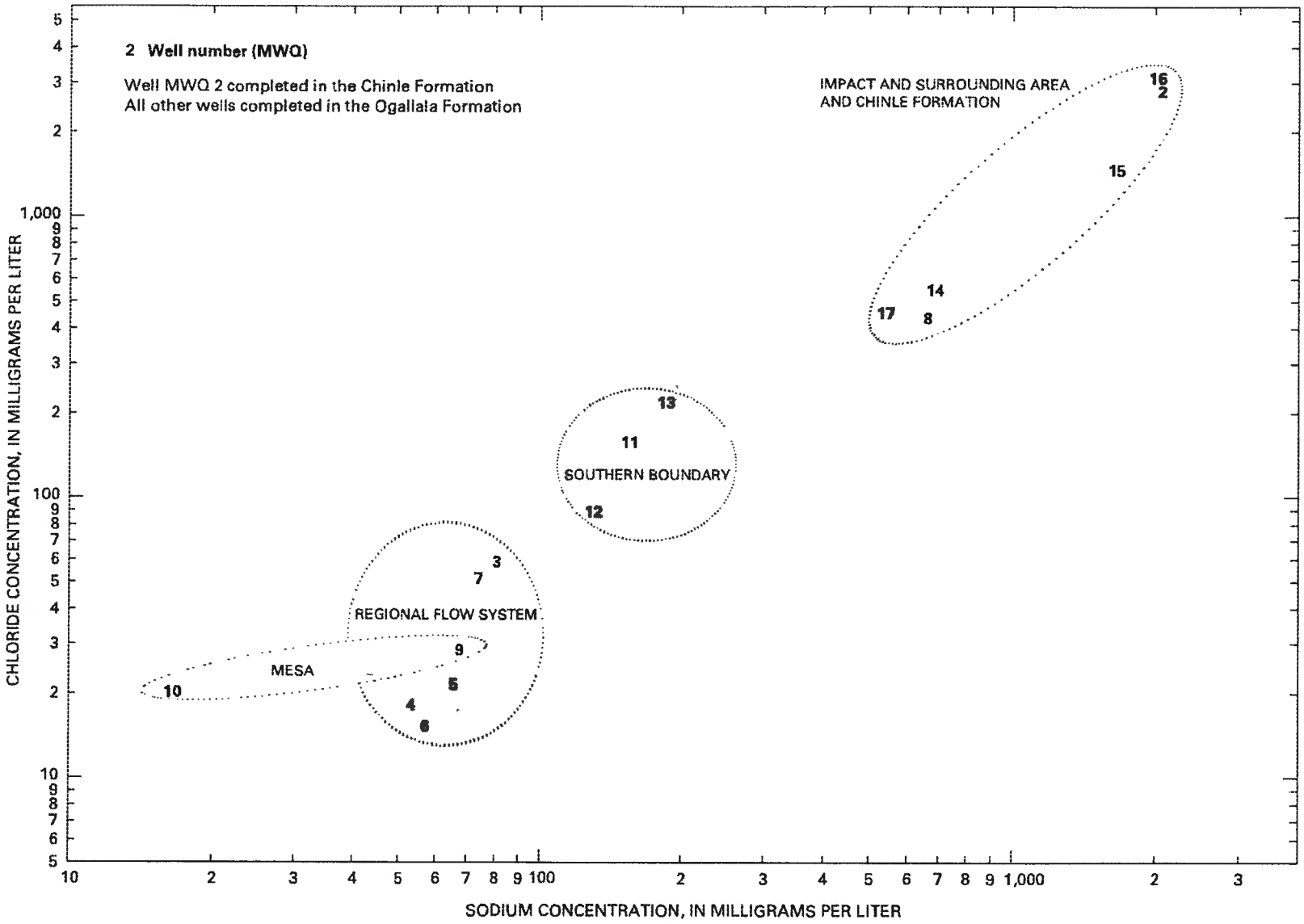


Figure 11. Median sodium and chloride concentrations in ground water at Melrose Air Force Range, 2002-03.

Table 5. Medians and ranges of nutrient and total organic carbon concentrations for ground-water samples collected at Melrose Air Force Range, June 2002 to March 2003.

[All wells, except MWQ 2, completed in the Ogallala Formation; mg/L, milligrams per liter; conc., concentration; DP, decreased concentration precision because of small concentration levels; <, less than; NR, concentration is potentially non-representative of the concentration in the surrounding formation because of well construction]

Well number (fig. 1)	Nitrogen, ammonia total (mg/L as N)		Nitrogen, nitrate-nitrite total (mg/L as N)		Orthophosphate, total (mg/L as P)		Phosphorus, total (mg/L as P)		Carbon, organic total (mg/L as C)	
	Median	Range	Median	Range	Conc.	Range	Median (DP)	Range	Median (DP)	Range
[1]MWQ 2	0.335	0.280-0.460	0.02	0.01-0.23	<0.04	<0.04	0.12	0.01-0.38	0.93	0.74-1.9
MWQ 3	0.019	0.008-0.043	0.91	0.85-0.93	<0.04	<0.04	0.05	0.03-0.12	0.45	0.14-0.69
MWQ 4	0.035	0.020-0.063	5.70	5.60-6.00	<0.04	<0.04	0.19	0.01-0.44	0.37	0.14-3.0
MWQ 5	0.040	0.020-0.087	6.25	5.90-6.50	<0.04	<0.04	0.08	0.01-0.16	0.55	0.29-0.92
MWQ 6	0.019	0.008-0.071	4.55	4.20-5.70	<0.04	<0.04	0.17	0.01-0.47	0.33	0.14-0.66
MWQ 7	0.008	0.008-0.074	1.65	1.40-1.70	<0.04	<0.04	0.03	0.01-0.28	0.65	0.14-0.70
MWQ 8	0.115	0.050-0.260	0.42	0.26-0.52	<0.04	<0.04	0.12	0.01-0.87	1.8	1.5-1.9
MWQ 9	25.0 NR	18.5-29.0	0.01 NR	0.01-0.07	2.0 NR	<0.04	2.9 NR	2.5-3.1	12 NR	10-16
MWQ 10	0.035	0.020-0.500	11.2	9.9-12.0	<0.04	<0.04	0.08	0.01-0.39	0.88	0.51-1.3
MWQ 11	0.040	0.020-0.068	7.45	3.30-11.0	<0.04	<0.04	0.06	0.01-0.09	0.84	0.66-1.3
MWQ 12	0.160	0.150-0.400	1.40	1.40-1.60	<0.04	<0.04	0.03	0.01-0.17	1.1	0.75-1.5
MWQ 13	0.025	0.020-0.079	6.20	5.50-6.30	<0.04	<0.04	0.08	0.04-0.64	0.82	0.61-1.1
MWQ 14	0.045	0.020-1.10	2.15	2.10-2.30	<0.04	<0.04	0.05	0.01-0.07	0.65	0.31-0.90
MWQ 15	0.093	0.030-0.100	5.30	4.00-5.80	<0.04	<0.04	0.05	0.007-0.160	6.5	6.2-6.5
MWQ 16	0.025	0.008-0.065	0.87	0.73-1.10	<0.04	<0.04	0.01	0.007-0.03	0.32	0.14-0.72
MWQ 17	0.035	0.020-0.42	0.25	0.18-0.26	<0.04	<0.04	0.08	0.01-0.12	0.61	0.15-0.76

[1]Well MWQ 2 completed in the Chinle Formation.

Table 6. Dissolved gas concentrations for ground-water samples collected at Melrose Air Force Range, December 2002.

[All wells, except MWQ 2, completed in the Ogallala Formation; mg/L, milligrams per liter]

Well number[1] (fig. 1)	Methane (mg/L)	Carbon dioxide (mg/L)	Nitrogen (mg/L)	Oxygen (mg/L)	Argon (mg/L)
[2]MWQ 2	0.0264	1.802	16.510	1.535	0.4746
MWQ 3	0.0000	4.487	15.867	6.084	0.5463
MWQ 4	0.0000	8.746	15.911	6.343	0.5501
MWQ 5	0.0000	7.258	17.593	6.174	0.5768
MWQ 6	0.0008	6.251	18.983	5.819	0.6021
MWQ 7	0.0000	6.872	16.226	7.004	0.5502
MWQ 8	0.0000	8.371	12.052	1.981	0.4364
MWQ 10	0.0000	16.067	19.252	8.309	0.6146
MWQ 11	0.0000	7.139	14.569	3.657	0.5271
MWQ 12	0.0121	15.622	13.915	3.896	0.5120
MWQ 13	0.0000	6.762	14.371	3.198	0.5028
MWQ 14	0.0106	3.508	22.829	3.118	0.6541
MWQ 15	0.0023	4.700	23.442	1.634	0.6558
MWQ 16	0.0028	1.676	18.290	5.217	0.5849
MWQ 17	0.0000	3.008	12.582	5.813	0.4707

[1]Ground water from MWQ 9 was not analyzed by the lab for dissolved gases because of its open-well construction.

[2]Well MWQ 2 completed in the Chinle Formation.

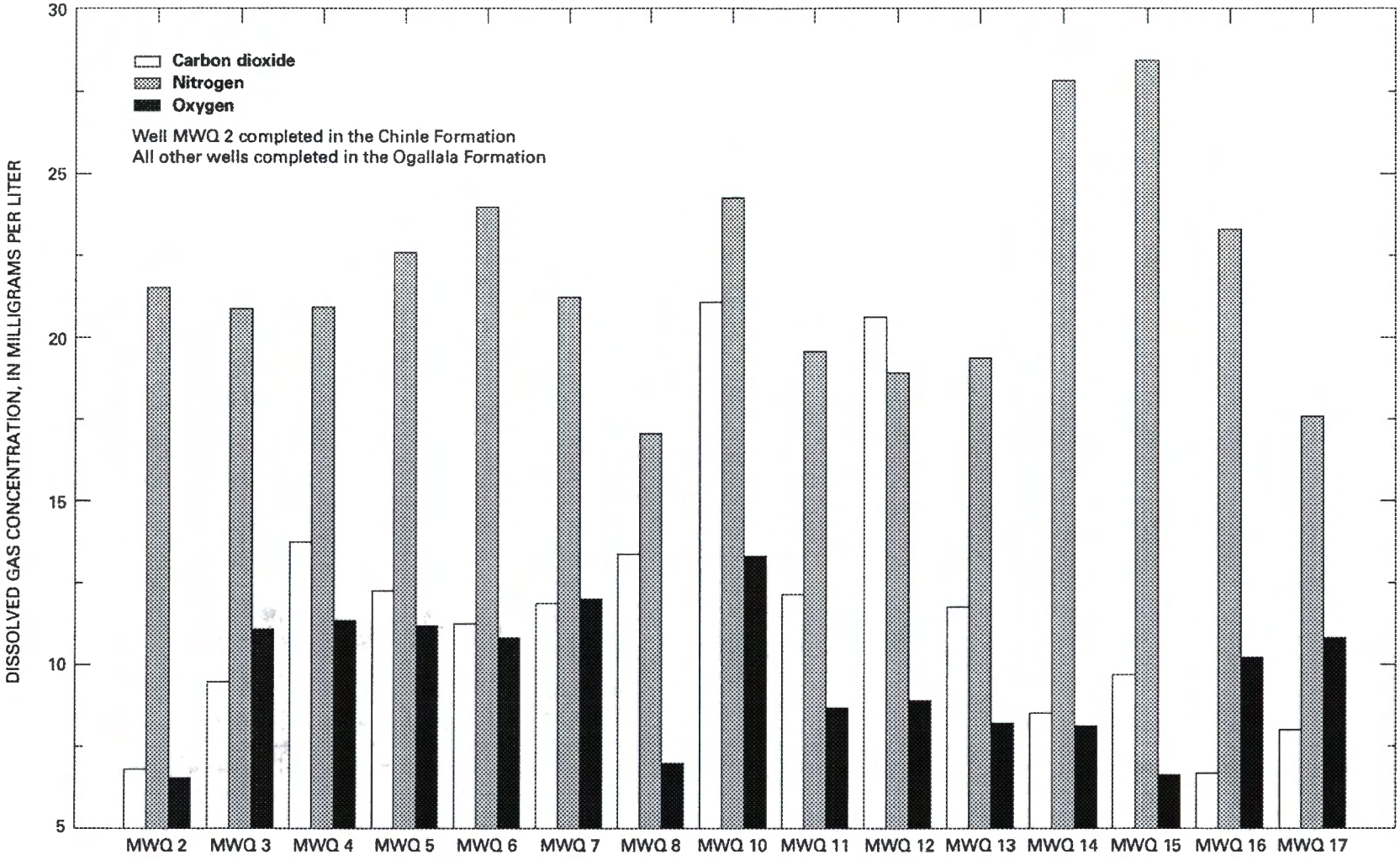


Figure 12. Carbon dioxide, nitrogen, and oxygen gas concentrations in ground water at Melrose Air Force Range, December 2002.

Table 7. Medians and ranges of trace element concentrations for ground-water samples collected at Melrose Air Force Range, June 2002 to March 2003.

[All wells, except MWQ 2, completed in the Ogallala Formation; µg/L, micrograms per liter; DP, decreased concentration precision because of small concentration levels; <, less than; O, outlier(s) removed from data set prior to statistical analysis; NA, not available; NR, concentration is potentially non-representative of the concentration in the surrounding formation because of well construction; V, concentrations lack validity because of potential contamination during sample collection and laboratory analysis]

Well number (fig. 1)	Aluminum, total (µg/L as Al)		Antimony, total (µg/L as Sb)		Arsenic, total (µg/L as As)		Barium, total (µg/L as Ba)		Beryllium, total (µg/L as Be)		Cadmium, total (µg/L as Cd)	
			6 µg/L		100 µg/L		1000 µg/L		4 µg/L		10 µg/L	
	Median	Range	Median	Range	Median (DP)	Range	Median	Range	Median	Range	Median	Range
[1]MWQ 2	<20 O	<20-21	<4	<4	<4	<4	81	32-130	<1	<1	<1	<1
MWQ 3	<20	<20-22	<4	<4	8	5-13	26	3.4-32	<1	<1	<1	<1
MWQ 4	<20	<20-24	<4	<4	4	<4-7	46	1.0-46	<1	<1	<1	<1
MWQ 5	<20	<20	<4	<4	6	<4-7	30	0.5-31	<1	<1	<1	<1
MWQ 6	<20	<20-21	<4	<4	6	4-7	32	0.9-33	<1	<1	<1	<1
MWQ 7	<20	<20-36	<4	<4	5	<4-9	31	1.9-33	<1	<1	<1	<1
MWQ 8	NA O	NA	<4	<4	<4	<4	17 O	9.8-35	<1	<1-1.5	<1	<1
MWQ 9	39 O, NR	<20-110	<4 NR	<4	<4 NR	<4	135 NR	7.1-140	<1 NR	<1-1.4	<1 NR	<1
MWQ 10	<20	<20-10	<4	<4	<4	<4	125	5.8-130	<1	<1-1.3	<1	<1
MWQ 11	<20	<20-20	<4	<4	<4	<4	32	7.9-33	<1	<1-2.2	<1	<1
MWQ 12	105	34-114	<4	<4	<4	<4	41	3.3-43	<1	<1	<1	<1
MWQ 13	157	<20-280	<4	<4	6	<4-9	49	5.6-52	<1	<1	<1	<1
MWQ 14	460 O	72-828	<4	<4	<4	<4	28	13-73	<1	<1	<1	<1
MWQ 15	672	180-1,600	<4	<4	<4	<4	15	3.7-19	<1	<1	<1	<1
MWQ 16	148	<20-280	<4	<4	<4	<4	20	2.6-24	<1	<1	<1	<1
MWQ 17	2,150 O	180-2,400	<4	<4	<4	<4	56	27-100	<1	<1	<1	<1

0.051

Table 7. Medians and ranges of trace element concentrations for ground-water samples collected at Melrose Air Force Range, June 2002 to March 2003.—Continued

Well number (fig. 1)	Chromium, total (µg/L as Cr)		Cobalt, total (µg/L as Co)		Copper, total (µg/L as Cu)		Iron, total (µg/L as Fe)		Lead, total (µg/L as Pb)		Manganese, total (µg/L as Mn)	
	50 µg/L		730 µg/L		1300 µg/L		—		50 µg/L		—	
	Median (DP)	Range	Median	Range	Median	Range	Median	Range	Median	Range	Median	Range
[1]MWQ 2	<1 O	<1-12	2 O	<1-4	3 O	1-4	NA	NA	3	1-9	355	280-500
MWQ 3	1	<1-4	<1	<1	1	<1-3	NA	NA	2	1-2.4	<1	<1
MWQ 4	<1	<1-1	<1	<1	3	<1-4	NA	NA	<2	<2	<1	<1
MWQ 5	1	<1-1	<1	<1	<1	<1	NA	NA	<2 O	<2	<1	<1
MWQ 6	1	<1-3	<1	<1	<1	<1	NA	NA	<2	<2	2	<1-5
MWQ 7	1	<1-6	<1	<1	<1	<1	NA	NA	<2	<2	1	<1-1
MWQ 8	7	<1-24	3	<1-6	13	2-24	NA	NA	<2 O	<2	20 O	2-110
MWQ 9	1 NR	<1-5	<1 NR	<1	2 NR	<1-7	NA	NA	<2 NR	<2	725 NR	670-820
MWQ 10	<1	<1-1	<1	<1-5	1	<1-2	NA	NA	<2	<2	1	<1-1
MWQ 11	1	<1-1	<1	<1	3	<1-6	NA	NA	<2	<2	2	1-4
MWQ 12	2	<1-5	<1	<1	5	4-8	NA	NA	<2	<2	13	9-14
MWQ 13	3	<1-8	<1	<1	15	<1-18	NA	NA	2	1-4	115	3-164
MWQ 14	17	3-39	1	<1-6	3	1-7	NA	NA	2	1-4	45	2-84
MWQ 15	6	2-20	1	<1-3	3	2-5	NA	NA	<2	<2	63	35-72
MWQ 16	7	5-13	2	<1-2	5	<1-8	NA	NA	<2 O	<2	7	4-12
MWQ 17	16	7-27	1	<1-2	3	<1-5	NA	NA	3	1-4	78	20-160

Table 7. Medians and ranges of trace element concentrations for ground-water samples collected at Melrose Air Force Range, June 2002 to March 2003.—Continued

Well number (fig. 1)	Molybdenum, total (µg/L as Mo)		Nickel, total (µg/L as Ni)		Selenium, total (µg/L as Se)		Silver, total (µg/L as Ag)		Thallium, total (µg/L as Tl)		Vanadium, total (µg/L as V)		Zinc, total (µg/L as Zn)	
			100 µg/L		50 µg/L		50 µg/L		2.0 µg/L		31 µg/L		10000 µg/L	
	Median	Range	Median	Range	Median (DP)	Range	Median	Range	Median	Range	Median	Range	Median	Range
[1]MWQ 2	28	18-31	13	7-34	<5	<5-6	<1	<1	<7	<7	1 O	1-6	28 V	<7-120
MWQ 3	7	6-8	<2 O	<2	6	<5-11	<1	<1	<7	<7	70	65-78	<7	<7-10
MWQ 4	4	3-5	<2 O	<2	<5	<5-6	<1	<1	<7	<7	53	49-55	12	11-19
MWQ 5	4	3-5	<2	<2-3	6	<5-7	<1	<1	<7	<7	58	54-60	25 O	7-490
MWQ 6	3	2-4	<2	<2-3	<5	<5-6	<1	<1	<7	<7	51	50-55	33	16-120
MWQ 7	5	4-5	<2 O	<2	7	<5-9	<1	<1	<7	<7	48	45-49	<7	<7-10
MWQ 8	19	14-19	7	<2-22	<5	<5	<1	<1	<7	<7	8	3-17	81 O,V	50-385
MWQ 9	3 NR	1-8	2 NR,O	<2-2	<5 NR	<5	<1 NR	<1	<7 NR	<7	14 NR	9-17	7 V,NR	<7-18
MWQ 10	5	4-5	<2	<2-2	<5	<5	<1	<1	<7	<7	33	27-37	8	<7-9
MWQ 11	10	8-13	<2 O	<2	22	13-23	<1	<1	<7	<7	6	1-9	27	19-51
MWQ 12	11	10-12	2 O	<2-3	38	34-43	<1	<1	<7	<7	19	11-22	53 V	32-150
MWQ 13	11	10-12	2 O	<2-3	14	7-17	<1	<1	<7	<7	52	32-65	102 V	13-115
MWQ 14	28	27-28	14	5-24	25	20-26	<1	<1	<7	<7	6	4-11	17 V	9-38
MWQ 15	18	14-22	<2 O	<2-3	150	120-160	<1	<1	<7	<7	9	6-10	19 V	<7-49
MWQ 16	13	10-14	4	<2-7	24	20-25	<1	<1-4	<7	<7	6	5-6	24 V	9-30
MWQ 17	7	5-8	11	3-13	<5	<5-6	<1	<1	<7	<7	14	9-20	20 V	10-24

[1]Well MWQ 2 completed in the Chinle Formation.

Selenium concentrations were less than or near the method detection limit for water from wells MWQ 2-10 and MWQ 17 (table 7). Selenium concentrations were greater than twice the method detection limit for water from wells in the southern part of the Range (MWQ 11-13) and for most wells in the Impact Area (MWQ 14-16).

Concentrations of molybdenum and vanadium in ground water at the Range varied the most of the trace elements. Molybdenum and vanadium may become mobile and migrate as oxides in a strongly oxidizing environment, whereas these trace elements typically become bound in sulfides and precipitate in strong reducing conditions (Goldschmidt, 1958). The distribution of molybdenum and vanadium concentrations across the Range suggests the possibility of different source waters and reduction/oxidation processes. Similar to specific conductance, dissolved solids, and major ions, ground water at the Range can be grouped either by concentrations of molybdenum or vanadium (fig. 13).

Concentrations of molybdenum in water from the regional flow system (MWQ 3-7) were similar, ranging from 3 to 7 µg/L, whereas vanadium concentrations had a larger range (48 to 70 µg/L). Wells near and in the Impact Area (MWQ 8 and 14-17) produced water with similar concentrations of vanadium (6 to 14 µg/L), but molybdenum concentrations ranged from 7 to 28 µg/L. The molybdenum concentration (28 µg/L) and vanadium concentration (1 µg/L) in water from the deeper, confined aquifer of the Chinle Formation (MWQ 2) were similar to concentrations in water from the unconfined aquifer in the Impact Area. Concentrations of molybdenum and vanadium in water from wells near the Mesa (MWQ 9-11) and in the southern part of the Range (MWQ 12-13) did not exhibit a similar grouping as seen with the other constituents.

Stable Isotopes

Results of stable isotope analysis (table 8) indicated variable isotopic ratios across the Range and a somewhat similar grouping of wells as seen with the previous constituents. In the regional flow system (MWQ 3-7), δD ranged from -45.79 to -42.78‰ and $\delta^{18}O$ ranged from -6.22 to -5.99‰. Isotopic ratios in water from wells MWQ 10, 12, and 15 were similar to those in the regional flow system, with δD of -45.35‰, -41.97‰, and -45.44‰, respectively, and $\delta^{18}O$ of -6.60‰, -6.24‰, and -6.47‰, respectively. Isotopic ratios in water from wells MWQ 8, 14, 16, and 17, near and in the Impact Area, were different from ratios found in the regional flow system, with δD ranging from -71.84 to -64.46‰ and $\delta^{18}O$ ranging from -10.00 to -8.77‰. Isotopic ratios were similar in water from wells MWQ 2 and MWQ 13, with δD ratios of -58.49‰ and -56.68‰, respectively, and $\delta^{18}O$ ratios of -7.95‰ and -7.99‰, respectively.

The stable isotope results are an indicator of local precipitation, formation conditions, and different water sources (fig. 14). The slopes of ground-water fit-lines for δD and $\delta^{18}O$ ratios for water from wells in Clovis (Nativ, 1988) and the Range (fig. 14) are similar and both less than 8 (enrichment of heavier isotopes), which is indicative of local effects. With minimal topographic relief and similar air temperatures in the area, recharge altitude and temperature would not be expected to play a substantial role in isotopic ratio differences for the local and regional flow system in the unconfined aquifer. The similar δD and $\delta^{18}O$ ratios for water in the regional flow system (MWQ 3-7), the local flow system on the Mesa (MWQ 10), and near an ephemeral stream (MWQ 12) indicate minimal change in isotope ratios because of recharge altitude or temperature (fig. 14; table 3).

For ground water near and in the Impact Area, another source of water of different isotopic composition appears to have a strong influence near MWQ 8, a lessening influence across the Impact Area, and its weakest influence near MWQ 14 (fig. 14). The smallest δD and $\delta^{18}O$ ratios were in water from well MWQ 8, followed by water from wells MWQ 17 and 16, and followed then by water from wells MWQ 14 and 2. The smaller δD and $\delta^{18}O$ ratios in and near the Impact Area indicate another source of water than what is being recharged near the Mesa or exists in the regional flow system. This observation is similar to the other water-quality constituents. Water from well MWQ 2 in the deeper, confined aquifer, however, does not appear to be the other source of water because the isotopic ratios in water from MWQ 2 are not similar to the isotopic ratios in water from MWQ 8.

Table 8. Stable isotopic ratios for hydrogen and oxygen for ground-water samples collected at Melrose Air Force Range, December 2002.

[All wells, except MWQ 2, completed in the Ogallala Formation]

Well number (fig. 1)	H-2/H-1 stable isotopic ratio, per mil (δD‰)	O-18/O-16 stable isotopic ratio, per mil ($\delta^{18}O$‰)
[1]MWQ 2	-58.49	-7.95
MWQ 3	-44.21	-5.99
MWQ 4	-42.78	-6.09
MWQ 5	-44.61	-6.19
MWQ 6	-45.79	-6.22
MWQ 7	-44.73	-6.11
MWQ 8	-71.84	-10.00
MWQ 10	-45.35	-6.60
MWQ 11	-60.87	-8.64
MWQ 12	-41.97	-6.24
MWQ 13	-56.68	-7.99
MWQ 14	-64.46	-8.77
MWQ 15	-45.44	-6.47
MWQ 16	-66.55	-9.23
MWQ 17	-66.81	-9.39

[1]Well MWQ 2 completed in the Chinle Formation.

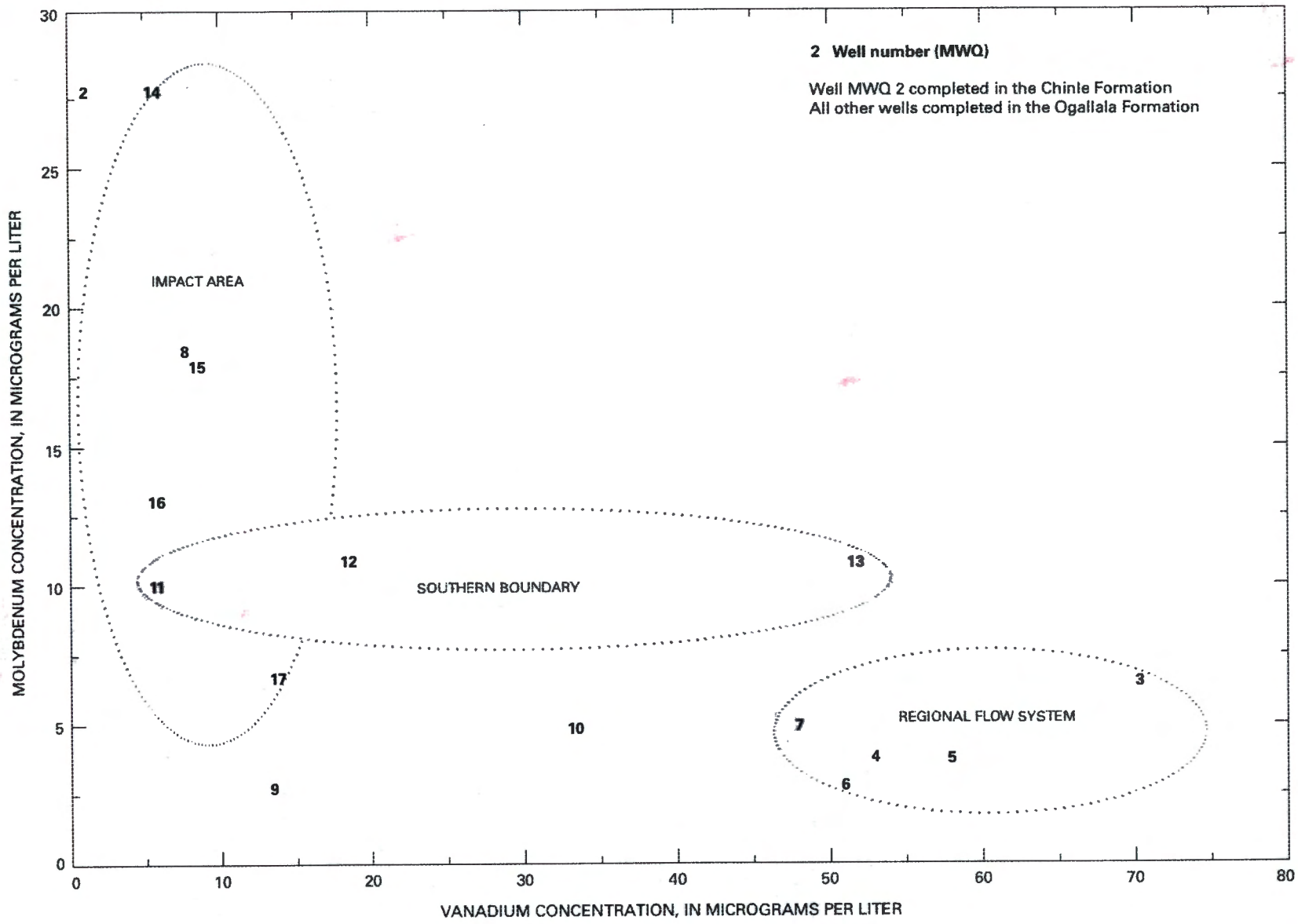


Figure 13. Median molybdenum and vanadium concentrations in ground water at Melrose Air Force Range, 2002-03.

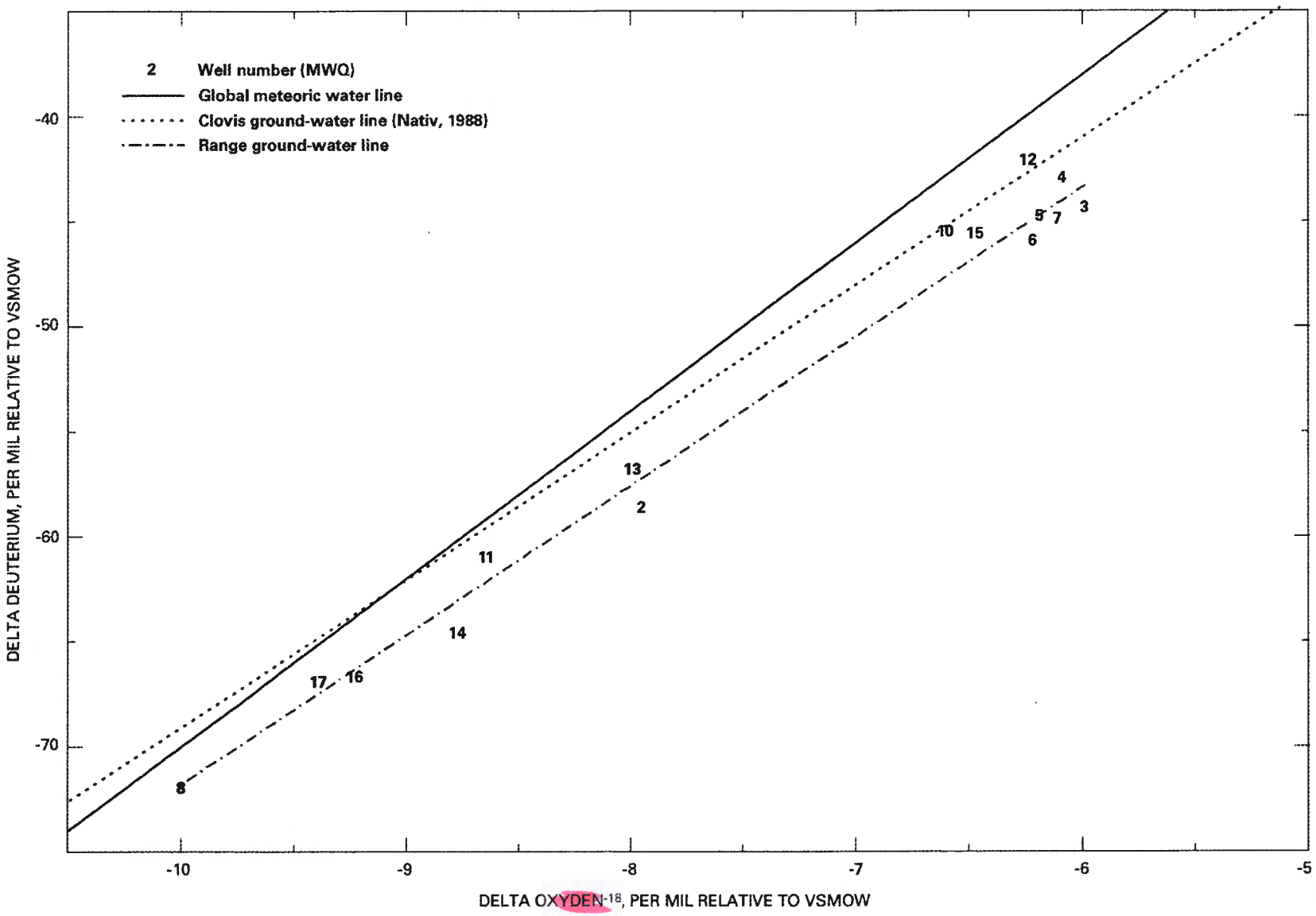


Figure 14. Hydrogen and oxygen stable isotopic ratios in ground water at Melrose Air Force Range, December 2002.

It is possible that leakage between the unconfined aquifer in the Ogallala Formation and confined aquifer in the Chinle Formation is occurring outside the Range area and creating ground water of mixed isotopic ratios in both the Ogallala and Chinle Formations. This mixed water may then be moving into the local flow system the Range where additional leakage is occurring near and in the Impact Area. Overall, the isotopic ratios in ground water from the Impact Area are similar to those historically documented for ground water in the Chinle Formation (Nativ, 1988).

Pesticides

Analysis of ground water for pesticides resulted in no detections larger than method reporting limits. One detection of 4,4'-DDT was reported for a sample from well MWQ 9 at an estimated concentration of 0.011 µg/L.

Explosives

Analysis of ground water for explosive compounds resulted in no detections larger than method detection limits.

Volatile Organic Compounds

No volatile organic compounds were detected at concentrations greater than method reporting limits. Estimated concentrations of chlorodibromomethane (0.20 µg/L) and acetone (2.9 µg/L) were detected in water from wells MWQ 16 and 17, respectively. Chlorodibromomethane and acetone are laboratory reagents, and because of the estimated concentrations, the detections are considered insignificant. Methylene chloride was detected at estimated concentrations (less than 0.5 µg/L) in all samples from wells near and in the Impact Area, but this compound also was detected in trip blanks and, thus, is considered to be a shipping or laboratory contaminant.

Semivolatile Organic Compounds

Analysis of semivolatile organic compounds indicated no detections larger than method reporting limits. An estimated concentration of bis (2-Ethylhexyl) phthalate (4.4 µg/L) was detected in water well MWQ 15. Bis (2-Ethylhexyl) phthalate is a manufactured chemical commonly added to plastics for flexibility. This detection is likely a field or laboratory contaminant and is considered insignificant.

Total Organic Halogens

A total organic halogen concentration of 32 µg/L was detected in water from well MWQ 15. Analysis of the MWQ 15 sample did show an analytical method interference because of a large chloride concentration (1,500 mg/L). Total organic halogen analysis provides a gross analysis for a wide range of compounds, including chlorinated solvents, polychlorinated biphenyls, and metal halides. Because of the large chloride concentration and the lack of detections of halogenated compounds from the semivolatile organic compound analysis, this detection is considered insignificant.

Perchlorate

Analysis of perchlorate indicated no detections larger than method detection limits in samples collected in June 2002. Perchlorate was detected at estimated concentrations in water from wells MWQ 14 (2.6 µg/L) and MWQ 15 (20 µg/L). Perchlorate analysis indicated analytical method interference because of large chloride concentrations in these samples. Because perchlorate was not detected in water from these wells in June 2002 and because of the analytical method interference associated with large chloride concentrations, these detections are considered insignificant.

Source Waters

Because of changes in water quality from the Mesa to the regional flow system in the unconfined aquifer, it is likely that upward leakage from the deeper, confined aquifer has influenced water quality in the unconfined aquifer near and in the Impact Area. The spatial distribution of most water-quality constituents consisted of three groups: local flow system outside the Impact Area, local flow system near and in the Impact Area, and the regional flow system. Ground-water quality at the Mesa (MWQ 10) was similar to that of the regional flow system (MWQ 3-7), but water quality in the Impact Area (MWQ 14-17), located in the direction of ground-water flow in the unconfined aquifer between these two areas, was substantially different.

Specific conductance, dissolved solids, water temperature, major ions, and the trace elements molybdenum and vanadium suggest that water may be leaking from the deeper, confined aquifer in the Chinle Formation into the unconfined aquifer in the Ogallala Formation and altering the water quality in the unconfined aquifer near and in the Impact Area. However, elevated CFC concentrations, nutrient concentrations, and stable isotope ratios in water near and in the Impact Area indicate that the deeper, confined aquifer may not be the only influence on water quality and that past land uses may be an influence on ground water near and in the Impact Area. Additionally, the deeper, confined aquifer likely has a variable influence near and in the Impact Area because various water-quality constituents indicated concentration variability near and in the Impact Area. Given the current (2004) understanding of the Range's ground-water hydrology and water quality, the different water quality near and in the Impact Area cannot be attributed solely to upward leakage from the deeper, confined aquifer of the Chinle Formation, but leakage between the Ogallala and Chinle Formations is likely.

Summary

This report, prepared in cooperation with the U.S. Air Force, Cannon Air Force Base, presents the results of an investigation to characterize the ground-water hydrology and water quality in the Southern High Plains aquifer at Melrose Air Force Range. This characterization provides Cannon Air Force Base resource managers with reliable, baseline ground-water data and a broad overview of the Southern High Plains aquifer in the Ogallala Formation at the Range for future planning efforts to protect the aquifer and ensure continued operation of the Range and all its current (2004) activities. A 29-well monitoring network was used to determine ground-water levels (five periods of measurement) and collect water-quality samples (four periods of sample collection) from across the Range in the unconfined aquifer of the Ogallala Formation of Tertiary age and the deeper, confined aquifer of the Chinle Formation of Triassic age. Twenty-eight wells were used to collect data from the unconfined aquifer that is part of the Southern High Plains aquifer, and 1 well was used to collect data from the deeper, confined aquifer in the upper unit of the Chinle Formation. Water-quality samples were collected as whole (unfiltered) water because unfiltered water is used on the Range for agriculture and a stock-tank system.

Water levels in most wells in the Southern High Plains aquifer at the Range have declined from 1 to 18 ft over various periods from 1962 to 2003. Ground-water flow in the unconfined aquifer is dictated by the Mesa in the southwestern part of the Range. Ground water flows northeastward away from the Mesa in the local flow system and into the Portales Valley regional flow system where ground water then flows southeast and east. Younger ground water (less than 25 years) was found near the Mesa and in the local flow system, and older water (25 to 55 years) was found within the regional flow system in the Portales Valley. The potentiometric surface of the Southern High Plains aquifer in the Ogallala Formation is likely lower in parts of the Range than the potentiometric surface of the deeper, confined aquifer in the upper unit of the Chinle Formation. Leakage between these two systems is unknown but appears likely.

Ground-water quality at the Range showed substantial differences in spatial distribution. Ground-water quality near the Mesa was similar to that of the regional flow system and also was fairly similar to water quality in the southern part of the Range. Ground water in the Impact Area was very different from ground water near the Mesa or in the regional flow system. Ground water in the Impact Area contains larger concentrations of dissolved solids, which probably result from upward leakage of ground water from the Chinle Formation.

Ground water across the Range consisted of various water types. Water from wells in and near the Impact Area and along the southern boundary of the Range generally is a sodium-chloride or sodium-mixed anion water type. Water from the Chinle Formation is a sodium-chloride water type. Water from some wells near the Mesa and water from some wells in the regional flow system is a mixed cation-bicarbonate water type.

A mixing pattern of source waters in the direction of ground-water flow was exhibited by ion concentrations in ground water. Mixed cation/bicarbonate ground water with small ion concentrations near the Mesa flows beneath the Impact Area where a second source of ground water or another influence on ground-water quality substantially increases ion concentrations and shifts the water type to sodium-mixed anion. Ground water from the local flow system then enters the regional flow system, where no distinct water type is present and ion concentrations decrease. Ion concentrations in water from the deeper, confined aquifer in the Chinle Formation were similar to ion concentrations in water from the unconfined aquifer in the Impact Area.

Specific conductance, dissolved solids, water temperature, major ion concentrations, and the concentrations of molybdenum and vanadium displayed similar spatial distributions indicating upward leakage from the deeper, confined aquifer of the Chinle Formation to the unconfined aquifer of the Ogallala Formation in the Impact Area of the Range. Values of these constituents in ground water in the Impact Area were similar to constituent values in water from a well completed in the Chinle Formation.

CFC, nutrient, and stable isotope spatial distributions were similar to the other constituents, but also produced spatial distribution differences that may indicate an influence of past land uses on ground-water quality in the Impact Area or a more complex mixing of waters between the Ogallala and Chinle Formations. CFC and nutrient concentrations were elevated in ground water near and in the Impact Area, and were not similar to concentrations in water from the Chinle Formation. Stable isotope results indicated that another source of water of different isotopic composition has a strong influence on ground water just west of the Impact Area with a lessening influence across the Impact Area, and that this source of water differs in isotopic ratios from water from the well in the Chinle Formation.

Given the current (2004) understanding of the Range's ground-water hydrology and water quality, the different ground-water quality in the Impact Area cannot be solely attributed to leakage from the Chinle Formation, although it is likely that leakage is occurring between the Ogallala and Chinle Formations.

Screening of potential human-induced contaminants in ground water across the Range indicated no significant concentrations of pesticides, explosives, volatile organic compounds, semivolatile organic compounds, total organic halogens, or perchlorate. Small concentrations of 4,4'-DDT (0.011 µg/L (estimated value), well MWQ 9), acetone (2.9 µg/L (estimated value), well MWQ 17), chlorodibromomethane (0.20 µg/L (estimated value), well MWQ 16), bis (2-Ethylhexyl) phthalate (4.4 µg/L (estimated value), well MWQ 15), total organic halogens (32 µg/L, well MWQ 15, large chloride concentration), and perchlorate (2.6 µg/L for well MWQ 14, 20 µg/L for well MWQ 15, and large chloride concentration in both wells) were detected, but all detections were considered insignificant because of estimated values, potential laboratory contamination, and (or) matrix interference from large chloride concentrations.

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Supplemental Information

Four types of quality-control samples were collected in the field as part of this study: replicates, field-equipment blanks, matrix spikes, and trip blanks. In addition to field quality-control samples, Severn Trent Laboratories had internal quality-assurance practices to provide quality control of analytical procedures, which included laboratory-control sample analysis and method-blank sample analysis. For comparison of quality-control sample results, data-quality objectives as defined by Severn Trent Laboratory were used to evaluate the quality of the laboratory results.

Evaluation of Quality-Control Samples

Replicate samples were evaluated for variability in environmental samples, data collection techniques, and laboratory precision (reproducibility). The Range replicate sample results indicated small relative percent differences (less than 20 percent; data-quality objectives, table S-1) among samples except for the constituents of phosphorus, arsenic, chromium, and selenium (table S-2). Concentrations of these constituents were generally less than reporting limits (estimated concentrations) at which precision typically decreases. All these constituents were qualified in the results section for decreased precision because of small concentrations.

Analysis of field equipment-blank samples indicated potential contamination for dissolved solids, alkalinity, cyanide, calcium, magnesium, sulfate, chloride, ammonia, phosphorus, organic carbon, aluminum, barium, copper, iron, manganese, and zinc. Field equipment-blank median concentrations for dissolved solids, cyanide, magnesium, sulfate, chloride, ammonia, phosphorus, organic carbon, aluminum, barium, copper, iron, and manganese were all smaller than reporting limits (data-quality objectives). Median alkalinity, calcium, and zinc concentrations were greater than reporting limits and did not meet the data-quality objectives. Results for alkalinity, calcium, and zinc in wells sampled using the portable submersible pump were qualified for lack of validity (bias) because of potential sample contamination during sample collection and laboratory analysis.

Matrix-spike samples were used to evaluate the ability of an analytical method to accurately measure a known amount of a constituent added to a sample. Matrix-spike-replicate samples were used to evaluate the precision of accurately measuring a known amount of a constituent added to a sample. Results of the matrix-spike samples collected from the Range indicated no bias due to matrix interference because all constituents showed percent recoveries (table S-2) within the recovery limits as specified in the data-quality objectives (table S-1). Matrix-spike-replicate results indicated acceptable precision (table S-2) given the data-quality objectives for relative percent differences (table S-1).

Trip-blank analysis provided an examination of potential volatile organic compound exposure during handling and shipping and also potential laboratory error. Methylene chloride (a common laboratory contaminant) was detected in trip blanks, but the median concentration was smaller than the reporting limit and met the data-quality objective.

Analysis of laboratory-control samples provided an indication of constituent recovery error (lack of precision) for a spiked concentration. Laboratory-control sample analysis used randomly selected customer-submitted samples to perform matrix-spike analyses. Results of laboratory-control sample analysis indicated no recovery errors for any constituent; all median percent recoveries (table S-2) were within recovery limits (table S-1).

Method-blank samples were contaminant-free samples that were analyzed for any potential residual contaminants in laboratory equipment. Results of method-blank sample analysis indicated potential contamination of dissolved solids, phosphorus, aluminum, and the pesticide Dieldrin (table S-2). All contaminant detections were smaller than reporting limits (table S-1) and met the data-quality objectives; therefore, potential contamination was not considered to be a significant factor that would bias environmental sample concentrations.

Evaluation of Data Outliers

Outliers were defined as concentrations three times larger than the mean concentration of the remaining three data points. Outliers occurred in analyses for specific conductance, dissolved solids, aluminum, barium, chromium, cobalt, copper, iron, lead, manganese, nickel, vanadium, and zinc (table S-3). Wells with the greatest number of outliers corresponded to wells in which purging was insufficient to decrease turbidity to values similar to the remaining wells. Outliers were removed from the data sets prior to statistical analysis. Because of the large variability of iron concentrations in ground water from nearly all wells, statistical results for iron are not presented in the results section. Additionally, because of large variability of aluminum concentrations in water from MWQ 8, no results are presented for this constituent for this well.

Table S-1. Data-quality objectives for water-quality analysis, Melrose Air Force Range.

[RPD, relative percent difference; <, less than; RL, reporting limit; NA, not applicable]

Constituent	Replicates	Field-equipment blanks	Matrix spikes	Matrix-spike replicates	Trip blanks	Laboratory-control samples	Method blanks
	RPD	Reporting limit	Recovery limit	RPD	Concentration	Recovery limit	Reporting limit
Physical and chemical properties:							
Solids, residue	20	<10	86 - 106	20	NA	86 - 106	<10
Alkalinity	10	<5.0	95 - 110	10	NA	95 - 110	<5.0
Cyanide	20	<0.010	89 - 109	20	NA	89 - 109	<0.010
Sulfide	20	<4.0	70 - 130	20	NA	70 - 130	<4.0
Major ions:							
Calcium	20	<0.20	90 - 110	20	NA	90 - 110	<0.20
Magnesium	20	<0.20	92 - 112	20	NA	92 - 112	<0.20
Sodium	20	<5.0	92 - 113	20	NA	92 - 113	<5.0
Potassium	20	<3.0	88 - 111	20	NA	88 - 111	<3.0
Sulfate	10	<5.0	90 - 110	10	NA	90 - 110	<5.0
Chloride	10	<3.0	90 - 110	10	NA	90 - 110	<3.0
Fluoride	10	<1.0	90 - 110	10	NA	90 - 110	<1.0
Bromide	10	<0.20	90 - 110	10	NA	90 - 110	<0.20
Nutrients and organic carbon:							
Ammonia	10	<0.10	90 - 110	10	NA	90 - 110	<0.10
Nitrate-nitrite	10	<0.10	90 - 110	10	NA	90 - 110	<0.10
Orthophosphate	10	<0.50	90 - 110	10		90 - 110	<0.50
Phosphorus	20	<0.050	85 - 113	20	NA	85 - 113	<0.050
Organic carbon	10	<1.0	90 - 110	10	NA	90 - 110	<1.0
Trace elements:							
Aluminum	20	<100	88 - 109	20	NA	88 - 109	<100
Antimony	20	<10	89 - 109	20	NA	89 - 109	<10
Arsenic	20	<15	90 - 110	20	NA	90 - 110	<15
Barium	20	<10	94 - 114	20	NA	94 - 114	<10
Beryllium	20	<5.0	89 - 112	20	NA	89 - 112	<5.0
Cadmium	20	<5.0	90 - 112	20	NA	90 - 112	<5.0
Chromium	20	<10	90 - 113	20	NA	90 - 113	<10
Cobalt	20	<10	88 - 108	20	NA	88 - 108	<10
Copper	20	<10	89 - 112	20	NA	89 - 112	<10
Iron	20	<100	91 - 112	20	NA	91 - 112	<100
Lead	20	<3.0	91 - 112	20	NA	91 - 112	<3.0

Table S-1. Data-quality objectives for water-quality analysis, Melrose Air Force Range.—Continued

Constituent	Replicates	Field-equipment blanks	Matrix spikes	Matrix-spike replicates	Trip blanks	Laboratory-control samples	Method blanks
	RPD	Reporting limit	Recovery limit	RPD	Concentration	Recovery limit	Reporting limit
Trace elements—Continued:							
Manganese	20	<10	90 - 113	20	NA	90 - 113	<10
Mercury	10	<0.20	84 - 114	10	NA	84 - 114	<0.20
Molybdenum	20	<20	87 - 112	20	NA	87 - 112	<20
Nickel	20	<40	92 - 112	20	NA	92 - 112	<40
Selenium	20	<15	87 - 109	20	NA	87 - 109	<15
Silver	20	<10	87 - 111	20	NA	87 - 111	<10
Thallium	20	<10	89 - 109	20	NA	89 - 109	<10
Vanadium	20	<10	90 - 114	20	NA	90 - 114	<10
Zinc	20	<20	86 - 111	20	NA	86 - 111	<20
Organics:							
Pesticides	40	<RL's	55 - 147	40	NA	55 - 147	<RL's
Explosives	40	<RL's	42 - 145	40	NA	42 - 145	<RL's
Volatile organic compounds	20	<RL's	64 - 134	20	<RL	64 - 134	<RL's
Semivolatile organic compounds	40	<RL's	36 - 114	40	NA	36 - 114	<RL's
Total organic halogens	30	<10	75 - 113	30	NA	75 - 113	<10
Perchlorate	20	<1.0	80 - 120	20	NA	80 - 120	<1.0

Table S-2. Quality-control results for water-quality sampling at Melrose Air Force Range.

[RPD, relative percent difference; mg/L milligrams per liter; NA, not applicable; µg/L, micrograms per liter; <, less than. All quality-control medians are based on four individual concentrations]

Constituent	Unit	Replicates	Field-equipment blanks	Matrix spikes	Matrix-spike replicates	Trip blanks	Laboratory-control samples	Method blanks
		Median RPD	Median concentration	Median percent recovery	Median RPD	Median concentration	Median percent recovery	Median concentration
Physical and chemical properties:								
Solids, residue	mg/L	2	7	NA	NA	NA	95	5
Alkalinity	mg/L	0	9	NA	NA	NA	100	<2
Cyanide	mg/L	9	0.004	93	3	NA	98	<0.002
Sulfide	mg/L	0	<0.97	76	10	NA	82	<0.97
Major ions:								
Calcium	mg/L	3	0.63	102	4	NA	100	<0.03
Magnesium	mg/L	0	0.12	101	4	NA	102	<0.02
Sodium	mg/L	0	<1.5	103	3	NA	102	<1.5
Potassium	mg/L	2	<0.49	103	4	NA	101	<0.49
Sulfate	mg/L	0	0.36	108	1	NA	95	<0.20
Chloride	mg/L	0	0.93	102	0	NA	94	<0.10
Fluoride	mg/L	0	<0.03	97	2	NA	94	<0.03
Bromide	mg/L	6	<0.03	96	2	NA	96	<0.03
Nutrients and carbon:								
Ammonia	mg/L	3	0.03	92	2	NA	100	<0.02
Nitrate-nitrite	mg/L	3	<0.01	94	2	NA	104	<0.01
Orthophosphate	mg/L	0	<0.04	98	3	NA	93	<0.04
Phosphorus	mg/L	72	0.02	102	6	NA	99	0.02
Organic carbon	mg/L	11	0.6	102	1	NA	102	<0.3
Trace elements:								
Aluminum	µg/L	5	52	98	3	NA	100	20
Antimony	µg/L	0	<4	104	4	NA	103	<4
Arsenic	µg/L	27	<4	100	4	NA	101	<4
Barium	µg/L	3	2	104	4	NA	104	<2
Beryllium	µg/L	0	<1	98	5	NA	102	<1
Cadmium	µg/L	0	<1	102	4	NA	103	<1
Chromium	µg/L	30	<1	102	4	NA	104	<1

Table S-2. Quality-control results for water-quality sampling at Melrose Air Force Range.—Continued

Constituent	Unit	Replicates	Field-equipment blanks	Matrix spikes	Matrix-spike replicates	Trip blanks	Laboratory-control samples	Method blanks
		Median RPD	Median concentration	Median percent recovery	Median RPD	Median concentration	Median percent recovery	Median concentration
Trace elements—Continued:								
Cobalt	µg/L	0	<1	99	4	NA	100	<1
Copper	µg/L	0	4	103	4	NA	102	<1
Iron	µg/L	14	96	100	3	NA	101	<13
Lead	µg/L	0	<2	103	3	NA	104	<2
Manganese	µg/L	12	6	101	4	NA	103	<1
Molybdenum	µg/L	10	<2	104	4	NA	102	<2
Nickel	µg/L	0	<2	102	5	NA	104	<2
Selenium	µg/L	27	<5	99	3	NA	98	<5
Silver	µg/L	0	<1	106	4	NA	104	<1
Thallium	µg/L	0	<7	101	3	NA	100	<7
Vanadium	µg/L	3	<2	101	4	NA	103	<2
Zinc	µg/L	17	20	97	5	NA	98	<7
Organics:								
Pesticides	µg/L	6 (Dieldrin)	<MDL's	80	3	NA	85	0.016 (Dieldrin)
Explosives	µg/L	NA	<MDL's	101	5	NA	98	<MDL's
Volatile organic compounds	µg/L	NA	<MDL's	104	1	0.31 (methylene chloride)	104	<MDL's
Semivolatile organic compounds	µg/L	NA	<MDL's	67	15	NA	67	<MDL's
Total organic halogens	µg/L	NA	<10	91	0	NA	90	<10
Perchlorate	µg/L	NA	<3.0	98	5	NA	94	<3.0

Table S-3. Turbidity values and outlier data points for ground-water samples collected at Melrose Air Force Range.

[NTU's, nephlometric turbidity units; std. dev., standard deviation]

Turbidity (NTU's)		Outliers	Constituent	Sample period
Median	Std. dev.	Well		
NA	NA	MWQ 2	Aluminum	June, August
			Chromium	August
			Cobalt	March
			Copper	August
			Iron	August
			Vanadium	August
0.5	0.2	MWQ 3	Nickel	August
0.6	0.4	MWQ 4	Nickel	August
0.7	0.2	MWQ 5	Lead	March
			Zinc	March
1.5	1.3	MWQ 6	Iron	June, December
0.8	0.3	MWQ 7	Nickel	August
165.5	96.5	MWQ 8	Aluminum	June, August, December
			Barium	June
			Iron	June, August, December
			Lead	June
			Manganese	June
			Zinc	June
28.5	12.5	MWQ 9	Aluminum	August
			Iron	December
			Nickel	August
0.7	0.4	MWQ 10	Zinc	August
1.0	1.7	MWQ 11	Nickel	August
12.3	3.6	MWQ 12	Iron	December
			Nickel	August
29.6	15.3	MWQ 13	Iron	June
			Nickel	August
16.5	57.9	MWQ 14	Aluminum	December
			Iron	December
8.3	9.7	MWQ 15	Iron	December
			Nickel	August
5.5	6.5	MWQ 16	Iron	June
			Lead	March
36.4	22.0	MWQ 17	Aluminum	August
			Dissolved solids	June
			Iron	August, March
			Dissolved solids	June

Prepared by the New Mexico District Office.
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Albuquerque, NM 87109

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This publication is available online at URL
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Langman and others—**Ground-Water Hydrology and Water Q f the Southern High Plains Aquifer, Melrose Air Force Range, Cannon Air F se, Curry and Roosevelt Counties, New Mexico, 2002-03**—SIR 2004-5158

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