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

Estimated Ground-Water Withdrawals from the Death Valley Regional Flow System, Nevada and California, 1913–98

Water-Resources Investigations Report 03-4245

Prepared in cooperation with the
U.S. DEPARTMENT OF ENERGY
NATIONAL NUCLEAR SECURITY ADMINISTRATION
NEVADA SITE OFFICE, under Interagency
Agreement DE-AI08-01NV13944

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By Michael T. Moreo, Keith J. Halford, Richard J. La Camera, and Randell J. Laczniak

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Carson City, Nevada
2003

U.S. DEPARTMENT OF THE INTERIOR
GALE A. NORTON, Secretary

U.S. GEOLOGICAL SURVEY
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CONTENTS

FIGURES

TABLES

CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square mile (mi^2)	2.590	square kilometer
acre	0.4047	hectare
acre	4,047	square meter
	Volume	
acre-foot (acre-ft)	1,233	cubic meter
million gallons (Mgal)	3,785	cubic meter
	Rate	
inch per year (in/yr)	25.4	millimeter per year
foot per day (ft/d)	0.3048	meter per day
foot per year (ft/yr)	0.3048	meter per year
mile per hour (mi/h)	1.609	kilometer per hour

Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929, formerly called “Sea-Level Datum of 1929”), which is derived from a general adjustment of the first-order leveling networks of the United States and Canada.

Location coordinates: In this report, horizontal-coordinate information is referenced to the North American Datum of 1927 (NAD 27).

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ABSTRACT

Ground-water withdrawals from 1913 through 1998 from the Death Valley regional flow system have been compiled to support a regional, three-dimensional, transient ground-water flow model. Withdrawal locations and depths of production intervals were estimated and associated errors were reported for 9,300 wells. Withdrawals were grouped into three categories: mining, public-supply, and commercial water use; domestic water use; and irrigation water use. In this report, groupings were based on the method used to estimate pumpage.

Cumulative ground-water withdrawals from 1913 through 1998 totaled 3 million acre-feet, most of which was used to irrigate alfalfa. Annual withdrawal for irrigation ranged from 80 to almost 100 percent of the total pumpage. About 75,000 acre-feet was withdrawn for irrigation in 1998. Annual irrigation withdrawals generally were estimated as the product of irrigated acreage and application rate.

About 320 fields totaling 11,000 acres were identified in six hydrographic areas. Annual application rates for high water-use crops ranged from 5 feet in Penoyer Valley to 9 feet in Pahrump Valley. The uncertainty in the estimates of ground-water withdrawals was attributed primarily to the uncertainty of application rate estimates. Annual ground-water withdrawal was estimated at about 90,000 acre-feet in 1998 with an assigned uncertainty bounded by 60,000 to 130,000 acre-feet.

INTRODUCTION

The U.S. Geological Survey (USGS), in cooperation with the U.S. Department of Energy (DOE), has been developing a transient ground-water flow model of the Death Valley region of southern Nevada and southeastern California since 1998 (D'Agnese and others, 2002). This model incorporates results from previous ground-water models and additional information from studies designed to improve input parameters. Ground-water simulation results are expected to guide future investigations within the Death Valley regional flow system (DVRFS).

Anthropogenic effects on flow paths, ground-water levels, and spring discharges are being characterized with the regional model. The most significant anthropogenic activity affecting regional ground-water flow paths is ground-water withdrawal, also referred to as pumpage. Pumpage from the flow system began around 1913, but records are periodic and incomplete. The objective of this study is to compile a digital database of spatially and temporally distributed ground-water pumpage throughout the Death Valley region. The resulting dataset consists of a compilation of existing data from various sources, and estimates where gaps in data exist.

Purpose and Scope

This report documents ground-water pumpage from the DVRFS as estimated to support the development of a transient ground-water flow model. Withdrawal locations and depths of production intervals are estimated and associated errors are reported. Methods for estimating irrigated acreage from pumpage inventories and remotely sensed images are documented and compared. Error ranges are assigned to annual withdrawals on the basis of water-use category and estimation method. Annual pumpage estimates from 1913 through 1998 for each identified withdrawal location have been compiled in an electronic database that is distributed with this report.

Acknowledgments

We thank Robert Bangerter, Bruce Hurley, Dirk Schmidhofer, and Bonnie Thompson (previously or currently with the U.S. Department of Energy, National Nuclear Security Administration, Nevada Site Office) for funding this work. We also thank Robert Coache (Nevada Department of Conservation and Natural Resources, Division of Water Resources) for allowing access to their databases and files. Finally, we thank numerous Federal, State of California, utility, and mining personnel that provided the data included in this report.

Description of Study Area

The study area, referred to as the DVRFS in this report, is within the Great Basin subdivision of the Basin and Range Physiographic Province (Fenneman, 1931) and generally coincides with the DVRFS as defined by D'Agnese and others (1997). The physiography of the flow system consists of northerly to northwesterly trending mountains separated by sediment-filled valleys. The study area is about 19,000 mi^2 in size and generally coincides with the boundaries of numerous valleys in southern Nevada and eastern California.

The study area (fig. 1) differs slightly from the revised boundary of the DVRFS given in D'Agnese and others (2002). Recent research has refined estimates of recharge areas, discharge areas, low-permeability rock distributions, fault locations, and hydraulic gradients near the boundary. The boundary of the DVRFS has been revised to reflect these refinements and recent changes in the geohydrologic framework and conceptual flow model.

About 90 percent of all ground water withdrawn from the study area was from basin-fill deposits in Pahrump Valley, Amargosa Desert, Penoyer Valley, and Mesquite Valley (fig. 1, table 1). The basin-fill deposits typically consist of unconsolidated to semi-consoli-

Table 1. Numbers and names of hydrographic areas in the study area

[See fig. 1]

Hydrographic Area	
Number	**Name**
144	Lida Valley
145	Stonewall Flat
146	Sarcobatus Flat
147	Gold Flat
148	Cactus Flat
157	Kawich Valley
158A	Groom Lake Valley
158B	Papoose Lake Valley
159	Yucca Flat
160	Frenchman Flat
161	Indian Springs Valley
162	Pahrump Valley
163	Mesquite Valley
168	Three Lakes Valley, Northern Part
169A	Tikaboo Valley, Northern Part
169B	Tikaboo Valley, Southern Part
170	Penoyer Valley
173A	Railroad Valley, Southern Part
209	Pahranagat Valley
211	Three Lakes Valley, Southern Part
225	Mercury Valley
226	Rock Valley
227A	Jackass Flats
227B	Buckboard Mesa
228	Oasis Valley
229	Crater Flat
230	Amargosa Desert
230AM [1]	Ash Meadows
231	Grapevine Canyon
232	Oriental Wash
240	Chicago Valley
241	California Valley
242	Lower Amargosa Valley
243	Death Valley

[1] The Ash Meadows spring discharge area is part of Amargosa Desert hydrographic area. In the database Ash Meadows is listed separately because of historical significance.

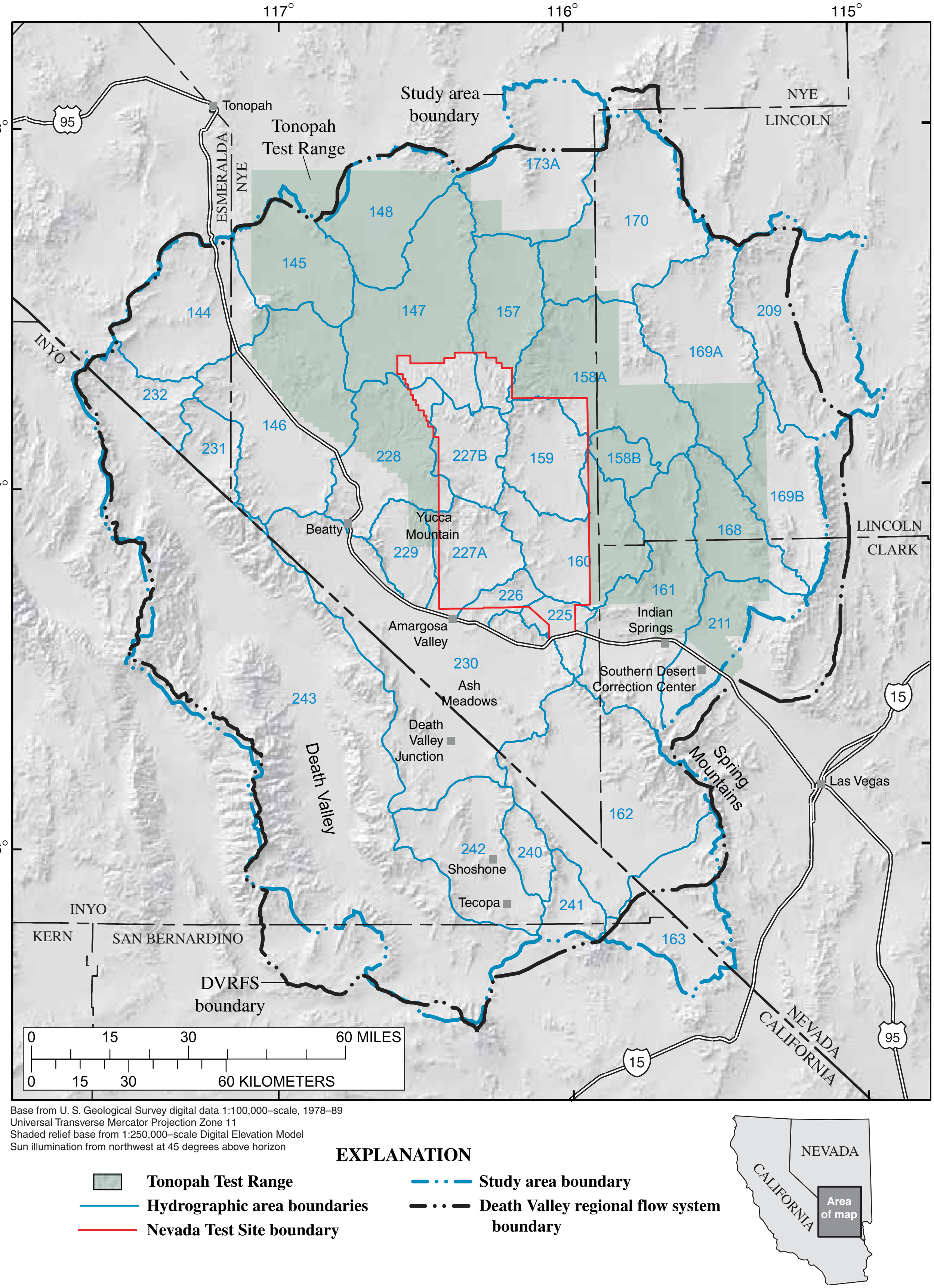


Figure 1. Extent of Death Valley regional flow system and hydrographic areas. Boundary of DVRFS as shown in D'Agnese and others (2002, fig. 13).

dated sand, silt, gravel, and clay that range in hydraulic conductivity from 0.02 to 140 ft/d (Harrill and Prudic, 1998). Hydraulic conductivities typically are larger toward the margins of the valleys and smaller near the basin axis (Plume, 1996).

The climate in the valleys is characterized by low annual precipitation, low humidity, and strong winds (Houghton and others, 1975). Annual precipitation ranges from less than 4 in/yr in Death Valley to more than 20 in/yr in the Spring Mountains. Relative humidity on the valley floors ranges from 10–30 percent during summer to 20–60 percent during winter. Strong winds that average 11 mi/h with peaks of as much as 60 mi/h typically occur from April to June.

Hydrographic Areas

The study area was subdivided into hydrographic areas (HA; fig. 1, table 1). Hydrographic areas generally consist of valleys that are separated by surface-water drainage divides (Rush, 1968). The USGS and Nevada Division of Water Resources (NDWR) systematically delineated hydrographic areas in Nevada for scientific and administrative purposes (Rush, 1968; Cardinalli and others, 1968). Official hydrographic-area names, numbers, and geographic boundaries continue to be used in USGS scientific reports and NDWR administrative activities pertaining to Nevada.

Selected Nevada hydrographic areas in the study area were extended into California (Amargosa Desert, Pahrump Valley, and Mesquite Valley). Lower Amargosa Desert, Chicago Valley, California Valley, and Death Valley are additional hydrographic areas in California previously delineated, named, and numbered by Harrill and others (1988).

Public Land Survey System

The Public Land Survey System (PLSS) is a legal land-reference system overseen by the U.S. Department of the Interior, Bureau of Land Management. The PLSS generally is a rectangular grid that is defined by township, range, and section. Irregularities exist because of surveying or protraction errors. These irregular sections typically are designated half townships or half ranges.

Townships are numbered progressively north and south of a baseline and ranges are numbered progressively east and west from a meridian. All townships and ranges in Nevada are referenced to the Mount Diablo baseline and meridian. Townships and ranges in the California part of the study area are referenced to the Mount Diablo or San Bernardino baseline and meridian.

A township and range typically is 6 mi on a side and is subdivided into 36 sections of 1 mi^2 (fig. 2). Sections are numbered progressively from north to south in an alternating east to west and west to east manner from section 1 in the northeast corner to section 36 in the southeast corner.

Mapped areas less than a section are defined by quartering. A 640-acre section can be subdivided into sub areas of 160, 40, or 10 acres by successively quartering. In Nevada, letters “A” through “D” indicate quarter sections, counterclockwise beginning with “A” in the northeast quarter section (fig. 2). Additional letters “A” through “D” also are assigned in counterclockwise sequence to further subdivide quarter sections into 40-acre and 10-acre tracts (Harrill, 1986). In California, sections are divided into 16 quarter-quarter sections of 40 acres and each are denoted with the letters “A” through “R”, excluding the letters “I” and “O” (fig. 2).

Water-Use Groupings and General Characteristics

The different water uses are grouped into three general categories based on the methods used to estimate pumpage. Mining, public-supply, and commercial wells, including DOE and Department of Defense supply wells, are grouped into one water-use class because their withdrawals frequently are metered. Domestic water use is an exclusive class because pumpage is estimated based on the number of wells. Irrigation use makes up the third class and is estimated as the product of acreage and application rates.

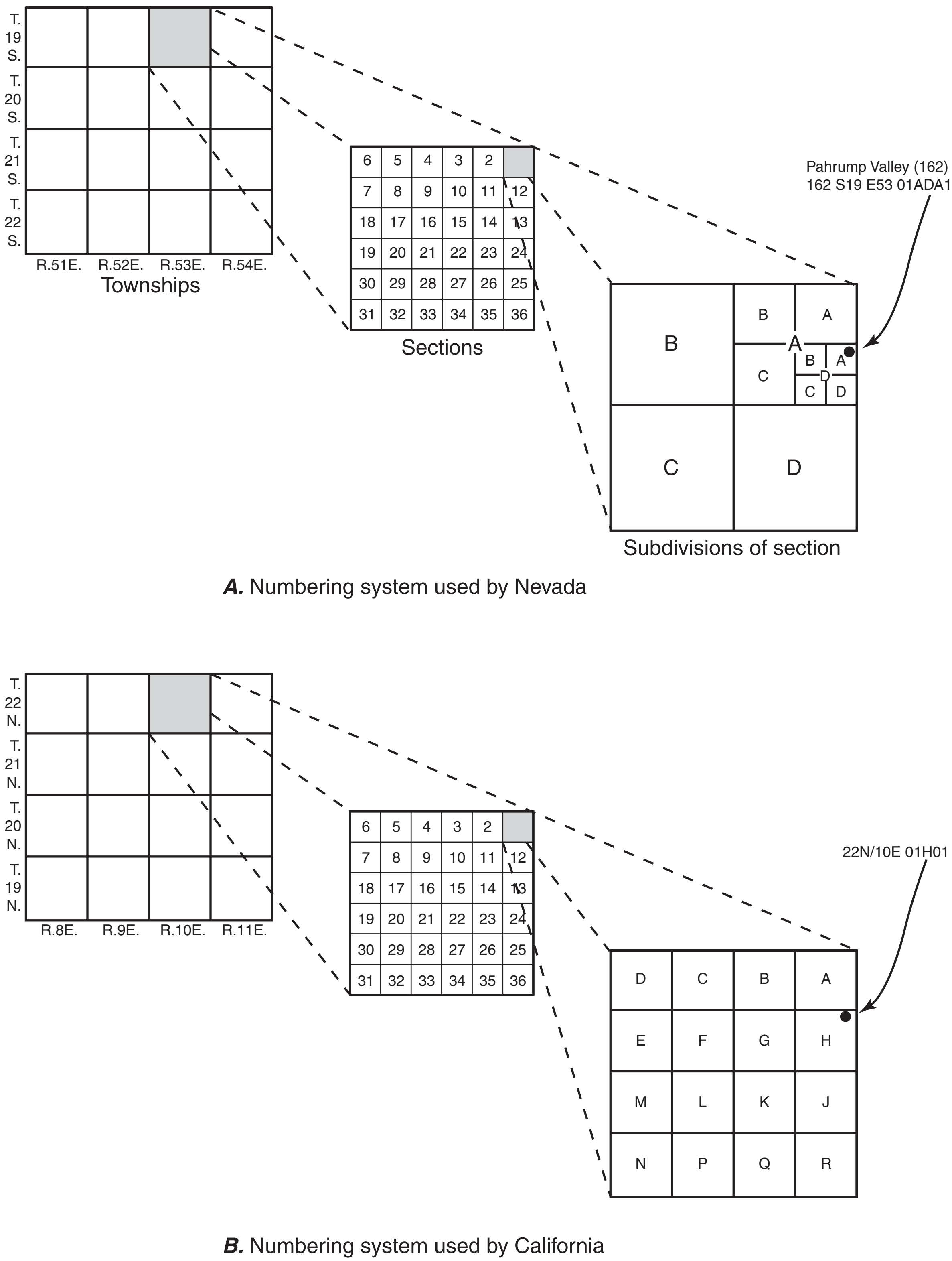


Figure 2. Grid for Public Land Survey System in Nevada and California.

METHODS FOR DETERMINING WELL LOCATION AND OPEN-INTERVAL DEPTH

Well Location

Ground water has been withdrawn from more than 9,300 wells across the study area. Locations for these wells have been determined using Global Positioning System (GPS), topographic maps, the NDWR well-log database, NDWR pumpage inventories, and a previous ground-water model (Harrill, 1986). Reported locations have errors that range from less than 100 ft to about 6,000 ft. Errors of greater than 1,000 ft occur only in about 3 percent of all reported wells. Even with these large uncertainties, locations are assumed adequate for DVRFS model simulation because the study area is discretized into cells measuring about 5,000 ft on a side.

Global Positioning System and Topographic Maps

Wells located with GPS were identified and inventoried through site visits. The accuracy of reported locations primarily is dependent on the accuracy of the GPS or the resolution of a topographic map. Wells located with GPS typically are accurate to within 100 ft. All wells on the Nevada Test Site, U.S. Air Force installations, and many public-supply and mining wells were located with GPS. Locations for more than 90 percent of the irrigation wells in Amargosa Desert were digitized from topographic maps. Locations determined from 1:24,000 and 1:62,500 topographic maps typically have errors of as much as 100 and 1,000 ft, respectively.

The locations of public-supply wells typically are well known and have been located with GPS or topographic maps. However, the reported locations have been deliberately obscured because of homeland security concerns. Specific locations for public-supply wells have been replaced with the identifier “99999”.

NDWR Well-Log Database

Where GPS or topographic map locations were unavailable, the NDWR well-log database at URL <http://water.nv.gov/IS/wlog/wlog.htm> was used as the source for well locations. Well locations reported by the NDWR are based on drillers’ reports and generally are given by township, range, and section to the quarter-quarter section. The existence and locations of these wells were not confirmed by site visits. Locations assigned by this method generally were considered accurate to within 1,000 ft. Locations assigned to all domestic wells were obtained from the well-log database.

NDWR Pumpage Inventories

The location of most irrigation supply wells were inferred from irrigated field locations identified by pumpage inventories. Since 1959, pumpage inventories have been conducted almost annually by the NDWR in Pahrump Valley (HA 162, fig. 1), and since 1983, almost annually in all valleys with irrigation. Pumpage inventories were conducted to estimate water usage, but often were helpful in locating active irrigation wells associated with specific fields. A field was associated with a well by a well-permit number that was common to both the NDWR pumpage inventory and the well-log database. Most irrigated fields within the study area were identified through pumpage inventories. The California side of Mesquite Valley (HA 163, fig.1) is the only hydrographic area of significance not inventoried by the NDWR.

All ground-water withdrawal locations in the database are referred to as withdrawal points because a specific well could not always be associated with a withdrawal location. Ambiguous withdrawal locations constituted less than 1 percent of all withdrawal points. If a well could not be associated with a specific field through an NDWR permit number, the nearest irrigation well within 1,000 ft of the northeast corner of a field was assigned to that field. Withdrawal points were created where no specific wells existed within 1,000 ft of the reported water-use location.

Previous Ground-Water Model

Ground-water withdrawal locations and water usage during the period 1913–58 were compiled previously for a ground-water flow model of Pahrump Valley (Harrill, 1986). This flow model simulated these withdrawals by model cell, and did not provide a discrete well location. In this report, withdrawals for each model cell were assigned to a discrete well (withdrawal point) to maintain continuity with pumpage information obtained from pumpage inventories available after 1958.

Depths of Withdrawals

Ground water enters a well through a slotted casing or an uncased interval or hole termed a completion interval. Slotted casing generally impedes movement of unconsolidated sediments into a well. Uncased or open-hole completions are most often used in competent rock like carbonates that are not likely to collapse. A completion interval is the distance between the top and bottom of the slotted casing in the saturated section of a well or the saturated open-hole section of a borehole. Depth to the top of a completion interval averaged 50 ft below the water table.

More than 97 percent of wells in the study area have reported completion intervals. Well completion information was reported for about 97 percent of more than 200 mining, public-supply, and commercial wells, for 98 percent of the 8,733 domestic wells, and for 85 percent of the 324 irrigation wells.

A well without construction information was assigned a completion interval based on the median depth to the top of completion and median completion length for similar wells within a hydrographic area. Depth to the bottom of completion was estimated by adding completion length to the depth to the top of completion. Depth to the bottom of completion was not estimated directly to assure that the bottom was deeper than the top. Uncertainty of assigned completion depths for wells with no reported completion-interval information was bracketed using a minimum and maximum value. The minimum completion depth was the first quartile of all depths to top of completion and the maximum was the third quartile of all depths to bottom of completion for a particular water-use class and hydrographic area. For example, in Pahrump Valley (HA 162), domestic wells had a first-quartile depth of 90 ft and a median depth of 110 ft to the top of completion, a median completion length of 40 ft, and a third-quartile depth of 180 ft to bottom of completion. Accordingly, domestic wells without construction information were assigned top and bottom completion depths of 110 and 150 ft, and minimum and maximum completion depths of 90 and 180 ft, respectively.

Depths to bottom of completion were shallower than 500 ft for more than 75 percent of domestic and irrigation wells, and 67 percent of mining, public-supply, and commercial wells (fig. 3). Less than 1 percent of domestic or irrigation wells were completed to depths greater than 1,000 ft below land surface. About 24 percent of mining and public-supply wells were completed to depths greater than 1,000 ft. The greatest completion depth was about 8,500 ft for a supply well at the Nevada Test Site.

ESTIMATES OF ANNUAL GROUND-WATER WITHDRAWALS

Ground-water withdrawals from the study area were estimated by water-use class for the period 1913–98 (fig. 4). Withdrawals from mining, public-supply, and commercial wells typically were metered and considered accurate to within 5 percent of the reported values. Domestic wells accounted for the greatest number of wells in the study area but the least amount of ground-water withdrawal. Irrigation wells accounted for more than 80 percent of the total ground water withdrawn during any year. Uncertainties of individual withdrawal estimates were reported as minimum and maximum withdrawals because estimation errors did not always represent a normal statistical distribution.

Mining, Public Supply, and Commercial

Annual withdrawal from the DVRFS for mining, public-supply, and commercial uses was estimated at about 10,000 acre-ft in 1998. These uses accounted for about 11 percent of the 1998 total withdrawal estimate (fig. 4). About 65 percent of this withdrawal was for public supply, of which 14 percent (or about 1 percent of total withdrawal) supported operations at the Nevada Test Site, Yucca Mountain, and Tonopah Test Range.

Mining, public-supply, and commercial wells typically were metered. Metered values typically were accurate to within 1 percent, although this accuracy may degrade after several years of use without calibration. Periodic comparisons between reported withdrawals and independent flowmeter measurements at Nevada Test Site and Yucca Mountain differed by less than 5 percent; accordingly, the uncertainty of these estimates was assumed to be ±5 percent of the reported values.

Withdrawal from public-supply wells at Nevada Test Site, Beatty, Pahranagat Valley (HA 209), Southern Desert Correctional Center, Mesquite Valley (HA 163), Tecopa, Shoshone, and Death Valley Junction (fig. 1) for periods when metered values were not available were estimated by correlating available

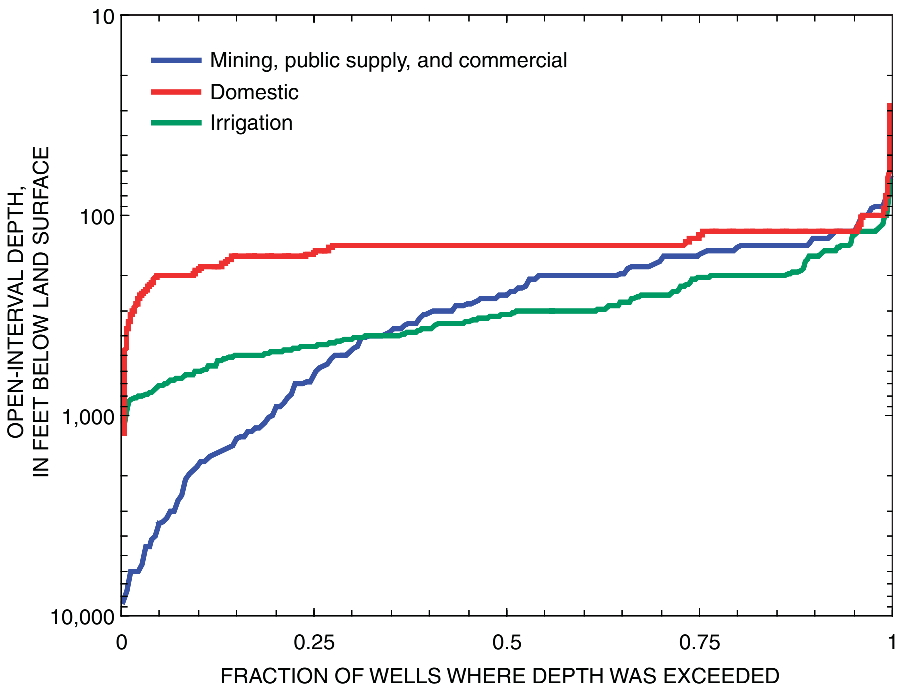


Figure 3. Distribution of bottom of open-interval depth by water-use class.

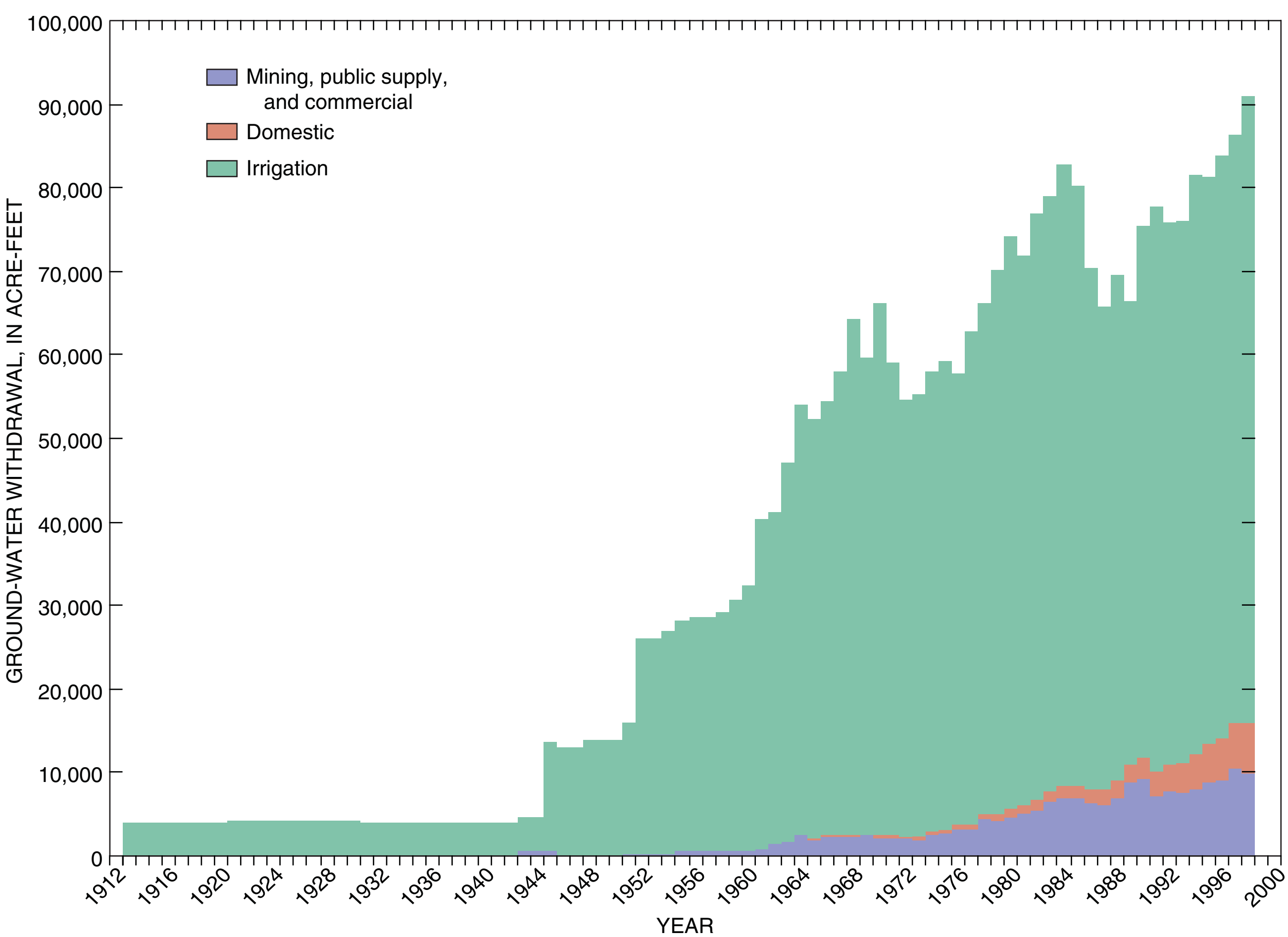


Figure 4. Total withdrawal from the Death Valley regional flow system by water-use class.

reported values and population. Water-use coefficients were calculated by dividing annual withdrawal by population during years when both population and public-supply withdrawals were known. An annual water-use coefficient between 0.2 and 0.3 acre-ft per capita was used for these areas and did not vary with time, except at the Nevada Test Site.

About 75 percent of estimated public-supply and domestic withdrawals were in Pahrump Valley. The population of Pahrump Valley has increased from 200 in 1958 to 20,000 in 1998 (Harrill, 1986; Hardcastle, 2001). Ground water withdrawn for public supply and domestic use in Pahrump Valley typically are disposed of through septic systems. No attempt was made to adjust withdrawal estimates for any water returned to the water table through infiltration.

The populations of other communities in the study area were small relative to Pahrump Valley. These small communities typically have experienced large population fluctuations in response to changes in mining and defense activities. Mining was the principal economic driving force prior to 1960 and activities at the Nevada Test Site and Tonopah Test Range since 1960.

Annual pumpage from the Nevada Test Site averaged 1,300 acre-ft and increased significantly from 1970 to 1985. Annual water-use coefficients for Nevada Test Site increased from 0.1 to 1.4 acre-ft per capita between 1961 and 1998. Water use between 1972 and 1982 was estimated from population with interpolated per capita consumption rates that ranged from 0.3 to 0.5 acre-ft per capita. For periods with reported withdrawal data (1961–71 and 1983–98), estimates of annual withdrawal were within 200 acre-ft of reported values (fig. 5).

Ground-water withdrawals to support mining activities were estimated from 1973 through 1998. About 85 percent of the ground water withdrawn to support mining activities was metered during this period. The remaining 15 percent was estimated from permit applications, approval dates, and permitted withdrawal amounts. Annual withdrawal for all mining activities between 1973 and 1998 averaged less than 2 percent of the total withdrawal estimate. Ground-water withdrawals to support mining activities prior to 1973 were not estimated because mining activity was not well documented and mining use during this period was insignificant relative to total withdrawal from the DVRFS.

Domestic

Domestic use from the DVRFS was estimated as the product of the number of domestic wells and the average annual domestic consumption. Domestic use accounts for the smallest percentage of the total withdrawal from the DVRFS. Although domestic withdrawal is the least important in terms of volume, it is most important in terms of number of wells. For example, in 1998, about 8,700 domestic wells pumped about 6,100 acre-ft of ground water, whereas, about 300 irrigation wells pumped about 75,000 acre-ft.

The annual withdrawal from a domestic well was estimated at 0.7 acre-ft. Annual estimates of 0.6, 0.7, and 0.9 acre-ft are given for Clark, Nye, and Lincoln Counties, respectively, by Nevada Department of Conservation and Natural Resources (1999). The estimate given for Nye County is assumed reasonable for the entire DVRFS considering that more than 95 percent of the domestic wells are in Nye County. An annual withdrawal estimate of 1 acre-ft is used for allocating water rights by the NDWR. Although their estimate is a reasonable value for conservative allocation of water resources, it possibly overestimates domestic ground-water withdrawals over the entire DVRFS.

The number of domestic wells that pumped ground water from the DVRFS was determined using the NDWR well-log database. The determination assumed that every domestic well reported in the database pumped ground water from the time of its reported completion. A typical domestic well in the DVRFS is serviceable on average for 25 years before being abandoned (Tim Hafen, land developer, oral commun., 2002). Because abandonment of domestic wells was not recorded and well destruction was not factored into estimating ground-water withdrawals, the number determined for computing domestic use may be overestimated. The potential error from this simplification is assumed small because 95 percent of domestic wells were drilled between 1973 and 1998—a period of only 26 years (fig. 6). Assuming 25 years of service, ground-water withdrawal for 1998 would be overestimated by less than 300 acre-ft.

The uncertainty associated with domestic withdrawal estimates from the DVRFS was given as a range determined from annual withdrawals estimated for domestic use throughout Nevada. A withdrawal of 0.5 acre-ft, estimated for domestic users in northern Nevada (Maurer, 1997), defined the minimum annual

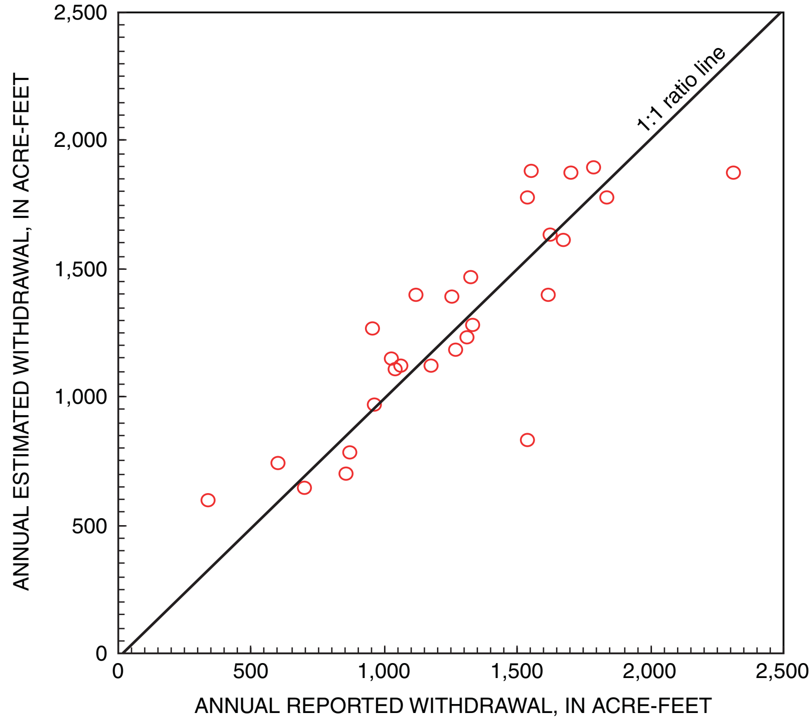


Figure 5. Comparison between reported and estimated annual ground-water withdrawals at Nevada Test Site, 1962–71 and 1983–98.

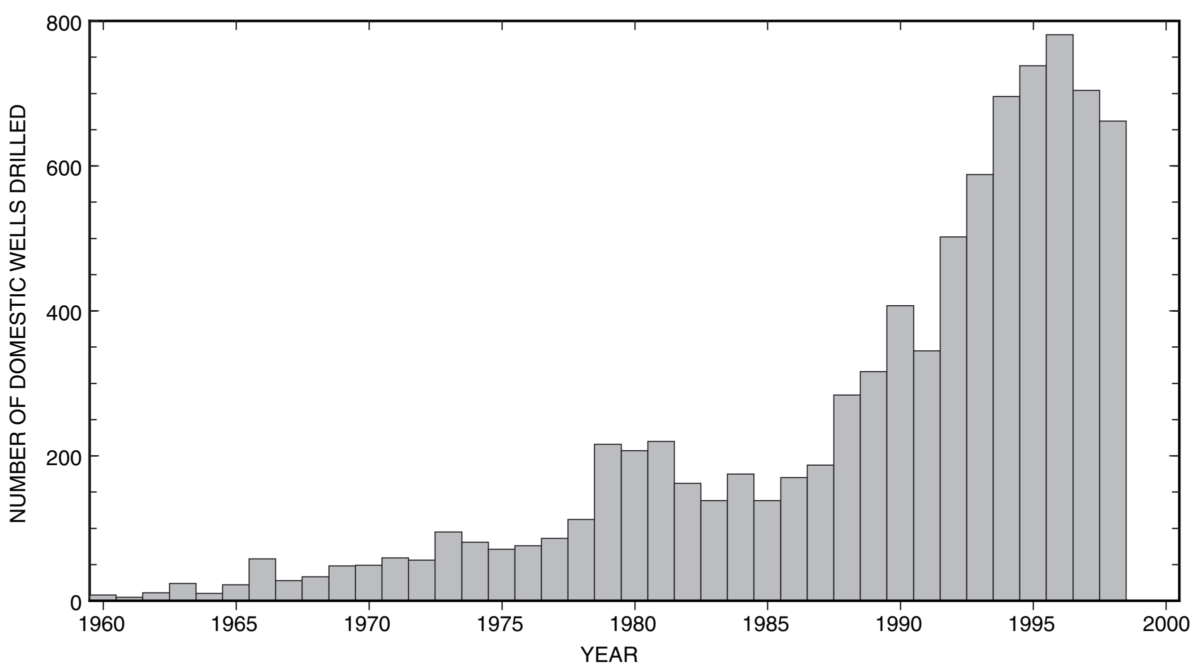


Figure 6. Number of domestic wells drilled, Death Valley regional flow system, 1960–98.

withdrawal rate. A withdrawal of 1.0 acre-ft defined the maximum annual withdrawal rate and represents the conservative planning estimate used by the NDWR. The minimum is 30 percent less and the maximum 40 percent more than that used to estimate domestic withdrawal throughout the DVRFS.

Irrigation

Annual irrigation use ranges from 80 to almost 100 percent of the withdrawal estimated for the DVRFS (fig. 4). The estimated withdrawal for irrigation was about 75,000 acre-ft in 1998. The irrigation withdrawal estimated for 1998 was the highest on record. Annual withdrawals generally were estimated as the product of irrigated acreage and application rate.

Crops grown throughout the DVRFS have been irrigated almost exclusively with ground water. The lone exception is Pahranagat Valley (HA 209, fig.1), where some surface water originating as upgradient springflow is available. Only 11 fields in Pahranagat Valley were identified as being wholly or partially irrigated with ground water. Within Pahranagat Valley, ground water is withdrawn for irrigation primarily in the northern part where ground-water levels are greater than 100 ft below land surface.

Withdrawals for irrigation of more than 200 acres occur in only 6 of the 33 hydrographic areas: Amargosa Desert, Pahranagat Valley, Pahrump Valley, Penoyer Valley, Railroad Valley, and Mesquite Valley (table 1, fig. 7). Ash Meadows is part of the Amargosa Desert hydrographic area but is listed separately in the database because of historical significance. The most northern hydrographic areas, Pahranagat, Penoyer, and Railroad Valleys, are characterized by altitudes above 3,600 ft and growing seasons that range from 150 days in Railroad Valley (Van Denburgh and Rush, 1974) to 170 days in Pahranagat Valley (Eakin, 1963). The southern hydrographic areas—Amargosa Desert, Pahrump Valley, and Mesquite Valley—are characterized by altitudes below 2,600 ft and growing seasons that range from 210 to 265 days (Glancy, 1968).

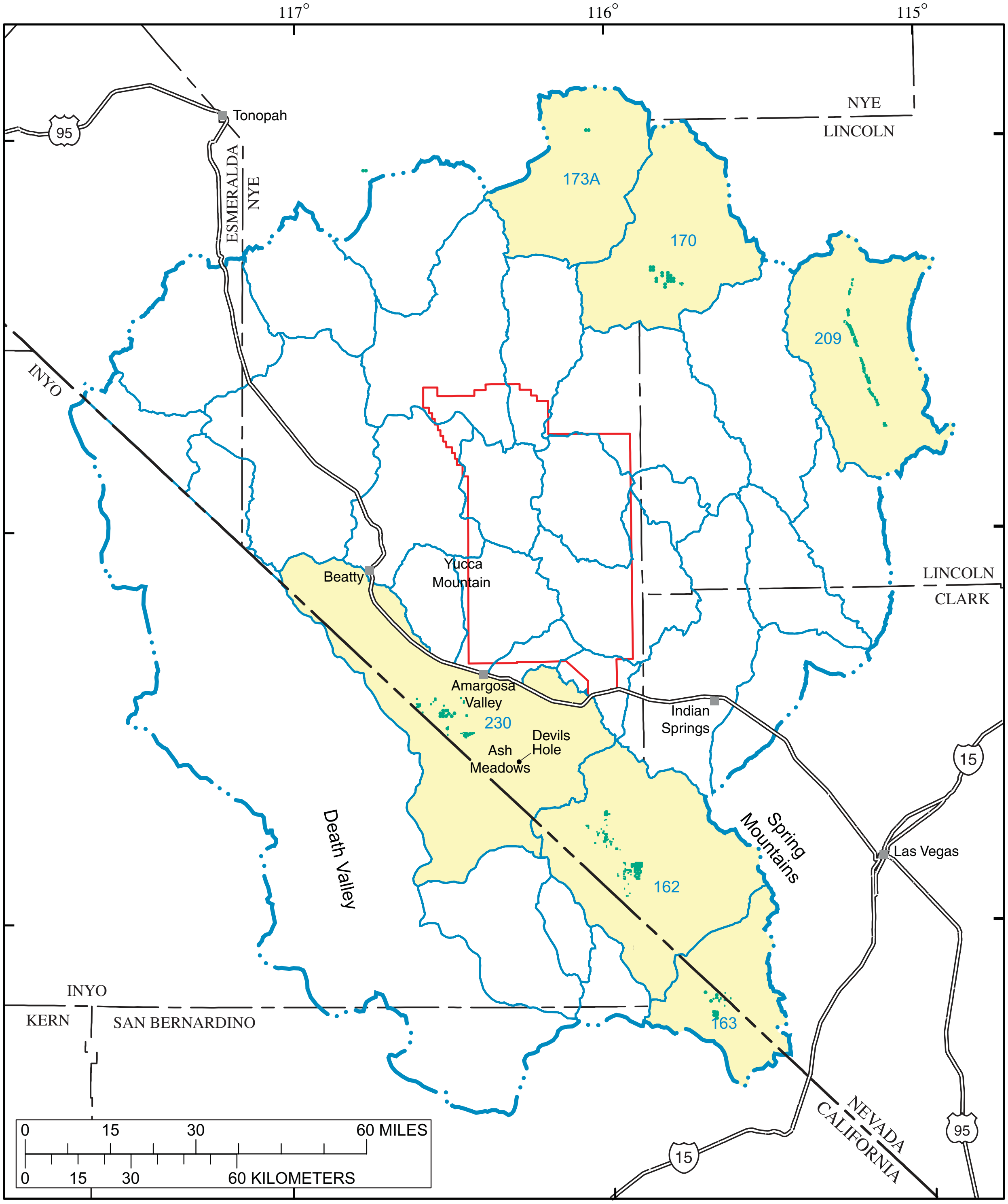
Fields within the DVRFS have been irrigated by flooding and center-pivot sprinklers. Flood irrigation distributed water along the edge of a field and gravity flow conveyed water across the field through furrows or ditches. Flood-irrigated fields typically were quarter-quarter sections of 40 acres and efficiencies ranged from 45 to 80 percent (U.S. Department of Agriculture, 2001). Center-pivot sprinklers sprayed water from many nozzles on long booms that were supplied water from the center of fields. Center-pivot sprinklers that irrigate circular and semi-circular fields range from 30 to 130 acres and have efficiencies that range from 55 to 90 percent (U.S. Department of Agriculture, 2001). These sprinklers generally were more efficient than flooding because infiltration losses were less. Center-pivot sprinklers irrigated most fields in Amargosa Desert, Penoyer Valley, and Mesquite Valley after 1980.

Irrigation efficiency is affected by conveyance, topography, wind, and management practices (U.S. Department of Agriculture, 2001). Management practices affect irrigation efficiency more than all other factors combined. Application rates for a poorly managed field can be 50 percent greater than for a well-managed field. Topography also significantly affects field efficiency because poorly leveled fields can be 25 percent less efficient than level fields. Conveyance losses and wind typically do not significantly affect irrigation efficiency in the study area.

About 320 fields that ranged from 1 to 130 acres were identified within the DVRFS. Together these fields totaled about 11,000 acres. A field is defined as an irrigated area with a unique geometric shape. Individual fields may or may not be irrigated in any given year. About 300 fields totaling about 10,000 acres were inventoried by the NDWR nearly every year since 1983 (fig. 8). Individual withdrawal points typically have estimates of pumpage, irrigated acreage, and water use. An additional 18 fields were mapped with remote sensing in California because the NDWR only inventories fields within Nevada. The California fields mapped in Mesquite Valley ranged from 30 to 130 acres and totaled 1,000 acres.

Irrigated Acreage

Irrigated acreage was identified using remote sensing and pumpage inventories. Similar estimates of irrigated acreage resulted where both methods could be applied. Irrigated acreage can be inventoried effectively with remote sensing because irrigated crops are distinguished easily from surrounding desert. Large-area irrigation inventories have been conducted successfully in Diamond Valley, Nevada (Arteaga and others, 1995), and in other western States with land uses similar to that of the DVRFS (Heimes and Luckey, 1983).



Base from U. S. Geological Survey digital data 1:100,000–scale, 1978–89
Universal Transverse Mercator Projection Zone 11
Shaded relief base from 1:250,000–scale Digital Elevation Model
Sun illumination from northwest at 45 degrees above horizon

EXPLANATION

- Irrigated fields
- Hydrographic area containing irrigated fields
- Study-area boundary
- Hydrographic area boundaries
- Nevada Test Site boundary

Figure 7. Hydrographic areas with more than 200 irrigated acres and extents of irrigated fields, 1998.

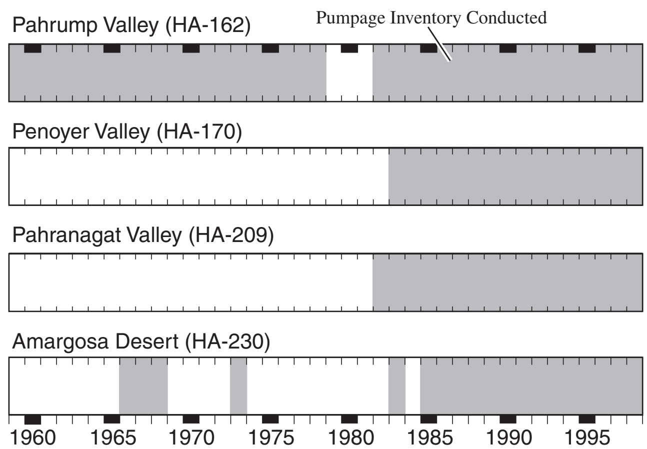


Figure 8. Years when pumpage inventories were conducted in Pahrump Valley, Penoyer Valley, Pahranagat Valley, and Amargosa Desert.

Irrigated acreages were delineated using aerial photographs, Multi-Spectral Scanner (MSS) images, and Thematic Mapper (TM) images (fig. 9). Aerial photographs taken between 1947 and 1954 confirm the absence of appreciable irrigation in Amargosa Desert, Penoyer Valley, Railroad Valley, and Mesquite Valley and limited irrigation in Pahranagat Valley (table 1, fig. 7). Irrigation between 1972 and 1998 was identified primarily with MSS and TM images. Darker areas in the red band of MSS and TM images were interpreted as irrigated acreage because healthy, chlorophyll-rich vegetation strongly absorbs visible red wavelengths in the electromagnetic spectrum. Color infrared composite images constructed from the green, red, and near infrared bands of MSS and TM images were used exclusively to delineate irrigated fields in Mesquite Valley where independent acreage estimates were unavailable. Healthy irrigated vegetation appeared red and contrasted strongly with colors representing rangeland and bare soil. Remotely sensed images were georeferenced to achieve spatial accuracies of better than 500 ft.

Irrigated acreage estimates from pumpage inventories and remotely sensed images were compared to determine if a systematic bias existed. Irrigated acreage estimates could be compared in Penoyer Valley (HA 170) because cross-referencing between the databases from State agencies (pumpage inventories, well logs, and water rights or permits) and remote sensing was the least ambiguous of all the hydrographic areas. Penoyer Valley had less ambigu-

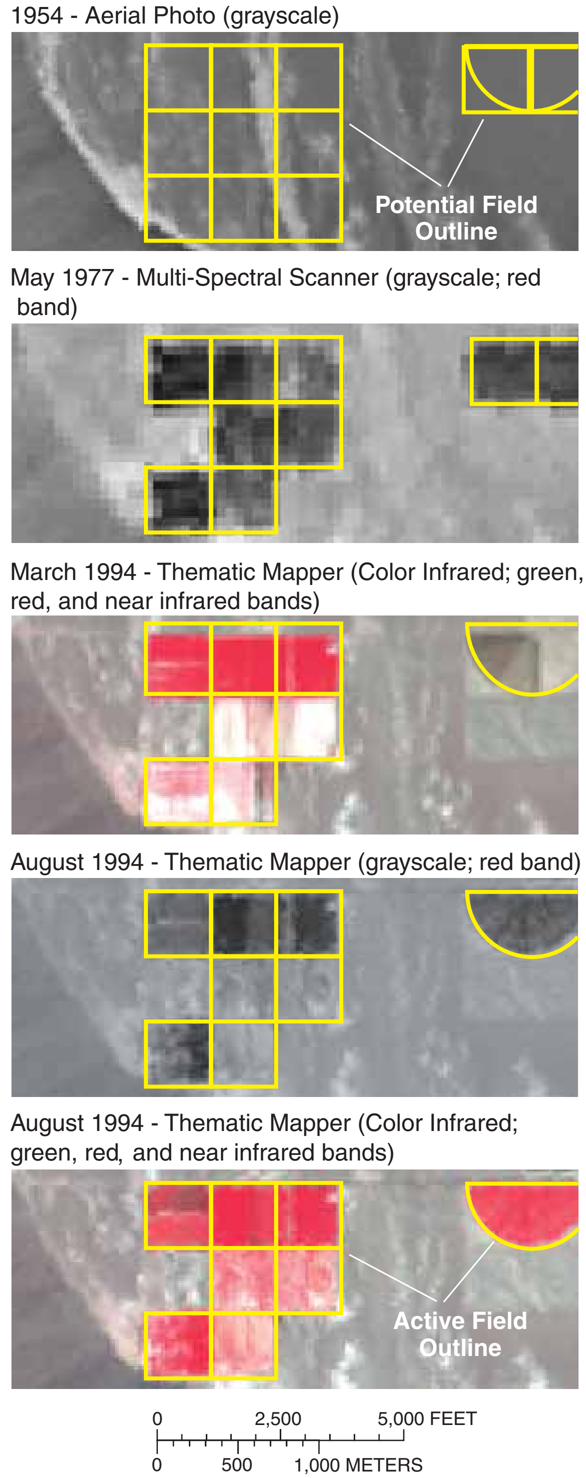


Figure 9. Image sources used to delineate irrigated fields and identify years of active irrigation.

ity because most fields were circular from center-pivot irrigation covering a quarter section, field sizes and irrigation practices remained relatively constant through time, and ownership of the land and crop type changed infrequently. Total irrigated acreage estimated by both methods between 1983 and 1998 agreed to within 10 percent for 14 of 16 years. During the same period, acreage from more than 95 percent of the irrigated fields estimated by both methods agreed to within 10 acres (fig. 10).

Discrepancies between acreage estimates of more than 10 percent affected about 3 percent of the estimated field-years in Penoyer Valley. These differences resulted from a pumpage inventory denoting a field as irrigated and remote sensing indicating the same field fallow. Contrariwise errors were of the same magnitude but of opposite sign. The greatest difference between estimates of acreage from pumpage inventories and remotely sensed images was 18 percent and occurred in 1991 (fig. 11).

Estimates of irrigated acreage prior to available data, 1983 for pumpage inventories, and 1972 for remotely sensed images, were extrapolated from direct measurements. A uniform acreage typically was extrapolated backwards in time from the last direct measurement to when the first supply well was drilled for a field. Irrigated acreage was estimated by back extrapolation in Amargosa Desert and Mesquite Valley (table 1, fig. 1). These estimates compared favorably with acreage estimates given in prior studies (Walker and Eakin, 1963; Glancy, 1968).

Irrigated acreage in Pahrump Valley from 1913 to 1958 was estimated primarily from sporadic measurements of total discharge from wells and springs (Malmberg, 1967, table 6) previously compiled for a ground-water flow model of Pahrump Valley (Harrill, 1986). From these measurements, average withdrawals from wells of 4,000, 13,000, and 22,000 acre-ft were estimated for the periods 1913–44, 1945–51, and 1952–58, respectively. This undifferentiated ground-

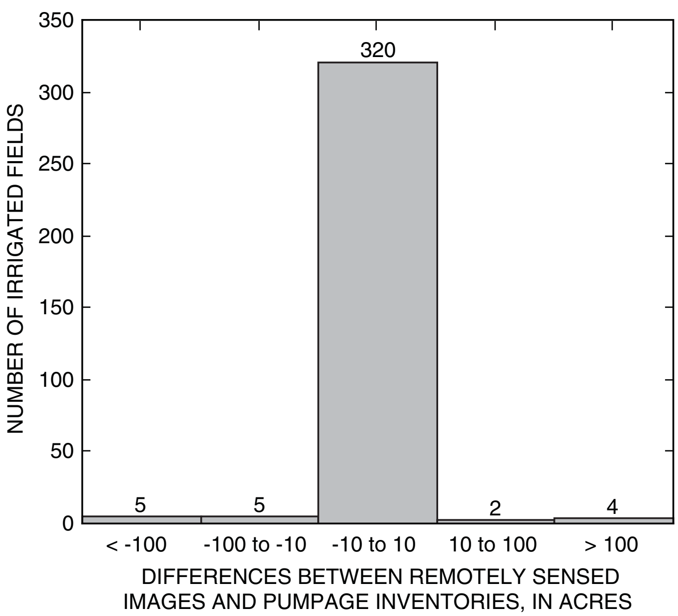


Figure 10. Differences between acreage estimates from pumpage inventories and remote sensing in Penoyer Valley (HA 170).

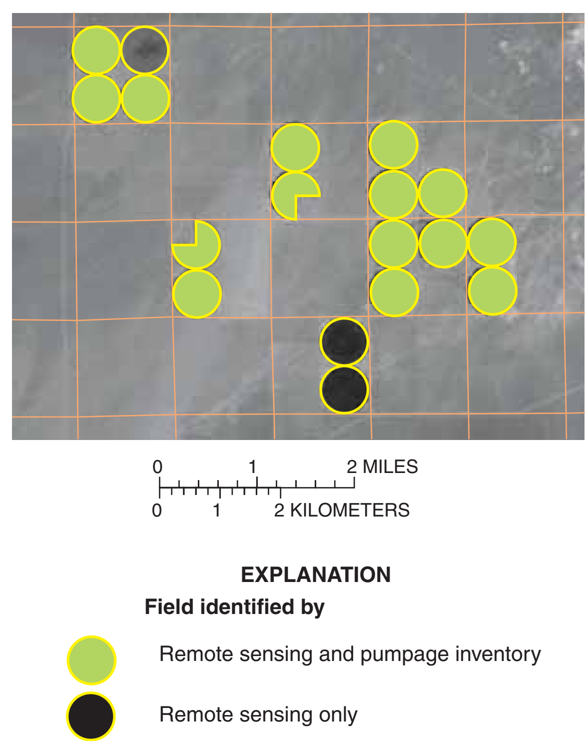


Figure 11. Active fields identified by remote sensing and pumpage inventories, Penoyer Valley (HA 170), 1991.

water withdrawal in Pahrump Valley prior to 1962 was assigned as irrigation use, because more than 99 percent of the pumpage in Pahrump Valley was for irrigation.

Application Rates

Annual application-rate estimates for alfalfa affected water-use estimates more than any other crop because about 75 percent of the 3 million acre-ft withdrawn during the period 1913–98 irrigated alfalfa. Alfalfa, grass hay, and turf grass were planted in about 70 percent of irrigated acreage in the southern hydrographic areas and almost all of the acreage in the northern hydrographic areas during the period 1913–98. Annual application rates for alfalfa, grass hay, and turf grass were similar and far exceeded application rates for all other crops. Alfalfa, grass hay, and turf grass were classed as high water-use crops. Application rates for high water-use crops ranged from 5 ft/yr in Penoyer Valley to 9 ft/yr in Pahrump Valley (table 2).

Application rates are dependant on the length of growing season, climate, prevailing management practices, and crop type. Application rates for each hydrographic area were estimated with the following equation (U.S. Department of Agriculture, 1994):

$$AR = ET_{crop}/Eff \qquad (1)$$

where

AR is application rate, in feet per year;

ET_{crop} is annual crop evapotranspiration, which is annual potential evapotranspiration, in feet per year, times a crop coefficient, dimensionless; and

Eff is irrigation efficiency, dimensionless.

Annual crop evapotranspiration was well defined in the study area because annual potential evapotranspiration and crop coefficients were well known. Annual potential evapotranspiration was estimated using a modified radiation method, which uses temperature and solar radiation (Shevenell, 1996). Potential evapotranspiration over the length of a growing season ranges from 3.8 ft in the northern hydrographic areas to 6.4 ft in the southern hydrographic areas (table 2, fig. 7). Estimates of annual potential evapotranspiration

Table 2. Range of application rates for alfalfa by hydrographic area

Elevation: Average elevation of irrigated fields in hydrographic area.
Annual precipitation: Average precipitation during the period 1961–90 at nearest weather station in hydrographic area (Owenby and Ezell, 1992).
Application rate: Calculated using equation 1. Most likely application rate determined using crop coefficient ($K_{alfalfa}$) = 0.92 and irrigation efficiency = 0.75 (except HA 162 = 0.65)

[Abbreviations: ET, evapotranspiration; ft/yr, feet per year]

Hydrographic area		Elevation (feet)	Annual precipitation (inches)	Growing season (days)	Cuttings per year	Potential ET (ft/yr)	Crop ET (ft/yr)	Application rate (ft/yr)		
Number	Name							Minimum	Most likely	Maximum
162	Pahrump Valley	2,600	6.0	240	6	6.4	5.9	5	9	14
163	Mesquite Valley	2,600	6.0	240	6	6.4	5.9	5	8	12
170	Penoyer Valley	4,800	8.0	150	4	3.8	3.5	3	5	7
173A	Railroad Valley, Southern Part	4,900	7.2	150	4	3.8	3.5	3	5	7
209	Pahranagat Valley	3,600	6.6	170	5	4.9	4.5	4	6	9
230	Amargosa Desert	2,350	5.4	240	6	6.4	5.9	5	8	12

with a modified Penman-Monteith method (Bureau of Reclamation, 2001) differ by less than 10 percent from the modified radiation method in the southern hydrographic areas. An annual crop coefficient for alfalfa of 0.92 was applied to all fields planted with high water-use crops (Bureau of Reclamation, 2001).

Irrigation efficiencies in the DVRFS were not well known but probably range from 60 to 80 percent. Efficiency of an irrigation application is affected by management practices, soil texture, and soil salinity (U.S. Department of Agriculture, 1997), and for the irrigation systems commonly used in the DVRFS do not exceed 80 percent (U.S. Department of Agriculture, 2001). An irrigation efficiency of 75 percent was assumed for fields irrigated with center-pivot sprinklers. In Pahrump Valley, where less efficient irrigation methods were practiced, fields were given an irrigation efficiency of 65 percent. Assigned irrigation efficiencies are less than maximum efficiency to account for additional management inefficiency, varying soil texture, and control of soil salinity in some irrigated parts of the DVRFS (Ayers and Westcot, 1985). Collectively, precipitation, wind, and conveyance losses were considered negligible.

Low water-use and mixed water-use crops also were defined for the southern hydrographic areas (HA 162, 163, and 230; table 3, fig. 7). Small grains, orchards, and cotton were classed as low water-use crops and assigned annual application rates of 3 to 4 ft (Bureau of Reclamation, 2001). Poorly documented fields and those likely to have been planted with both low and high water-use crops were classed as mixed water-use crops. Low water-use and mixed water-use crops were not defined for Penoyer and Railroad Valleys because none were known to have been planted.

The uncertainty of annual withdrawal estimates was defined by estimates of a minimum withdrawal and a maximum withdrawal for each field (table 3). Minimum annual withdrawals were calculated by assuming irrigation occurred with maximum irrigation efficiency over the shortest growing season. Maximum annual withdrawals were calculated by assuming irrigation occurred with minimum irrigation efficiency over the longest growing season. Uncertainties of withdrawal estimates were reported as minimum and maximum annual withdrawals because estimation errors were not normally distributed. Estimated application rates were closer to the minimum rate, which caused the uncertainty distribution to be asymmetrical.

Estimated application rates compared favorably to field estimates when both ground-water withdrawals and irrigated acreage were reported. However, field estimates, when available, typically were poor because acreage was not documented. Reported annual water applications for undifferentiated crops of alfalfa,

Table 3. Range of application rates by crop type group and hydrographic area

[Abbreviations: ft/yr, feet per year; NA, not applicable]

Hydrographic area		Low water-use crops annual application (ft/yr)			Mixed high and low water-use annual application (ft/yr)			High water-use crops annual application (ft/yr)		
Number	Name	Minimum	Most likely	Maximum	Minimum	Most likely	Maximum	Minimum	Most likely	Maximum
162	Pahrump Valley	2	4	6	2	6	14	5	9	14
163	Mesquite Valley	2	3	4	NA	NA	NA	5	8	12
170	Penoyer Valley	NA	NA	NA	NA	NA	NA	3	5	7
173A	Railroad Valley, Southern Part	NA	NA	NA	NA	NA	NA	3	5	7
209	Pahranagat Valley	2	3	4	NA	NA	NA	4	6	9
230	Amargosa Desert	2	3	4	2	6	12	5	8	12

grains, orchards, and vineyards in Pahrump Valley between 1900 and 1916 ranged from 8 to 20 ft (Mendenhall, 1909; Waring, 1921). Annual applications reported for alfalfa in Ash Meadows ranged from 11 to 14 ft during 1972 (Dudley and Larson, 1976). In Pahrump Valley between 1959 and 1978, NDWR estimated irrigation withdrawal as the product of pumping rate and number of days a well was pumped. Averaging their estimates resulted in an application rate of about 5 ft/yr when cotton predominated and about 7 ft/yr when alfalfa predominated.

GROUND-WATER DEVELOPMENT FROM 1913 THROUGH 1998

The first three irrigation wells within the DVRFS were drilled in Pahrump Valley in 1913 (HA 162, fig. 1) after earlier attempts in 1910 were unsuccessful (Harrill, 1986). Between 1913 and 1916, an additional 27 wells were drilled in Pahrump Valley and annual discharge from wells increased from 500 to 4,000 acre-ft (Waring, 1921). Ground-water use remained relatively stable prior to 1945 because withdrawals were limited by the amount of water available from flowing wells.

Ground-water withdrawals from Pahrump Valley increased after 1945 with the introduction of high-capacity, turbine pumps (Harrill, 1986). Irrigated acreage increased from less than 1,000 acres in the early 1940s to about 3,800 in 1958 (fig. 12). Irrigated acreage increased after 1952 with the paving of the road to Las Vegas and as people acquired land under the Desert Land Act and Homestead Act (Tim Hafen, land developer, oral commun., 2003). A maximum of 3,400 acres of cotton were planted in Pahrump Valley during 1962, which was about 50 percent of all irrigated acreage. Irrigated agriculture reached its peak in 1968 with about 8,100 acres under cultivation.

Irrigated acreage in Pahrump Valley began being converted to suburban communities after 1970 as economic factors precipitated the decline of cotton production (McCracken, 1990). Cotton was planted in less than 25 percent of the irrigated acreage in Pahrump Valley after 1975 and was not grown after 1982.

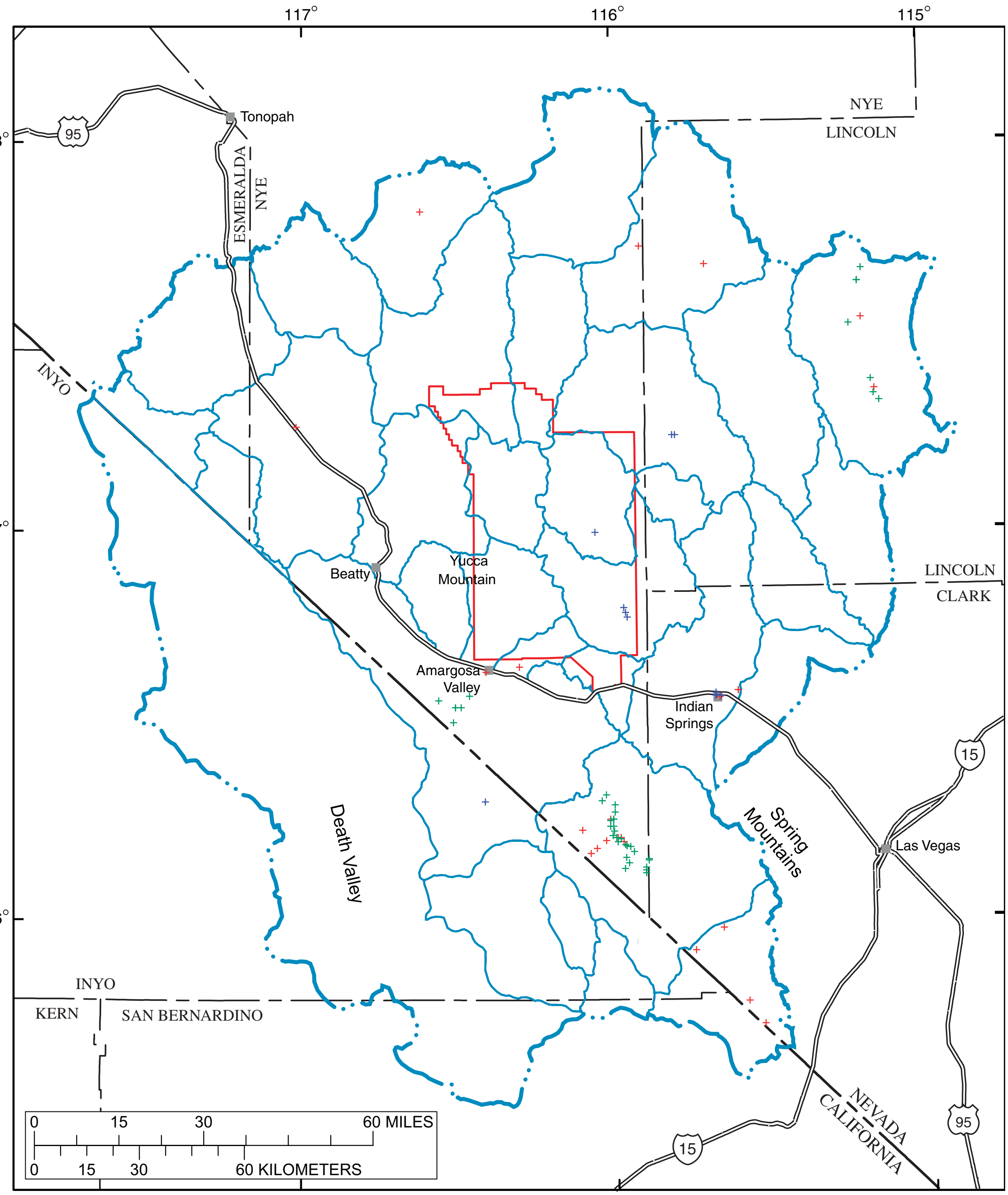
Domestic and public-supply water use in Pahrump Valley increased exponentially between 1960 and 1998 (fig. 6). The number of domestic wells increased from less than 50 to 700 between 1962 and 1978 as the population increased from 200 to 2,000 (fig. 13; Harrill, 1986). By 1998, 9,000 acre-ft of water was used for domestic and public supply to support a population of 20,000 (Hardcastle, 2001). About 75 percent of the domestic and public-supply withdrawal from the DVRFS in 1998 was pumped from Pahrump Valley (fig. 14).

Irrigation in Amargosa Desert began in 1916 with 10 acres of alfalfa, grapes, and vegetables at the T & T Ranch (McCracken, 1992). Intensive agriculture in Amargosa Desert began in 1954 as land was patented under the Desert Land Act (Bureau of Reclamation, 1975) and irrigated acreage exceeded 2,000 acres by 1965. Farming and the associated irrigated acreage contracted and expanded twice between 1965 and 1998. Annual ground-water withdrawals for irrigation in Amargosa Desert fluctuated considerably over the last 20 years, ranging from 2,100 acre-ft in 1989 to 22,000 acre-ft in 1998.

Ground-water withdrawals in Amargosa Desert other than irrigation were predominantly from American Borate Mine, Industrial Mineral Ventures, and Barrick Bullfrog Mine. Ground-water withdrawals for mining accounted for 10 percent of the 25,000 acre-ft pumped from Amargosa Desert in 1998. Annual ground-water withdrawals from domestic wells in Amargosa Desert were trivial and never exceeded 250 acre-ft.

Ground-water withdrawals from Mesquite Valley, Penoyer Valley, and Railroad Valley have been less extensive than from Pahrump Valley and Amargosa Desert. Ground-water withdrawals from Mesquite, Penoyer, and Railroad Valleys have been almost exclusively for irrigation of alfalfa or sod. Annual ground-water withdrawals from Mesquite Valley have averaged 6,700 acre-ft and increased from 3,300 acre-ft in 1966 to 10,000 acre-ft in 1998. Annual ground-water withdrawals from Penoyer Valley have averaged 10,000 acre-ft and increased from 5,700 acre-ft in 1978 to 13,000 acre-ft in 1998. Annual ground-water withdrawals from Railroad Valley have been minimal and the only reported estimate is less than 1,300 acre-ft in 1998.

The Ash Meadows area of Amargosa Desert (HA 230, fig. 7) was irrigated intensively from 1969 through 1976 by the Spring Meadows Corporation. Pumping from wells drilled after 1968 caused the water level to decline in nearby Devils Hole (fig. 7). Ground-water withdrawals ceased by 1982 to maintain a minimum water level in Devils Hole mandated by the U.S. Supreme Court in 1976.



Base from U. S. Geological Survey digital data 1:100,000–scale, 1978–89
Universal Transverse Mercator Projection Zone 11
Shaded relief base from 1:250,000–scale Digital Elevation Model
Sun illumination from northwest at 45 degrees above horizon

EXPLANATION

Study-area boundary

Hydrographic area boundaries

Nevada Test Site boundary

Water-use class

+ Mining, public supply, and commercial

+ Domestic

+ Irrigation

Figure 12. Locations of ground-water withdrawal sites in the Death Valley regional flow system, 1958.

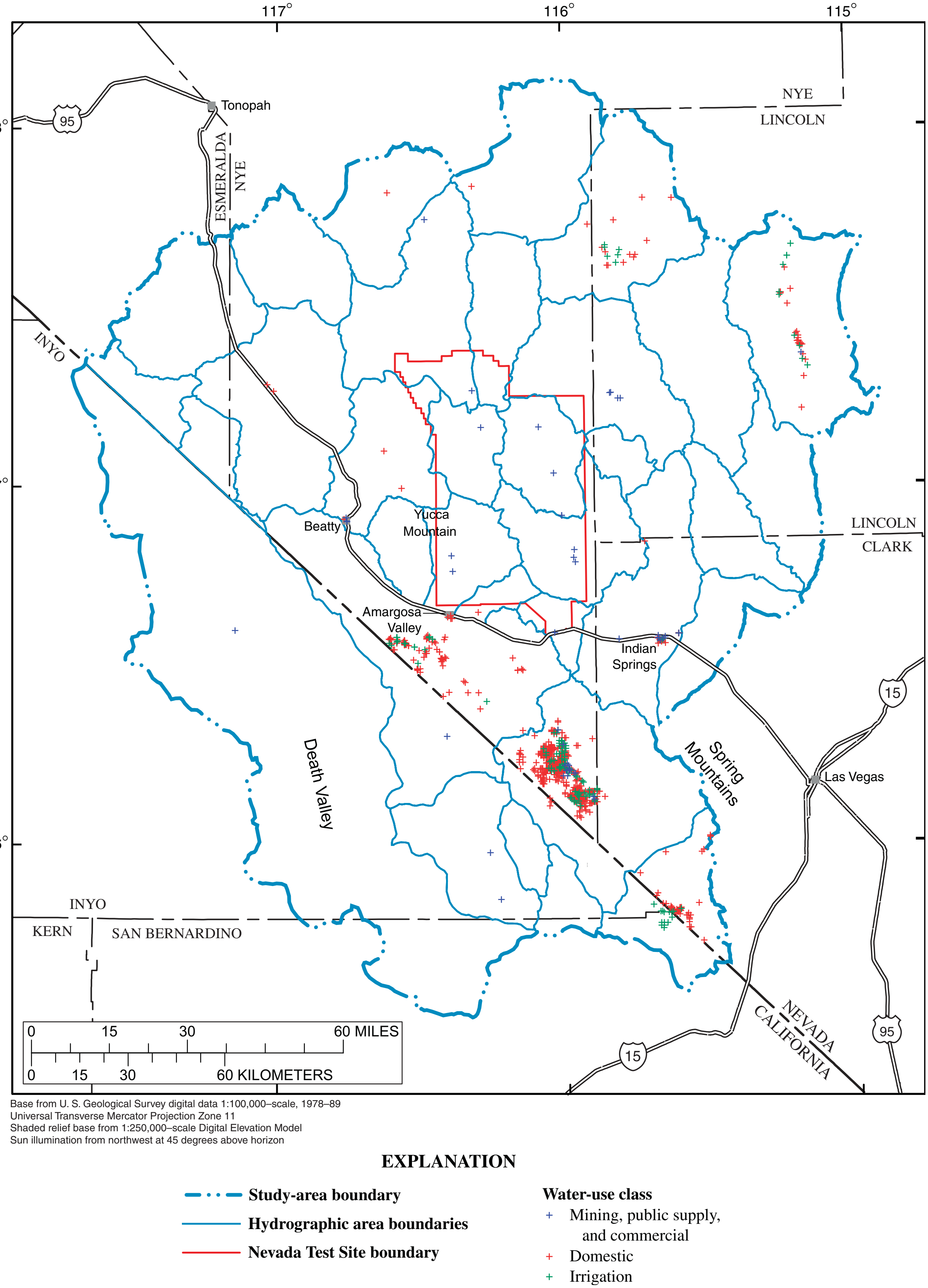
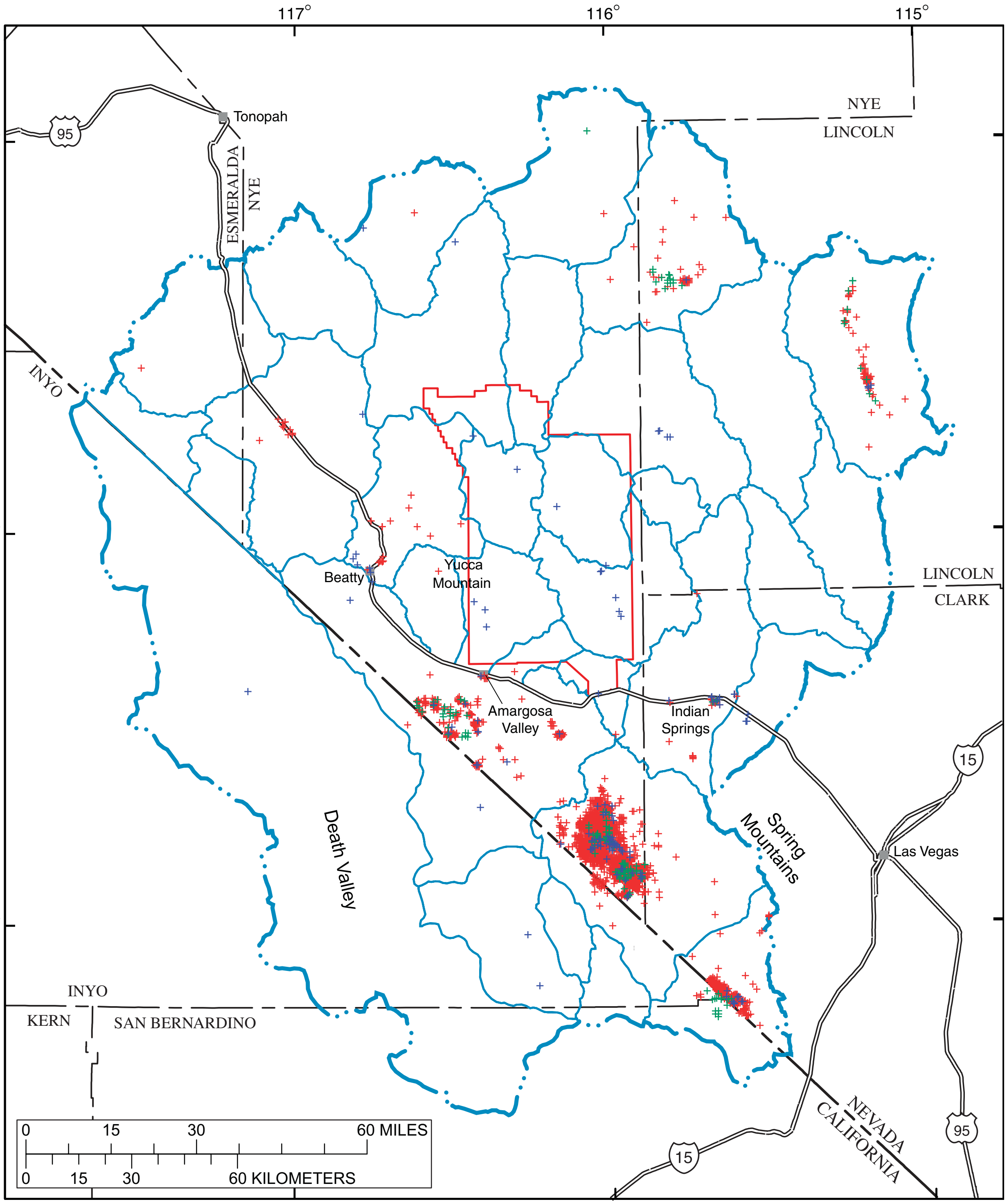


Figure 13. Locations of ground-water withdrawal sites in the Death Valley regional flow system, 1978.



Base from U. S. Geological Survey digital data 1:100,000–scale, 1978–89
Universal Transverse Mercator Projection Zone 11
Shaded relief base from 1:250,000–scale Digital Elevation Model
Sun illumination from northwest at 45 degrees above horizon

EXPLANATION

Study-area boundary

Hydrographic area boundaries

Nevada Test Site boundary

Water-use class

\+ Mining, public supply, and commercial

\+ Domestic

\+ Irrigation

Figure 14. Locations of ground-water withdrawal sites in the Death Valley regional flow system, 1998.

Ground-water withdrawals from the Nevada Test Site were primarily for public supply and operational support to U.S. Department of Energy personnel. Personnel and water use have fluctuated in response to changes in program by more than a factor of four since 1958 when withdrawals were about 200 acre-ft (fig. 12). Ground-water withdrawals were 950 acre-ft in 1978, which was slightly more than the average annual withdrawal of 900 acre-ft between 1959 and 1978 (fig. 13). Pumpage from the Nevada Test Site was 740 acre-ft or about 1 percent of total ground-water withdrawals in the DVRFS in 1998 (fig. 14).

UNCERTAINTY OF GROUND-WATER WITHDRAWAL ESTIMATES

The uncertainty of ground-water withdrawals from the DVRFS is attributed primarily to the uncertainty in irrigation-application rates. Incomplete records of past pumpage, annual acreage estimates, and estimates of water-use coefficients also contribute to the uncertainty of ground-water withdrawal estimates, but collectively were less significant than application rates. The collective effect of all uncertainties has been presented as reasonable estimates of minimum and maximum annual pumpage (fig. 15). The uncertainty of estimated annual ground-water withdrawals is reported as the difference between minimum and maximum withdrawal estimates. Uncertainties in annual irrigation estimates exceeded ±20 percent of best estimates for individual wells.

Additional uncertainties were introduced to ground-water withdrawal estimates for irrigation when acreages were interpolated or extrapolated. Acreages were interpolated between periods of reported acreages and extrapolated from the date of the first acreage report to the date when the well assigned to that field was drilled. An additional uncertainty of ±20 percent was assigned to ground-water withdrawal estimates with interpolated acreage. An additional uncertainty of ±40 percent was assigned to ground-water withdrawal estimates with extrapolated acreage. The assigned uncertainties reflected the variability of reported acreage estimates (fig. 16).

Potential misidentification of crop type also contributes to the uncertainty of ground-water withdrawal estimates. High and low water-use crops were not differentiated when cultivated acreage was reported prior to 1945 (Mendenhall, 1909; Waring, 1921). Subsequent reports specified the cultivated acreage of specific crop types, but reported sporadic, synoptic surveys (Dudley and Larson, 1976; Eakin, 1963; Glancy, 1968; Malmberg, 1967; Maxey and Robinson,

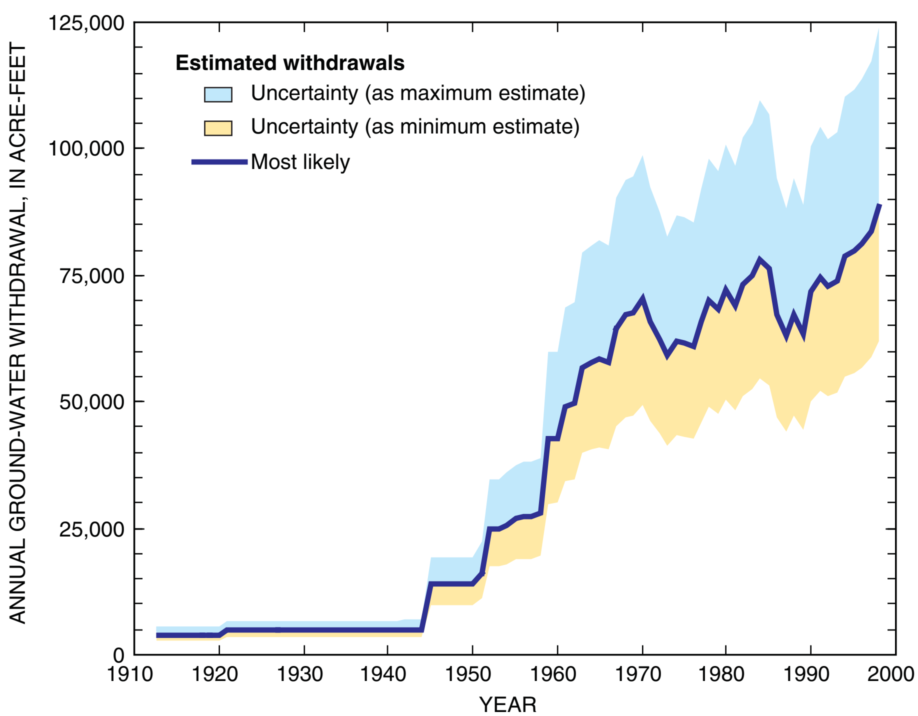


Figure 15. Range of estimated ground-water withdrawals and assigned uncertainty, Death Valley regional flow system, 1913–98.

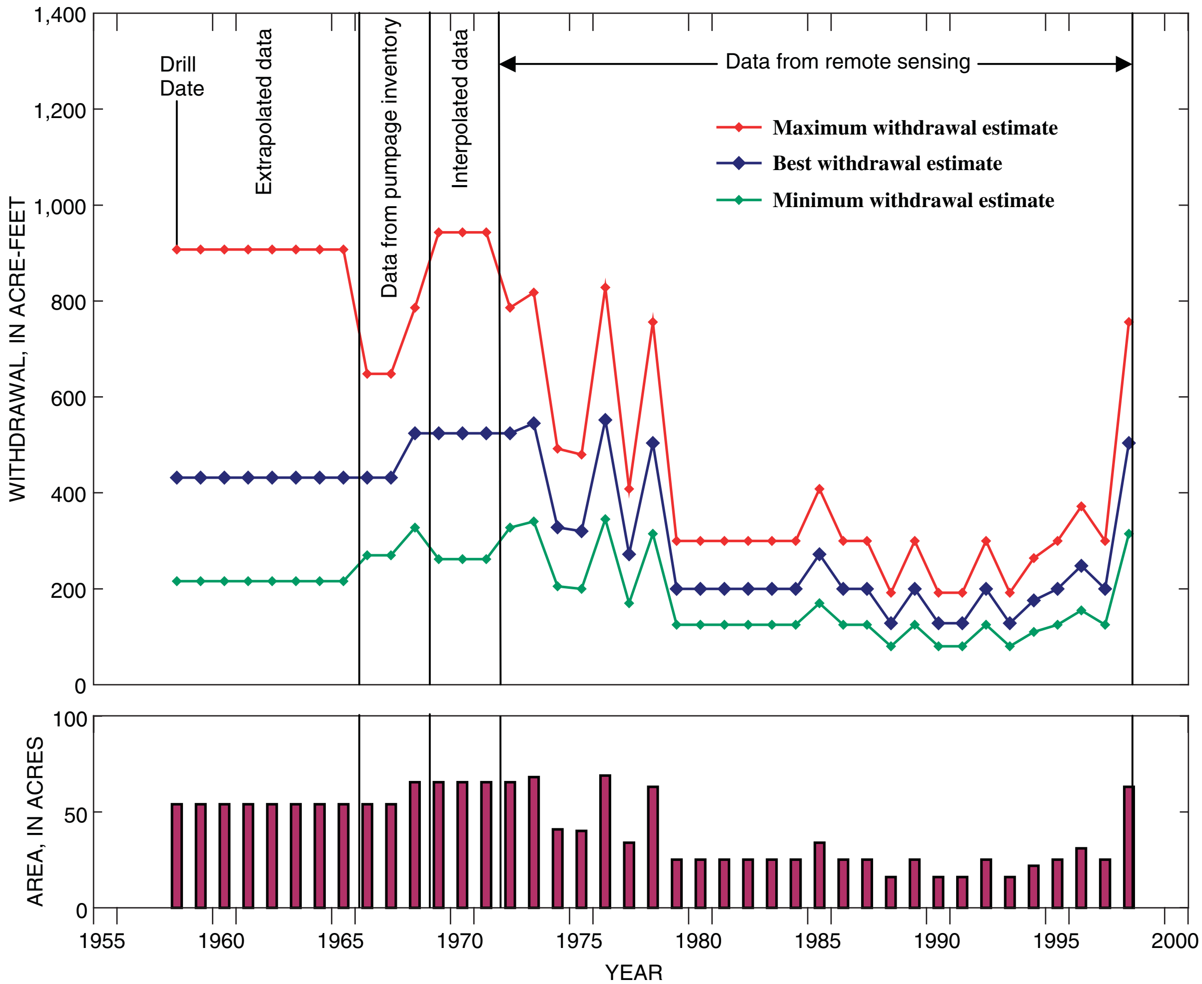


Figure 16. Example of extrapolated and interpolated annual withdrawal for a single withdrawal point in Amargosa Desert (HA 230), 1958–98.

1947). Annual pumpage inventories were not routinely conducted throughout the study area until after 1983 and frequently do not list crop type.

SUMMARY

Ground-water withdrawals from 1913 through 1998 from the DVRFS have been compiled to support a regional, three-dimensional, transient ground-water flow model. Withdrawal locations and depths of production intervals were estimated and associated errors were reported for 9,300 wells. Locations of about 97 percent of wells in the study area were mapped to within 1,000 ft and have reported completion intervals. About 90 percent of all ground-water withdrawal in the study area was from basin-fill deposits in Pahrump Valley, Amargosa Desert, Penoyer Valley, and Mesquite Valley.

Withdrawals were categorized into three general classes: mining, public-supply, and commercial water use; domestic water use; and irrigation water use. Water-use categories were based on the method of estimating pumpage. Mining, public-supply, and commercial wells typically were metered and withdrawals ranged from 2 to 13 percent of annual withdrawals from the study area. Withdrawals for domestic water use, estimated as the number of domestic wells times a consumption rate, ranged from 1 to 7 percent of total annual withdrawals. Irrigation was estimated as the product of acreage and application rates and accounted for more than 80 percent of all withdrawals in DVRFS during any year.

Annual withdrawal for irrigation ranged from 80 to almost 100 percent of the pumpage from the study area. The maximum annual withdrawal for irrigation was about 75,000 acre-ft in 1998. Annual withdrawals generally were estimated as the product of irrigated acreage and application rate. About 320 fields that ranged from 1 to 130 acres and totaled 11,000 acres were identified within the study area. Irrigation of more than 200 acres occurs in only six hydrographic areas (Amargosa Desert, Pahranagat Valley, Pahrump Valley, Penoyer Valley, Railroad Valley, and Mesquite Valley). Annual application-rate estimates for alfalfa affected water-use estimates more than any other crop because 75 percent of the 3 million acre-ft withdrawn from 1913 through 1998 irrigated alfalfa. Annual application rates for high water-use crops ranged from 5 ft in Penoyer Valley to 9 ft in Pahrump Valley.

The uncertainty of ground-water withdrawals from the DVRFS was due primarily to the uncertainty of application-rate estimates. Total annual ground-water withdrawals were estimated to be 90,000 acre-ft in 1998, but because of uncertainty could range from a minimum of 60,000 to a maximum 130,000 acre-ft. The uncertainties of individual withdrawal estimates were reported as minimum and maximum withdrawals because estimation errors did not represent a normal statistical distribution.

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APPENDIX

APPENDIX

The database distributed with this report is in Microsoft® Access 2000 format. Table names are prefixed with "tbl_" and queries with "qry_" (table 4). After opening the database select "view", then "details" for column descriptions to appear in the project window. To obtain a description, which appears at the bottom of the screen, move the cursor to the column of interest.

Table 4. Description of Microsoft® Access database

Table/query/column headings: Table names preceded by tbl_; query names preceded by qry_.

Table/Query/Column Headings	
Tables	**Description**
tbl_application rates	Rates applied to irrigation and domestic uses
tbl_raw_data	Raw annual data
tbl_spatial	Location and depths of withdrawal points
tbl_withdrawals	Withdrawals summed by withdrawal point and year

Queries	Description
qry_domestic_withdrawals_ha	Domestic withdrawals summed by hydrographic area and year
qry_domestic_withdrawals_withdrawal point	Domestic withdrawals summed by withdrawal point and year
qry_irrigation_withdrawals_ha	Irrigation withdrawals and irrigated acres summed by hydrographic area and year
qry_irrigation_withdrawals_record	Irrigation withdrawals summed by record
qry_irrigation_withdrawals_withdrawal point	Irrigation withdrawals and irrigated acres summed by withdrawal point and year
qry_other_withdrawals_ha	All withdrawals other than irrigation and domestic summed by hydrographic area and year
qry_other_withdrawals_record	All withdrawals other than irrigation and domestic summed by record
qry_other_withdrawals_withdrawal point	All withdrawals other than irrigation and domestic summed by withdrawal point and year

Column	Description
acres_irrigated	Number of acres irrigated
altitude	Withdrawal point altitude, in feet above mean sea level
application_rate_best	Best estimate application rate (acre-feet per year)
application_rate_max	Maximum estimated application rate (acre-feet per year)
application_rate_min	Minimum estimated application rate (acre-feet per year)
bottom_completion	Lower end of interval in which ground water is withdrawn, in feet below land surface
bottom_max_completion	Maximum lower end of interval in which ground water is withdrawn, in feet below land surface

Column—Continued	**Description**—Continued
crop_type	L = low water-use crops; H = high water-use crops; M = undifferentiated crop types; X = not applicable
east_utm	Easting of withdrawal point, in meters
error_coefficient	-4 = no use extrapolated; -3 = no use interpolated; -2,-1, 0 = no use reported or interpreted; 1,2 = withdrawal reported or interpreted; 3 = withdrawal interpolated; 4 = withdrawal extrapolated; 5 = withdrawal metered
ha	Hydrographic area designator
ha_plss_id	Hydrographic area, township, range, section
latitude	Latitude of withdrawal point, in decimal degrees
longitude	Longitude of withdrawal point, in decimal degrees
north_utm	Northing of withdrawal point, in meters
remarks	Point of withdrawal description
top_completion	Upper end of interval in which ground water is withdrawn, in feet below land surface
top_min_completion	Minimum upper end of interval in which ground water is withdrawn, in feet below land surface
withdrawal_best	Best withdrawal estimate, in acre-feet
withdrawal_coefficient	Irrigation use = number of acres irrigated, domestic use = number of wells, all other water uses = amount of withdrawal, in acre-feet per year
withdrawal_max	Maximum withdrawal estimate, in acre-feet
withdrawal_min	Minimum withdrawal estimate, in acre-feet
withdrawal_point	Point of withdrawal designator
withdrawal_point_accuracy	Accuracy of latitude/longitude placement of withdrawal point, in feet
wtr_use	Water use; C = commercial; H = domestic; I = irrigation; K = mining; N = industrial; P = public supply; R = recreation; S = stock; W = wildlife; Z = other
year	Calendar year of withdrawal