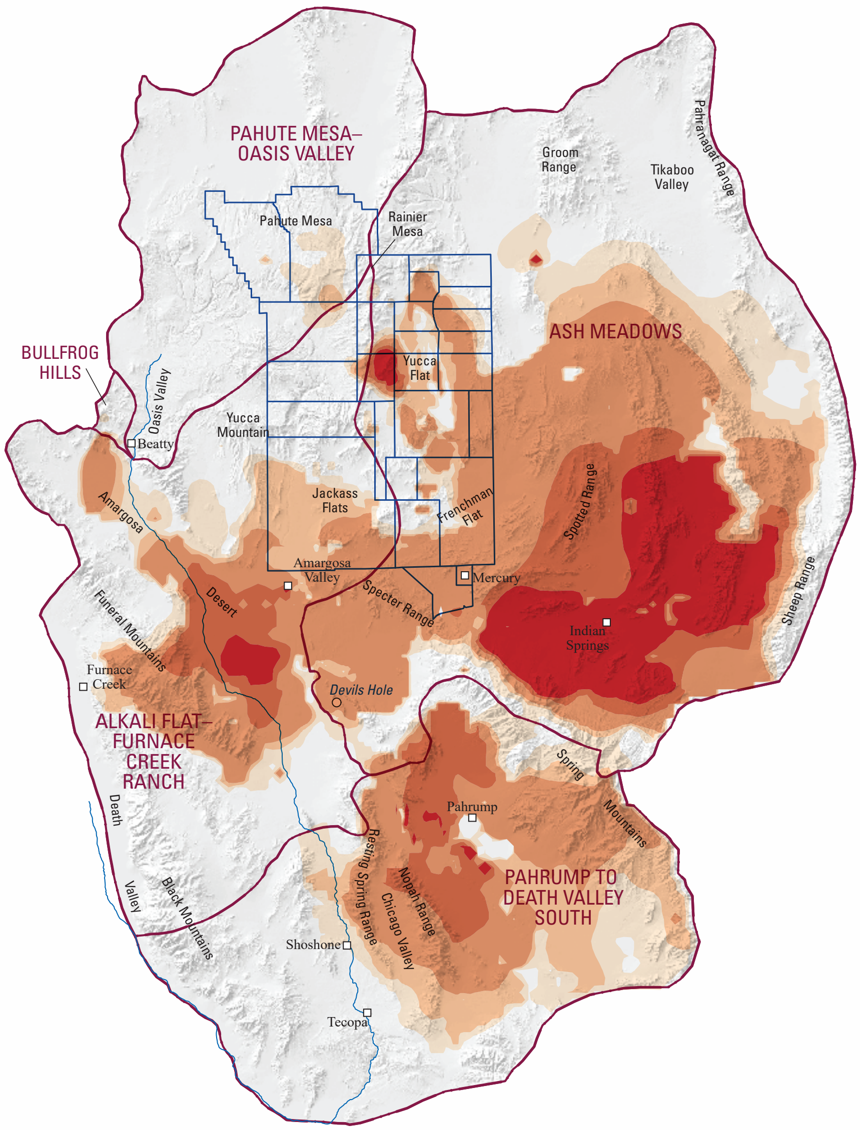
Prepared in cooperation with the Bureau of Land Management; National Park Service; Nevada Division of Wildlife; Nye County, Nevada; and U.S. Fish and Wildlife Service

Simulated Effects of Pumping in the Death Valley Regional Groundwater Flow System, Nevada and California—Selected Management Scenarios Projected to 2120



Scientific Investigations Report 2020-5103

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

Cover. Map of study area showing Alkali Flat–Furnace Creek Ranch, Ash Meadows, Bullfrog Hills, Pahrump to Death Valley South, and Pahute Mesa–Oasis Valley groundwater basins; and Nevada National Security Site boundary and internal operations area, in the Death Valley regional flow system, Nevada and California. Source: U.S. Geological Survey.

Simulated Effects of Pumping in the Death Valley Regional Groundwater Flow System, Nevada and California—Selected Management Scenarios Projected to 2120

By Nora C. Nelson and Tracie R. Jackson

Prepared in cooperation with the Bureau of Land Management; National Park Service; Nevada Division of Wildlife; Nye County, Nevada; and U.S. Fish and Wildlife Service

Scientific Investigations Report 2020–5103

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

U.S. Department of the Interior
DAVID BERNHARDT, Secretary

U.S. Geological Survey
James F. Reilly II, Director

U.S. Geological Survey, Reston, Virginia: 2020

Suggested citation:
Nelson, N.C., and Jackson, T.R., 2020, Simulated effects of pumping in the Death Valley Regional Groundwater Flow System, Nevada and California—Selected management scenarios projected to 2120: U.S. Geological Survey Scientific Investigations Report 2020–5103, 30 p., https://doi.org/10.3133/sir20205103.

Associated data for this publication:
Nelson, N.C., and Jackson, T.R., 2020, MODFLOW-2005 models used to simulate effects of pumping in the Death Valley Regional Groundwater Flow System, Nevada and California—Selected management scenarios projected to 2120: U.S. Geological Survey data release, https://doi.org/10.5066/P9OBUPXU.

ISSN 2328-0328 (online)

Acknowledgments

The authors gratefully acknowledge the reviewers of this report for their helpful comments: Kyle W. Davis (U.S. Geological Survey [USGS]), Joseph M. Fenelon (USGS), Philip M. Gardner (USGS), Nina Hemphill (Bureau of Land Management [BLM]), John Klenke (Nuclear Waste Repository Project Office, Nye County, Nevada), Tim Mayer (U.S. Fish and Wildlife Service), Boris Poff (BLM), and Russel Scofield (BLM).

Contents

Figures

Tables

Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm^2)
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year (m^3/yr)
acre-foot per year (acre-ft/yr)	0.001233	cubic hectometer per year (hm^3/yr)
	Transmissivity	
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)

Datums

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).

Altitude, as used in this report, refers to distance above the vertical datum.

Abbreviations

AFFCR	Alkali Flat–Furnace Creek Ranch
BLM	Bureau of Land Management
DV3-PRED	Death Valley version 3 predictive model
NNSS	Nevada National Security Site
PDVS	Pahrump to Death Valley South
PMOV	Pahute Mesa–Oasis Valley
USGS	U.S. Geological Survey

Simulated Effects of Pumping in the Death Valley Regional Groundwater Flow System, Nevada and California—Selected Management Scenarios Projected to 2120

By Nora C. Nelson and Tracie R. Jackson

Abstract

Declining water levels and reduced natural discharge at springs, seeps, and phreatophyte areas primarily are the result of decades of groundwater development in the Death Valley regional flow system, in Nevada and California. A calibrated groundwater-flow model was used to simulate potential future effects of groundwater pumping on water levels and natural groundwater discharge in the study area. Effects of climate change on future groundwater pumping were not considered and were beyond the scope of the study. Four groundwater-pumping scenarios were developed by stakeholders to predict and compare (1) the extent of regional water-level declines; (2) drawdown at Devils Hole; and (3) reductions in natural discharge at select discharge areas, including the Amargosa Wild and Scenic River, the Ash Meadows discharge area, the Furnace Creek area, and Stump Spring. Scenarios were simulated from 1913 to 2120, with historical pumping occurring from 1913 to 2010, historical 2010 pumping rates projected from 2010 to 2020, and scenario pumping beginning in 2020. Pumping scenarios included a base case and scenarios A, B, and C. The base case projected 2010 pumping rates from 2010 to 2120, and scenarios A, B, and C projected base case pumping plus additional pumping at various locations from 2020 to 2120. By 2020, historical (1913–2020) pumping resulted in the propagation of simulated drawdown of 1 foot (ft) or more westward from Pahrump Valley to areas north of Shoshone in the Pahrump to Death Valley South (PDVS) groundwater basin and the merging of simulated 1-ft drawdown contours between the Alkali Flat–Furnace Creek Ranch (AFFCR) and Ash Meadows groundwater basins. In the base case scenario, extent and magnitude of simulated drawdown continued to increase in the Ash Meadows and AFFCR groundwater basins from 2020 to 2120. In the base case, the magnitude of simulated drawdown continued to increase in western Pahrump Valley from 2020 to 2120, whereas simulated water levels rose in eastern Pahrump Valley from 2020 to 2070 and then stabilized from 2070 to 2120. Scenarios A and B primarily affected the PDVS and AFFCR groundwater basins by increasing the magnitude of drawdown in 2120, compared to the base case. In scenario C, drawdown propagated throughout a high-transmissivity part of the carbonate aquifer known as the megachannel, greatly affecting water levels in the Ash Meadows discharge area. Scenario C resulted in an additional 10–100 ft of drawdown (compared to the base case) throughout the southeastern part of the Ash Meadows groundwater basin by 2120. Simulated drawdowns in Devils Hole in 2120 were 3.2, 3.4, 3.8, and 25.4 ft for the base case and scenarios A, B, and C, respectively. The federally mandated minimum water level for Devils Hole is 2.7 ft below a reference point. In 2020, the simulated water level in Devils Hole was above the minimum water level, at 1.7 ft below the reference. Simulated water levels in Devils Hole fell below the federally mandated water level by 2078, 2073, 2058, and 2025 for the base case and scenarios A, B, and C, respectively, assuming a hypothetical recharge scenario of constant natural recharge. Simulated reductions in predevelopment (natural) discharge at select discharge areas ranged from 3 to 38 percent by 2120 for all scenarios. Amargosa Wild and Scenic River was the least affected discharge area with simulated capture rates ranging from 3 to 4 percent of predevelopment discharge by 2120. Ash Meadows discharge area was greatly affected by groundwater pumping in scenario C with a simulated capture rate of 38 percent, compared to simulated capture rates of 8, 8, and 9 percent for the base case, scenario A, and scenario B, respectively, in 2120. Simulated capture rates in the Furnace Creek area ranged from 10 to 11 percent for all scenarios in 2120. Simulated capture rates at Stump Spring ranged from 32 to 36 percent for all scenarios in 2120.

Introduction

Declining water levels and reduced natural discharge at springs, seeps, and phreatophyte areas primarily are the result of decades of groundwater development in the Death Valley regional flow system, in Nevada and California (Halford and Jackson, 2020). A calibrated groundwater-flow model (Halford and Jackson, 2020; Jackson and Halford, 2020) was used to simulate potential future effects of groundwater pumping on water levels and natural groundwater discharge in the study area for four pumping scenarios developed by stakeholders. Effects of climate change on future groundwater pumping were not considered and were beyond the scope of the study.

The study area includes four groundwater basins within the Death Valley regional flow system (Harrill and others, 1988) in southwestern Nevada and southeastern California (fig. 1). The four groundwater basins include Pahute Mesa–Oasis Valley (PMOV), Alkali Flat–Furnace Creek Ranch (AFFCR), Ash Meadows, and Pahrump to Death Valley South (PDVS; fig. 1). Declining water levels and reduced natural discharge at some springs, seeps, and evapotranspiration areas are the result of decades of groundwater development in this dry region (Halford and Jackson, 2020). This report was prompted by concern from local and Federal managers of the potential future effects of groundwater pumping on water levels and natural groundwater discharge, with special regard to several federally protected groundwater-dependent ecosystems in the study area.

Pahrump Valley and central Amargosa Desert historically are the two primary pumping centers in the study area. Pahrump Valley and central Amargosa Desert have had measured drawdowns of as much as 80 and 50 ft, respectively (Halford and Jackson, 2020). Halford and Jackson (2020) also reported that groundwater pumping from central Amargosa Desert and Pahrump Valley affected areas of 300 and 600 mi^2, respectively, based on the delineation of areas where measured water levels declined at a rate greater than 0.1 ft per decade. Continued groundwater pumping at current (estimated from 2010) rates in Pahrump Valley, the central Amargosa Desert, and other nearby pumping centers likely will increase the magnitude and extent of regional drawdown. Effects of groundwater pumping can include water-level declines; land subsidence; and capture from springs, streams, and phreatophytic vegetation, which can adversely affect species that use these groundwater-dependent ecosystems. These effects are of concern to a variety of land-, water-, and wildlife-management agencies.

A high-profile concern within the study area is the effect of pumping on the water level in Devils Hole in the Ash Meadows discharge area (fig. 2). Devils Hole is the exclusive habitat of an endangered species, *Cyprinodon diabolis* (Devils Hole pupfish). During the 1970s, groundwater development in the Ash Meadows discharge area by Cappaert Enterprises, formerly Spring Meadows, Inc., caused a 2.3-ft water-level decline in Devils Hole, which temporarily reduced the spawning habitat of the Devils Hole pupfish (Dudley and Larson, 1976). The correlation of nearby pumping to water-level declines in Devils Hole was sufficient evidence for the U.S. Supreme Court, in the 1976 court case *Cappaert v. United States* (426 U.S. 128), to limit pumping of groundwater so that a minimum pool elevation is maintained in Devils Hole (Williams and others, 1996). The mandated minimum pool elevation is 2.7 ft below a reference point in Devils Hole and was established without differentiating between water-level changes that are due solely to pumping or to a combination of pumping and climate (Williams and others, 1996). Therefore, water-level changes in Devils Hole from natural stresses should be considered in addition to changes from pumping.

Groundwater pumping has caused declines in natural groundwater discharge within the study area (Halford and Jackson, 2020). Natural groundwater discharge occurs either by diffuse upward flow into shallow alluvium, where water is either evaporated or transpired by phreatophytes; or from springs and seeps, some of which support perennial reaches of the Amargosa River. The groundwater-discharge areas investigated for this report are the Amargosa Wild and Scenic River, the Ash Meadows discharge area, the Furnace Creek area, and Stump Spring (fig. 2). Natural discharge in the Amargosa Wild and Scenic River includes all discharge from springs and phreatophytes along a 33-mi perennial reach between Shoshone and Dumont Dunes in California (fig. 2). The Ash Meadows discharge area includes Amargosa Flat, more than 30 springs and seeps at Ash Meadows, and evapotranspiration areas extending downgradient from springs (fig. 2). Furnace Creek area groundwater discharge includes discharge from Texas, Nevares, and Travertine Springs; evapotranspiration from phreatophytes on the alluvial fan; and water diverted from Furnace Creek Wash that would have discharged as evapotranspiration on the alluvial fan before groundwater development (fig. 2; see Halford and Jackson [2020] for details). The four groundwater-discharge areas investigated in this report are federally protected:

1. The Ash Meadows discharge area, which contains Devils Hole, is within a detached unit of Death Valley National Park;
2. The Amargosa River between Shoshone and Dumont Dunes in California is a designated National Wild and Scenic River (Interagency Wild and Scenic Rivers Coordinating Council, 2018);
3. The Furnace Creek area is within Death Valley National Park; and
4. Stump Spring is a designated Area of Critical Environmental Concern (Bureau of Land Management, 1998).

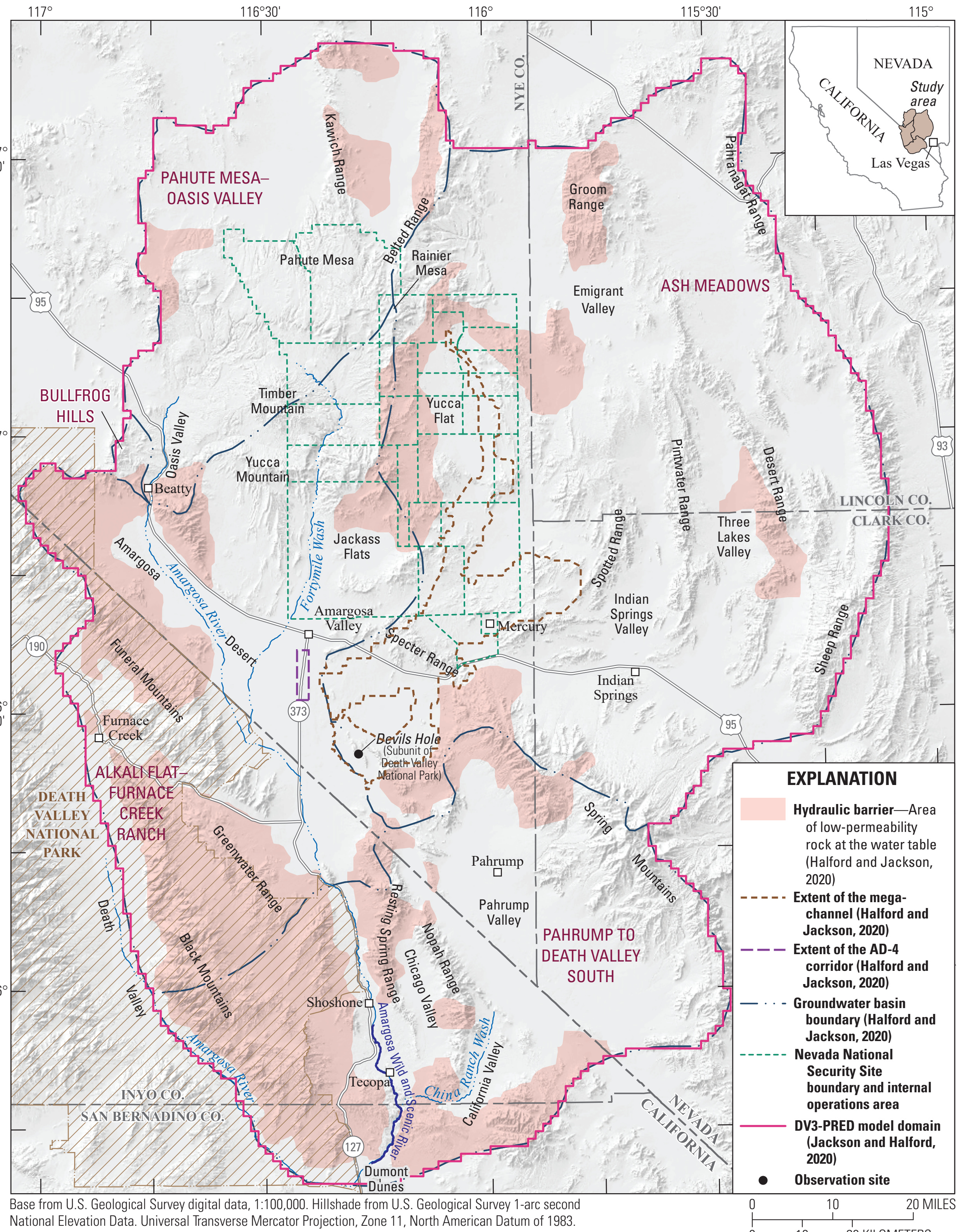


Figure 1. Study area with groundwater basins and hydraulic barriers, Death Valley regional flow system, Nevada and California.

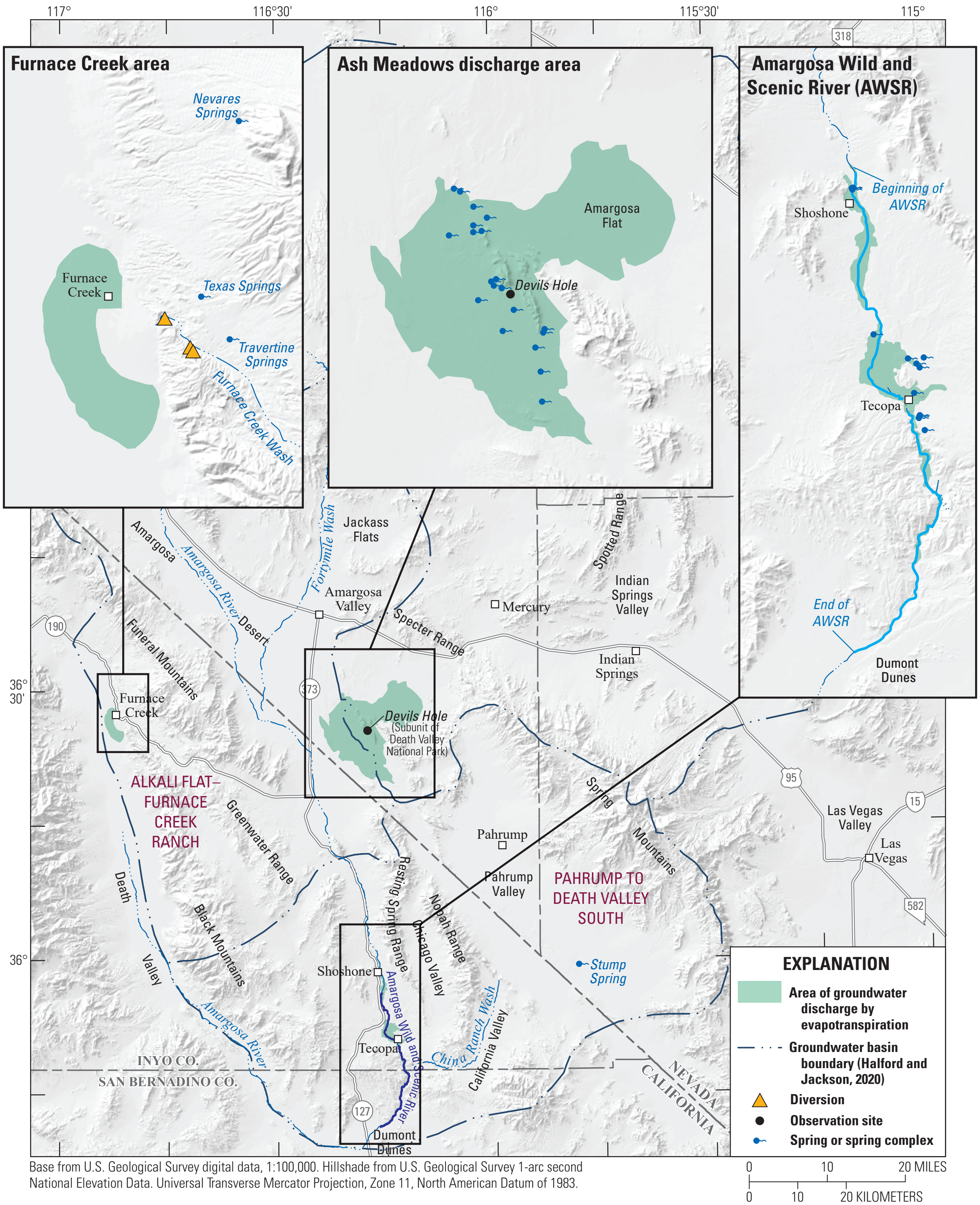


Figure 2. Study area including discharge areas, Death Valley regional flow system, Nevada and California.

Purpose and Scope

The purpose of this report is to simulate four groundwater-pumping scenarios to forecast (1) the extent of regional drawdowns; (2) drawdown in Devils Hole; and (3) pumping-induced reductions in natural discharge from the Ash Meadows discharge area, the Furnace Creek area, Amargosa Wild and Scenic River, and Stump Spring. A “base case” pumping scenario simulates historical development from 1913 to 2010 and assumes that pumping continues at current (2010) rates, with 2010 pumping rates projected through 2120. Three additional groundwater-pumping scenarios (scenarios A, B, and C) were provided by the Bureau of Land Management; National Park Service; Nevada Division of Wildlife; Nye County, Nevada; and U.S. Fish and Wildlife Service. Pumping rates (magnitudes) and locations in scenarios A, B, and C were selected by cooperators to determine potential future effects of additional pumping through 2120 on federally protected, groundwater-dependent ecosystems. The pumping rates and locations provided are hypothetical and do not necessarily represent the water usage plans or forecasts of any of the listed agencies or of the U.S. Geological Survey.

Groundwater-pumping scenarios were simulated using a previously developed numerical groundwater-flow model, referred to as the Death Valley version 3 predictive model (DV3-PRED; Halford and Jackson, 2020). The four scenarios simulate historical pumping from 1913 to 2010 in the PMOV, AFFCR, Ash Meadows, and PDVS groundwater basins. The base case scenario projects 2010 pumping rates through 2120; the other three scenarios (A, B, and C) simulate the base case pumping plus additional pumping through 2120 from two or more of the following areas: the Amargosa Desert, Pahrump Valley, Indian Springs area, and north of Ash Meadows discharge area.

Description of Study Area

The 6,720,000-acre study area consists of four groundwater basins: PMOV, AFFCR, Ash Meadows, and PDVS (fig. 1). Altitudes in the study area range from 11,916 ft in the Spring Mountains to −282 ft in Death Valley (Halford and Jackson, 2020). Recharge occurs primarily in high-altitude areas (above 6,000 ft) because high-altitude areas receive higher rates of precipitation than lower-altitude areas. Recharge principally occurs after winters with greater-than-average precipitation, when spring snowmelt replenishes the soil reservoir beyond its storage capacity, allowing downward percolation below the root zone and into the groundwater system (Smith and others, 2017). Primary recharge locations for the study area include Pahute Mesa; the Spring Mountains; Timber Mountain; and the Belted, Groom, Pahranagat, and Sheep Ranges. Natural discharge occurs primarily along the Amargosa Wild and Scenic River and in Ash Meadows discharge area, Furnace Creek area, Oasis Valley, and Pahrump Valley. Recharge generally occurs in the northern and eastern parts of the study area and discharge occurs in the southern and western parts of the study area (fig. 1; Halford and Jackson, 2020).

The PDVS groundwater basin is hydraulically isolated, whereas the AFFCR and Ash Meadows groundwater basins are hydraulically connected (Halford and Jackson, 2020). Low-permeability siliciclastic rocks in the northern part of the Spring Mountains and Resting Spring Range form a hydraulic barrier between Pahrump Valley and the Ash Meadows discharge area (fig. 1). Low-permeability rocks in the Resting Spring Range, Greenwater Range, and Black Mountains impede the propagation of drawdown from the PDVS groundwater basin toward the central Amargosa Desert. Instead, drawdowns from pumping in Pahrump Valley extend westward and southwestward toward discharge areas along the Amargosa Wild and Scenic River.

The Ash Meadows and AFFCR groundwater basins are hydraulically connected by a 2–5 mi wide corridor near well AD-4, referred to as the well AD-4 corridor (fig. 1; Halford and Jackson, 2020). The well AD-4 corridor is an area of groundwater upwelling, as indicated by a potentiometric high in water-level contours around well AD-4 that decreases radially into the central Amargosa Desert (Walker and Eakin, 1963, plate 3; Claassen, 1985). The hydraulic connection through the well AD-4 corridor allows groundwater from the Ash Meadows groundwater basin to move upward from carbonate rocks into basin fill in the central Amargosa Desert. Drawdowns from pumping basin fill in the central Amargosa Desert have propagated through the well AD-4 corridor into carbonate rocks within the Ash Meadows groundwater basin by 2018 (Halford and Jackson, 2020).

In the Ash Meadows groundwater basin, drawdowns propagate quickly and recover slowly in a hydrologic feature known as the megachannel (Halford and Jackson, 2020). The megachannel is an areally extensive, highly transmissive feature in carbonate rocks (fig. 1), where transmissivity exceeds 20,000 ft^2/d. As delineated by Halford and Jackson (2020), the megachannel extends from the Ash Meadows discharge area to the northern extent of Yucca Flat. The megachannel was delineated from interpretations of hydrochemical data at Ash Meadows springs and aquifer-test results in Yucca Flat (Winograd and Pearson, 1976; Jackson, 2017; Jackson and Halford, 2020).

Death Valley Version 3 Predictive Model

The DV3-PRED model (Halford and Jackson, 2020; Jackson and Halford, 2020) is a three-dimensional, finite-difference, numerical groundwater-flow model (MODFLOW–2005; Harbaugh, 2005). The DV3-PRED model simulates the effect of historical and future potential groundwater development in the Ash Meadows, AFFCR, PMOV, and PDVS groundwater basins (fig. 1). The model domain is the areal extent of the four combined groundwater basins. Historical groundwater development (1913–2010) was simulated with the MODFLOW Well package using groundwater-withdrawal data compiled by Elliott and Moreo (2018). Historical annual groundwater withdrawals were simulated from 1913 to 2010, and current (2010) pumping rates were projected from 2010 to 2020. Capture-limited boundary conditions (Halford and Plume, 2011) were used to simulate discharges from springs and evapotranspiration areas. Capture is the decrease in discharge from springs and evapotranspiration areas that is the result of pumping. Capture-limited boundary conditions ensured that the total amount of discharge captured from springs and evapotranspiration areas cannot exceed predevelopment discharges.

Hydraulic properties in the DV3-PRED model were distributed using a simplified hydrogeologic framework of carbonate rocks, volcanic rocks, basin fill, volcanic-sedimentary rocks, and low-permeability granitic and siliciclastic rocks. For each of these geologic units, heterogeneous hydraulic-conductivity, specific-yield, and specific-storage distributions were estimated from calibration of the model to predevelopment (steady-state) and groundwater-development (transient) conditions. Measured water-level altitudes in wells, spring pools, and evapotranspiration areas; transmissivity estimates from aquifer tests and specific capacity; drawdowns in wells from pumping; and spring capture were compared to simulated equivalents during model calibration (Halford and Jackson, 2020; Jackson and Halford, 2020). See Halford and Jackson (2020) for detailed descriptions of model development and calibration.

Pumping Scenarios

Four groundwater-pumping scenarios were developed to examine potential effects of future pumping on water levels and groundwater discharges in the study area. Each scenario simulates historical pumping at annual rates from 1913 to 2010 (Elliott and Moreo, 2018), and 2010 pumping rates are projected through 2020; therefore, pumping rates from 1913 to 2020 are the same for all four scenarios. Future pumping scenarios begin in 2020 and are projected for 100 years to 2120. The base case scenario simulates future groundwater withdrawals by assuming that all pumping continues at current (2010) rates through 2120. The other three scenarios (A, B, and C) simulate the same historical pumping rates through 2120 as the base case plus increased groundwater pumping from 2020 to 2120 within the AFFCR, Ash Meadows, and (or) PDVS groundwater basins. The four pumping scenarios are summarized in table 1 and figure 3. Locations and rates of base case pumping wells are shown in figure 4. Locations and rates of additional pumping wells used in scenarios A–C are shown in figures 5–7 and are provided in the model archive (Nelson and Jackson, 2020).

The base case scenario simulates the effect of continued pumping at current (2010) rates through 2120. A total of 970 wells were used to simulate annual pumping volumes of 37,873 acre-ft from 2010 to 2120 (table 1). The maximum pumping rate from an individual well during the simulation period from 2010 to 2120 is 1,127 acre-ft/yr, which was pumped from a well open to basin fill in the central Amargosa Desert (fig. 4). The main pumping areas are in Pahrump Valley and the central Amargosa Desert. Notable pumping also occurs near Indian Springs, Emigrant Valley, Furnace Creek, and Beatty and on the Nevada National Security Site (NNSS; fig. 4).

Scenario A adds 222 wells to base case pumping, increasing total (gross) pumping by 13 percent from 37,873 acre-ft/yr (in the base case) to 42,609 acre-ft/yr (table 1). Domestic and municipal wells were added in Pahrump Valley, including three municipal wells pumping 667 acre-ft/yr and 216 domestic wells pumping 3.4 acre-ft/yr (fig. 5). The Nevada State Engineer limits net consumptive use from domestic wells to 0.5 acre-ft/yr (Geter, 2015, p. 2); however, domestic pumping rates greater than 0.5 acre-ft/yr likely were provided by cooperators to simulate multiple domestic wells in the same model cell. Three pumping wells were added in the Amargosa Desert with pumping rates ranging from 500 to 1,000 acre-ft/yr (fig. 5).

Scenario B adds 226 wells to base case pumping, increasing total pumping by 6 percent from 37,873 to 39,963 acre-ft/yr, compared to the base case (table 1). Scenario B includes the same locations of domestic and municipal wells in Pahrump Valley as scenario A (figs. 5–6), except that pumping rates are decreased by a factor of two for domestic (1.7 acre-ft/yr) and municipal (333 acre-ft/yr) wells. Compared to scenario A, scenario B increases the number of wells in the Amargosa Desert from 3 to 5 but decreases the total pumping in the Amargosa Desert from 2,000 to about 710 acre-ft/yr, with individual pumping rates in the Amargosa Desert ranging from 7.5 to 500 acre-ft/yr (fig. 6). Unlike scenario A, scenario B has two new wells open to carbonate rock about 14 and 20 mi northeast of Devils Hole, respectively. The carbonate well closer to Devils Hole occurs within the megachannel, whereas the farther well is about 2 mi east of the megachannel. These two carbonate wells have pumping rates of 5 acre-ft/yr (fig. 6).

Table 1. Summary of pumping scenarios.

[—, not applicable]

Pumping scenario	Total number of pumping wells from 2020 to 2120	Total pumpage from 2020 to 2120 (acre-feet per year)	Increase from base case pumping (percent)
Base case	970	37,873	—
A	1,192	42,609	13
B	1,196	39,963	6
C	1,203	73,587	94

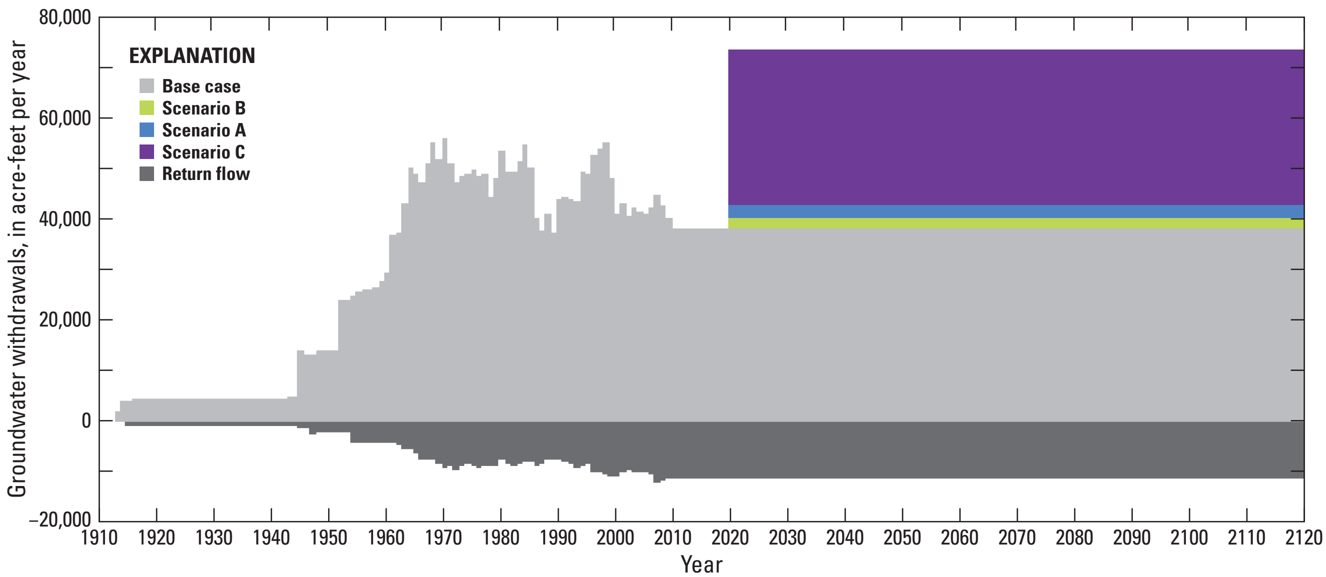


Figure 3. Total annual pumping and return flow for the base case scenario and additional annual pumpage in scenarios A, B, and C, Death Valley regional flow system, Nevada and California.

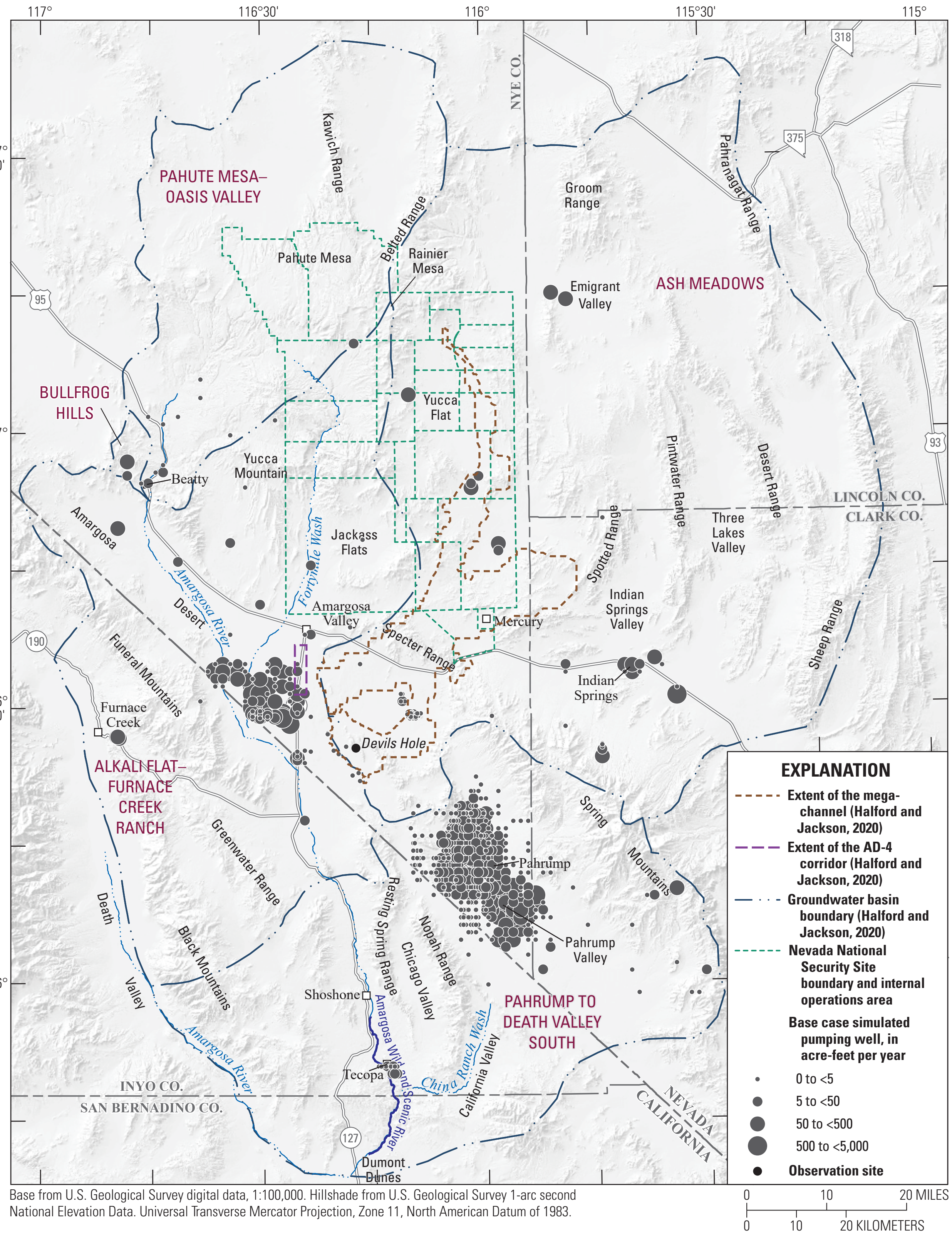


Figure 4. Location of pumping wells simulated in the base case scenario, Death Valley regional flow system, Nevada and California.

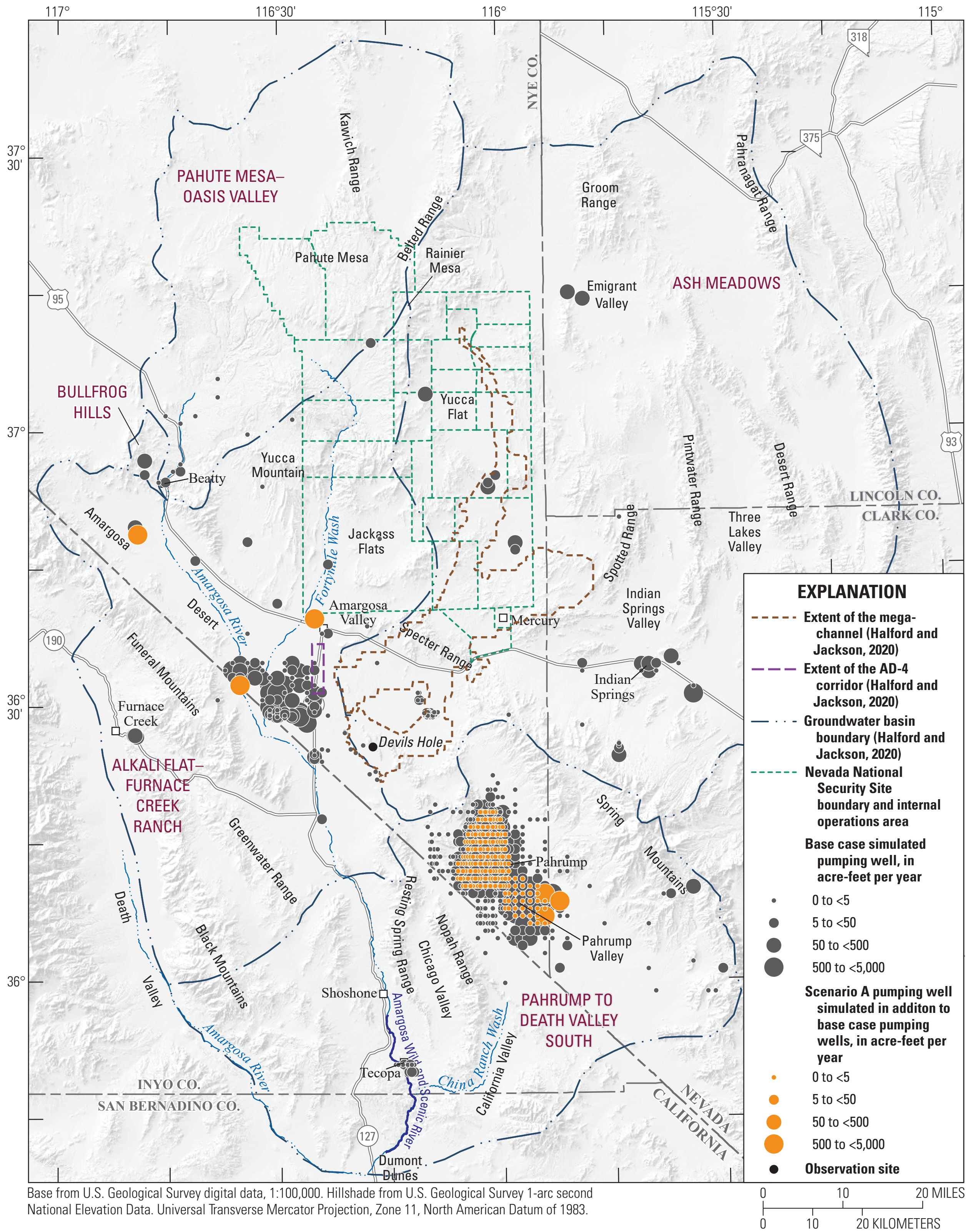


Figure 5. Location of additional pumping wells in scenario A that were simulated together with the base case pumping wells, Death Valley regional flow system, Nevada and California.

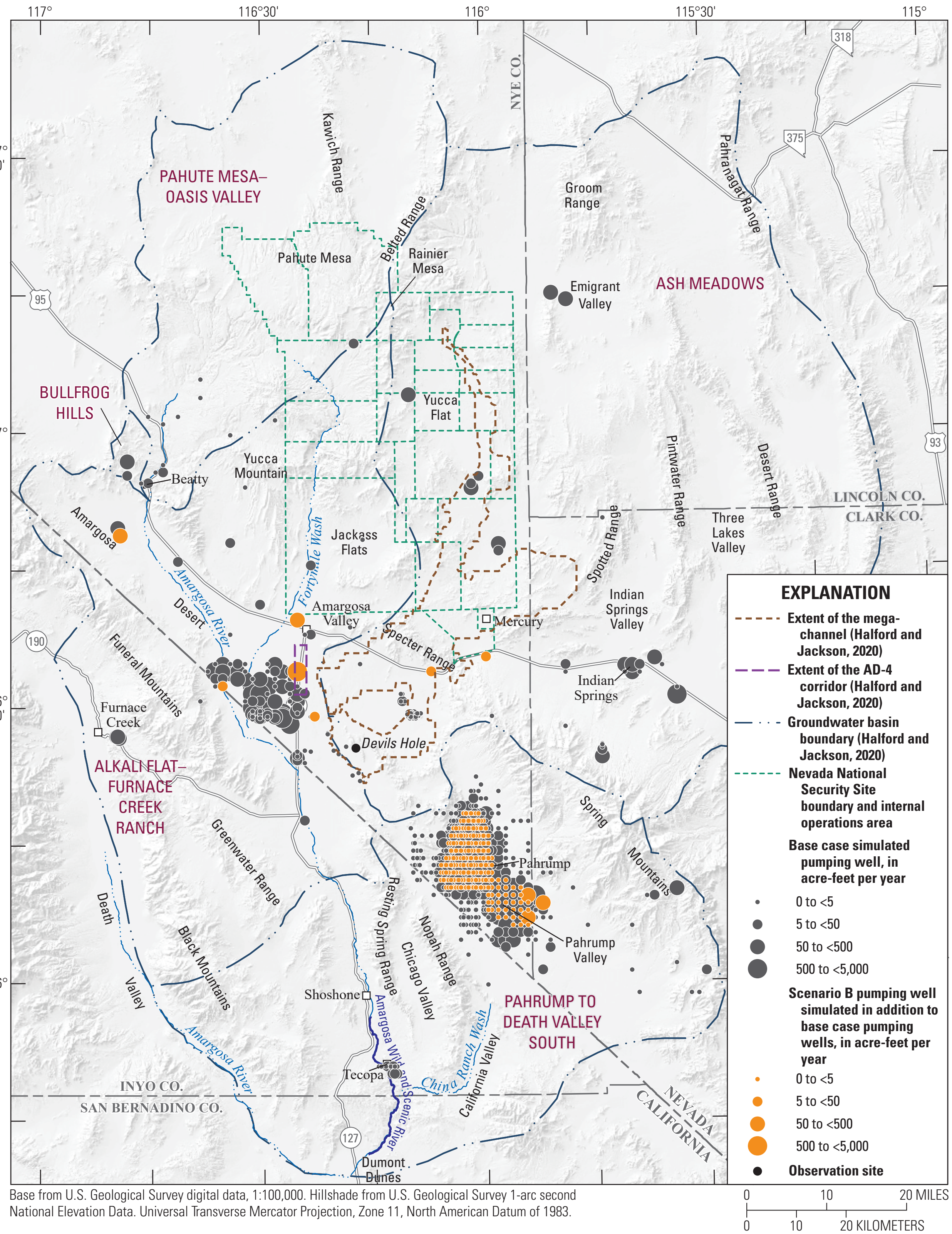
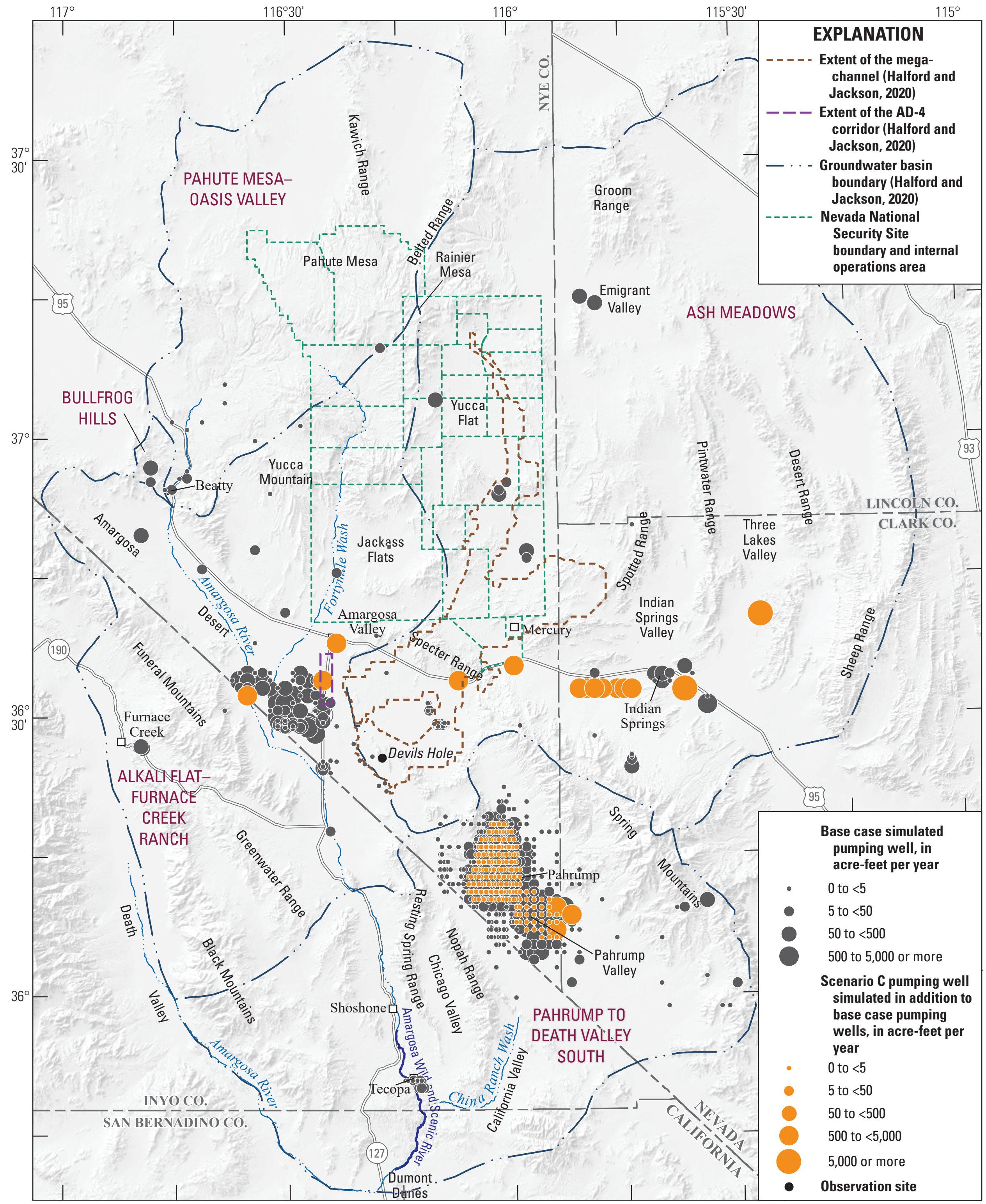


Figure 6. Location of additional pumping wells in scenario B that were simulated together with the base case pumping wells, Death Valley regional flow system, Nevada and California.



Base from U.S. Geological Survey digital data, 1:100,000. Hillshade from U.S. Geological Survey 1-arc second National Elevation Data. Universal Transverse Mercator Projection, Zone 11, North American Datum of 1983.

0 10 20 MILES
0 10 20 KILOMETERS

Figure 7. Location of additional pumping wells in scenario C that were simulated together with the base case pumping wells, Death Valley regional flow system, Nevada and California.

Scenario C adds 233 wells to base case pumping, increasing total pumping to 73,587 acre-ft/yr, which is an increase of 94 percent compared to the base case scenario (table 1). Scenario C has the same locations and pumping rates for domestic and municipal wells in Pahrump Valley as scenario A. Scenario C includes only three new wells in the central Amargosa Desert, each pumping at rates of 500 acre-ft/yr. Scenario C has the same locations as scenario B for two carbonate wells about 14 and 20 mi northeast of Devils Hole, respectively; however, pumping rates are increased to 500 acre-ft/yr. Unlike the other scenarios, scenario C adds nine new wells in the carbonate aquifer in the Indian Springs area. These nine wells account for most of the increased pumping in scenario C. At Indian Springs, seven high-capacity wells each pump 2,286 acre-ft/year; two wells pump at 7,239 acre-ft/yr, one just east of Indian Springs and the other to the northeast in Three Lakes Valley (fig. 7).

Simulated Effects of Future Groundwater Pumping

The following sections discuss DV3-PRED model results for each pumping scenario: simulated regional drawdown, simulated water levels in Devils Hole, and simulated capture of natural discharge. Magnitude and extent of simulated regional drawdown are presented for the base case as water-level drawdown from predevelopment in 2020, 2040, 2070, and 2120, and drawdown difference from 2020 in 2120. Magnitude and extent of simulated regional drawdown are presented for scenarios A, B, and C as water-level drawdown from predevelopment in 2120 and drawdown difference from the base case in 2120 for each respective scenario in 2120. Water levels in Devils Hole are presented using two hydrographs: (1) simulated drawdown only, and (2) combined water-level changes from natural stresses and pumping in each pumping scenario. Simulated capture of natural discharge is presented for the following discharge areas: Amargosa Wild and Scenic River, Ash Meadows discharge area, Furnace Creek area, and Stump Spring.

Regional Drawdown

The magnitude and extent of simulated drawdown is presented in the following sections. All drawdowns were calculated using simulated hydraulic heads from model layer 2 (layer 1 is 1 ft thick and was created for the purpose of estimating specific yield and simulating groundwater/surface-water interaction [Halford and Jackson, 2020]). Simulated drawdown maps are presented in two formats: drawdown from predevelopment conditions and drawdown differences. For example, a map of drawdown in 2120 from predevelopment conditions is the simulated drawdown in year 2120 from all historical and future pumping that occurred from 1913 to 2120. Drawdown maps from predevelopment conditions have 1-ft drawdown thresholds; therefore, simulated drawdowns of less than 1 ft are not shown.

Drawdown difference maps are used to visually assess small changes in drawdown between the pumping scenarios and the base case. Drawdown difference maps have thresholds of 0.1 ft. For the base case scenario, the drawdown difference map was computed by subtracting drawdown in 2120 from drawdown in 2020. Scenarios A, B, and C are compared to the base case by subtracting simulated drawdowns in each scenario from drawdown in the base case. For example, the drawdown difference map for scenario A in 2120 is computed by subtracting scenario A drawdowns in 2120 from base case drawdowns in 2120.

Base Case

In the PDVS groundwater basin, the maximum extent of simulated drawdown (1 ft or greater) remained relatively unchanged in 2120 compared to 2020 because effects from historical pumping had propagated to all groundwater-discharge areas in the PDVS basin by 2020 (figs. 8–12). Simulated effects of pumping in Pahrump Valley propagated downgradient into Chicago Valley and through the Resting Spring Range to discharge areas north of Shoshone, California, by 2020 (fig. 8). Pumping in Pahrump Valley peaked in 1968 because of irrigation and decreased from the 1970s to 2010 (fig. 13) because of a transition from irrigation to use in domestic, industrial, municipal, and public supply. The changes in pumping resulted in declining water levels in western Pahrump Valley and rising water levels in eastern Pahrump Valley from 1980 to 2019 (Halford and Jackson, 2020). Continued simulated pumping at 2010 rates for the base case scenario results in continued water-level declines in western and southern Pahrump Valley, whereas water levels rise from 2010 to 2070 and then stabilize from 2070 to 2120 in eastern Pahrump Valley (figs. 9–11). From 2040 to 2120, pumping in western Pahrump causes large drawdowns between 50 and 100 ft through northern Pahrump Valley (figs. 9–11) as pumping propagates toward low-permeability rock in the Spring Mountains (fig. 1).

In the AFFCR and Ash Meadows groundwater basins, simulated drawdowns of less than 5 ft have merged between pumping centers in the central Amargosa Desert, the NNSS, Indian Springs, and the Ash Meadows discharge area by 2020 (fig. 8). By 2120, drawdown from the pumping center south of Beatty coalesces with the other merged pumping centers in the Amargosa Desert, NNSS, and the Ash Meadows groundwater basin (fig. 11). Areas of drawdown from pumping in the PMOV groundwater basin and Emigrant Valley remain isolated from one another and from other areas of drawdown through 2120.

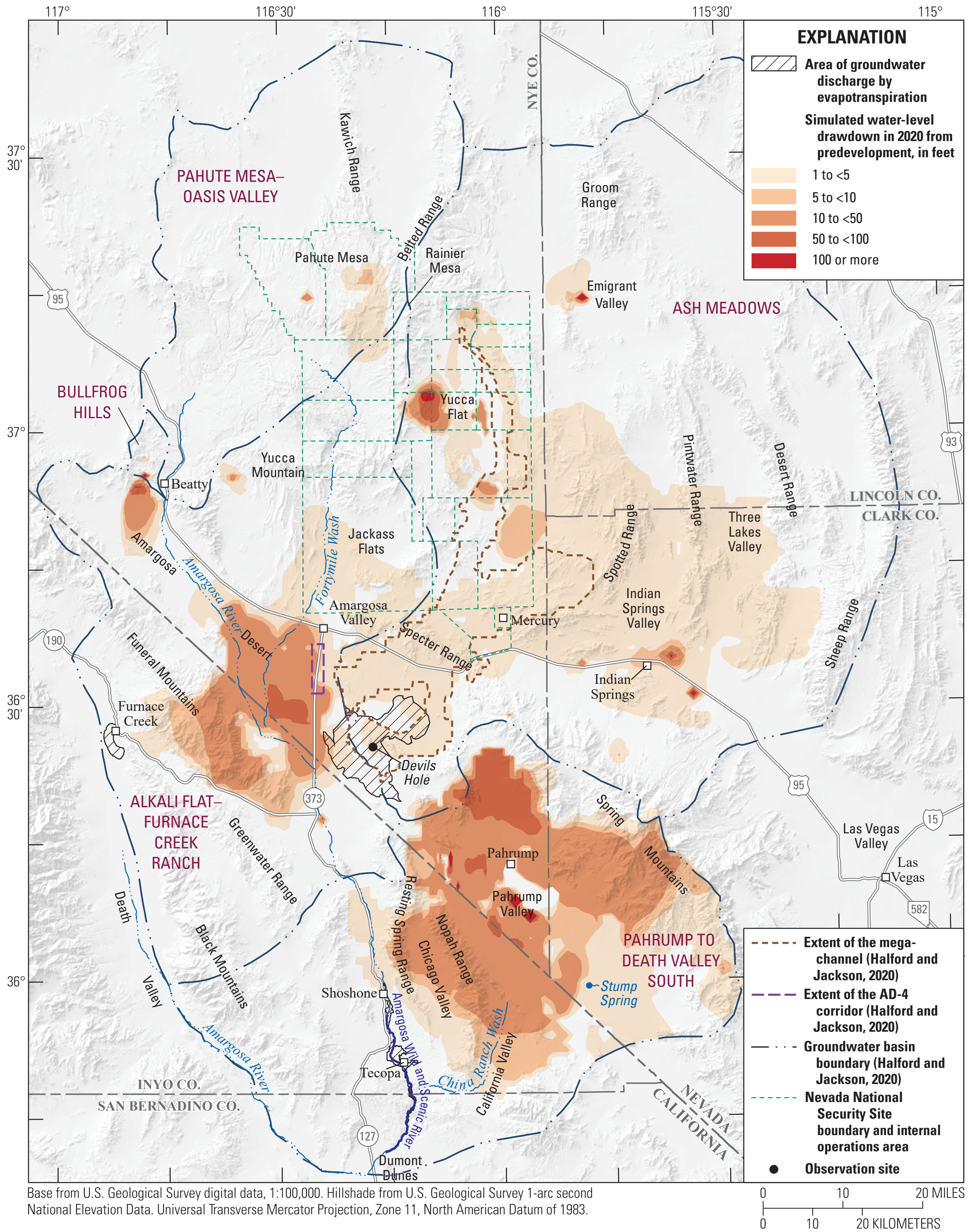


Figure 8. Water-level drawdown from predevelopment for base case scenario in 2020, Death Valley regional flow system, Nevada and California.

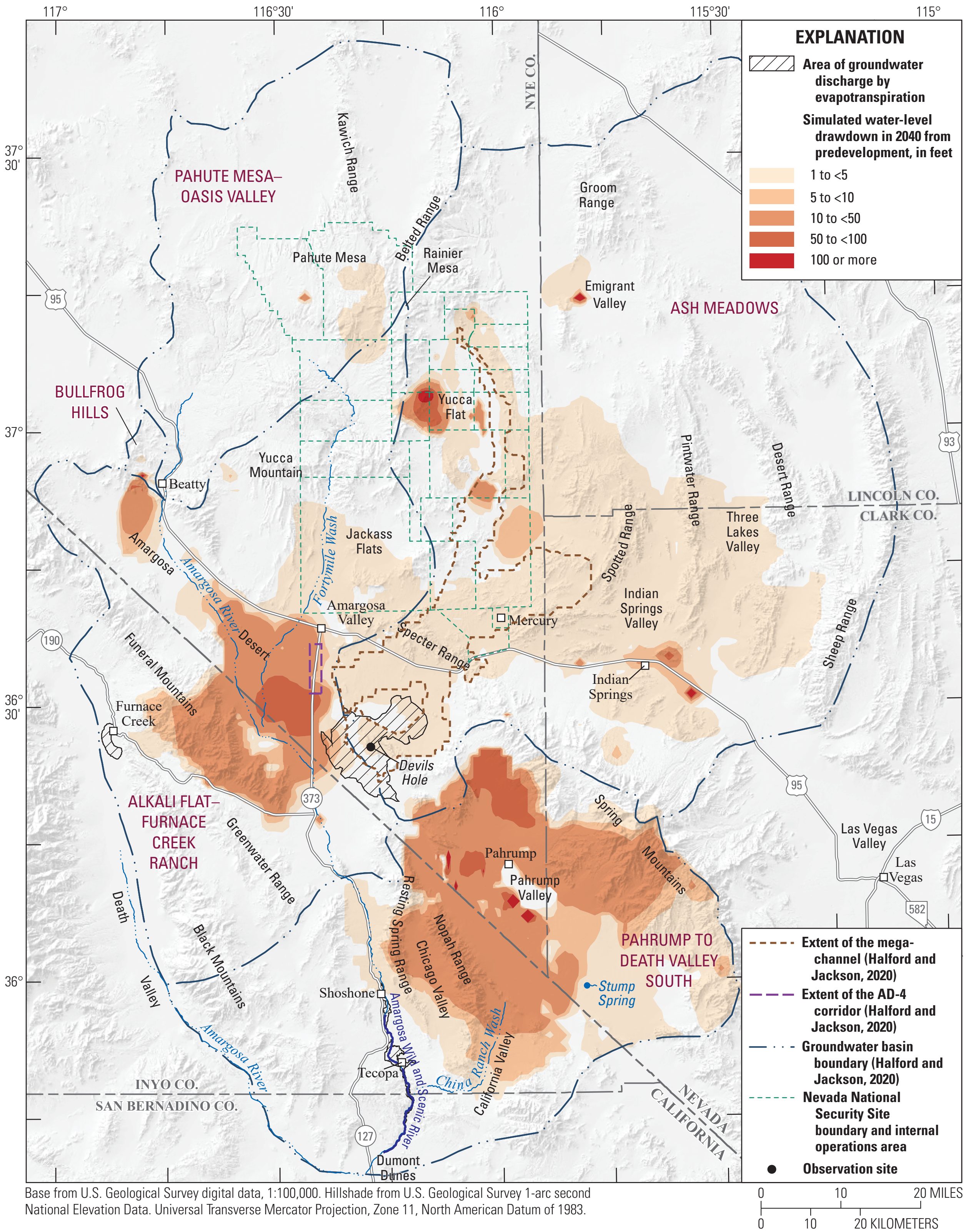
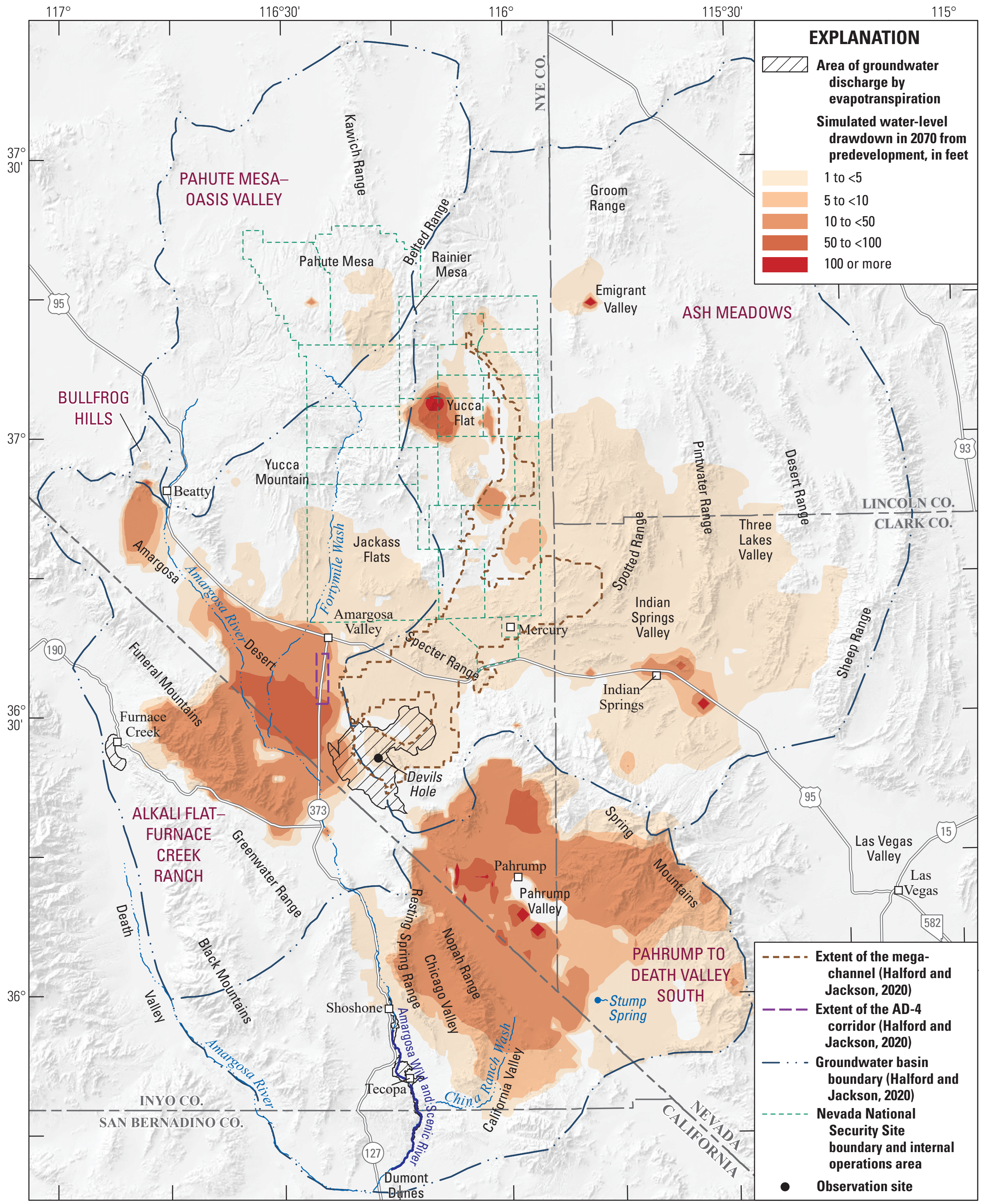


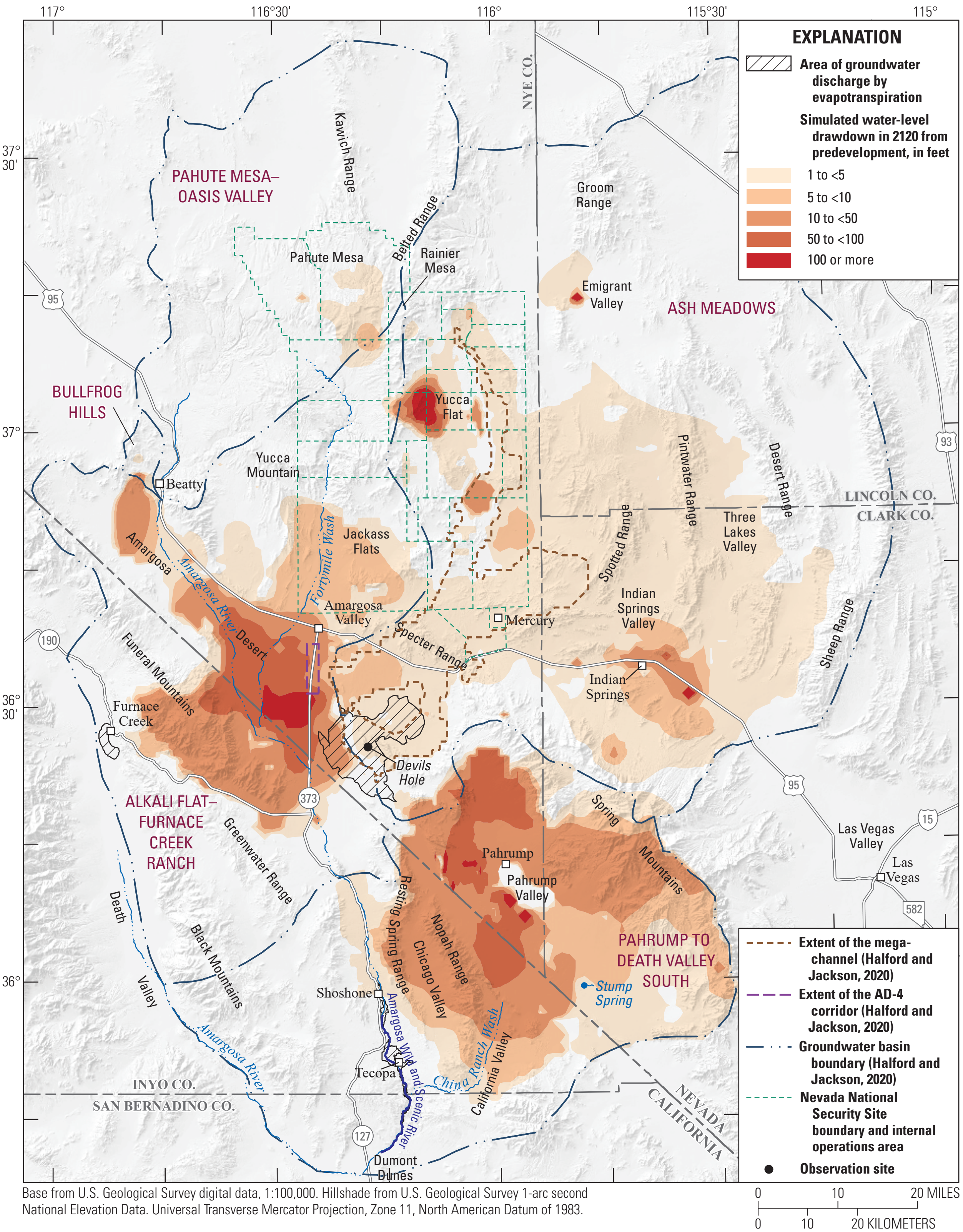
Figure 9. Water-level drawdown from predevelopment for base case scenario in 2040, Death Valley regional flow system, Nevada and California.



Base from U.S. Geological Survey digital data, 1:100,000. Hillshade from U.S. Geological Survey 1-arc second National Elevation Data. Universal Transverse Mercator Projection, Zone 11, North American Datum of 1983.

0 10 20 MILES
0 10 20 KILOMETERS

Figure 10. Water-level drawdown from predevelopment for base case scenario in 2070, Death Valley regional flow system, Nevada and California.



Base from U.S. Geological Survey digital data, 1:100,000. Hillshade from U.S. Geological Survey 1-arc second National Elevation Data. Universal Transverse Mercator Projection, Zone 11, North American Datum of 1983.

Figure 11. Water-level drawdown from predevelopment for base case scenario in 2120, Death Valley regional flow system, Nevada and California.

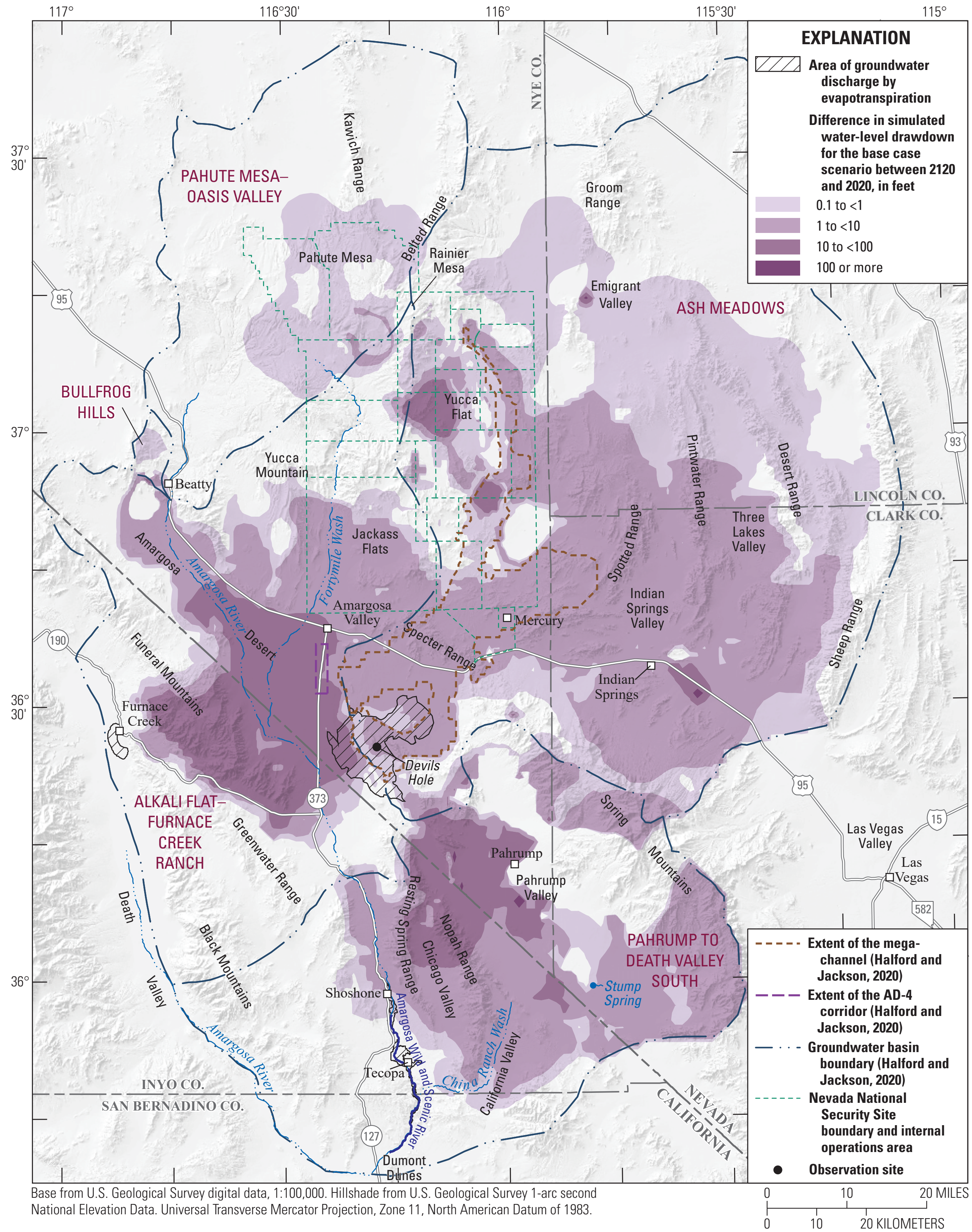


Figure 12. Difference in water-level drawdown between the base case scenario in 2020 and 2120, Death Valley regional flow system, Nevada and California.

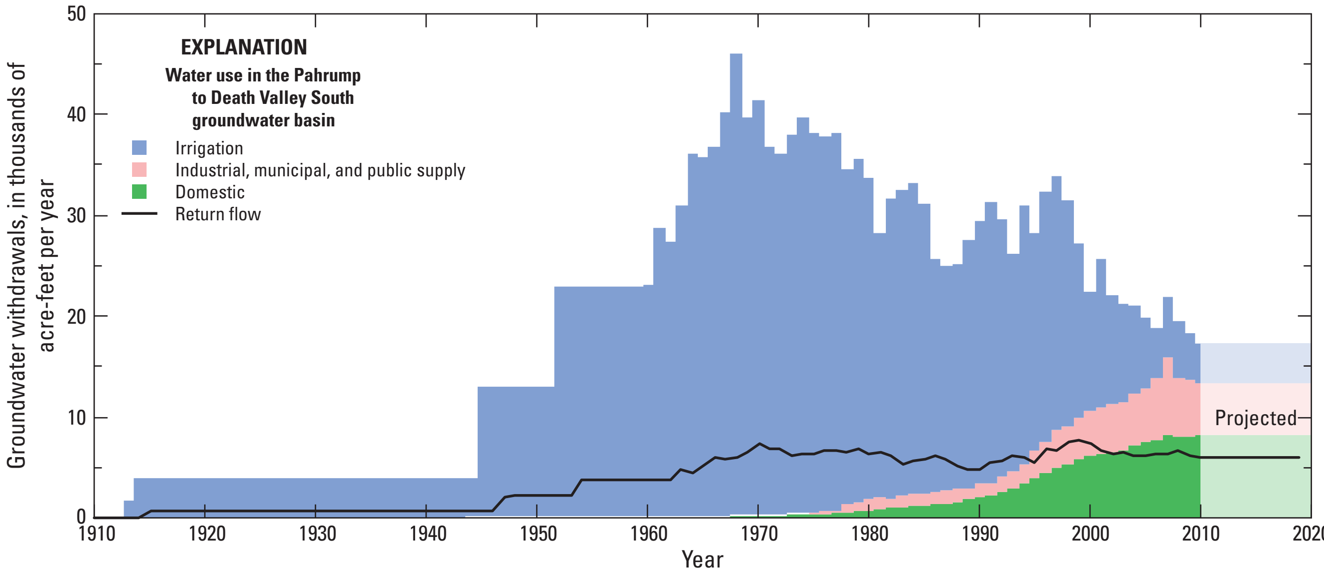


Figure 13. Groundwater withdrawals by water use in the Pahrump to Death Valley South groundwater basin from 1913 to 2020 (modified from Halford and Jackson, 2020).

Simulated drawdown from the central Amargosa Desert extends into the Furnace Creek area, Jackass Flats, and the megachannel by 2020 (fig. 8). The maximum drawdown in the central Amargosa Desert increases from about 65 ft in 2020 to about 120 ft in 2120. Continued pumping from the central Amargosa Desert causes drawdown to propagate farther westward and northward into the Furnace Creek area and Jackass Flats between 2020 and 2120 (figs. 8–11). Drawdowns from pumping in the central Amargosa Desert, NNSS, and Indian Springs propagate into the megachannel, and due to the hydraulic connection through this transmissive zone (Halford and Jackson, 2020), result in drawdown in the Ash Meadows discharge area. Drawdown in the megachannel increases from roughly 2 to 4 ft from 2020 to 2120. The extent of drawdown in the Ash Meadows groundwater basin from pumping in the central Amargosa Desert, NNSS, and Indian Springs increases to the north and east from 2020 to 2120, and drawdown extends 20 mi along the Sheep Range by 2120.

Scenario A

In the PDVS groundwater basin, the addition of 216 domestic wells and 3 municipal wells in Pahrump Valley causes additional drawdown above simulated base case conditions but does not noticeably increase the maximum drawdown extent in the PDVS groundwater basin (figs. 14 and 15). Additional drawdown is the difference in drawdown between a model scenario (A, B, or C) in 2120 and the base case in 2120. Scenario A results in an additional drawdown of 1–10 ft throughout most of Pahrump Valley by 2120 (fig. 15). Moreover, simulated drawdown near municipal wells in Pahrump Valley increases by about 35 ft by 2120 (fig. 15).

The addition of three wells in the Amargosa Desert increases simulated drawdowns above base case conditions throughout the Amargosa Desert and the Ash Meadows groundwater basin (fig. 15). A new well pumping at 1,000 acre-ft/yr south of Beatty induces about 75 ft of additional drawdown (fig. 15). Two wells in the central Amargosa Desert, which each pump at rates of 500 acre-ft/yr, induce about 9 and less than 1 ft of additional drawdown in the Amargosa Desert and megachannel, respectively (fig. 15).

Scenario B

Pumping rates of the 219 new wells in Pahrump Valley were reduced by 50 percent in scenario B as compared to scenario A. Total drawdown from predevelopment exceeded 100 ft in 2120 in western Pahrump (fig. 16). Although the extent of simulated additional drawdowns in the PDVS groundwater basin for scenarios A and B appears somewhat similar, reducing the pumping rates in scenario B resulted in a smaller areal extent of additional drawdowns exceeding 1 ft in the PDVS groundwater basin (fig. 17).

The areal extent of drawdown difference from the base case in the Amargosa Desert is smaller in scenario B (fig. 17), compared to scenario A (fig. 15). Scenario B simulates five new Amargosa Desert wells that pump a total of 710 acre-ft/yr and less than the three new Amargosa Desert wells that pump a total of 2,000 acre-ft/yr in scenario A. For the Ash Meadows groundwater basin, two hypothetical wells that are in or near the megachannel and a new hypothetical well near the well AD-4 corridor contribute to the maximum extent of simulated additional drawdown. Compared to scenario A, the maximum extent of simulated drawdown in scenario B propagated farther northward and eastward toward the Sheep Range.

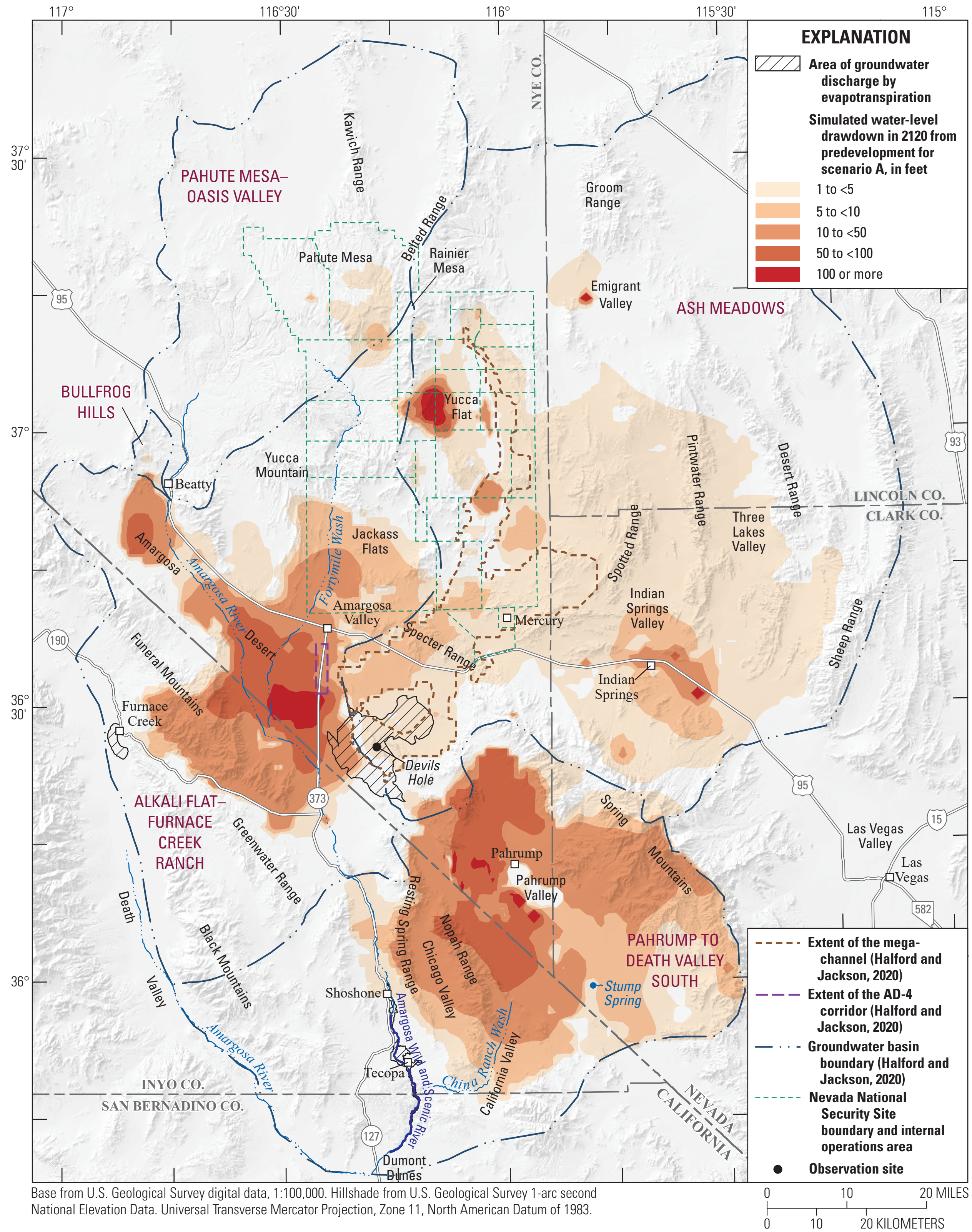


Figure 14. Water-level drawdown from predevelopment for scenario A in 2120, Death Valley regional flow system, Nevada and California.

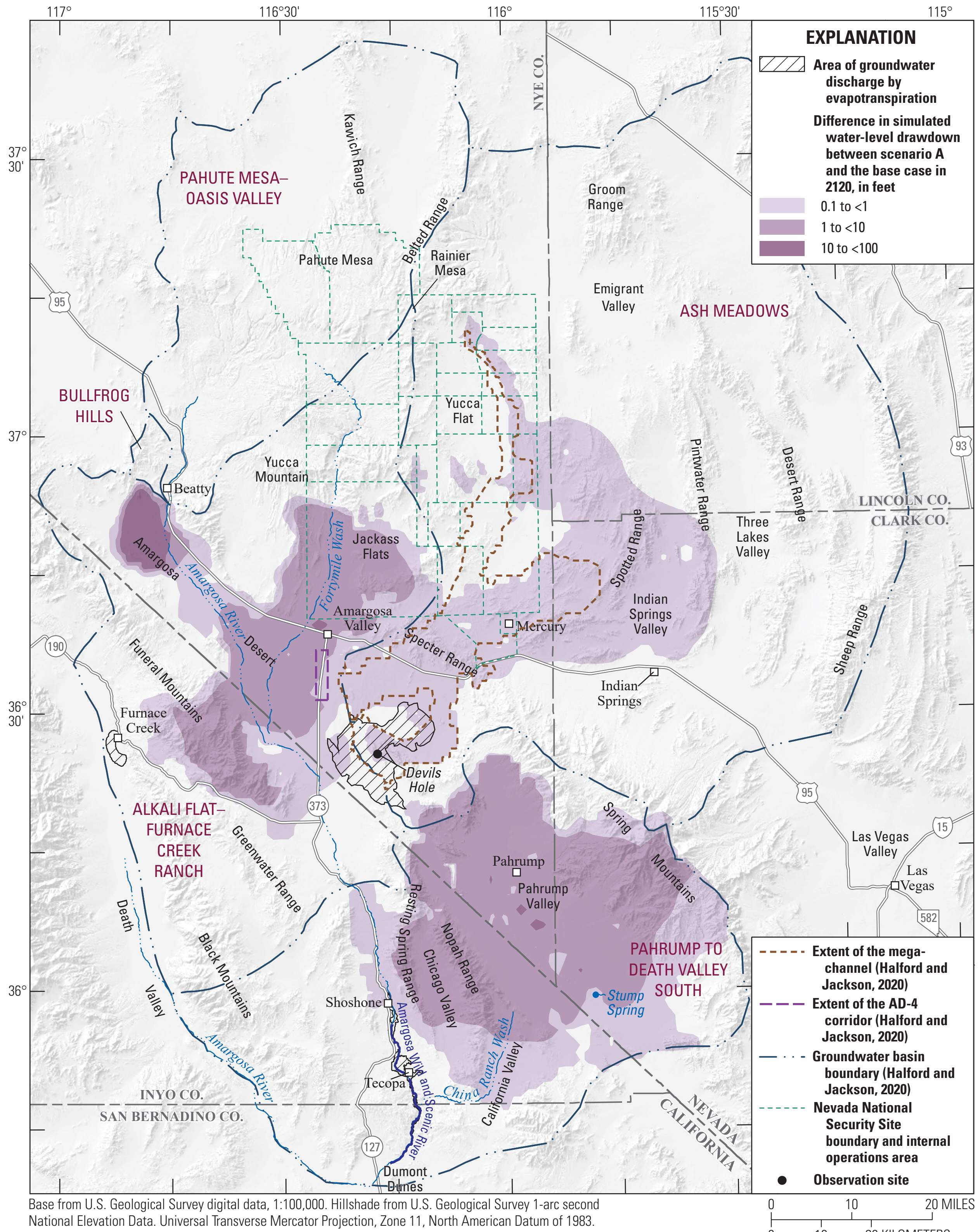


Figure 15. Difference in water-level drawdown between the base case scenario and scenario A in 2120, Death Valley regional flow system, Nevada and California.

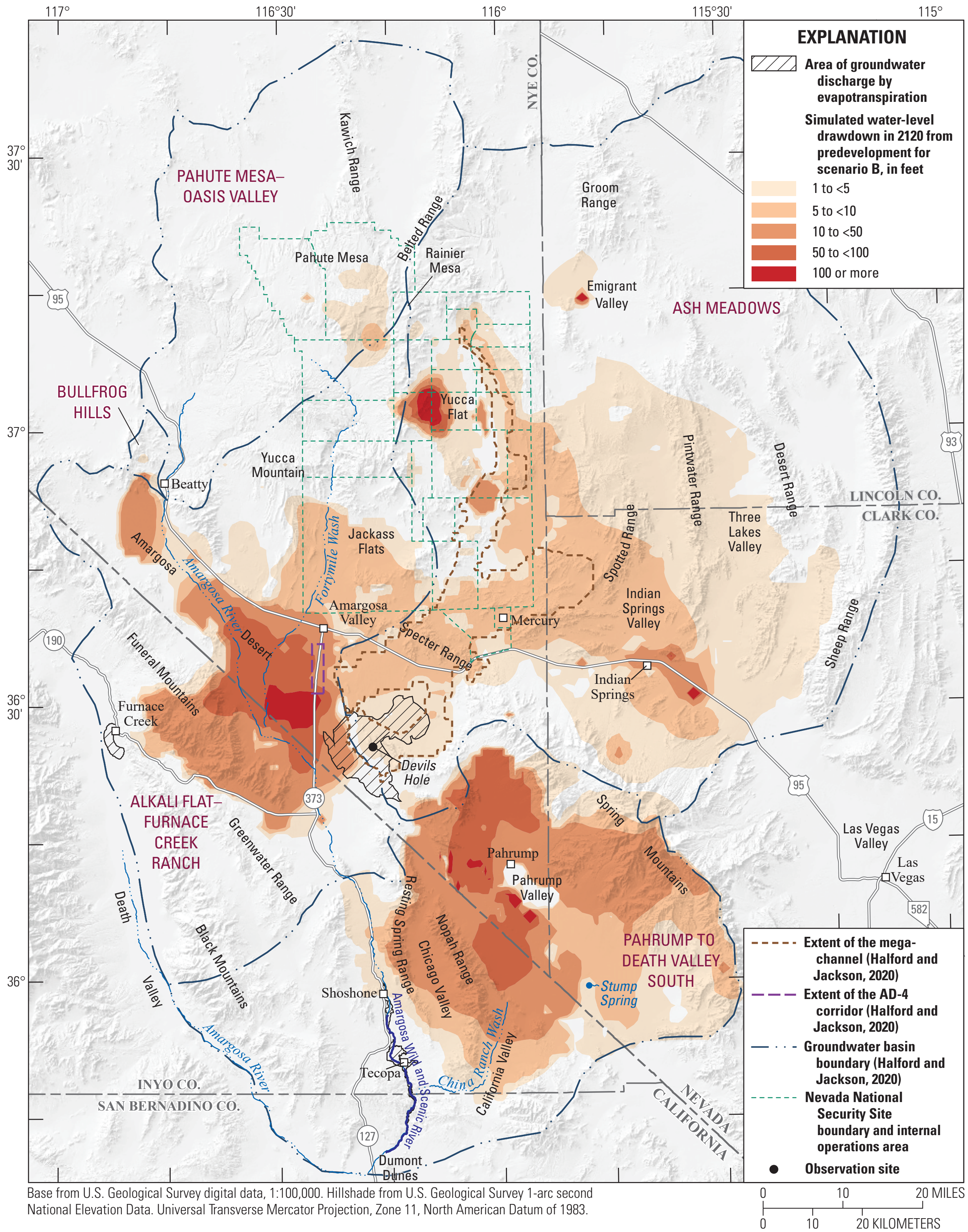


Figure 16. Water-level drawdown from predevelopment for scenario B in 2120, Death Valley regional flow system, Nevada and California.

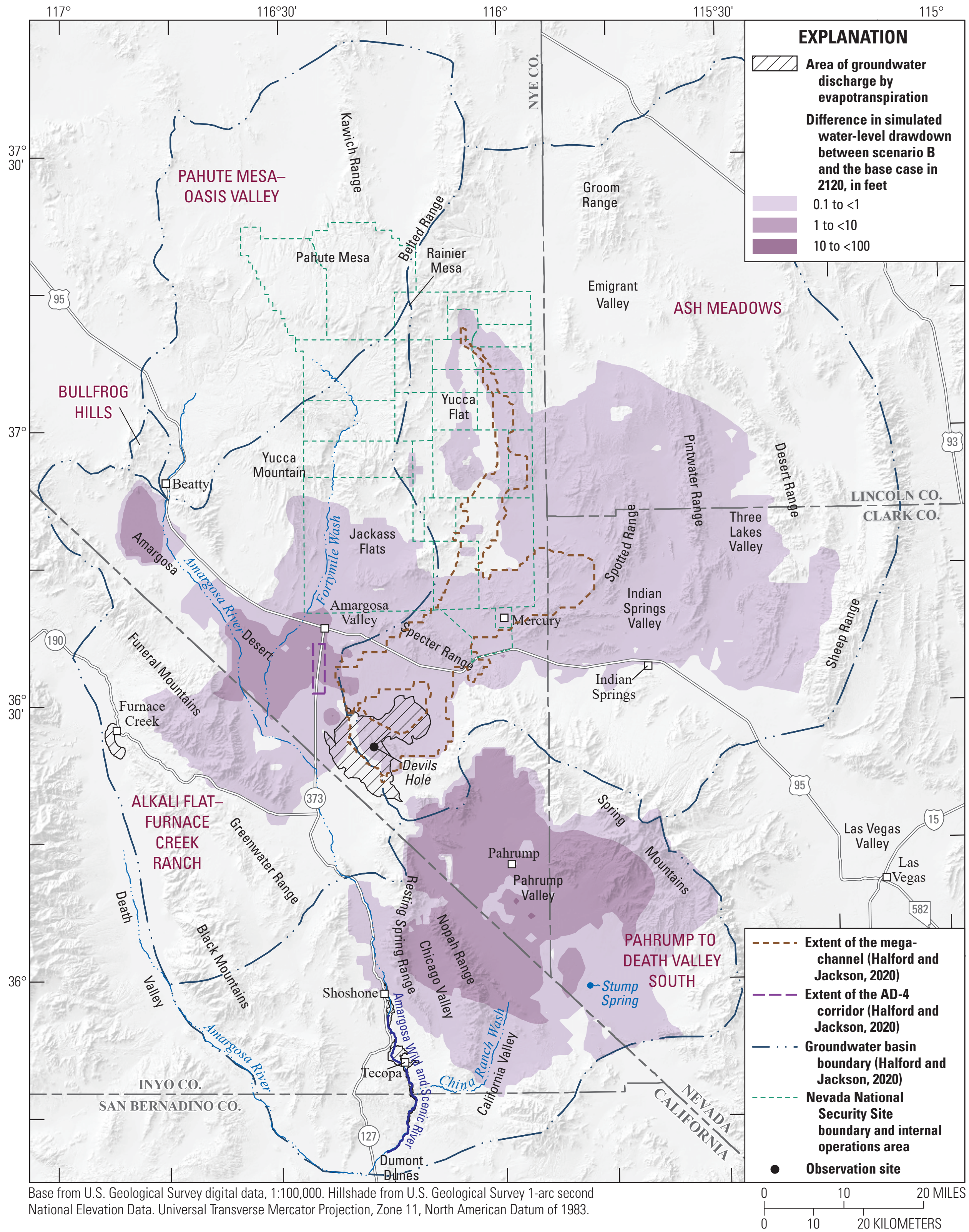


Figure 17. Difference in water-level drawdown between the base case scenario and scenario B in 2120, Death Valley regional flow system, Nevada and California

Scenario C

Scenario C simulates three new central Amargosa Desert wells that each pump 500 acre-ft/yr. Total drawdown from predevelopment exceeds 100 ft in 2120 in parts of Pahrump Valley, the Amargosa Desert, central NNSS, and a large area in the Ash Meadows groundwater basin, extending through Three Lakes Valley (fig. 18). The magnitude and extent of additional drawdown in the central Amargosa Desert is similar between scenarios A (fig. 15) and C (fig. 19) because similar volumes of groundwater are withdrawn from wells.

Simulated additional drawdowns in the megachannel are substantially larger in scenario C (fig. 19) compared to scenarios A and B (figs. 15 and 17). In scenario C, two additional wells in or near the megachannel and nine new pumping wells in the Indian Springs area induce additional drawdowns that propagate throughout the megachannel. The additional pumping induces about 35 ft of additional drawdown in the megachannel compared to the base case.

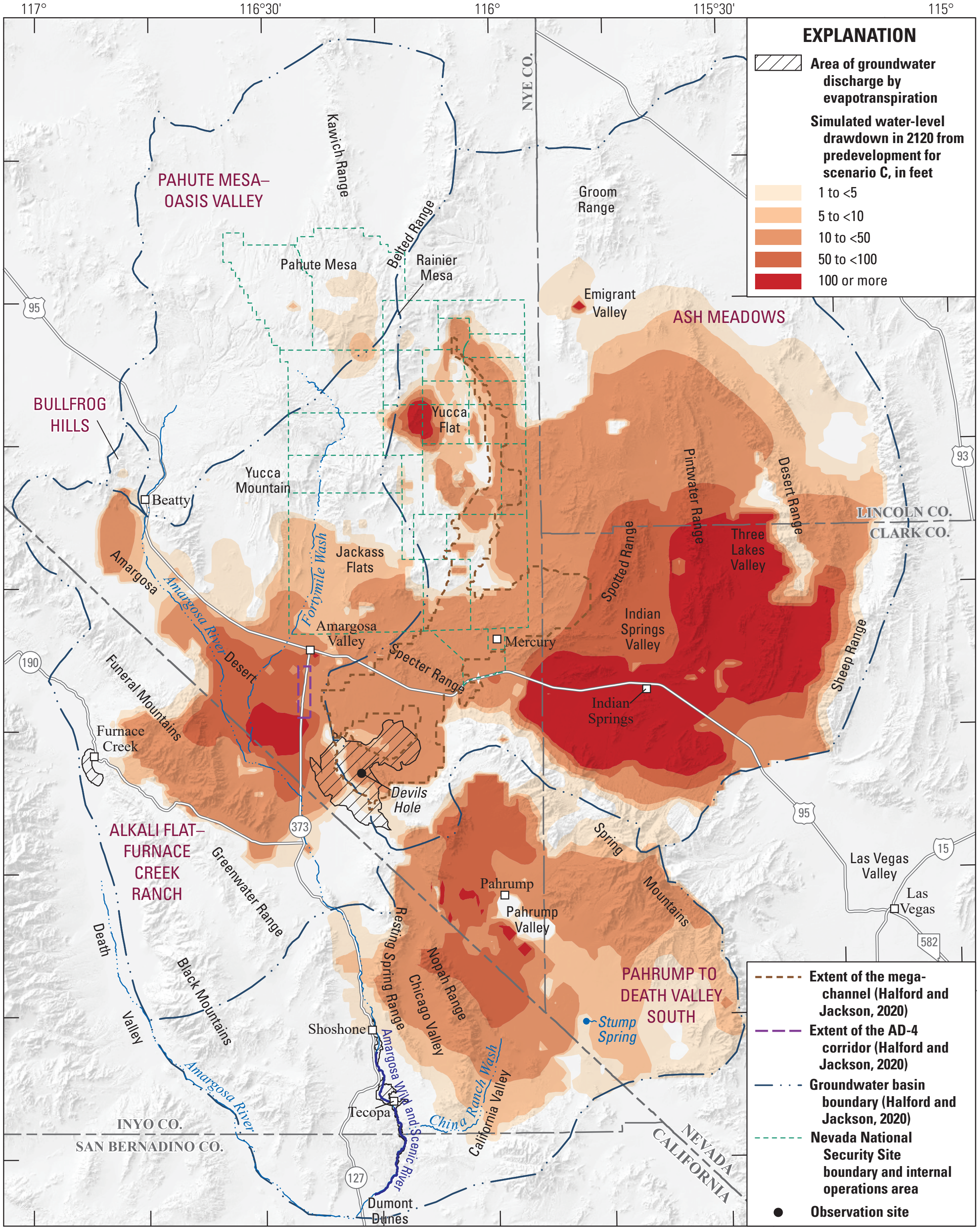
Total drawdown and drawdown difference from the base case in 2120 for scenario C show merged drawdowns of less than 5 ft between the PDVS and Ash Meadows groundwater basins (figs. 18 and 19). A merged drawdown of less than 5 ft induced 30 acre/yr of simulated groundwater flow from PDVS to Ash Meadows, which is 0.2 percent of the predevelopment discharge in the Ash Meadows discharge area (18,500 acre-ft/yr; Halford and Jackson, 2020). This result is speculative and uncertain because of a lack of water-level data in wells to constrain flow between Pahrump Valley and the Ash Meadows discharge area.

Water Levels in Devils Hole

For each model scenario, two Devils Hole hydrographs were constructed to show (1) the component of drawdown (water-level decline) resulting from historical and future pumping simulated using the DV3-PRED model (fig. 20*A*), and (2) the combined water-level changes from fluctuations in natural stresses and pumping (fig. 20*B*). The combined effect of natural stresses and pumping on water levels in Devils Hole is needed to accurately forecast the timing of simulated water-level declines below the U.S. Supreme Court-mandated minimal water level.

The DV3-PRED model simulates drawdown in Devils Hole only due to pumping, from 1940 to 2120, and does not simulate natural stresses such as recharge (fig. 20*A*). Pumping-induced simulated drawdown in Devils Hole ranged from 3.2 to 25.4 ft by 2120 (fig. 20*A*; simulated drawdown of 25.4 ft in 2120 for scenario C not shown in fig. 20*A*). If pumping continues at 2010 rates (the base case), then the simulated drawdown in Devils Hole by 2120 will be about 3.2 ft. Scenario A includes three new wells in basin fill in the Amargosa Desert, which result in 3.4 ft of simulated drawdown (an additional 0.2 ft compared to the base case) in Devils Hole by 2120 (fig. 20*A*). In scenario B, simulated drawdown in 2120 was 3.8 ft (0.6 ft more than for the base case; fig. 20*A*). Pumping wells in or near the megachannel and in the well AD-4 corridor likely are responsible for much of the additional drawdown in scenario B compared to the base case and scenario A. Pumping of about 30,500 acre-ft/yr from nine new wells in the Indian Springs area in scenario C substantially affected water levels in Devils Hole, resulting in a maximum simulated drawdown of 25.4 ft at Devils Hole by 2120 (maximum drawdown not shown in fig. 20*A*). Simulated groundwater pumping in the Indian Springs area causes water-level drawdown to propagate through the carbonate aquifer into the megachannel and downgradient to Devils Hole.

The DV3-PRED model simulates drawdown due to pumping and does not have the capacity to simulate natural stresses (fig 20*A*); however, natural stresses such as recharge and earthquakes have a substantial effect on water levels in Devils Hole (to as much as 0.8 ft from 1940 to 2018, fig. 20*B*). To accurately simulate the effect of natural stresses on water levels in Devils Hole, the DV3-PRED model was modified to include both natural and pumping-induced stresses. Previously simulated water-level fluctuations at Devils Hole due to natural stresses (Halford and others, 2012; Jackson and Halford, 2020) were combined with pumping-induced simulated drawdowns using DV3-PRED to evaluate the effect of both stresses on water levels in Devils Hole. Simulated water-level fluctuations caused by natural stresses and pumping compare reasonably well to observed water levels from 1940 to 2018 (fig. 20*B*) and provide an accurately simulated water-level depth in 2018 to initiate model forecast scenarios from 2019 to 2120. However, forecasting future change in recharge effects on water levels from 2019 to 2120 is highly uncertain and beyond the scope of this study. From 2019 to 2120, a constant value was used to simulate year-to-year model recharge by assuming recharge to be equal to natural groundwater discharge (fig. 20*B*). A constant recharge approach, in essence, negates the effect of natural stresses and simulates only pumping-induced water-level change from 2019 to 2120. Although not necessarily a realistic forecast of future climate effects on water levels in Devils Hole, the approach does provide useful information on the general rate and timing of pumping-induced water-level change. The resulting simulated water levels for all model scenarios were compared to the U.S. Supreme Court-mandated minimum water level of 2.7 ft below an established reference point in Devils Hole.



Base from U.S. Geological Survey digital data, 1:100,000. Hillshade from U.S. Geological Survey 1-arc second National Elevation Data. Universal Transverse Mercator Projection, Zone 11, North American Datum of 1983.

0 10 20 MILES
0 10 20 KILOMETERS

Figure 18. Water-level drawdown from predevelopment for scenario C in 2120, Death Valley regional flow system, Nevada and California.

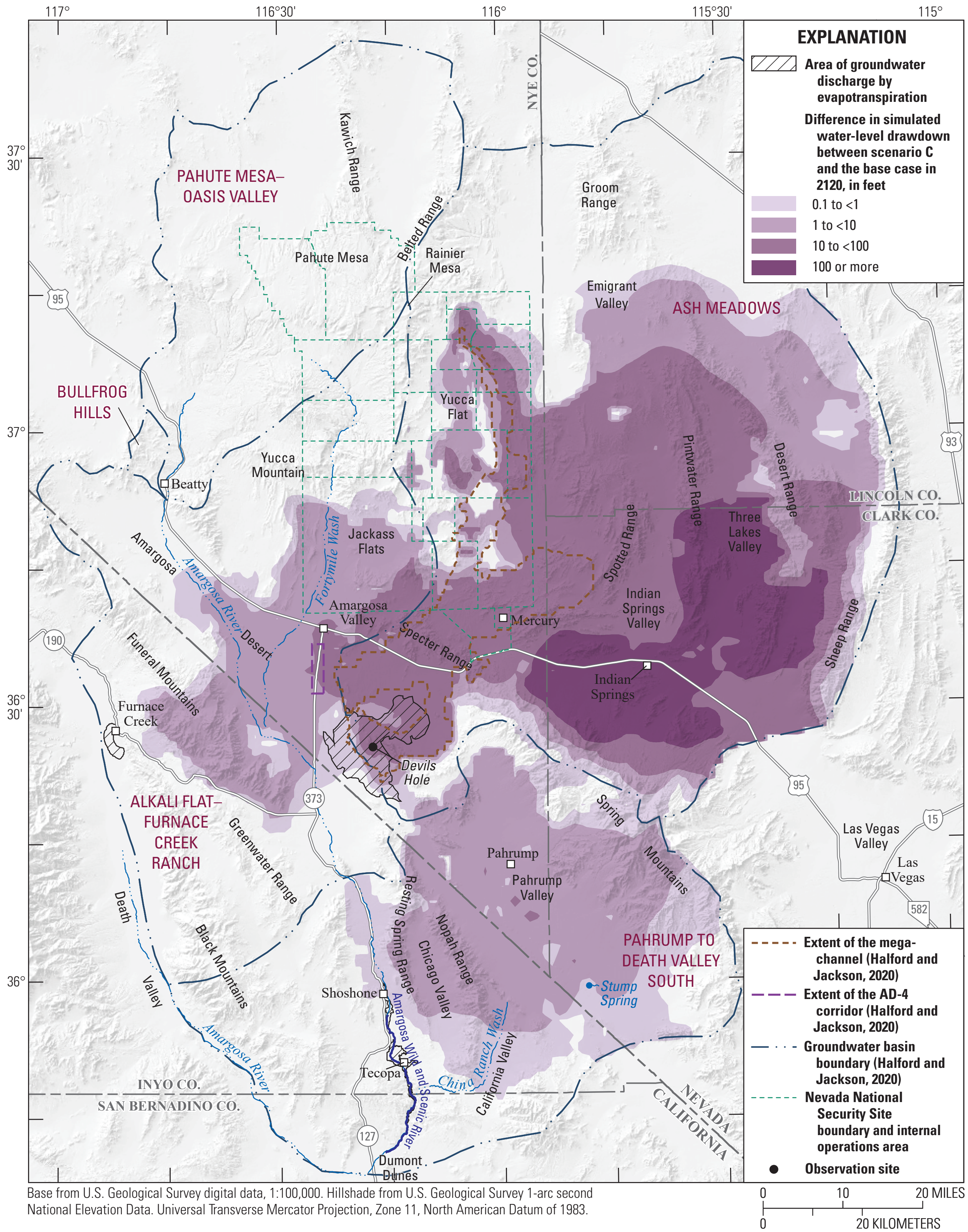


Figure 19. Difference in water-level drawdown between the base case scenario and scenario C in 2120, Death Valley regional flow system, Nevada and California

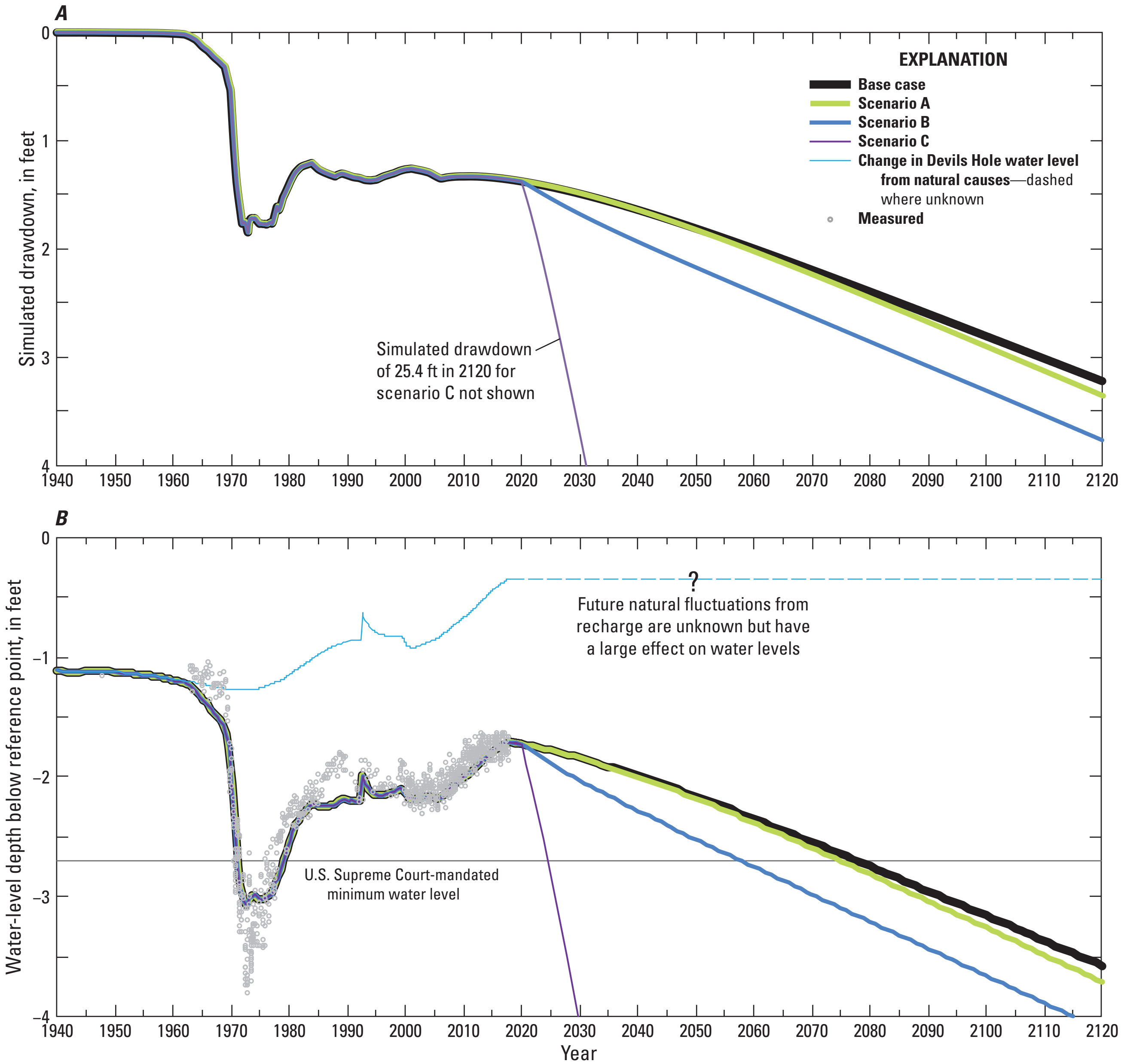


Figure 20. Water levels in Devils Hole, southern Nevada. *A*, Simulated drawdowns for four pumping scenarios from the predictive Death Valley version 3 model (DV3-PRED). *B*, Measured (1940–2017) water-level depth below reference point, estimated (1940–2018) and projected (2019–2120) changes in Devils Hole water level from natural stresses, and summation of simulated drawdowns and natural water-level changes for four pumping scenarios.

For all model scenarios simulated using a constant recharge value, water levels in Devils Hole declined below the mandated minimum water level by 2120 (fig. 20*B*). The base case and scenarios A, B, and C water levels decline below 2.7 ft by 2078, 2073, 2058, and 2025, respectively. However, natural water-level fluctuations in the future (after 2019) may influence the timing of when water levels decline below the mandated minimum water level. For example, an extended dry period (less than average recharge) will accelerate the timing when water levels will drop below the mandated minimum water level, whereas an extended wet period (greater than average recharge) will prolong the timing. For scenario C, the relatively large simulated groundwater withdrawals have caused a steep decline of water levels in Devils Hole (fig. 20*A*), compared to other model simulations. Under the higher pumping stress of scenario C, natural fluctuations would likely have a minimal effect on the timing of when water levels decline below the mandated minimum water level of 2.7 ft. For the base case, scenario A, and scenario B, the timing of when water levels will decline below the mandated minimum water level is much more dependent on future natural water-level fluctuations.

Capture of Natural Discharge

Simulated discharges for the Amargosa Wild and Scenic River, the Ash Meadows discharge area, the Furnace Creek area, and Stump Spring were computed using ZONEBUDGET, a computer program for calculating subregional water budgets for MODFLOW groundwater-flow models (Harbaugh, 1990). Simulated discharges and percentages of captured discharge for each of the four scenarios are presented in table 2.

Amargosa Wild and Scenic River

The Amargosa Wild and Scenic River is the least affected discharge area, by percentage of capture, examined for this report. The Amargosa Wild and Scenic River has a simulated predevelopment discharge of 6,700 acre-ft/yr (table 2; Halford and Jackson, 2020). The base case reduces simulated discharge by 3 percent, and scenarios A, B, and C reduce simulated discharge by 4 percent by 2120.

Table 2. Simulated effects from four scenarios of groundwater pumping on natural discharge at select discharge areas, Death Valley regional flow system, Nevada and California.

[**Predevelopment discharge:** Values are simulated values from Halford and Jackson (2020)]

Discharge area	Pre-development discharge (acre-feet per year)	Pumping scenario	Simulated discharge (acre-feet per year)				Capture (percent)			
			2020	2040	2070	2120	2020	2040	2070	2120
Amargosa Wild and Scenic River	6,700	Base case	6,500	6,500	6,500	6,500	3	3	3	3
		A	6,500	6,500	6,500	6,400	3	3	3	4
		B	6,500	6,500	6,500	6,400	3	3	3	4
		C	6,500	6,500	6,500	6,400	3	3	3	4
Ash Meadows discharge area	18,500	Base case	17,900	17,800	17,500	17,100	3	4	5	8
		A	17,900	17,800	17,500	17,000	3	4	5	8
		B	17,900	17,600	17,400	16,900	3	5	6	9
		C	17,900	16,200	14,000	11,500	3	12	24	38
Furnace Creek area	6,300	Base case	5,800	5,800	5,700	5,700	8	8	10	10
		A	5,800	5,800	5,700	5,600	8	8	10	11
		B	5,800	5,800	5,700	5,600	8	8	10	11
		C	5,800	5,800	5,700	5,600	8	8	10	11
Stump Spring	250	Base case	180	180	180	170	28	28	28	32
		A	180	180	170	160	28	28	32	36
		B	180	180	170	160	28	28	32	36
		C	180	180	170	160	28	28	32	36

Ash Meadows Discharge Area

Simulated predevelopment discharge from Ash Meadows discharge area is 18,500 acre-ft/yr (table 2; Halford and Jackson, 2020). In the base case, simulated discharge is reduced by 8 percent to 17,100 acre-ft/yr by 2120. Scenarios A and B induce the capture of 8 and 9 percent of predevelopment discharge, respectively. In scenario C, simulated discharge is reduced by 38 percent to 11,500 acre-ft/yr by 2120. Scenario C has a large effect on simulated discharge at Ash Meadows discharge area. This is because, in scenario C, 1–10 ft of drawdown were induced in the megachannel from the high withdrawal rates near Indian Springs (fig. 18), whereas additional pumping in scenarios A and B induced less than 1 ft of drawdown (figs. 14 and 16).

Furnace Creek Area

The Furnace Creek area has a simulated predevelopment discharge of 6,300 acre-ft/yr (table 2; Halford and Jackson, 2020). The base case predicts a 10-percent reduction in predevelopment discharge at Furnace Creek area by 2120. Scenarios A, B, and C all predict an 11-percent reduction in predevelopment discharge by 2120.

Stump Spring

Simulated predevelopment discharge at Stump Spring is 250 acre-ft/yr (table 2; Halford and Jackson, 2020). In the base case, simulated discharge is reduced by 32 percent to 170 acre-ft/yr by 2120. Scenarios A, B, and C all reduce simulated discharge by 36 percent to 160 acre-ft/yr.

Summary

Declining water levels and reduced natural discharge at springs, seeps, and phreatophyte areas primarily are the result of decades of groundwater development in the Death Valley regional flow system, in Nevada and California. The calibrated Death Valley version 3 predictive groundwater-flow model was used to simulate four future groundwater-pumping scenarios in the Death Valley regional flow system. The model was used to predict (1) the extent of regional water-level declines; (2) drawdown at Devils Hole; and (3) reductions in natural discharge in the Amargosa Wild and Scenic River, the Ash Meadows discharge area, the Furnace Creek area, and Stump Spring. Each scenario simulates historical pumping at annual rates from 1913 to 2010, and historical 2010 pumping is projected from 2010 to 2120. Future pumping scenarios begin in 2020 and are projected for 100 years to 2120. The base case scenario simulated no additional groundwater development within the study area and simulated projected 2010 pumping rates through 2120. The other three scenarios (A, B, and C) simulated base case pumping rates plus additional groundwater pumping from 2020 to 2120 within the Alkali Flat–Furnace Creek Ranch (AFFCR), Ash Meadows, and (or) Pahrump to Death Valley South (PDVS) groundwater basins.

By 2020, historical (1913–2020) pumping resulted in the propagation of simulated drawdown of 1 foot (ft) or more westward from Pahrump Valley to areas north of Shoshone in the PDVS groundwater basin and the merging of simulated 1-ft drawdown contours between the AFFCR and Ash Meadows groundwater basins. In the base case scenario, the extent and magnitude of simulated drawdown continued to increase in the Ash Meadows and AFFCR groundwater basins from 2020 to 2120. In the base case, the magnitude of simulated drawdown continued to increase in western Pahrump Valley from 2020 to 2120, whereas simulated water levels rose in eastern Pahrump Valley from 2020 to 2070 and then stabilized from 2070 to 2120. Scenarios A and B primarily affected the PDVS and AFFCR groundwater basins by increasing the magnitude of drawdown in 2120, compared to the base case. In scenario C, drawdown propagated throughout a high-transmissivity part of the carbonate aquifer known as the megachannel, greatly affecting water levels in the Ash Meadows discharge area. Scenario C resulted in an additional 10–100 ft of drawdown (compared to the base case) throughout the southeastern part of the Ash Meadows groundwater basin by 2120.

Simulated drawdown at Devils Hole in 2120 was 3.2, 3.4, 3.8, and 25.4 ft for the base case and scenarios A, B, and C, respectively. Simulated water levels in Devils Hole fell below the federally mandated water level by 2078, 2073, 2058, and 2025 for the base case and scenarios A, B, and C, respectively, assuming a hypothetical case of constant natural recharge for the period 2020—2120. In scenario A, pumping of about 2,000 acre-feet per year (acre-ft/yr) from three new Amargosa Desert wells results in an additional 0.2 ft of water-level decline in Devils Hole compared to the base case by 2120. In scenario B, pumping of about 710 acre-ft/yr is more than the base case in the Amargosa Desert but less than the pumping from this area in scenario A. For the pumping level simulated in scenario B, simulated drawdown in Devils Hole is 0.2 ft greater than simulated drawdown in scenario A by 2120 because of the proximity of the pumping to the megachannel. Scenario C shows that high withdrawal rates (combined pumping of more than 30,000 acre-ft/yr) from the carbonate aquifer near Indian Springs result in rapid declines in Devils Hole water levels and capture of a large fraction of groundwater in the Ash Meadows discharge area.

Reductions in natural discharge at select discharge areas ranged from 3 to 38 percent by 2120. The four pumping scenarios had a limited effect on discharge at the Amargosa Wild and Scenic River, where capture rates ranged from 3 to 4 percent for all scenarios. Capture rates in 2120 at Ash Meadows discharge area ranged from 8 to 9 percent for the base case, scenario A, and scenario B, and the simulated capture rate was 38 percent for scenario C. The four pumping scenarios had moderate effects on discharge at the Furnace Creek area, where capture rates ranged from 10 to 11 percent for all scenarios in 2120. The capture rate at Stump Spring was 32 percent for the base case scenario and 36 percent for scenarios A, B, and C in 2120.

References Cited

Bureau of Land Management, 1998, Record of decision for the approved Las Vegas Resource Management Plan and final Environmental Impact Statement: Las Vegas, Nevada, Bureau of Land Management, 52 p., accessed November 19, 2019, at https://eplanning.blm.gov/epl-front-office/projects/lup/78155/128947/156899/1998_LV_RMP_ROD.pdf.

Claassen, H.C., 1985, Sources and mechanisms of recharge for ground water in the west-central Amargosa Desert, Nevada; a geochemical interpretation: U.S. Geological Survey Professional Paper 712-F, 31 p., https://doi.org/10.3133/pp712F.

Dudley, W.W., Jr., and Larson, J.D., 1976, Effect of irrigation pumping on desert pupfish habitats in Ash Meadows, Nye County, Nevada: U.S. Geological Survey Professional Paper 927, 52 p. [Also available at https://doi.org/10.3133/pp927.]

Elliott, P.E., and Moreo, M.T., 2018, Update to the groundwater withdrawals database for the Death Valley regional groundwater flow system, Nevada and California, 1913–2010: U.S. Geological Survey data release, accessed November 19, 2019, at https://doi.org/10.5066/F75H7FH3.

Geter, T., 2015, Amargosa Desert (hydrographic basin 14–230) groundwater pumpage inventory water year 2015: Department of Nevada Department of Conservation and Natural Resources, 126 p.

Halford, K., Garcia, C.A., Fenelon, J., and Mirus, B., 2012, Advanced methods for modeling water-levels and estimating drawdowns with SeriesSEE, an Excel add-In (ver. 1.1, July 2016): U.S. Geological Survey Techniques and Methods, book 4, chap. F4, 28 p., accessed November 19, 2019, at https://dx.doi.org/10.3133/tm4F4.

Halford, K.J., and Jackson, T.R., 2020, Groundwater characterization and effects of pumping in the Death Valley regional groundwater flow system, Nevada and California, with special reference to Devils Hole: U.S. Geological Survey Professional Paper 1863, 178 p., accessed March 5, 2020, at https://doi.org/10.3133/pp1863.

Halford, K.J., and Plume, R.W., 2011, Potential effects of groundwater pumping on water levels, phreatophytes, and spring discharges in Spring and Snake Valleys, White Pine County, Nevada, and adjacent areas in Nevada and Utah: U.S. Geological Survey Scientific Investigations Report 2011–5032, 52 p., https://doi.org/10.3133/sir20115032.

Harbaugh, A.W., 1990, A computer program for calculating subregional water budgets using results from the U.S. Geological Survey Modular Three-Dimensional Finite-Difference Ground-Water Flow Model: U.S. Geological Survey Open-File Report 90–392, 46 p. [Also available at https://doi.org/10.3133/ofr90392.]

Harbaugh, A.W., 2005, MODFLOW-2005—The U.S. Geological Survey modular ground-water model—The ground-water flow process: U.S. Geological Survey Techniques and Methods, book 6, chap. A16 [variously paged], accessed November 19, 2019, at https://doi.org/10.3133/tm6A16.

Harrill, J.R., Gates, J.S., and Thomas, J.M., 1988, Major ground-water flow systems in the Great Basin region of Nevada, Utah, and adjacent states: U.S. Geological Survey Hydrologic Atlas 694–C, 2 plates. [Also available at https://doi.org/10.3133/ha694C.]

Interagency Wild and Scenic Rivers Coordinating Council, 2018, National Wild and Scenic Rivers System—Amargosa River, California: National Wild and Scenic Rivers System web page, accessed January 2, 2018, at https://www.rivers.gov/rivers/amargosa.php.

Jackson, T.R., 2017, AQUIFER TEST PACKAGE—Drawdown estimation and analysis of the *ER-4-1 m1* multiple-well aquifer test of the lower carbonate aquifer, Yucca Flat, Nevada National Security Site: U.S. Geological Survey, aquifer test package, accessed June 1, 2017, at https://nevada.usgs.gov/aquifertests/studies/tests.html?test_pg=ER-4-1m1.

Jackson, T.R., and Halford, K.J., 2020, MODFLOW-2005 model and supplementary data used to characterize groundwater flow and effects of pumping in the Death Valley regional groundwater flow system, Nevada and California, with special reference to Devils Hole: U.S. Geological Survey data release, https://doi.org/10.5066/P9HIYVG2.

Nelson, N.C., and Jackson, T.R., 2020, MODFLOW-2005 models used to simulate effects of pumping in the Death Valley Regional Groundwater Flow System, Nevada and California—Selected management scenarios projected to 2120: U.S. Geological Survey data release, https://doi.org/10.5066/P9OBUPXU.

Smith, D.W., Moreo, M.T., Garcia, C.A., Halford, K.J., and Fenelon, J.M., 2017, A process to estimate net infiltration using a site-scale water-budget approach, Rainier Mesa, Nevada National Security Site, Nevada, 2002–05: U.S. Geological Survey Scientific Investigations Report 2017–5078, 22 p., https://doi.org/10.3133/sir20175078.

Walker, G.E., and Eakin, T.E., 1963, Geology and ground water of Amargosa Desert, Nevada-California: Nevada Department of Conservation and Natural Resources, Water Resources—Reconnaissance Series Report 14, 45 p., http://images.water.nv.gov/images/publications/recon%20reports/rpt14-Amargosa_valley.pdf.

Williams, O.R., Albright, J.S., Christensen, P.K., Hansen, W.R., Hughes, J.C., Johns, A.E., McGlothlin, D.J., Pettee, C.W., and Ponce, S.L., 1996, Water rights and Devil's Hole pupfish at Death Valley National Monument, *in* Halvorson, W.L., and Davis, G.E., eds., Science and ecosystem management in the National Parks: Tucson, University of Arizona Press, p. 161–183.

Winograd, I.J., and Pearson, F.J., Jr., 1976, Major carbon-14 anomaly in a regional carbonate aquifer—Possible evidence for megascale channeling, south-central Great Basin: Water Resources Research, v. 12, no. 6, p. 1125–1143, https://doi.org/10.1029/WR012i006p01125.

Publishing support provided by the U.S. Geological Survey
Science Publishing Network, Tacoma Publishing Service Center

For more information concerning the research in this report, contact the
Director, Nevada Water Science Center
U.S. Geological Survey
2730 N. Deer Run Road
Carson City, Nevada 89701
https://www.usgs.gov/centers/nv-water

USGS

Nelson and Jackson—**Simulated Effects of Pumping, Death Valley Regional Groundwater Flow System, Nevada and California**—SIR 2020-5103

ISSN 2328-0328 (online)
https://doi.org/10.3133/sir20205103