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

# Trend Analysis of Ground-Water Levels and Spring Discharge in the Yucca Mountain Region, Nevada and California, 1960–2000

Water-Resources Investigations Report 02-4178

Prepared in cooperation with the
NEVADA OPERATIONS OFFICE of the
U.S. DEPARTMENT OF ENERGY, under
Interagency Agreement, DE-AI08-01NV13944

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*By* Joseph M. Fenelon and Michael T. Moreo

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2002

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

U.S. GEOLOGICAL SURVEY
CHARLES G. GROAT, Director



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For additional information contact:

District Chief
U.S. Geological Survey
333 West Nye Lane, Room 203
Carson City, NV 89706–0866

email: GS-W-NVpublic-info@usgs.gov

http://nevada.usgs.gov

Copies of this report can be purchased from:

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Box 25286, Federal Center
Denver, CO 80225–0286

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## 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 |
| | **Volume** | |
| acre-foot (acre-ft) | 1,233 | cubic meter |
| million gallons (Mgal) | 3,785 | cubic meter |
| million gallons (Mgal) | 3.069 | acre-foot |
| | **Hydraulic gradient** | |
| foot per mile (ft/mi) | 0.1894 | meter per kilometer |
| | **Transmissivity** | |
| cubic foot per day per foot width of aquifer ($ft^2$/d) | 0.09290 | cubic meter per day per meter width of aquifer |
| | **Rate** | |
| foot per year (ft/yr) | 0.3048 | meter per year |
| inch per year (in/yr) | 2.54 | centimeter per year |
| | **Volumetric Rate** | |
| acre-foot per year (acre-ft/yr) | 1,233 | cubic meter per year |
| cubic foot per second ($ft^3$/s) | 0.02832 | cubic meter per second |
| gallon per minute (gal/min) | 0.06309 | liter per second |
| million gallons per year (Mgal/yr) | 3,785 | cubic meters per year |

**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.

**Temperature**: Degrees Fahrenheit (° F) can be converted to degrees Celsius (° C) by using the formula ° C=0.556(° F-32).

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## ABSTRACT

Ground-water level and discharge data from 1960 to 2000 were analyzed for the Yucca Mountain region of southern Nevada and eastern California. Included were water-level data from 37 wells and a fissure (Devils Hole) and discharge data from five springs and from a flowing well. Data were evaluated for variability and for upward, downward, or cyclic trends with an emphasis on the period 1992–2000. Potential factors causing trends in water levels and discharge include ground-water withdrawal, infiltration of precipitation, earthquakes, evapotranspiration, barometric pressure, and earth tides.

Statistically significant trends in ground-water levels or spring discharge from 1992 to 2000 were upward at 12 water-level sites and downward at 14 water-level sites and 1 spring-discharge site. In general, the magnitude of the change in water level from 1992 to 2000 was small (less than 2 feet), except where influenced by pumping or local effects such as possible equilibration from well construction or diversion of nearby surface water.

Seasonal trends are superimposed on some of the long-term (1992–2000) trends in water levels and discharge. Factors causing seasonal trends include barometric pressure, evapotranspiration, and pumping. The magnitude of seasonal change in water level can vary from as little as 0.05 foot in regional aquifers to greater than 5 feet in monitoring wells near large supply wells in the Amargosa Farms area.

Three major episodes of earthquake activity affected water levels in wells in the Yucca Mountain region between 1992 and 2000: the Landers/Little Skull Mountain, Northridge, and Hector Mine earthquakes. The Landers/Little Skull Mountain earthquakes, in June 1992, had the largest observed effect on water levels and on discharge during the study period. Monthly measurements of wells in the study network show that earthquakes affected water levels from a few tenths of a foot to 3.5 feet.

In the Ash Meadows area, water levels remained relatively stable from 1992 to 2000, with some water levels showing small rising trends and some declining slightly. Possible reasons for water-level fluctuations at sites AD-6 (Tracer Well 3), AM-5 (Devils Hole Well), and AM-4 (Devils Hole) from 1960 to 2000 include climate change, local and regional ground-water withdrawals, and tectonic activity.

In Jackass Flats, water levels from 1992 to 2000 in six wells adjacent to Fortymile Wash displayed either small upward trends or no upward or downward trend. Comparison of trends in water levels from 1983 to 2000 for these six wells shows good correlations between all wells and suggests a common mechanism controlling water levels in the area. Of the likely controls on the system—precipitation or pumping in Jackass Flats—precipitation appears to be the predominant factor controlling water levels near Fortymile Wash.

Water levels in the heavily pumped Amargosa Farms area declined from about 10 to 30 feet from 1964 to 2000. Water-level declines accelerated beginning in the early 1990’s as pumping rates increased substantially. Pumping in the Amargosa Farms area may affect water levels in some wells as far away as 5–14 miles.

The water level at site DV-3 (Travertine Point 1 Well) and discharge at site DV-2 (Navel Spring), both in the Death Valley hydrographic area, had downward trends from 1992 to 2000. The cause of these downward trends may be linked to earthquakes, pumping in the Amargosa Farms area, or both.

# INTRODUCTION

Since the late 1970's, investigations to determine the potential suitability of Yucca Mountain for storage of high-level nuclear waste have been done by the U.S. Geological Survey (USGS) and other organizations. The U.S. Department of Energy (DOE) has stated that all facilities and activities associated with such investigations of Yucca Mountain will be operated in a manner that maintains or protects environmental quality, and has established programs to assess environmental quality. In April 1989, the USGS began a cooperative program with DOE to develop a ground-water-resources Environmental Monitoring Program in the vicinity of Yucca Mountain. The purposes of the Environmental Monitoring Program are to: (1) document historical and current conditions of ground-water resources, including water levels and water quality, (2) detect changes in these resources, and (3) provide a basis for analyzing and identifying potential adverse effects on ground-water resources. The primary focus of the Environmental Monitoring Program is on Jackass Flats, where ground water is withdrawn to support several DOE activities, including Yucca Mountain site characterization. If these withdrawals affect ground-water levels, the effects may be detected in Jackass Flats before they are detected elsewhere within the Yucca Mountain region.

The USGS has monitored two Yucca Mountain ground-water networks through 2000. The earliest-monitored network is a local Yucca Mountain network that was first monitored in 1981 as part of a site-characterization plan (U.S. Department of Energy, 1988). The purpose of this network is to gain a better understanding of the ground-water flow system at Yucca Mountain for site characterization purposes. The focus of this report, however, is a regional network, part of the Environmental Monitoring Program described previously. Seven wells in Jackass Flats are included in the Environmental Monitoring Program network and the site-characterization network. Water levels from the remaining wells in the site-characterization network were not analyzed for this report.

The study area is within the Yucca Mountain region of southern Nevada and eastern California (fig. 1*A*). For the purpose of study, this area includes all of Crater Flat and Jackass Flats to the north; all of Rock Valley, Mercury Valley, and eastern Amargosa Desert to the east; and parts of western Amargosa Desert and Death Valley to the south and west. The southern and western extents of the study area are approximately denoted by Death Valley Junction and Furnace Creek Ranch, respectively (fig. 1*B*). The study area includes Yucca Mountain as well as the southwestern part of the Nevada Test Site (NTS), which lies immediately east of Yucca Mountain. The Yucca Mountain region is within the Great Basin, a subdivision of the Basin and Range Physiographic Province (Fenneman, 1931, p. 328).

## Purpose and Scope

This report analyzes ground-water level and spring-discharge data collected or compiled as part of the cooperative USGS/DOE Environmental Monitoring Program for Yucca Mountain. Data collected between 1960 and 2000 from the primary monitoring network include water levels at 37 wells and a fissure (Devils Hole), and discharge at 5 springs and a flowing well. Total reported ground-water withdrawals within the study area (Crater Flat, Jackass Flats, Mercury Valley, and Amargosa Desert) and from the surrounding regional area (Pahrump, Las Vegas, NTS, Penoyer Valley, and Pahranagat Valley) were compiled. Most of the water-level and withdrawal data analyzed for this report were previously published in a series of annual reports (La Camera and Westenburg, 1994; Hale and Westenburg, 1995; Westenburg and La Camera, 1996; La Camera and others, 1996; La Camera and Locke, 1998; La Camera and others, 1999; Locke, 2001a; and Locke, 2001b). Also compiled were precipitation data from major recharge areas in the Spring Mountains, Pahute Mesa area, and Pahranagat Valley area. Miscellaneous water levels and discharge from several wells and springs were included to aid in interpretation of trends in the primary monitoring network.

The principal emphasis of this report is to explain the various trends or fluctuations in water levels or discharge collected or compiled as part of the Environmental Monitoring Program. The report provides a basis for comparing water levels and discharge between primary monitoring sites and for determining how the data fit into a regional understanding of the ground-water flow system. Anomalous changes in water levels or discharge for individual wells or springs that do not appear to be caused by regional effects are identified and explained, if possible. Special attention is given to the discussion of water-level trends in Jackass Flats, their possible causes, and any noticeable effects on water levels from ground-water withdrawals in Jackass Flats.

Water levels and spring discharge were analyzed for variability and for upward, downward, or cyclic trends with an emphasis on the period 1992–2000, when water levels were measured monthly for the Environmental Monitoring Program. Measurements prior to 1992 generally were made sporadically, with few wells or springs having data for the entire period of 1960–2000.

Trends were analyzed statistically to detect significant upward or downward changes and graphically to compare trends between sites. For many of the wells and springs with significant trends, an attempt was made to identify the cause. Potential causes of change in water levels and spring discharge may be local or regional. Local causes include possible improper well construction, nearby diversions of surface water, and pumping in or nearby the monitoring well. Regional causes include ground-water withdrawal, recharge from precipitation, earthquakes, evapotranspiration, barometric pressure, and earth tides.

### Acknowledgments

Several organizations and programs contributed to this report. Specifically, data were provided by the National Park Service (NPS); U.S. Fish and Wildlife Service (USFWS); Nevada Department of Conservation and Natural Resources, Division of Water Resources (NDWR); Nevada Department of Transportation; Barrick Bullfrog, Inc.; Bechtel Nevada; Cathedral Gold U.S. Corporation; Cind-R-Lite Company; Daisy Gold Mining Company; U.S. Borax Corporation; U.S. Nevada Gold Search; USGS–Hydrologic Resources Management and Environmental Restoration Programs; and USGS–Yucca Mountain Project Branch studies of saturated-zone site hydrology and saturated-zone regional hydrology.

Individuals who provided data and information for this study include Bradley Gillies (NPS), Tim Mayer and Wendy Yao (USFWS), Desiree Brantley (NDWR), Hans Arlt (U.S. Nuclear Regulatory Commission), and David Buesch (USGS–Yucca Mountain Project Branch). The authors also acknowledge the cooperation of property owners throughout the Amargosa Desert who allowed access to their property to collect hydrologic data.

Additionally, the following USGS employees contributed significantly to the design, management, or collection of data for the primary monitoring network: John Armino, Richard J. La Camera, Glenn L. Locke, Rodney H. Munson, Charles S. Savard, and Craig L. Westenburg. Special thanks go to Randell J. Laczniak (USGS) for general guidance in the analysis and interpretation of data; to Peggy E. Elliott (USGS) for contributing to the earthquake section of the report and reviewing early drafts; and to Donald P. Harper (USGS) for creating the maps used in the report.

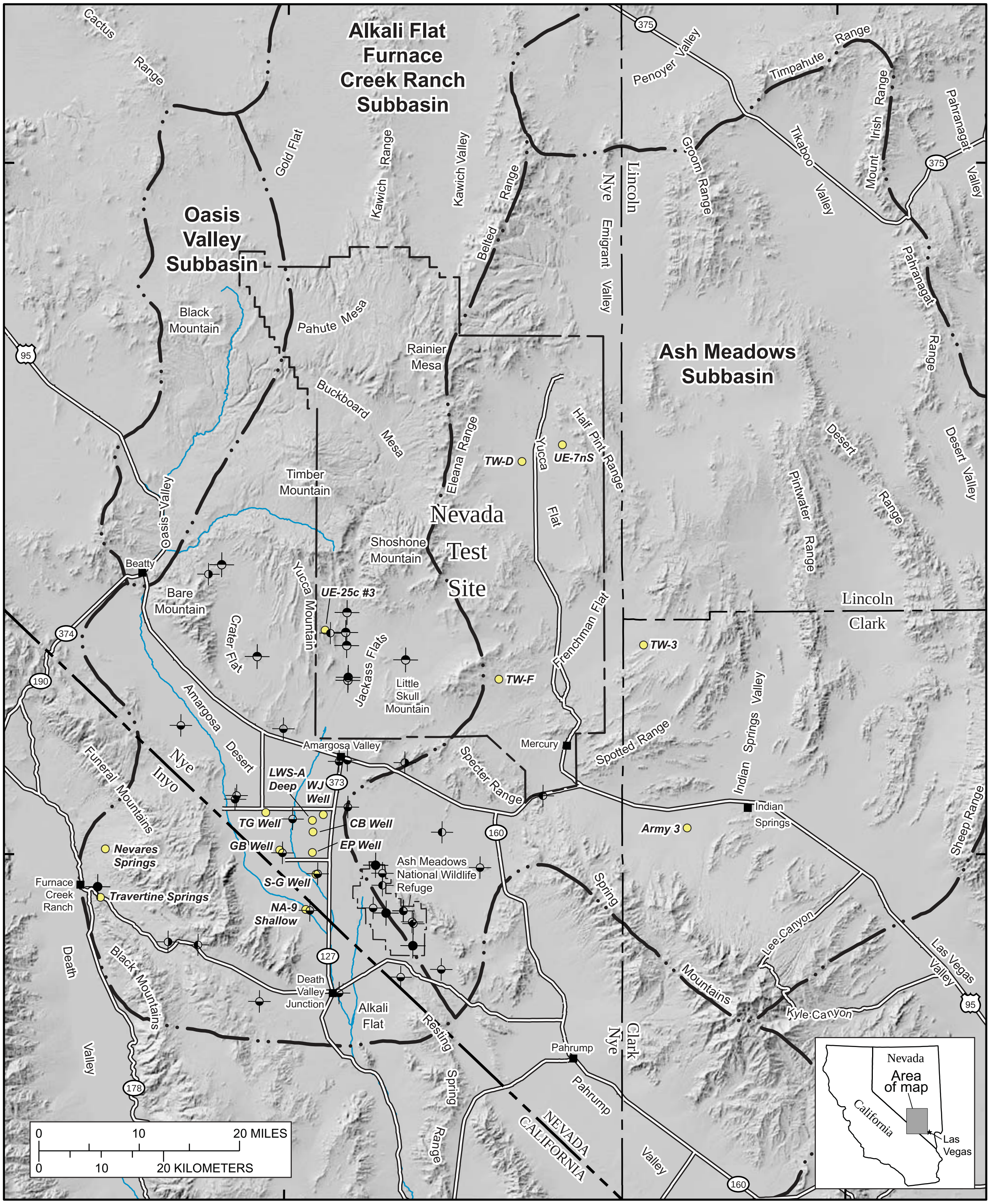
## DESCRIPTION OF STUDY AREA AND GENERAL HYDROGEOLOGY

The study area is within the Death Valley regional ground-water flow system (Harrill and others, 1988, sheet 1) and, more specifically, within the southern Alkali Flat–Furnace Creek Ranch and southwestern Ash Meadows ground-water subbasins (fig. 1*B*). Each ground-water subbasin defines an area of ground-water recharge and flow paths to major area(s) of discharge at land surface (Waddell and others, 1984, p. 36; Laczniak and others, 1996, p. 16, pl. 1). Boundaries of the subbasins (fig. 2) are based on the location of recharge areas, discharge areas, low-permeability rocks, hydraulic gradients, and water chemistry. These boundaries are general indicators of restrictions on ground-water movement in the region.

The study area also is subdivided by hydrographic areas[1] (fig. 1*B*). As defined by Rush (1968, p. 4), hydrographic areas generally consist of valleys (topographic lows) extending to surrounding surface-water drainage divides (topographic highs). Hydrographic

[1]Formal hydrographic areas in Nevada were delineated systematically by the U.S. Geological Survey and Nevada Division of Water Resources in the late 1960's (Rush, 1968; Cardinalli and others, 1968) for scientific and administrative purposes.

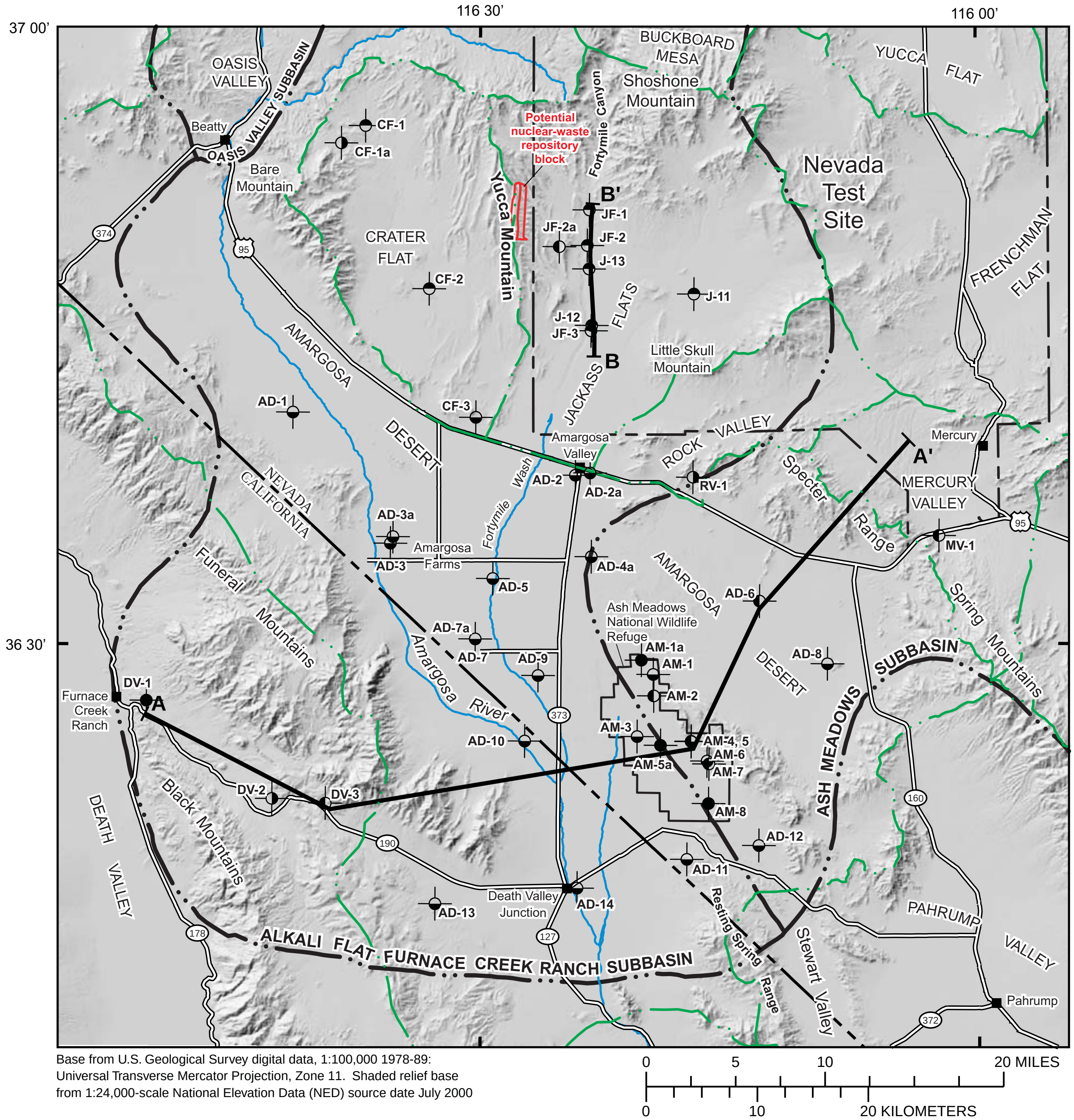
**A**




Base from U.S. Geological Survey digital data, 1:100,000 1978 - 89:
Universal Transverse Mercator Projection, Zone 11. Shaded relief base
from 1:24,000-scale National Elevation Data (NED) source date July 2000

**Figure 1.** Yucca Mountain region, southern Nevada and eastern California, showing (*A*) regional area and location of primary and miscellaneous monitoring sites and (*B*) study area and location of primary monitoring sites.

**B**




Base from U.S. Geological Survey digital data, 1:100,000 1978-89:
Universal Transverse Mercator Projection, Zone 11. Shaded relief base
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**EXPLANATION**

**Primary monitoring site—Site number (table 1) and primary contributing unit are indicated**

- AD-6 — Carbonate rock
- CF-1a — Undifferentiated sedimentary rock
- AD-1 — Valley fill
- JF-1 — Volcanic rock
- DV-1 — Combined carbonate rock and valley fill

*TG Well* — **Miscellaneous monitoring site—Site name (table 3) indicated**

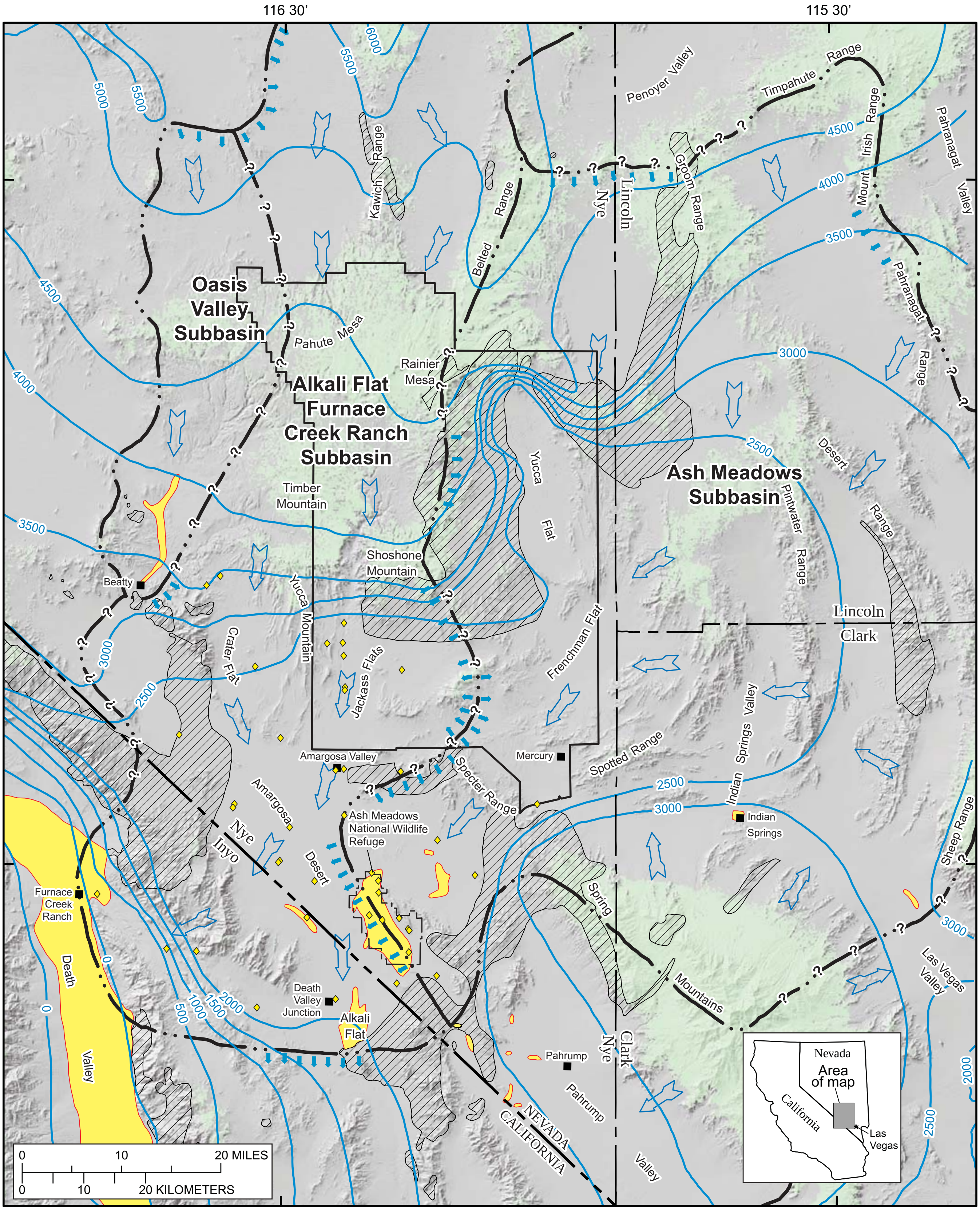
**Ground-water subbasin boundary—From Laczniak and others (1996, pl. 1)**

**Nevada Test Site boundary**

A — A' **Trace of section. Sections shown in figs. 3 and 21**

**Hydrographic area boundary**—Hydrographic-area names in capital letters


**Figure 1.** Continued




Base from U.S. Geological Survey digital data, 1:100,000 1978 89:
Universal Transverse Mercator Projection, Zone 11. Shaded relief base
from 1:24,000-scale National Elevation Data (NED) source date July 2000

**Figure 2.** Major factors controlling ground-water flow in the Yucca Mountain region, southern Nevada and eastern California.

areas in the study area include Crater Flat, Jackass Flats, Rock Valley, Mercury Valley, most of Amargosa Desert, and part of Death Valley (Rush, 1968; Harrill and others, 1988, sheet 2).

Three primary aquifer types are present within the study area: Cenozoic valley fill, Tertiary volcanic rock, and Paleozoic carbonate rock. Valley-fill aquifers consist of poorly consolidated alluvial fan and fluvial deposits and fractured and bedded Tertiary carbonates. The valley-fill aquifers are present in most of the valleys or basins in the study area (fig. 3). Fine-grained lakebed and playa deposits, volcanic-ash beds, and mudflows may function as valley-fill confining units for the valley-fill aquifers. Volcanic-rock aquifers, consisting of unaltered, partly to densely welded ash-flow tuff, typically are found in the northern part of the study area. These aquifers commonly are interlayered with confining units consisting of altered or non-welded ash-flow tuffs and bedded ash-fall tuff. Lithologic variations, extent, and thickness of basin-filling rocks (valley-fill deposits and volcanic rocks) in the study area are described in Sweetkind and others (2001). The carbonate-rock aquifer underlying the carbonate-rock province, which covers almost 100,000 $mi^2$ of the Great Basin (Plume, 1996, p. 4), is the principal regional aquifer in the Death Valley ground-water flow system (Laczniak and others, 1996, p. 19). Flow in this aquifer is predominately controlled by fractures, fault zones, and solution channels. Because the aquifer is regional, ground water is able to move laterally across basins as interbasin flow (fig. 3). The aquifer is confined beneath most intermontane basins and commonly unconfined beneath ridges. The saturated thickness throughout most of the study area probably is at least 4,000 ft (Winograd and Thordarson, 1975, p. 62). The carbonate-rock aquifer is underlain by a confining unit consisting of Cambrian and pre-Cambrian quartzite and siltstone (Laczniak and others, 1996, p. 14). This semi-permeable basement confining unit is present throughout the study area but is particularly important to ground-water flow in areas in which it occurs at the water table (fig. 2). In these areas, the confining unit impedes lateral ground-water flow, causing large ground-water gradients as water moves through the unit.

**EXPLANATION**

**Area of ground-water discharge**—From Laczniak and others (1996, pl. 1)

**Area of ground-water recharge**—Modified from D'Agnese and others (1997, fig. 25)

**Known distribution of confining units at water table**—From Laczniak and others (1996, pl. 1)

**General direction of regional ground-water flow**—Modified from Laczniak and others (1996, pl. 1)

—?— **Ground-water subbasin boundary**—Arrow indicates location and direction of lateral flow across boundary. Queried where uncertain. Modified from Laczniak and others (1996, pl. 1)

—3000— **Water-level contour**—Shows altitude of regional water-level. Interval 500 feet. Datum is sea level. Modified from Laczniak and others (1996, pl. 1)

**Primary monitoring site**

## Ash Meadows Ground-Water Subbasin

Part of Rock Valley, Mercury Valley, and the eastern part of the Amargosa Desert are within the Ash Meadows ground-water subbasin (fig. 1*B*). The principal aquifer controlling flow in the subbasin is the regional Paleozoic carbonate-rock aquifer (fig. 3). However, nearer to the Ash Meadows discharge area, where most of the study area lies, valley-fill deposits also are an important aquifer (Laczniak and others, 1996, p. 16).

Regional ground-water flow in the subbasin (fig. 2) is generally to the south, west, or southwest (Harrill and others, 1988, sheet 2; Laczniak and others, 1996, p. 16–18, pl. 1). A major trough in the potentiometric surface extends for about 40 mi from eastern Frenchman Flat, through the Specter Range, to Ash Meadows. In general, the trough is highly transmissive, and, in the area between the Specter Range and Ash Meadows, the hydraulic gradient is about 0.3 ft/mi (Winograd and Thordarson, 1975, p. 73–74). About 17,000 acre-ft/yr (5,500 Mgal/yr) of ground water flows through the Specter Range, an estimate approximating the volume of spring discharge at Ash Meadows (Winograd and Thordarson, 1975, p. 115). Minor flow from valley-fill aquifers to the carbonate-rock aquifer occurs in some basins such as Yucca Flat and Frenchman Flat (Winograd and Thordarson, 1975, p. 62). In other basins, such as southern Indian Springs Valley, east-central Amargosa Desert, and possibly eastern Jackass Flats, valley-fill aquifers are recharged predominately by upward flow from the carbonate-rock aquifer (Winograd and Thordarson, 1975, p. 62).