Prepared in cooperation with the Bureau of Land Management

Potential Effects of Existing and Proposed Groundwater Withdrawals on Water Levels and Natural Groundwater Discharge in Snake Valley, Juab and Millard Counties, Utah, White Pine County, Nevada, and Surrounding Areas in Utah and Nevada

Open-File Report 2014–1176

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

Cover photograph: Looking west towards Wheeler Peak, Great Basin National Park, May 2010. Photograph by Melissa Masbruch, U.S. Geological Survey.

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Inch/Pound to SI

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	0.004047	square kilometer (km^2)
square foot (ft^2)	0.09290	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
cubic mile (mi^3)	4.168	cubic kilometer (km^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
	Flow rate	
acre-foot per day (acre-ft/d)	0.01427	cubic meter per second (m^3/s)
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year (m^3/yr)
foot per second (ft/s)	0.3048	meter per second (m/s)
foot per day (ft/d)	0.3048	meter per day (m/d)
foot per year (ft/yr)	0.3048	meter per year (m/yr)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per day (ft^3/d)	0.02832	cubic meter per day (m^3/d)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)
	Transmissivity*	
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)

Temperature in degrees Celsius (°C), degrees Fahrenheit (°F), and Kelvin (K) may be converted using the following equations:

$$\text{Temp °F}=(1.8\ \text{temp °C})+32$$

$$\text{Temp °C}=(\text{temp °F}-32)/1.8$$

$$\text{Temp °F}=(1.8\ \text{temp K})-459.67$$

$$\text{Temp °C}=\text{temp K}-273.15$$

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

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.

*Transmissivity: The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness $[(ft^3/d)/ft^2]ft$ or $[(m^3/d)/m^2]m$. In this report, the mathematically reduced form, foot squared per day (ft^2/d) or meters squared per day (m^2/d), is used for convenience.

Potential Effects of Existing and Proposed Groundwater Withdrawals on Water Levels and Natural Groundwater Discharge in Snake Valley, Juab and Millard Counties, Utah, White Pine County, Nevada, and Surrounding Areas in Utah and Nevada

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Abstract

Applications have been filed for several water-right changes and new water rights, with total withdrawals of about 1,800 acre-feet per year, in Snake Valley near Eskdale and Partoun, Utah. The Bureau of Land Management has identified 11 sites where the Bureau of Land Management holds water rights and 7 other springs of interest that could be affected by these proposed groundwater withdrawals. This report presents a hydrogeologic analysis of areas within Snake Valley to assess the potential effects on Bureau of Land Management water rights and other springs of interest resulting from existing and proposed groundwater withdrawals. A previously developed numerical groundwater-flow model was used to quantify potential groundwater drawdown and the capture, or groundwater withdrawals that results in depletion, of natural discharge resulting from existing and proposed groundwater withdrawals within Snake Valley. Existing groundwater withdrawals were simulated for a 50-year period prior to adding the newly proposed withdrawals to bring the model from pre-development conditions to the start of 2014. After this initial 50-year period, existing withdrawals, additional proposed withdrawals, and consequent effects were simulated for periods of 5, 10, 25, 50, and 100 years.

Downward trends in water levels measured in wells indicate that the existing groundwater withdrawals in Snake Valley are affecting water levels. The numerical model simulated similar downward trends in water levels. The largest simulated drawdowns caused by existing groundwater withdrawals ranged between 10 and 26 feet and were near the centers of the agricultural areas by Callao, Eskdale, Baker, Garrison, and along the Utah-Nevada state line in southern Snake Valley. The largest simulated water-level declines were at the Bureau of Land Management water-rights sites near Eskdale, Utah, where simulated drawdowns ranged between 2 and 8 feet at the start of 2014. These results were consistent with, but lower than, observations from several wells monitored by the U.S. Geological Survey that indicated water-level declines of 6 to 18 feet near the Eskdale area since the mid-1970s and 1980s. The model cells where the simulated capture of natural groundwater discharge resulting from the existing withdrawals was greatest were those containing Kane Spring, Caine Spring, and Unnamed Spring 5, where existing groundwater withdrawals capture 13 to 29 percent of the total simulated natural discharge in these cells.

Simulated drawdown and simulated capture of natural groundwater discharge resulting from the proposed withdrawals started in as few as 5 years at seven of the sites. After 100 years, four sites showed simulated drawdowns ranging between 1 and 2 feet; eight sites showed simulated drawdowns ranging between 0.1 and 0.9 feet; and five sites showed no simulated drawdown resulting from the proposed withdrawals. The largest amounts of simulated capture of natural groundwater discharge resulting from the proposed withdrawals after 100 years were in the model cells containing Coyote Spring, Kane Spring, and Caine Spring, which had capture amounts ranging between 5.5 and 9.1 percent of the total simulated natural discharge in these cells.

Introduction

Snake Valley is a sparsely populated basin along the Utah-Nevada border in the eastern part of the Great Basin Physiographic Province described by Fenneman (1931). Several water-right change applications have been filed with the State of Nevada to change the point of diversion from six existing water rights near Baker, Nevada, to three points of diversion approximately 5 to 6 miles (mi) to the north, just west of Eskdale, Utah, that have a combined planned groundwater withdrawal of about 1,270 acre-feet per year (acre-ft/yr) for irrigation (fig. 1; table 1). Additionally, new water-rights applications have been filed with the State of Utah for two

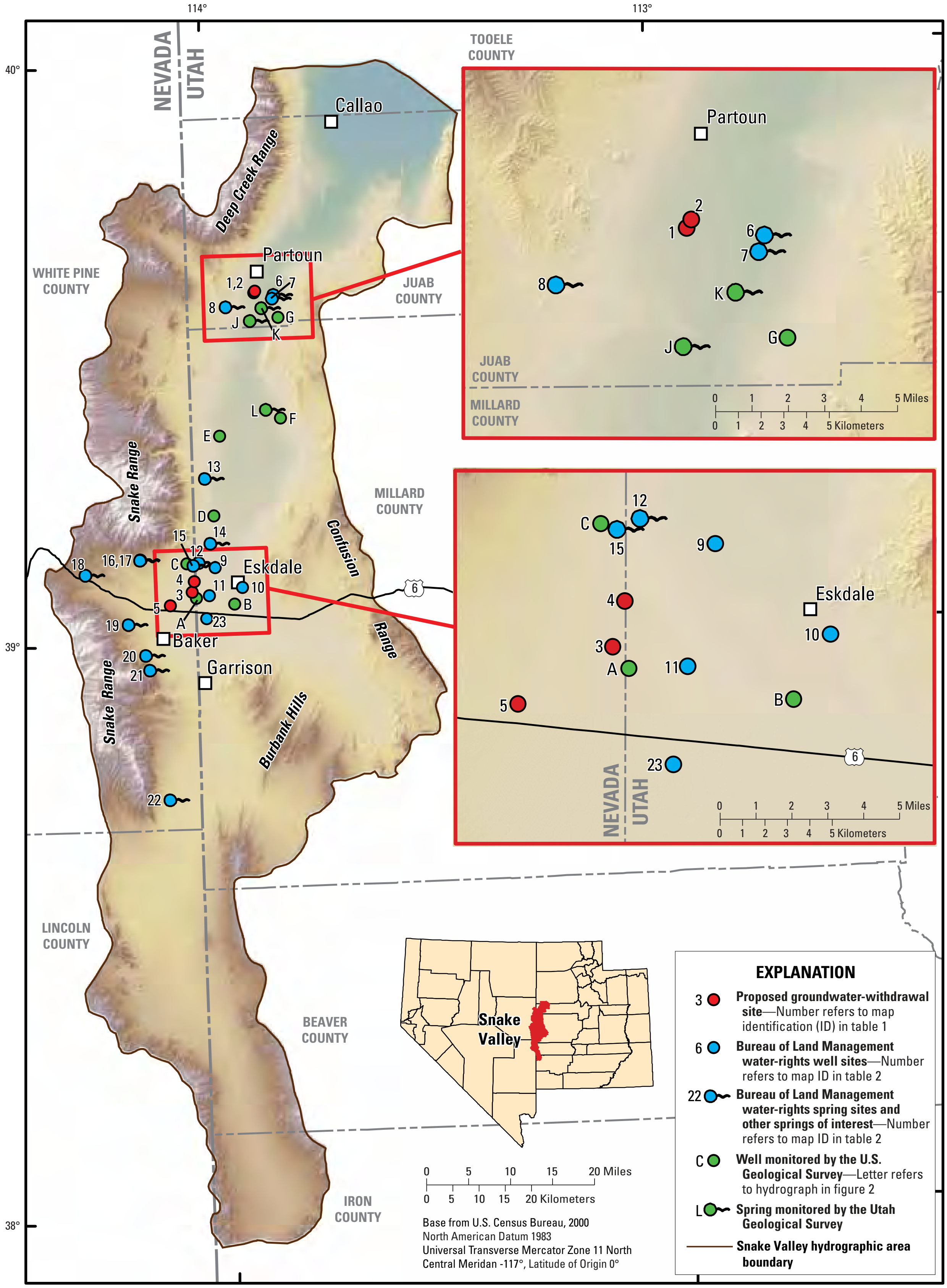


Figure 1. Location of Snake Valley, proposed groundwater-withdrawal sites, Bureau of Land Management water-rights sites and other springs of interest, wells monitored by the U.S. Geological Survey, and springs monitored by the Utah Geological Survey.

Table 1. Summary of proposed groundwater-withdrawal sites in Snake Valley.

[Refer to figure 1 for location of sites. Application number: state and application number. Latitude and longitude are referenced to the North American Datum of 1983 (NAD 83). Abbreviations: ID, identification; acre-ft/yr, acre-feet per year; UT, Utah; NV, Nevada]

Map ID	Application number	Latitude (decimal degrees)	Longitude (decimal degrees)	Proposed withdrawals (acre-ft/yr)
1	UT 79901	39.606	-113.895	544.00
2	UT 79901	39.609	-113.893	6.05
3	NV 83217; NV 83218	39.092	-114.055	393.20
4	NV 83219; NV 83220	39.110	-114.049	393.20
5	NV 83327; NV 83328	39.069	-114.104	482.68

new wells near Partoun, Utah, that have a combined planned withdrawal of about 550 acre-ft/yr for irrigation, stock watering, and domestic supply (fig. 1; table 1).

The Bureau of Land Management (BLM) has identified 11 sites where the BLM holds water rights and 7 other springs of interest (fig. 1; table 2) that could be affected by these proposed groundwater withdrawals. Of most importance, and nearest to the new points of diversion, are (sites 6–12 and 23 on fig. 1) four wells and one spring near Eskdale, Utah (Utah Division of Water Rights numbers 18-304, also known as the Eskdale Well; 18-719, also known as Flowing Well 2; 18-555, also known as the West Buckskin Well; 18-168, also known as the Shell Baker Creek Well; and 18-406, also known as Kane Spring), and three springs or spring complexes near Partoun, Utah (Utah Division of Water Rights numbers 18-596, also known as Coyote Spring; 18-701, also known as Snake Valley North Spring Complex; and 18-702, also known as Snake Valley South Spring Complex). These water rights are primarily used for stock and wildlife watering. Additional water resources of interest are springs that have been designated by the United States as “Public Water Reserves” (PWRs) or are on public or state lands (sites 13–22 on fig. 1). Historically, PWRs have been withdrawn from public-domain lands by the Department of the Interior to prevent monopolization of scarce water resources on public lands. This reservation of lands enables the U.S. to claim reserved water rights on these water sources. Reserved water rights have not yet been claimed or adjudicated for the PWRs that are discussed in this report.

Purpose and Scope

This report presents a hydrogeologic analysis of areas within Snake Valley to assess potential effects on BLM water rights and other springs of interest resulting from existing and proposed groundwater withdrawals. A previously developed numerical groundwater-flow model (Halford and Plume, 2011) was used to quantify potential drawdown and capture (withdrawals that results in depletion) of natural discharge resulting

Table 2. Summary of Bureau of Land Management water-rights sites and other springs of interest in Snake Valley.

[Refer to figure 1 for location of sites. Water-right number: state and water right number. Latitude and longitude are referenced to the North American Datum of 1983 (NAD83). Depth to water, below land surface: negative (-) depth indicates height of water level above land surface. Abbreviations: ID, identification; ft, feet; ft^3/s, cubic feet per second; USGS, U.S. Geological Survey; NV, Nevada; UT, Utah; N/A, not applicable; —, no data]

Map ID	Site name	Water right number	Latitude (decimal degrees)	Longitude (decimal degrees)	USGS site number	Land-surface altitude (ft)	Date of most recent discharge or water-level measurement	Discharge (ft^3/s)	Depth to water, below land surface (ft)
6	Snake Valley North Spring Complex	UT 18-701	39.603	-113.850	N/A	4,755	—	—	N/A
7	Snake Valley South Spring Complex	UT 18-702	39.596	-113.853	N/A	4,755	—	—	N/A
8	Coyote spring	UT 18-596	39.584	-113.958	393501113572701	5,085	1984-02-07	0.190	N/A
9	Eskdale Well	UT 18-304	39.133	-114.002	390758114000701	4,965	2010-03-17	N/A	13.73
10	West Buckskin Well	UT 18-555	39.097	-113.942	390549113562901	4,985	2014-03-05	N/A	-1.67
11	Flowing Well 2	UT 18-719	39.084	-114.016	390503114005901	5,030	2014-03-05	N/A	6.95
12	Kane Spring	UT 18-406	39.143	-114.036	N/A	4,995	—	—	N/A
13	Phil Spring	UT 18-742	39.289	-114.017	N/A	4,980	—	—	N/A
14	Unnamed Spring 1	unknown	39.176	-114.009	N/A	4,970	—	—	N/A
15	Caine Spring	unknown	39.138	-114.049	390818114025501	5,024	2005-12-12	0.003	N/A
16	Unnamed Spring 2	unknown	39.151	-114.166	N/A	6,540	—	—	N/A
17	Unnamed Spring 3	unknown	39.150	-114.167	N/A	6,480	—	—	N/A
18	Want Spring	NV R05275	39.127	-114.289	N/A	6,680	—	—	N/A
19	Unnamed Spring 4	unknown	39.040	-114.197	N/A	6,180	—	—	N/A
20	Kious Spring	unknown	38.985	-114.160	385911114093101	6,023	—	—	N/A
21	Mahogany Spring	unknown	38.959	-114.152	N/A	6,500	—	—	N/A
22	Unnamed Spring 5	NV R05271	38.734	-114.116	N/A	5,545	—	—	N/A
23	Shell Baker Creek Well	UT 18-168	39.045	-114.024	390243114012201	5,079	2014-03-05	N/A	44.22

from existing and proposed groundwater withdrawals. Limitations in time and funding precluded the collection of additional data, revisions to the existing model, or the development of an updated groundwater-flow model of the area. This assessment provides a general understanding of the relative susceptibility of BLM water rights to existing and proposed groundwater withdrawals in Snake Valley.

General Description of Snake Valley

Snake Valley, which covers approximately 3,685 square miles (mi^2), is part of the Great Basin carbonate and alluvial aquifer system (GBCAAS), which comprises aquifers and confining units in unconsolidated basin-fill and volcanic deposits, carbonate, and other bedrock units (Heilweil and others, 2011). Altitudes in Snake Valley range from less than 4,400 feet (ft) at the bottom of the basin in the northern end of the valley to more than 13,000 ft for the highest peaks of the Snake Range. Climatic conditions range from temperate in the high-altitude Snake and Deep Creek Ranges to semiarid and arid across much of the rest of the area. Annual precipitation varies from about 6 inches in the low altitudes of northernmost Snake Valley to about 30 inches in the highest altitudes of the Snake and Deep Creek Ranges, based on 30-year average PRISM (Parameter-Elevation Regressions on Independent Slopes Model) precipitation data (Daly and others, 1994; 2008). The majority of precipitation falls during the winter months and is often snow that accumulates in the mountains. Most groundwater in the valley is derived from snowmelt and rainfall that fell above altitudes of 6,000 ft where precipitation amounts generally exceed losses from evapotranspiration (Hood and Rush, 1965).

The local economy is dominated by irrigated agriculture and ranching. Few perennial streams flow into the basins, and those that do are fully appropriated. Total annual withdrawal of groundwater on the Utah side of Snake Valley was approximately 14,900 acre-ft/yr in 2011 and 22,900 acre-ft/yr in 2012 (Burden and others, 2013), nearly all of which was used to irrigate approximately 9,200 acres of land (Welch and others, 2007). Existing groundwater withdrawals have affected water levels in Snake Valley. For example, several wells monitored by the U.S. Geological Survey have shown water-level declines of 6 to 20 ft near the Eskdale area since the mid-1970s and 1980s (fig. 2).

In recent years, groundwater withdrawals for irrigation in the unconsolidated basin fill have increased, especially in the southern part of Snake Valley. The source of water for these withdrawals is partially from groundwater in storage, but is also from the capture of natural discharge. One such example of this is Needle Point Springs in southern Snake Valley, which was a watering source for stock and wild horses; water levels in the vicinity of the spring, however, have declined so that the spring is no longer flowing (P. Summers, Bureau of Land Management, written commun., March 2013). Increasing groundwater withdrawals in Snake Valley will continue to affect the groundwater system by removing more groundwater from storage, decreasing groundwater levels, and decreasing natural discharge to springs and evapotranspiration in the basin.

Additionally, the Southern Nevada Water Authority (SNWA) has proposed developing unappropriated groundwater resources in Snake Valley and surrounding basins in eastern Nevada to supply water to the growing urban population of Las Vegas, Nevada. SNWA proposes to pump groundwater from five valleys in eastern Nevada by using a network of 144 to 174 wells, up to 430 mi of collector pipelines, and approximately 300 mi of main and lateral pipeline to deliver water to Las Vegas, which is more than 250 mi south of Baker, Nevada (Southern Nevada Water Authority, 2011). SNWA has proposed developing up to 185,000 acre-ft/yr of its existing water rights and applications in Spring, Snake, Cave, Dry Lake, and Delamar Valleys of eastern Nevada.

Previous Studies

Early evaluations of groundwater in Snake Valley were published by Hood and Rush (1965). This reconnaissance study provided general descriptions of groundwater resources and water quality. Gates and Kruer (1981) summarized and compiled data from this and earlier studies of basins in the vicinity of Snake Valley to evaluate the southern Great Salt Lake Desert better as an integrated groundwater flow system.

During the 1980s, the U.S. Geological Survey (USGS) Regional Aquifer System Analysis (RASA) program assessed the Nation’s major aquifer systems and, as part of this effort, delineated major aquifer systems in the Great Basin (GB) and evaluated regional flow in the Carbonate-Rock Province of the Great Basin (Harrill and Prudic, 1998). The RASA-GB study included hydrogeology (Plume and Carlton, 1988), geochemistry (Thomas and others, 1996), hydrology (Thomas and others, 1986; Harrill and others, 1988), and a numerical groundwater-flow model (Prudic and others, 1995) for a large geographic area that includes Snake Valley.

Kirby and Hurlow (2005) revisited the hydrogeology of the Snake Valley area with the goal of assessing the potential effects of the proposed SNWA groundwater-development project on groundwater resources in Utah by using an existing, basin-scale geologic framework and numerical groundwater-flow model. Their conclusion that the current understanding of geology and hydrology for the area was insufficient prompted the State of Utah to fund a long-term groundwater-monitoring network in the Snake Valley area. This network includes wells and spring gages in Snake Valley and wells in Tule Valley and Fish Springs Flat, where groundwater levels and discharge are monitored continuously (Utah Geological Survey, 2009).

A more recent regional investigation, the Basin and Range carbonate-rock aquifer system study (BARCAS), was completed by the USGS and the Desert Research Institute in compliance with federal legislation to investigate the groundwater-flow system of White Pine County and adjacent

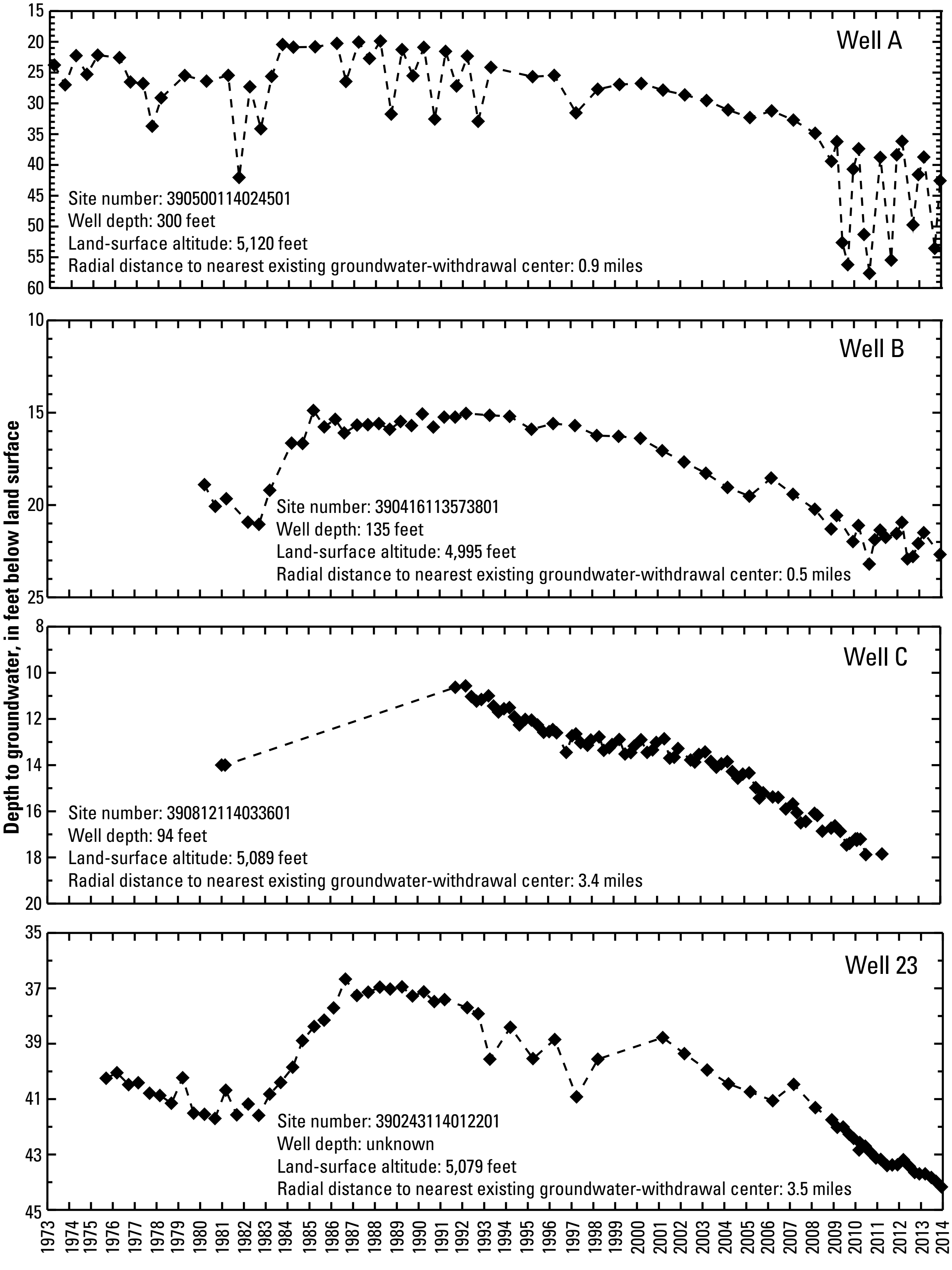


Figure 2. Water-level hydrographs from four wells near Eskdale, Utah. Well identifications on each hydrograph correspond to the wells on figure 1.

counties in Nevada and Utah. The BARCAS study developed potentiometric-surface maps showing groundwater-flow directions both in alluvial and carbonate aquifers; derived new groundwater-budget estimates; and assessed interbasin groundwater flow by using a combination of basin-boundary geology, hydraulic head data, and geochemistry. The results of the BARCAS study are available in a summary report (Welch and others, 2007).

A comprehensive summary of hydrologic data for the entire Great Basin carbonate and alluvial aquifer system (GBCAAS) presents an updated conceptual model of groundwater flow for an 110,000 mi^2 area predominantly in eastern Nevada and western Utah (Heilweil and Brooks, 2011) that includes Snake Valley. This study was part of a national water census program summarizing groundwater availability on regional scales across the U.S. In addition to providing a summary and compilation of data collected from numerous sources, the GBCAAS report also includes a new hydrogeologic framework created by extracting and combining information from a variety of datasets, a regional potentiometric-surface map for the entire study area, and groundwater-budget estimates compiled for 165 individual hydrographic areas (HAs) and 17 regional groundwater-flow systems.

To assess the hydrologic effects of the proposed SNWA groundwater development in Snake Valley, Halford and Plume (2011), in cooperation with the National Park Service, refined and recalibrated the RASA-GB numerical model (Prudic and others, 1995) in Spring and Snake Valleys (Great Basin National Park calibration, or GBNP-C, model). A variant of this model (Great Basin National Park predictive, or GBNP-P, model) was used to estimate potential effects of the SNWA groundwater development on water levels, groundwater evapotranspiration, and spring discharges around the southern Snake Range. Results of the study showed that (1) simulated drawdown was attenuated where natural groundwater discharge by springs and evapotranspiration was captured, which causes less drawdown than would have occurred if all of this groundwater came from storage depletion; (2) capture rates (capture distributed areally) of natural groundwater discharge by well withdrawals in Snake Valley were generally less than 1 cubic foot per year per square foot, (ft^3/yr/ft^2), but could be as great as 3 ft^3/yr/ft^2 locally; and (3) simulated drawdowns greater than 1 ft propagated outside of Spring and Snake Valleys after 200 years of groundwater pumping in all scenarios.

Hydrogeology

Snake Valley is a deep structural basin composed of carbonate and siliciclastic-sedimentary rocks of Precambrian and Paleozoic age and igneous intrusive rocks of Jurassic to Tertiary age. Basin-fill deposits of Tertiary and Quaternary age and volcanic rocks of Tertiary age have accumulated in the basin, reaching thicknesses of 5,000–10,000 ft (Sweetkind and others, 2007, pl. 1).

The groundwater system in the study area consists of water in unconsolidated deposits in the basins and in consolidated rock underlying the basins and in the adjacent mountain blocks. The consolidated rock and basin-fill aquifers are well connected hydraulically (Gardner and others, 2011; Sweetkind and others, 2011b), with most of the recharge occurring in the consolidated rock mountain blocks and most of the discharge occurring in the lower altitude basin-fill deposits.

Hydrogeologic Units and Hydraulic Properties

Halford and Plume (2011) used a simplified hydrogeologic framework to define hydrogeologic units (HGUs) in their model. An HGU has considerable lateral extent and reasonably distinct physical characteristics that can be used to infer the capacity of a sediment or rock to transmit water. Halford and Plume (2011) identified seven HGUs in Snake Valley (fig. 3), and further simplified these to six HGUs that were used in the numerical model (Halford and Plume, 2011, figs. 2, 3, and 9, and table 2): (1) a low-permeability unit representing low- to moderate-permeability Triassic- to Precambrian-age siliciclastic formations as well as Tertiary- to Jurassic-age intrusive igneous rocks that are locally exposed in the mountain ranges and underlie parts of Snake Valley; (2) a carbonate unit representing predominantly high- to moderate-permeability Pennsylvanian- through Cambrian-age carbonate rocks that are locally exposed in the mountain ranges and underlie portions of Snake Valley and also includes low-permeability Mississippian-age siliciclastic rocks, predominantly shales, that are limited in area; (3) a volcanic unit representing low- to high-permeability Cenozoic-age volcanic rocks that are locally exposed in the mountain ranges and underlie parts of Snake Valley; (4) a coarse-grained basin-fill unit representing moderate- to high-permeability Cenozoic-age basin fill and volcanic rocks buried within the basin fill; (5) a fine-grained basin-fill unit representing Cenozoic-age basin fill that includes a wide variety of low- to moderate-permeability basin-fill sediments; and (6) a karstic unit, representing high-permeability karstic rocks locally exposed in and near Great Basin National Park.

The USGS Nevada Water Science Center (NVWSC) has done eight aquifer tests in Snake and Spring Valleys (Halford and Plume, 2011, table 1). These included single and multiple pumping well tests in the basin-fill and carbonate aquifers and were analyzed by a variety of methods, including Cooper-Jacob analyses and three-dimensional numerical simulations (*http://nevada.usgs.gov/water/AquiferTests/aqtests.htm* accessed on September 4, 2012).

The wells and springs where the BLM holds water rights are near Partoun (sites 6–8) and Eskdale (sites 9–15) in discharge areas of the basin fill (fig. 3). There are no known geologic barriers to groundwater flow between the proposed withdrawal locations and the BLM water sources of interest, except near Coyote Spring (UT 18-596, site 8). There is a fault that lies near Coyote Spring; it is unknown, however, whether this fault acts as a barrier, especially since at the surface basin

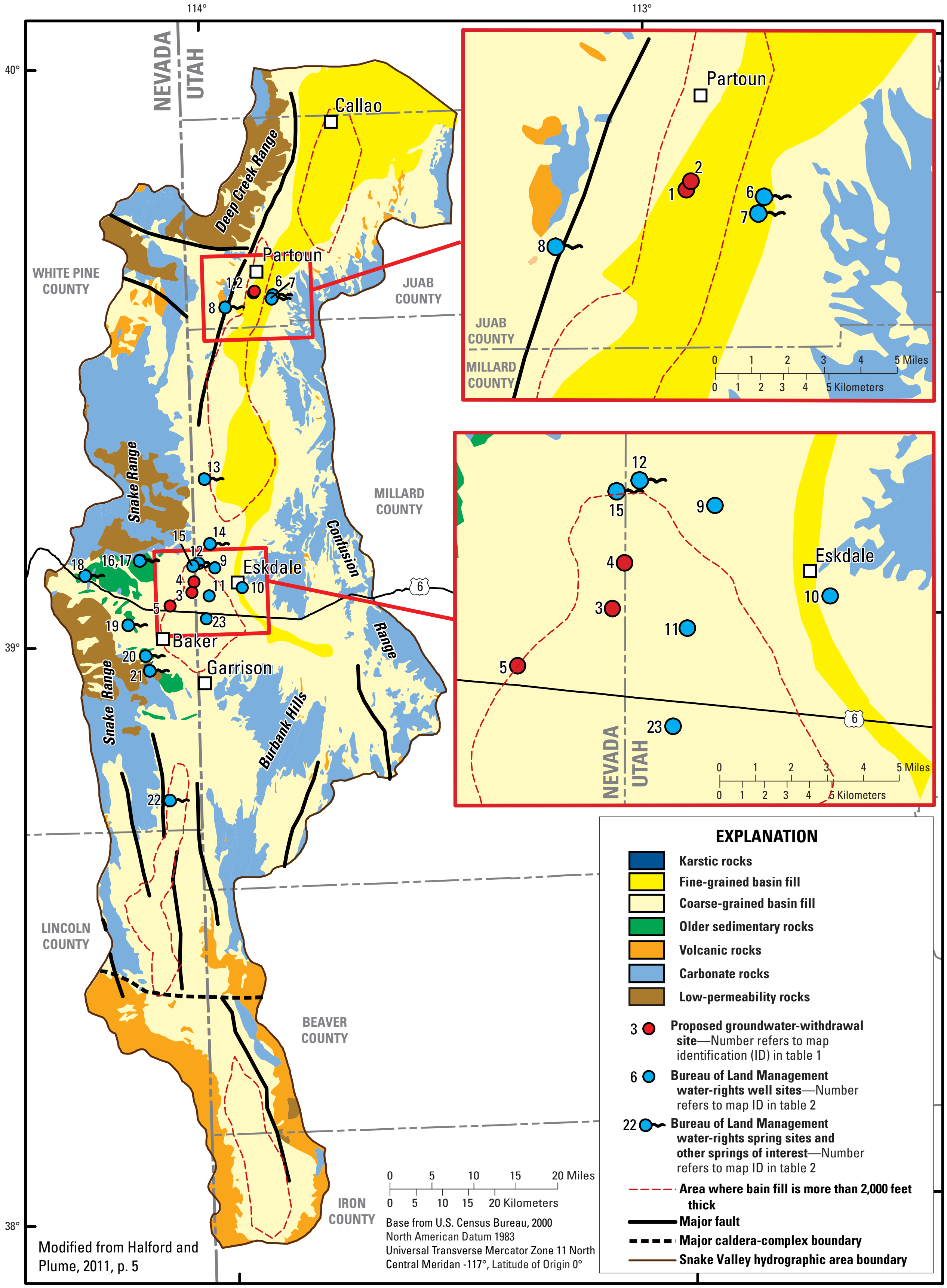


Figure 3. Surficial extent of hydrogeologic units, thickness of basin fill, and prominent structural geologic features in Snake Valley.

fill is juxtaposed against basin fill. Although the area around Partoun is underlain by fine-grained basin fill, transmissivities of the basin fill near Partoun are only slightly less than transmissivities in the basin fill elsewhere in Snake Valley. Transmissivity of the basin fill ranges between 100 and 10,000 square feet per day (ft^2/d) near Partoun and ranges between 1,000 and 10,000 ft^2/d near Eskdale and the Utah-Nevada border. East of Eskdale, where carbonate rocks predominate, transmissivity ranges between 10,000 and 50,000 ft^2/d.

Occurrence and Movement of Groundwater

Groundwater is recharged mostly from the infiltration of precipitation at higher altitudes (Welch and others, 2007; San Juan and others, 2010; Masbruch and others, 2011). Much of this recharge is from snowmelt. Additional, but limited recharge, results from the infiltration of runoff from precipitation near the mountain front and from infiltration along stream channels (Hevesi and others, 2003; Flint and Flint, 2007a, b; Flint and others, 2011; Masbruch and others, 2011). There also could be recharge (return flow) from applied irrigation. Groundwater moves from areas of recharge to springs and streams in the mountains and to evapotranspiration areas, springs, and wells in the basin.

Gardner and others (2011) published a potentiometric map of Snake Valley and surrounding areas. This map presents contours based on water levels measured during the spring of 2010 from 190 wells completed in consolidated rock and unconsolidated basin fill. Evaluation of vertical and horizontal hydraulic gradients within Snake Valley indicated that (1) aquifers within the consolidated rock and unconsolidated basin fill are generally hydraulically well connected and often act as a single aquifer unit; (2) potential groundwater flow in Snake Valley is primarily north-northeastward, and eastward interbasin flow out of Snake Valley could be restricted in places by steeply dipping, northeast trending, siliciclastic rocks extending from the Mountain Home Range as far north as the Confusion Range; and (3) there is the potential for some groundwater flow out of the study area toward the Great Salt Lake Desert to the north from Snake Valley. Groundwater generally flows in an eastward direction from the Snake Range to Partoun and Eskdale.

Water-Level and Discharge Fluctuations

Groundwater levels fluctuate in response to imbalances between groundwater recharge and discharge and are driven both by natural and anthropogenic processes. Gardner and others (2011) presented multiple-year water-level hydrographs for 32 wells completed in the basin fill in Snake Valley and the surrounding valleys, which showed that patterns of water-level fluctuation are distinctly different across the study area.

Water levels in several wells near agricultural withdrawal centers appeared to be influenced by groundwater withdrawals (fig. 2). Water levels in these areas rose in response to a period of above-average precipitation during the mid-1980s (Wilkowske and others, 2003), and most reached a maximum around the late 1980s to early 1990s. Since that time, water levels in these areas have fallen steadily and showed little to no recovery during subsequent periods of above-average precipitation (for example, 1996–98 and 2004–05). These declines are most likely caused by groundwater withdrawal used for irrigation.

Water levels in wells farther from the agricultural withdrawal centers showed much different responses to natural processes. Wells on the western side of Snake Valley are close to high-altitude mountain areas that receive substantial winter precipitation and groundwater recharge. Water levels in these wells clearly responded to annual recharge or to multiple-year periods of above- or below-average precipitation. Wells close to the Snake and Deep Creek Ranges (for example, fig. 4, wells D and E) showed water-level fluctuations of 10–20 ft over periods of only a few years. In the eastern half of the Snake Valley, however, water-level fluctuations were minimal, varying by less than about 2 ft over the period of record (for example, fig. 4, wells F and G). These steady water levels are likely due to a combination of low recharge rates in the nearby mountains and negligible groundwater pumping in these areas.

Water levels also have been monitored near springs throughout Snake Valley since 2009 by the Utah Geological Survey. Data from Leland-Harris Spring, Miller Spring, and Twin Springs (sites J, K, and L, respectively, on fig. 1) indicated seasonal water-level fluctuations of 1 to 2 feet (available at *http://geology.utah.gov/databases/groundwater/map.php?proj_id=1* accessed on April 4, 2014). These seasonal fluctuations could be a response to seasonal recharge (snowmelt) in the spring, to well withdrawals during the summer irrigation season, or both, because water levels are lowest in the summer, and recover through the fall, winter, and spring. Average daily discharge at Miller Spring for the period May 2010 to December 2013 ranged from 0.22 to 0.45 cubic feet per second (ft^3/s), average daily discharge at Twin Springs North for the period December 2009 to January 2014 ranged from 1.3 to 1.6 ft^3/s, and average daily discharge at Twin Springs South for the period May 2010 to January 2014 ranged from 1.1 to 1.5 ft^3/s. It is difficult to distinguish seasonal responses in these discharge rates.

Effects of Existing and Proposed Groundwater Withdrawals

The GBNP-P model (Halford and Plume, 2011) was used to quantify potential groundwater drawdown and capture of natural discharge from existing and proposed groundwater withdrawals in Snake Valley for the BLM water-rights sites and other springs of interest. The GBNP-P model is a transient, numerical groundwater-flow model that uses the direct-drawdown approach. Water-level changes and decreases in groundwater discharges are simulated rather than total water

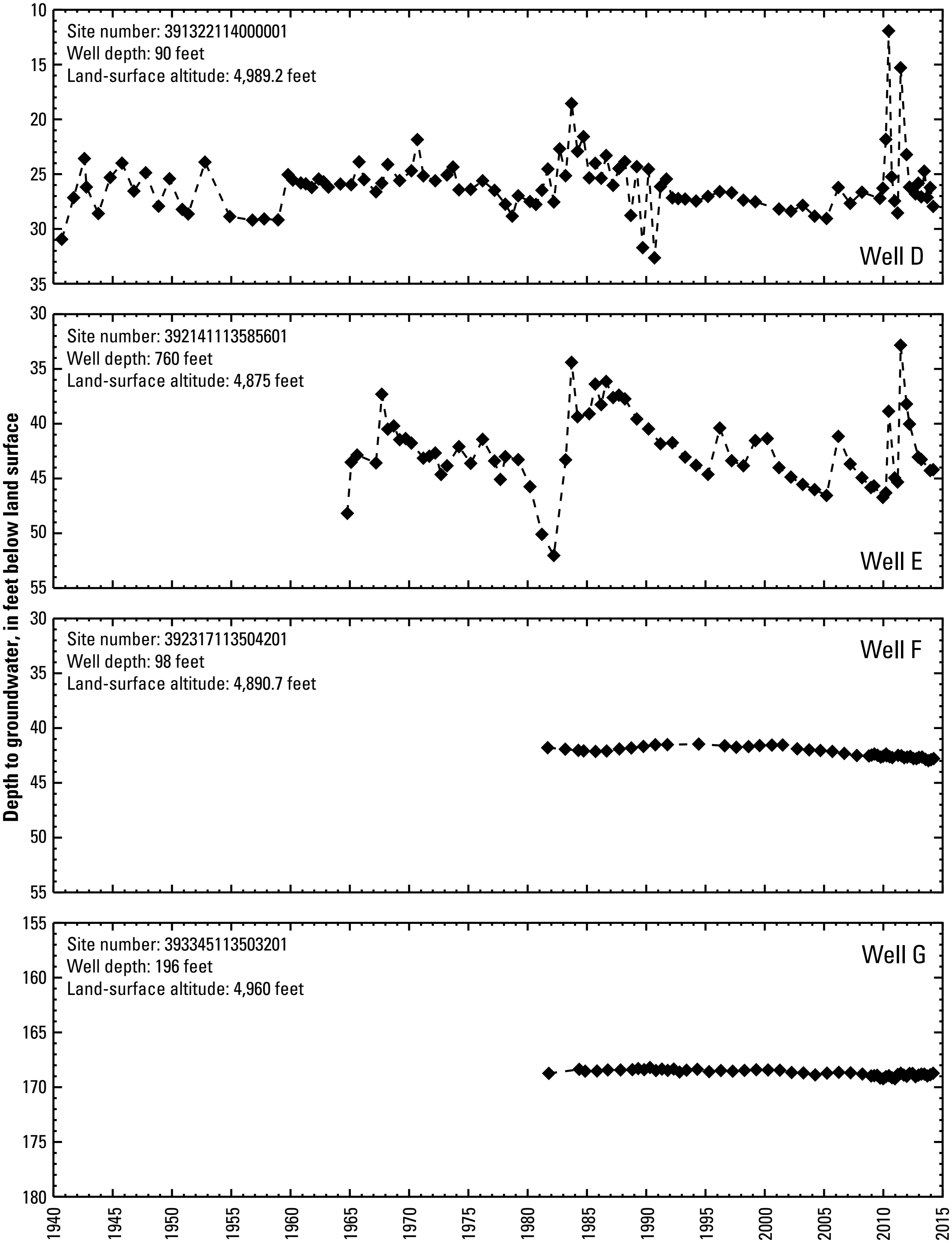


Figure 4. Water-level hydrographs from four wells between Eskdale and Partoun, Utah, not affected by existing groundwater withdrawals. Well identifications on each hydrograph correspond to the wells on figure 1.

levels and discharges. Model input includes hydraulic-conductivity, transmissivity, storage coefficient, and groundwater-discharge (including well withdrawal) distributions (Leake and others, 2010). The hydraulic conductivity of basin fill and transmissivity of basement rock were estimated with the GBNP-C model (Halford and Plume, 2011). Specific yield was estimated from aquifer tests in Spring and Snake Valleys and distributed with the surface geology (Halford and Plume, 2011).

The GBNP-C and GBNP-P models (Halford and Plume 2011), which incorporate the same area as the RASA-GB numerical model (Prudic and others, 1995), are divided into 230 rows and 184 columns of variably-spaced rectangular cells (fig. 5) and were locally refined in the area around Great Basin National Park. The smallest cells are 1,640 ft on a side; cell lengths and widths are multiplied successively by 1.2 going outward from this area of uniform cells. The models are divided into four layers (Halford and Plume, 2011, fig. 10): layer 1 is 10 ft thick and used to simulate groundwater and surface-water interaction, layer 2 is 50 ft thick and used to simulate extensive fine-grained deposits in Snake Valley, layer 3 simulates basin fill more than 60 ft thick, and layer 4 simulates carbonate rocks and low permeability bedrock. The thicknesses of layers 3 and 4 are variable and range from 1 to 2,000 ft. Hydraulic properties and boundary conditions were defined primarily from the RASA-GB model, except in Spring and Snake Valleys, where the RASA-GB model was recalibrated.

Existing groundwater withdrawals in Snake Valley were simulated by assuming an average application rate of 2.5 ft/yr (Halford and Plume, 2011) on the acreage irrigated during 2002 (fig. 5; Welborn and Moreo, 2007). This application rate, multiplied by the irrigated acreage, resulted in existing withdrawals of about 19,000 acre-ft/yr. The additional proposed withdrawals (table 1) were simulated as withdrawals from the model cells that contained these new points of diversion. Because the GBNP-P model starts at the end of pre-development conditions, existing groundwater withdrawals need to be simulated for a span of time to bring the model from pre-development conditions to the start of 2014. In the original GBNP-P model, a 40-year initial period was used to simulate the cumulative withdrawals (760,000 acre-ft) from 1945 to 2004 (Halford and Plume, 2011). This 40-year initial period was used instead of a 60-year period because the average withdrawals between 1945 and 2004 of 13,000 acre-ft/yr were less than the simulated withdrawals of 19,000 acre-ft/yr used in the model. In this study, the GBNP-P model was used to determine effects after 2014 and, therefore, existing groundwater withdrawals were simulated for a 50-year period prior to adding the proposed future withdrawals. After this initial 50-year period, existing withdrawals, additional proposed withdrawals, and resulting effects were simulated for periods of 5, 10, 25, 50, and 100 years. All groundwater withdrawals from wells were simulated from the basin fill in layer 3 of the GBNP-P model (Halford and Plume, 2011).

Effects of Existing Well Withdrawals

Long-term declines in water levels indicate existing groundwater withdrawals in Snake Valley are affecting water levels (fig. 2). The numerical model simulated similar declining trends in water levels; simulated drawdowns from the model, however, were less than observed water-level declines. For example, the hydrographs in figure 2 show observed water-level declines (drawdowns) in wells A, B, C, and 23, of 18, 6, 7, and 7 ft, respectively; simulated drawdowns after the initial 50-year period (prior to 2014) for these same wells are 11, 5, 3, and 3 ft, respectively. Because the GBNP-P model was not calibrated to observed water-level declines, it is difficult to determine the source of the error of the simulated drawdown for these wells. These errors could be the result of simplification of the conceptual model, discretization effects, difficulty obtaining sufficient measurements to account for all the spatial variation in hydraulic properties, or from some process that the model is either not simulating or not simulating accurately. Simulated drawdowns reported in the following sections and in table 3, therefore, could be different than what actually occurs.

After the initial 50-year period (prior to 2014), the largest simulated drawdowns resulting from existing groundwater withdrawals were near the large agricultural areas next to Callao, Eskdale, Baker, Garrison, and along the state line in southern Snake Valley (fig. 6). Simulated drawdowns in the center of these areas ranged between 10.1 and 26 ft. Simulated drawdowns at the BLM water-rights sites and other springs of interest resulting from existing withdrawals are summarized in table 3 (and in appendix 1). The largest potential water-level declines were at the BLM water-rights sites near Eskdale, namely the Eskdale Well (UT 18-304, site 9), West Buckskin Well (UT 18-555, site 10), Flowing Well 2 (UT 18-719, site 11), Kane Spring (UT 18-406, site 12), Caine Spring (site 15), Shell Baker Creek Well (UT 18-168, site 23), and at Unnamed Spring 5 (NV R05271, site 22). Simulated drawdowns at these sites ranged between 2 and 8 ft at the start of 2014.

After an additional 100 years of groundwater withdrawals from the existing wells, simulated drawdowns at the above mentioned sites near Eskdale only increased between 0.1 and 0.6 ft (fig. 7; table 3; appendix 1); this is likely because these sites are within a large area of natural discharge so that capture of natural discharge supplies some of the water, causing less drawdown than if all of the groundwater came from storage depletion. Simulated drawdowns after 150 years (including the initial 50-year period) of groundwater withdrawals from the existing wells were greater than this at a number of other BLM sites (fig. 7; table 3; appendix 1). For example, simulated drawdowns at Coyote Springs (UT 18-596, site 8) increased by 1 ft, and at Unnamed Springs 2 and 3 (sites 16 and 17) simulated drawdowns increased by over 2 ft. This is likely because the area of influence for the existing wells expanded over time to these sites, which are farther from the pumping centers, are in areas where there is less natural groundwater discharge available for capture, or both.

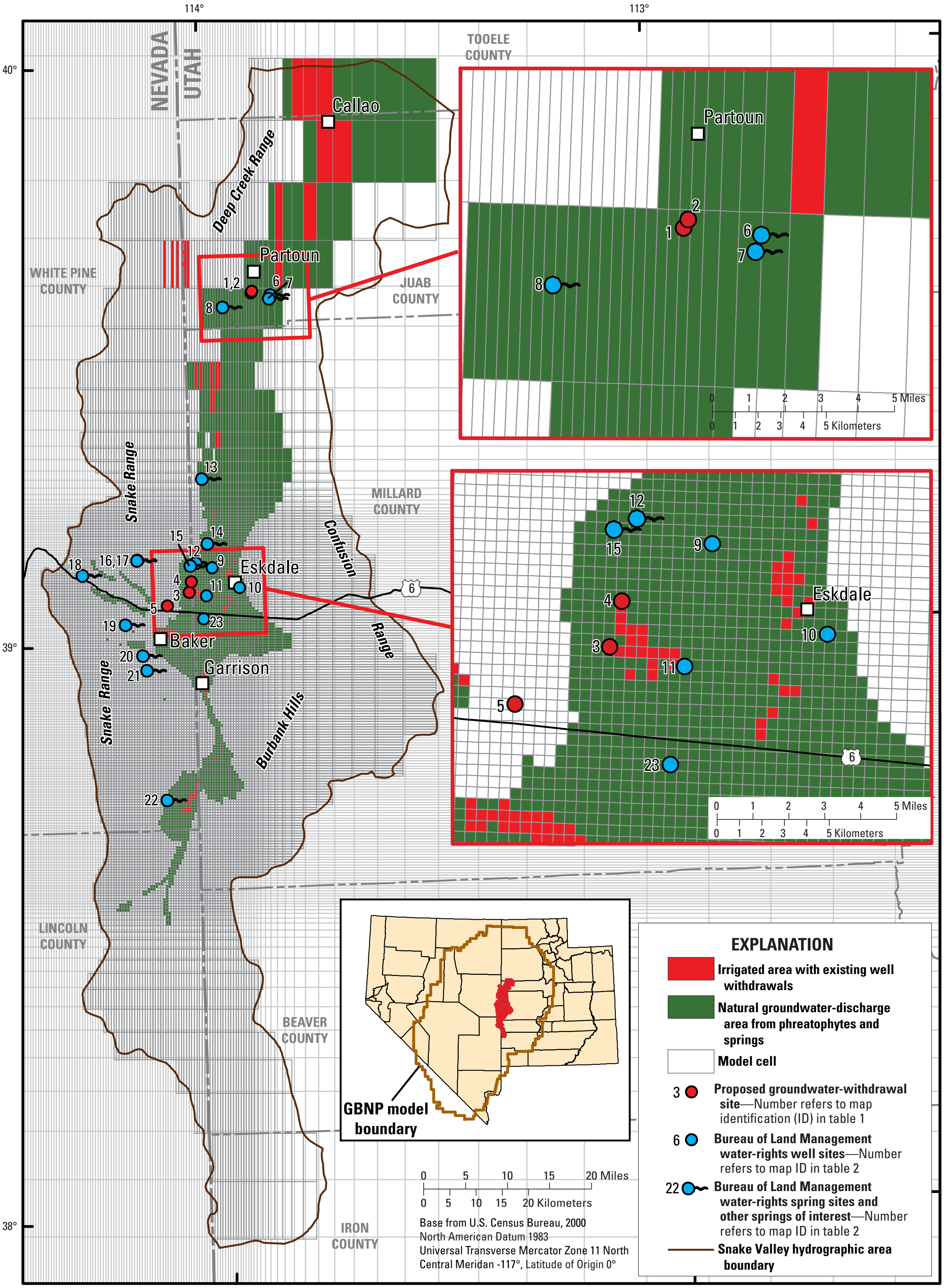


Figure 5. Model discretization, irrigated areas with existing groundwater withdrawals, and areas of natural groundwater discharge from evapotranspiration and springs simulated in the GBNP-P model in Snake Valley.

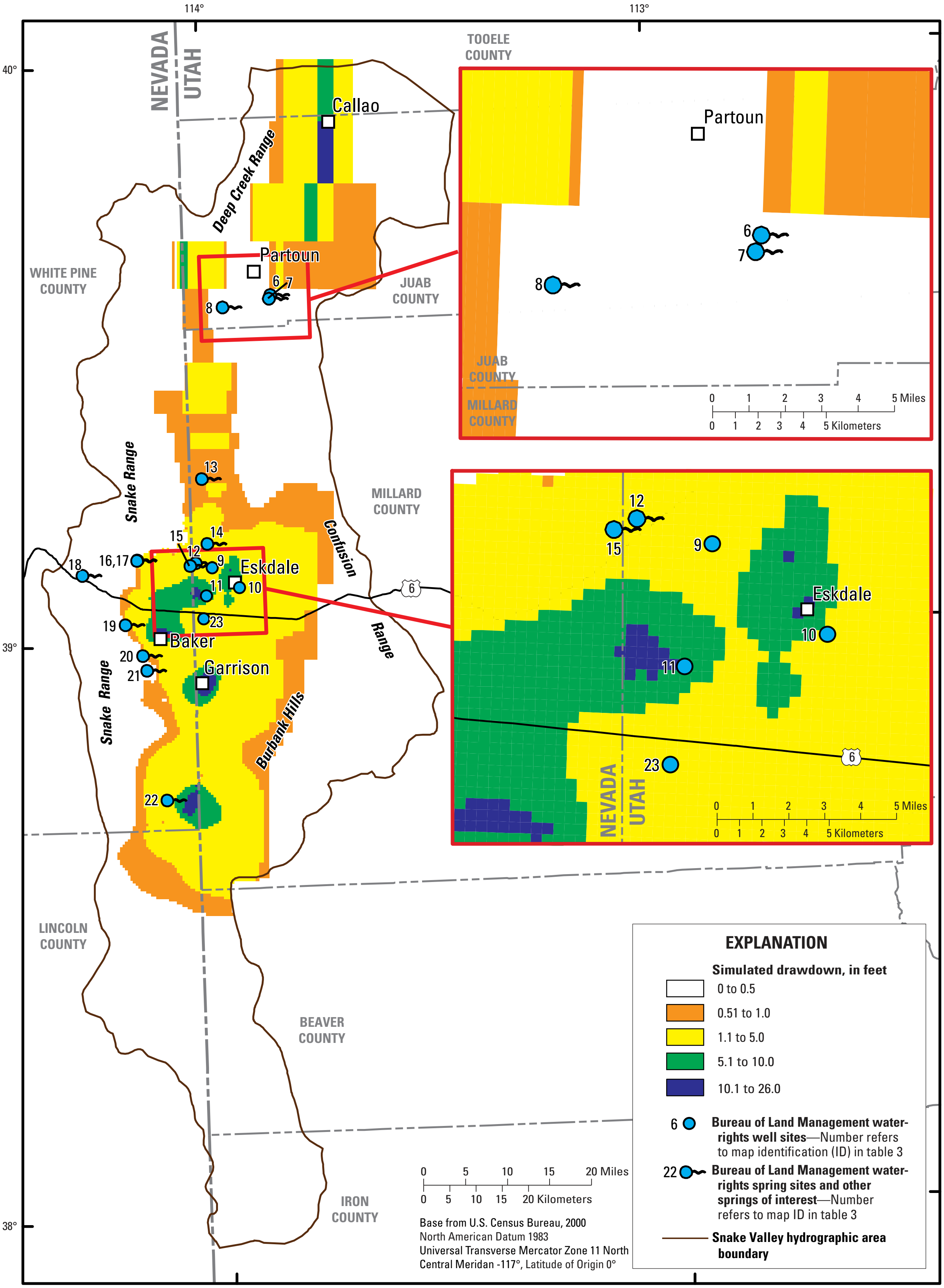


Figure 6. Simulated drawdowns of the water table after 50 years of existing groundwater withdrawals of 19,000 acre-feet per year for irrigation in Snake Valley.

Table 3. Simulated drawdowns of the water table resulting from existing groundwater withdrawals and proposed groundwater withdrawals at Bureau of Land Management water-rights sites and springs of interest.

[Refer to figure 1 for location of sites. Site name: includes state and water right number. Abbreviations: ID, identification; UT, Utah; NV, Nevada]

Map ID	Site name	Total simulated time (years)	Elapsed time from 2014 (years)	Existing with-drawals	Existing withdrawals plus proposed withdrawals	Proposed with-drawals only
				Simulated drawdown (feet)	Simulated drawdown (feet)	Simulated drawdown (feet)
6	Snake Valley North Spring Complex (UT 18-701)	50	0	0.2	0.2	0.0
		55	5	0.2	0.3	0.1
		60	10	0.2	0.4	0.2
		75	25	0.2	0.5	0.3
		100	50	0.3	0.6	0.3
		150	100	0.3	0.6	0.3
7	Snake Valley South Spring Complex (UT 18-702)	50	0	0.2	0.2	0.0
		55	5	0.2	0.3	0.1
		60	10	0.2	0.4	0.2
		75	25	0.2	0.5	0.3
		100	50	0.2	0.6	0.4
		150	100	0.2	0.6	0.4
8	Coyote Spring (UT 18-596)	50	0	0.3	0.3	0.0
		55	5	0.4	0.4	0.1
		60	10	0.4	0.6	0.2
		75	25	0.6	1.1	0.5
		100	50	0.8	1.5	0.7
		150	100	1.3	2.1	0.8
9	Eskdale Well (UT 18-304)	50	0	3.5	3.5	0.0
		55	5	3.5	3.7	0.2
		60	10	3.5	3.8	0.3
		75	25	3.5	4.0	0.4
		100	50	3.6	4.1	0.5
		150	100	3.6	4.1	0.5
10	West Buckskin Well (UT 18-555)	50	0	4.2	4.2	0.0
		55	5	4.2	4.2	0.0
		60	10	4.2	4.2	0.0
		75	25	4.2	4.3	0.1
		100	50	4.3	4.4	0.1
		150	100	4.3	4.4	0.1
11	Flowing Well 2 (UT 18-719)	50	0	7.8	7.8	0.0
		55	5	7.8	8.2	0.4
		60	10	7.8	8.4	0.6
		75	25	7.9	8.6	0.8
		100	50	7.9	8.7	0.9
		150	100	7.9	8.8	0.9
12	Kane Spring (UT 18-406)	50	0	2.4	2.4	0.0
		55	5	2.4	2.7	0.3
		60	10	2.5	2.9	0.5
		75	25	2.5	3.3	0.8
		100	50	2.6	3.6	1.0
		150	100	2.6	3.8	1.1
13	Phil Spring (UT 18-742)	50	0	0.9	0.9	0.0
		55	5	0.9	0.9	0.0
		60	10	0.9	0.9	0.0
		75	25	1.0	1.0	0.0
		100	50	1.0	1.0	0.0
		150	100	1.0	1.0	0.0
14	Unnamed Spring 1	50	0	1.1	1.1	0.0
		55	5	1.1	1.1	0.0
		60	10	1.1	1.2	0.0
		75	25	1.2	1.3	0.1
		100	50	1.2	1.4	0.1
		150	100	1.2	1.4	0.2
15	Caine Spring	50	0	2.8	2.8	0.0
		55	5	2.8	3.3	0.5
		60	10	2.9	3.6	0.7
		75	25	3.0	4.2	1.2
		100	50	3.1	4.6	1.5
		150	100	3.2	4.8	1.7
16	Unnamed Spring 2	50	0	1.1	1.1	0.0
		55	5	1.3	1.3	0.0
		60	10	1.4	1.4	0.0
		75	25	1.9	2.1	0.2
		100	50	2.6	3.4	0.8
		150	100	3.5	5.3	1.8
17	Unnamed Spring 3	50	0	1.0	1.0	0.0
		55	5	1.2	1.2	0.0
		60	10	1.3	1.3	0.0
		75	25	1.8	2.0	0.2
		100	50	2.5	3.2	0.7
		150	100	3.3	5.1	1.7

Table 3. Simulated drawdowns of the water table resulting from existing groundwater withdrawals and proposed groundwater withdrawals at Bureau of Land Management water-rights sites and springs of interest.—Continued

[Refer to figure 1 for location of sites. Site name: includes state and water right number. Abbreviations: ID, identification; UT, Utah; NV, Nevada]

Map ID	Site name	Total simulated time (years)	Elapsed time from 2014 (years)	Existing withdrawals	Existing withdrawals plus proposed withdrawals	Proposed withdrawals only
				Simulated drawdown (feet)	Simulated drawdown (feet)	Simulated drawdown (feet)
18	Want Spring (NV R05275)	50	0	0.0	0.0	0.0
		55	5	0.0	0.0	0.0
		60	10	0.0	0.0	0.0
		75	25	0.0	0.0	0.0
		100	50	0.0	0.0	0.0
		150	100	0.0	0.0	0.0
19	Unnamed Spring 4	50	0	0.4	0.4	0.0
		55	5	0.5	0.5	0.0
		60	10	0.5	0.5	0.0
		75	25	0.6	0.7	0.1
		100	50	0.7	0.8	0.1
		150	100	0.8	1.0	0.2
20	Kious Spring	50	0	0.2	0.2	0.0
		55	5	0.3	0.3	0.0
		60	10	0.3	0.3	0.0
		75	25	0.3	0.3	0.0
		100	50	0.4	0.4	0.0
		150	100	0.4	0.4	0.0
21	Mahogany Spring	50	0	0.1	0.1	0.0
		55	5	0.2	0.2	0.0
		60	10	0.2	0.2	0.0
		75	25	0.3	0.3	0.0
		100	50	0.4	0.4	0.0
		150	100	0.6	0.7	0.0
22	Unnamed Spring 5 (NV R05271)	50	0	3.9	3.9	0.0
		55	5	4.0	4.0	0.0
		60	10	4.0	4.0	0.0
		75	25	4.1	4.1	0.0
		100	50	4.3	4.3	0.0
		150	100	4.4	4.4	0.0
23	Shell Baker Creek Well (UT 18-168)	50	0	2.5	2.5	0.0
		55	5	2.5	2.7	0.2
		60	10	2.6	2.8	0.2
		75	25	2.6	3.0	0.4
		100	50	2.6	3.1	0.5
		150	100	2.6	3.2	0.6

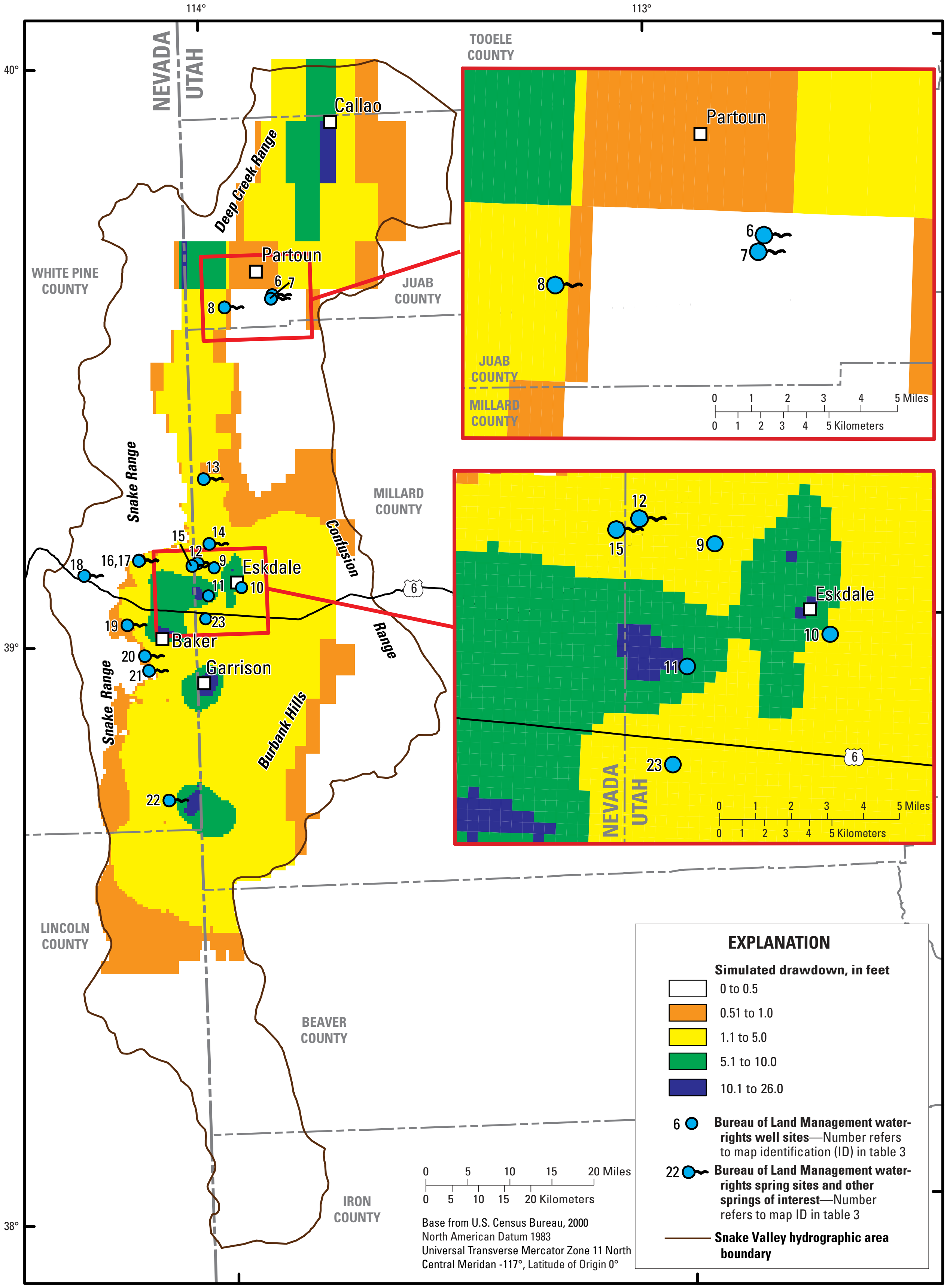
In addition to simulated drawdowns, the simulated amount of capture of natural groundwater discharge resulting from existing groundwater withdrawals also was computed by using the GBNP-P model. Although most of the springs identified by the BLM are not explicitly simulated in the model, the model simulates natural discharge as evapotranspiration in most of the model cells containing these springs. Assuming that some part of this natural discharge is related to spring flow, the amount of discharge captured from these cells also is likely to affect spring flow. Because the spring orifice could be discharging only a small percentage of the total groundwater discharge from the model cell, however, the percentage of simulated natural groundwater capture reported cannot be directly translated to a percentage of reduction in spring flow. Additionally, the model could continue to show that well withdrawals capture groundwater discharge from the model cell even when the hydraulic gradient and groundwater levels decline to the point where spring flow through the orifice ceases. The model would continue to simulate capture of transpiration from phreatophytes, which can have roots as deep as 35 to 60 ft below the land surface (Moreo and others, 2007) that could be much deeper than the spring orifice.

The amount of simulated natural groundwater capture resulting from existing groundwater withdrawals was calculated for 10 spring sites and is summarized in table 4 (and in appendix 2). The capture of simulated natural discharge could not be calculated at Unnamed Spring 2 (site 16), Unnamed Spring 3 (site 17), Want Spring (NV R05275, site 18), and Mahogany Spring (site 21) because no natural discharge was simulated in the model cells containing these springs in the GBNP-P model. The model cells where the simulated capture of natural groundwater discharge was largest are those containing Kane Spring, (UT 18-406, site 12), Caine Spring (site 15) and Unnamed Spring 5 (NV R05271, site 22). In the model cell containing Kane Spring, existing groundwater withdrawals captured 13 to 15 percent of the total amount of simulated natural discharge (18 acre-ft/yr). In the model cell containing Caine Spring, existing groundwater withdrawals captured 15 to 18 percent of the total amount of simulated natural discharge (18 acre-ft/yr). In the model cell containing Unnamed Spring 5, existing groundwater withdrawals captured 25 to 29 percent of the total amount of simulated natural discharge (9 acre-ft/yr).

Effects of Proposed Well Withdrawals

Because of seasonal changes in recharge and changes in precipitation over longer periods, water levels naturally vary annually and over longer periods of wet and dry years. Annual water-level variations in Snake Valley are about 1 to 2 ft, and, during longer wet to dry cycles, water-level variations range from 2 to 20 ft (fig. 4). Effects of groundwater withdrawals on water levels are superimposed over this natural variation.

Figure 8 shows the combined simulated drawdowns in Snake Valley resulting from the existing groundwater



Base from U.S. Census Bureau, 2000
North American Datum 1983
Universal Transverse Mercator Zone 11 North
Central Meridian -117°, Latitude of Origin 0°

Figure 7. Simulated drawdowns of the water table after 150 years (100 years after 2014) of existing groundwater withdrawals of 19,000 acre-feet per year in Snake Valley.

Table 4. Simulated capture of natural discharge resulting from existing groundwater withdrawals and proposed groundwater withdrawals at Bureau of Land Management water-rights sites and other springs of interest.

[Refer to figure 1 for location of sites. Capture, as used in this report, is capture of groundwater by withdrawals that would otherwise discharge naturally to springs or evapotranspiration. Abbreviations: ID, identification; acre-ft/yr, acre-feet per year; ft^3/d, cubic feet per day; %, percent; =, equals; N/A, not applicable]

				Existing withdrawals			Existing withdrawals plus proposed withdrawals			Proposed withdrawals only		
Map ID	**Site name**	**Total simulated time (years)**	**Elapsed time from 2014 (years)**	**Simulated capture of natural discharge (ft^3/d)**	**Simulated capture of natural discharge (acre-ft/yr)**	**Simulated capture (% of total simulated natural discharge)**	**Simulated capture of natural discharge (ft^3/d)**	**Simulated capture of natural discharge (acre-ft/yr)**	**Simulated capture (% of total simulated natural discharge)**	**Simulated capture of natural discharge (ft^3/d)**	**Simulated capture of natural discharge (acre-ft/yr)**	**Simulated capture (% of total simulated natural discharge)**
6 and 7	Snake Valley North and South Spring Complexes (total simulated natural discharge in model cell = 463 acre-ft/yr)	50	0	116	1.0	0.21	116	1.0	0.21	0	0.0	0.00
		55	5	125	1.0	0.23	358	3.0	0.65	233	2.0	0.42
		60	10	133	1.1	0.24	746	6.3	1.35	613	5.1	1.11
		75	25	155	1.3	0.28	1,261	10.6	2.28	1,106	9.3	2.00
		100	50	186	1.6	0.34	1,450	12.2	2.63	1,264	10.6	2.29
		150	100	233	2.0	0.42	1,556	13.0	2.82	1,323	11.1	2.40
8	Coyote Spring (total simulated natural discharge in model cell = 5 acre-ft/yr)	50	0	10	0.1	1.54	10	0.1	1.54	0	0.0	0.00
		55	5	12	0.1	1.81	13	0.1	2.07	2	0.0	0.26
		60	10	13	0.1	2.08	21	0.2	3.17	7	0.1	1.09
		75	25	19	0.2	2.93	41	0.3	6.37	22	0.2	3.43
		100	50	28	0.2	4.38	60	0.5	9.26	32	0.3	4.88
		150	100	46	0.4	7.06	81	0.7	12.60	36	0.3	5.54
12	Kane Spring (total simulated natural discharge in model cell = 18 acre-ft/yr)	50	0	293	2.5	13.32	293	2.5	13.32	0	0.0	0.00
		55	5	299	2.5	13.61	328	2.8	14.93	29	0.2	1.32
		60	10	304	2.6	13.86	360	3.0	16.38	55	0.5	2.52
		75	25	315	2.6	14.34	412	3.5	18.74	97	0.8	4.40
		100	50	324	2.7	14.74	448	3.8	20.39	124	1.0	5.64
		150	100	330	2.8	15.03	469	3.9	21.35	139	1.2	6.33
13	Phil Spring (total simulated natural discharge in model cell = 52 acre-ft/yr)	50	0	365	3.1	5.90	365	3.1	5.90	0	0.0	0.00
		55	5	373	3.1	6.03	373	3.1	6.03	0	0.0	0.00
		60	10	379	3.2	6.13	379	3.2	6.13	0	0.0	0.00
		75	25	391	3.3	6.32	392	3.3	6.34	1	0.0	0.01
		100	50	401	3.4	6.48	403	3.4	6.52	2	0.0	0.04
		150	100	407	3.4	6.59	412	3.5	6.66	4	0.0	0.07
14	Unnamed Spring 1 (total simulated natural discharge in model cell = 31 acre-ft/yr)	50	0	233	2.0	6.35	233	2.0	6.35	0	0.0	0.00
		55	5	237	2.0	6.48	239	2.0	6.53	2	0.0	0.04
		60	10	241	2.0	6.59	247	2.1	6.73	5	0.0	0.15
		75	25	249	2.1	6.79	266	2.2	7.26	17	0.1	0.47
		100	50	255	2.1	6.95	283	2.4	7.73	28	0.2	0.78
		150	100	259	2.2	7.06	294	2.5	8.02	35	0.3	0.96
15	Caine Spring (total simulated natural discharge in model cell = 18 acre-ft/yr)	50	0	337	2.8	15.32	337	2.8	15.32	0	0.0	0.00
		55	5	345	2.9	15.71	389	3.3	17.72	44	0.4	2.01
		60	10	352	3.0	16.04	433	3.6	19.73	81	0.7	3.69
		75	25	367	3.1	16.70	506	4.2	23.04	139	1.2	6.33
		100	50	380	3.2	17.27	558	4.7	25.38	178	1.5	8.11
		150	100	388	3.3	17.67	588	4.9	26.76	200	1.7	9.09
16	Unnamed Spring 2 (total simulated natural discharge in model cell = 0 acre-ft/yr)	50	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		55	5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		60	10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		75	25	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		100	50	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		150	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Table 4. Simulated capture of natural discharge resulting from existing groundwater withdrawals and proposed groundwater withdrawals at Bureau of Land Management water-rights sites and other springs of interest.—Continued

[Refer to figure 1 for location of sites. Capture, as used in this report, is capture of groundwater by withdrawals that would otherwise discharge naturally to springs or evapotranspiration. Abbreviations: ID, identification; acre-ft/yr, acre-feet per year; ft^3/d, cubic feet per day; %, percent; =, equals; N/A, not applicable]

Map ID	Site name	Total simulated time (years)	Elapsed time from 2014 (years)	Existing withdrawals			Existing withdrawals plus proposed withdrawals			Proposed withdrawals only		
				Simulated capture of natural discharge (ft^3/d)	Simulated capture of natural discharge (acre-ft/yr)	Simulated capture (% of total simulated natural discharge)	Simulated capture of natural discharge (ft^3/d)	Simulated capture of natural discharge (acre-ft/yr)	Simulated capture (% of total simulated natural discharge)	Simulated capture of natural discharge (ft^3/d)	Simulated capture of natural discharge (acre-ft/yr)	Simulated capture (% of total simulated natural discharge)
17	Unnamed Spring 3 (total simulated natural discharge in model cell = 0 acre-ft/yr)	50	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		55	5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		60	10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		75	25	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		100	50	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		150	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
18	Want Spring (total simulated natural discharge in model cell = 0 acre-ft/yr)	50	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		55	5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		60	10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		75	25	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		100	50	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		150	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
19	Unnamed Spring 4 (total simulated natural discharge in model cell = 145 acre-ft/yr)	50	0	498	4.2	2.88	498	4.2	2.88	0	0.0	0.00
		55	5	544	4.6	3.15	546	4.6	3.16	2	0.0	0.01
		60	10	585	4.9	3.39	592	5.0	3.43	7	0.1	0.04
		75	25	677	5.7	3.92	736	6.2	4.26	59	0.5	0.34
		100	50	770	6.5	4.46	931	7.8	5.39	161	1.3	0.93
		150	100	850	7.1	4.92	1,113	9.3	6.44	263	2.2	1.52
20	Kious Spring (total simulated natural discharge in model cell = 362 acre-ft/yr)	50	0	456	3.8	1.06	456	3.8	1.06	0	0.0	0.00
		55	5	494	4.1	1.14	494	4.1	1.14	0	0.0	0.00
		60	10	526	4.4	1.22	527	4.4	1.22	1	0.0	0.00
		75	25	599	5.0	1.39	607	5.1	1.41	8	0.1	0.02
		100	50	675	5.7	1.56	703	5.9	1.63	28	0.2	0.06
		150	100	743	6.2	1.72	801	6.7	1.85	58	0.5	0.13
21	Mahogany Spring (total simulated natural discharge in model cell = 0 acre-ft/yr)	50	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		55	5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		60	10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		75	25	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		100	50	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		150	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
22	Unnamed Spring 5 (total simulated natural discharge in model cell = 9 acre-ft/yr)	50	0	279	2.3	25.39	279	2.3	25.39	0	0.0	0.00
		55	5	285	2.4	25.88	285	2.4	25.88	0	0.0	0.00
		60	10	289	2.4	26.28	289	2.4	26.28	0	0.0	0.00
		75	25	299	2.5	27.14	299	2.5	27.14	0	0.0	0.00
		100	50	308	2.6	28.00	308	2.6	28.00	0	0.0	0.00
			100	318	2.7	28.85	318	2.7	28.85	0	0.0	0.00

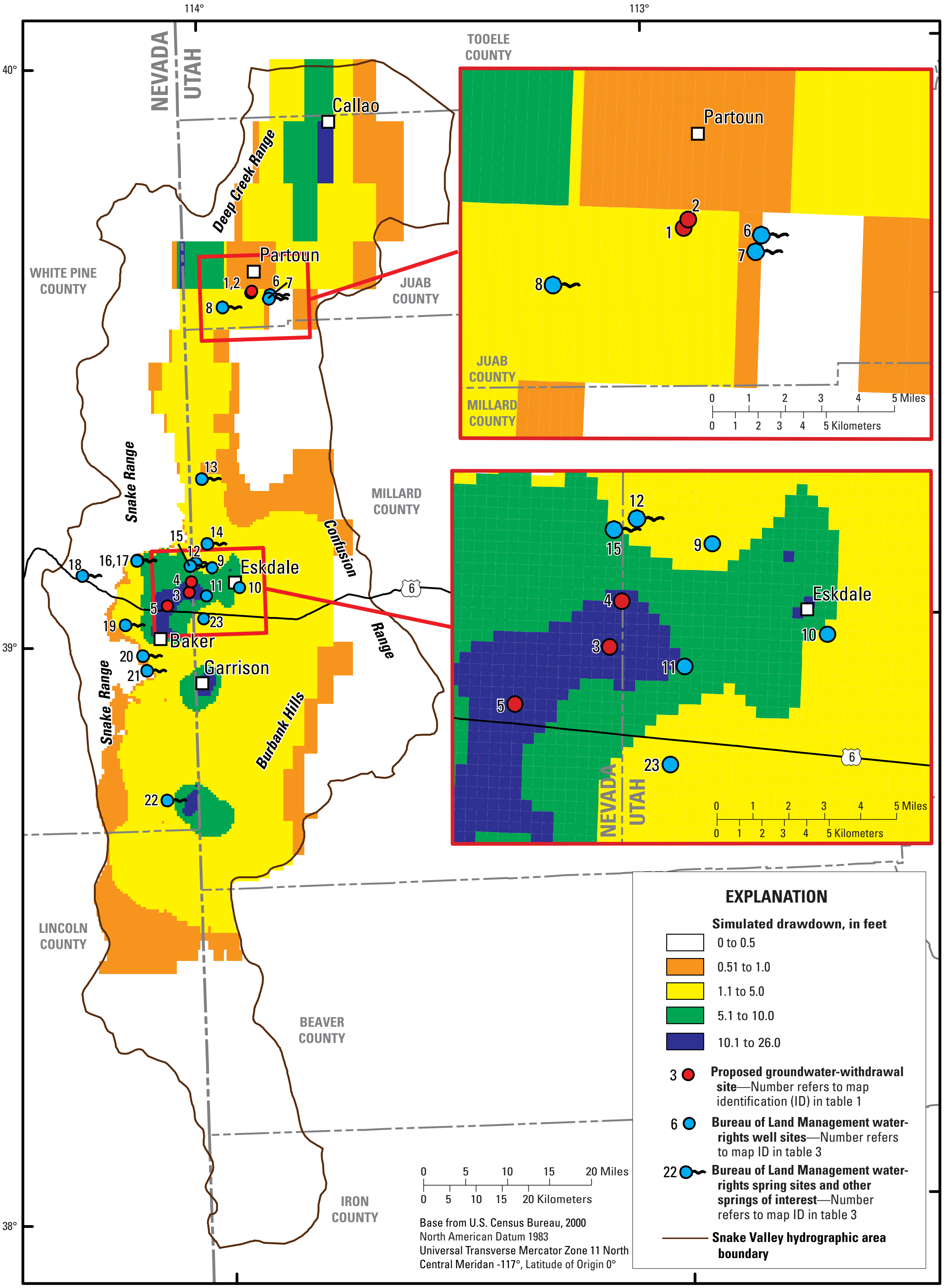


Figure 8. Simulated drawdowns of the water table after 100 years (from 2014) of existing groundwater withdrawals of 19,000 acre-feet per year and proposed groundwater withdrawals of 1,800 acre-feet per year in Snake Valley.

withdrawals and proposed groundwater withdrawals after 100 years (from 2014). The most notable differences compared to drawdown resulting from existing groundwater withdrawals alone were in the area just south of Partoun, where drawdowns increased from less than 0.5 ft to up to 5 ft, and in the area between Baker and Eskdale, where the areas with drawdowns of greater than 10 ft increased (figs. 8 and 9).

The effects of the proposed withdrawals on water levels at the BLM water-rights sites and other springs of interest in Snake Valley are summarized in table 3, appendix 1, and figure 9. Simulated drawdown resulting from the proposed withdrawals started in as few as 5 years at seven of the sites. The sites with the largest simulated drawdowns, 1 to 2 ft, after 100 years of proposed withdrawals are Kane Spring (UT 18-406, site 12), Caine Spring (site 15), Unnamed Spring 2 (site 16), and Unnamed Spring 3 (site 17). Coyote Spring (UT 18-596, site 8), Eskdale Well (UT 18-304, site 9), Flowing Well 2 (UT 18-719, site 11), and Shell Baker Creek Well (UT-168, site 23) showed simulated drawdowns ranging between 0.5 and 0.9 ft after 100 years. Simulated drawdowns after 100 years at Snake Valley North (UT 18-701) and South (UT 18-702) Spring Complexes (sites 6 and 7), West Buckskin Well (UT 18-555, site 10), and Unnamed Springs 1 and 4 (sites 14 and 19) ranged between 0.1 and 0.4 ft. Phil Spring (UT 18-742, site 13), Want Spring (NV R05275, site 18), Kious Spring (site 20), Mahogany Spring (site 21), and Unnamed Spring 5 (NV R05271, site 22) showed no simulated drawdown resulting from the proposed withdrawals even after 100 years.

The simulated capture of natural groundwater discharge resulting from the proposed withdrawals is summarized in table 4 (and in appendix 2), with the same limitations presented in the “Effects of Existing Well Withdrawals” section of this report. Similar to the simulated drawdowns, simulated capture of natural groundwater discharge resulting from the proposed withdrawals started in as few as 5 years for model cells containing seven of the sites. The largest amounts of simulated capture of natural groundwater discharge resulting from the proposed groundwater withdrawals after 100 years were in the model cells containing Coyote Spring (UT 18-596, site 8), which had a simulated capture amount of 5.5 percent of the total simulated natural discharge (5 acre-ft/yr); Kane Spring (UT 18-406, site 12), which had a simulated capture amount of 6.3 percent of the total simulated natural discharge (18 acre-ft/yr); and Caine Spring (site 15), which had a simulated capture amount of 9.1 percent of the total simulated natural discharge (18 acre-ft/yr). There were slightly lesser amounts of simulated groundwater capture after 100 years at the cells containing Snake Valley North (UT 18-701) and South (UT 18-702) Spring Complexes (sites 6 and 7), which had a simulated capture amount of 2.4 percent of the total simulated natural discharge (463 acre-ft/yr), and Unnamed Spring 4 (site 19), which had a simulated capture amount of 1.5 percent of the total simulated natural discharge (145 acre-ft/yr). Simulated natural groundwater capture amounts of less than 1 percent occurred in the model cells containing Phil Spring (UT 18-742, site 13), Unnamed Spring 1 (site 14), and Kious Spring (site 20). There was no simulated capture of natural groundwater discharge from the model cell containing Unnamed Spring 5 (NV R05271, site 22), even after 100 years. The capture of simulated natural discharge could not be calculated for Unnamed Spring 2 (site 16), Unnamed Spring 3 (site 17), Want Spring (NV R05275, site 18), and Mahogany Spring (site 21) because no natural discharge was simulated in the model cells containing these springs in the GBNP-P model.

Model Limitations

The GBNP-P model is a regional model designed to address questions about regional groundwater development in Snake Valley, but, like all models, it is a simplification and cannot incorporate all of the complexities of the actual groundwater-flow system. The model is limited by a simplified conceptual model, discretization effects, and the difficulty of obtaining sufficient measurements to account for all spatial variation in hydraulic properties (Halford and Plume, 2011). The extent of drawdown projections could be displaced horizontally by 0.5 mi along the contacts between basin fill and low permeability bedrock. Because of discretization errors, a minimum uncertainty of 1,640 ft exists in the map location and areal extent of drawdown (Halford and Plume, 2011). Errors in hydraulic diffusivity, which is the transmissivity divided by the storage coefficient, inversely affect the timing of groundwater capture. Errors in hydraulic diffusivity estimates of up to 50 percent in the GBNP-P model are possible, so 50-percent errors in the timing of groundwater-capture predictions can also occur (Halford and Plume, 2011). Simulated drawdown and groundwater capture will also change if recharge changes. Water levels will decline further than projections indicate if recharge decreases (Halford and Plume, 2011).

Estimates of historical and existing groundwater withdrawals are a generalization. Simulated amounts of groundwater withdrawals were estimated by application rates distributed on fields rather than withdrawal rates at specific wells. This causes errors in the amount and location of simulated drawdown near the irrigation withdrawal centers. These errors decrease with increasing distance from the withdrawal centers.

Because the BLM water-rights springs and other springs of interest are not explicitly simulated in the model, there is uncertainty in the estimate of groundwater capture from these springs. The model does simulate natural discharge as evapotranspiration in most of the model cells containing these springs. Assuming that some part of this natural discharge is related to spring flow, the amount of discharge potentially captured from these cells also is likely to affect spring flow. Because the spring orifice could be discharging only a small percentage of the total groundwater discharge from the model cell, however, the percentage of simulated natural groundwater capture reported cannot be directly translated to a percentage of reduction in spring flow. Additionally, the model could continue to show that well withdrawals are capturing groundwater

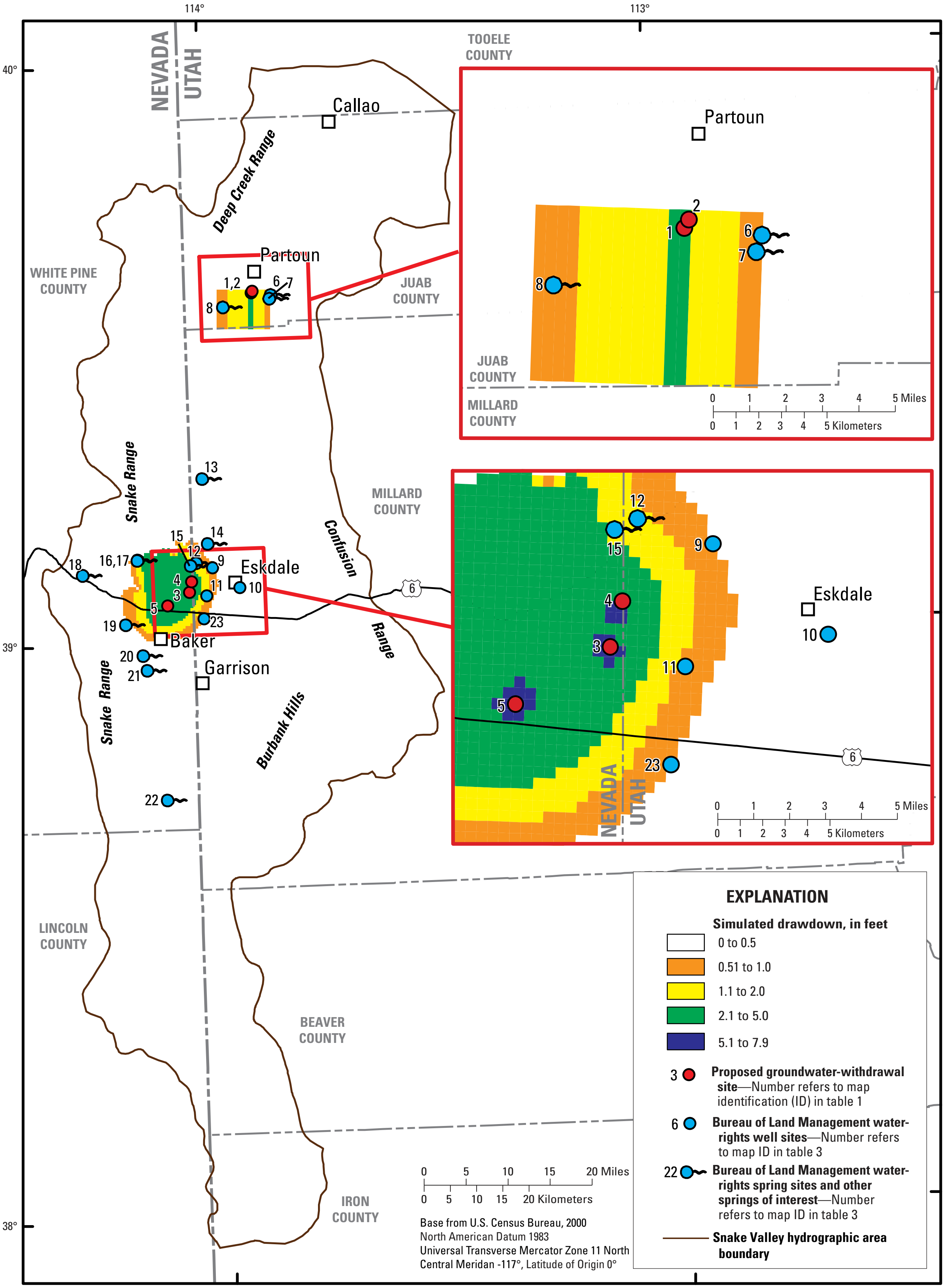


Figure 9. Simulated drawdowns of the water table after 100 years (from 2014) of proposed groundwater withdrawals of 1,800 acre-feet per year in Snake Valley.

discharge from the model cell even when the hydraulic gradient and groundwater levels decline to the point where spring flow through the orifice ceases. The model would continue to simulate capture of transpiration from phreatophytes, which can have roots much deeper than the spring orifice. Because the springs are not explicitly simulated in the model, it is impossible to determine how much of the potential captured groundwater is coming from the springs compared to how much is coming from evapotranspiration. Additionally, different types of springs respond differently to changing groundwater levels caused by well withdrawals. Springs that are sourced near the water table could be very sensitive to groundwater-level change, whereas springs that are sourced deeper in the system might not be as sensitive.

Appropriate Uses of the Model

The model can be used to simulate potential effects of groundwater withdrawals within the limitations described previously. It is difficult to assess the extent of the limitations on use and interpretation of results because of the lack of discharge data for the spring sites. With limited information on spring flow and source of water to these springs, it is difficult to precisely quantify how the BLM water-right springs and other springs of interest will be affected by the proposed groundwater withdrawals. A more exact determination could be made by physically monitoring spring flow while a long-term aquifer test was in progress. Given the absence of historical and current monitoring data, the modeling demonstrates that the proposed groundwater withdrawals could affect groundwater levels at certain BLM water-rights sites and other springs of interest. Monitoring of discharge, nearby water levels, or both, is important for long-term assessment and management of these water resources.

Summary

Several water-right change applications have been filed with the State of Nevada to change the point of diversion for six existing water rights near Baker, Nevada, to three points of diversion approximately 5 to 6 miles to the north, just west of Eskdale, Utah, with a combined planned groundwater withdrawal of about 1,270 acre-feet per year (acre-ft/yr). Additionally, new water rights have been filed with the State of Utah for two new wells near Partoun, Utah, with a combined planned withdrawal of about 550 acre-ft/yr. The Bureau of Land Management (BLM) has identified 11 sites where BLM holds water rights and 7 other springs of interest that could be affected by these proposed groundwater withdrawals. Of most importance and nearest to the new points of diversion are three wells and one spring near Eskdale, Utah, and three springs or spring complexes located near Partoun, Utah. Additional water resources of interest are springs that have public water rights, or are on public or state lands.

This report presents a hydrogeologic analysis of areas in Snake Valley to assess the potential range of effects on BLM water rights and other springs of interest resulting from existing and proposed groundwater withdrawals. A previously developed numerical groundwater-flow model was used to quantify potential drawdown and capture (groundwater withdrawals that result in depletion) of natural discharge resulting from existing and proposed groundwater withdrawals. This assessment provides a general understanding of the susceptibility of BLM water rights to existing and proposed groundwater withdrawals in Snake Valley.

The BLM water-right wells and springs near Partoun and Eskdale are in discharge areas of the basin fill, where it exceeds thicknesses of 2,000 feet (ft). There are no known geologic barriers to groundwater flow between the proposed withdrawal locations and the BLM water sources of interest. Transmissivity of the basin fill ranges between 100 and 10,000 square feet per day (ft^2/d) near Partoun and ranges between 1,000 and 10,000 ft^2/d near Eskdale and the Utah-Nevada border. East of Eskdale, transmissivity ranges between 10,000 and 50,000 ft^2/d where carbonate rocks predominate.

The GBNP-P model (Halford and Plume, 2011) was used to quantify potential drawdown and capture of natural groundwater discharge resulting from existing and proposed groundwater withdrawals in Snake Valley for the BLM water rights and other springs of interest. The GBNP-P model is a transient, numerical groundwater-flow model that uses the direct-drawdown approach. Water-level changes and decreases in groundwater discharges are simulated rather than total water levels and discharges. Existing withdrawals in Snake Valley were simulated by multiplying an average groundwater application rate of 2.5 feet per year (ft/yr) by the amount of irrigated acreage that was observed during 2002, which resulted in simulated existing withdrawals of approximately 19,000 acre-ft/yr. Existing groundwater withdrawals were simulated for a 50-year period prior to adding the proposed withdrawals to bring the model from pre-development conditions to the start of 2014. After this initial 50-year period, existing withdrawals, additional proposed withdrawals, and resulting effects were simulated for periods of 5, 10, 25, 50, and 100 years.

Downward trends in water levels measured in wells indicated that the existing groundwater withdrawals in Snake Valley are affecting water levels. The numerical model simulated similar downward trends in water levels. The largest simulated drawdowns caused by existing groundwater withdrawals were near the large agricultural areas adjacent to Callao, Eskdale, Baker, Garrison, and along the Utah-Nevada border in southern Snake Valley and ranged between 10 and 26 ft near the centers of these areas. The largest simulated water-level declines were at the BLM water-rights sites near Eskdale, where simulated drawdowns ranged between 2 and 8 ft at the start of 2014. These simulated drawdowns were consistent with, but lower than, water-level declines observed in wells near Eskdale.

After an additional 100 years of existing groundwater withdrawals, simulated drawdowns at the sites near Eskdale only increased between 0.1 and 0.4 ft; this likely is because these sites are within a large area of natural discharge, so that capture of natural discharge supplied some of the water, causing less drawdown than if all of the groundwater came from storage depletion. Simulated drawdowns at a number of the other sites, however, showed increases of 1 to 2 ft, likely because the area of influence for the existing wells expanded over time to these sites, which are farther from the pumping centers, are in areas where there is less natural groundwater discharge available for capture, or both. These sites included Coyote Springs, and Unnamed Springs 2 and 3. The model cells where the amounts of simulated capture of natural groundwater discharge resulting from the existing groundwater withdrawals was largest are those containing Kane Spring, Caine Spring, and Unnamed Spring 5; existing groundwater withdrawals captured 13 to 29 percent of the simulated total natural discharge in these model cells.

Simulated drawdowns and the simulated capture of natural groundwater discharge resulting from the proposed withdrawals started in as few as 5 years at seven of the sites. The largest simulated drawdowns of 1 to 2 ft caused by the proposed withdrawals after 100 years were at Kane Spring, Caine Spring, Unnamed Spring 2, and Unnamed Spring 3. Coyote Spring, Eskdale Well, and Flowing Well 2 showed simulated drawdowns ranging between 0.5 and 0.9 ft after 100 years. Simulated drawdowns after 100 years at Snake Valley North and South Spring Complexes, West Buckskin Well, and Unnamed Springs 1 and 4 ranged between 0.1 and 0.4 ft. Phil Spring, Want Spring, Kious Spring, Mahogany Spring, and Unnamed Spring 5 showed no simulated drawdown resulting from the proposed withdrawals even after 100 years. The largest amounts of simulated capture of natural groundwater discharge resulting from the proposed withdrawals after 100 years were in the model cells containing Coyote Spring, Kane Spring, and Caine Spring, which had simulated capture amounts ranging between 5.5 and 9.1 percent of the total simulated natural groundwater discharge. Six sites had lesser simulated capture amounts than this, which ranged between less than 1 and 2.4 percent of the total simulated natural discharge in the cell after 100 years. The capture of simulated natural discharge could not be calculated for four sites because no natural discharge was simulated in the model cells containing these springs in the GBNP-P model.

The GBNP-P model is a regional model designed to address questions about regional groundwater development in Snake Valley, but, like all models, it is a simplification and cannot incorporate all of the complexities of the actual groundwater-flow system. Given the absence of historical and current monitoring data, the modeling demonstrated that the proposed groundwater withdrawals could affect groundwater levels at some of the BLM water rights sites and other springs of interest. Monitoring of discharge, nearby water levels, or both, is important for long-term assessment and management of these water resources.

References Cited

Burden, C.B. and others, 2013, Groundwater conditions in Utah, spring of 2012: Utah Department of Natural Resources Cooperative Investigations Report No. 54, 118 p.

Daly, C., Neilson, R.P., and Phillips, D.L., 1994, A statistical-topographic model for mapping climatological precipitation over mountain terrain: Journal of Applied Meteorology, v. 33, p. 140–158.

Daly, C., Halbleib, M., Smith, J.I., Gibson, W.P., Doggett, M.K., Taylor, G.H., Curtis, J., and Pasteris, P.A., 2008, Physiographically-sensitive mapping of temperature and precipitation across the conterminous United States: International Journal of Climatology, v. 28, p. 1977–2087.

Fenneman, N.M., 1931, Physiography of western United States: New York, McGraw-Hill Book Company, Inc., 534 p.

Flint, A.L., and Flint, L.E., 2007a, Application of the basin characterization model to estimate in-place recharge and runoff potential in the Basin and Range carbonate-rock aquifer system, White Pine County, Nevada, and adjacent areas in Nevada and Utah: U.S. Geological Survey Scientific Investigations Report 2007–5099, 20 p.

Flint, L.E., and Flint, A.L., 2007b, Regional analysis of ground-water recharge, *in* Stonestrom, D.A., Constantz, J., Ferré, T.P.A., and Leake, S.A., eds., Ground-water recharge in the arid and semiarid southwestern United States: U.S. Geological Survey Professional Paper 1703, p. 29–59.

Flint, A.L., Flint, L.E., and Masbruch, M.D., 2011, Input, calibration, uncertainty, and limitations of the Basin Characterization Model, Appendix 3 *of* Heilweil, V.M. and Brooks, L.E., eds., Conceptual model of the Great Basin carbonate and alluvial aquifer system: U.S. Geological Survey Scientific Investigations Report 2010–5193, p. 149–163.

Gardner, P.M., Masbruch, M.D., Plume, R.W., and Buto, S.G., 2011, Regional potentiometric-surface map of the Great Basin carbonate and alluvial aquifer system in Snake Valley and surrounding areas, Juab, Millard, and Beaver Counties, Utah, and White Pine and Lincoln Counties, Nevada: U.S. Geological Survey Scientific Investigations Map 3193, 2 sheets.

Gates, J.S., and Kruer, S.A., 1981, Hydrologic reconnaissance of the southern Great Salt Lake Desert and summary of the hydrology of west-central Utah: Utah Department of Natural Resources Technical Publication No. 71, 55 p.

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.

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 Hydrogeologic Investigations Atlas HA–694–C, 2 sheets, scale 1:1,000,000.

Harrill, J.R., and Prudic, D.E., 1998, Aquifer systems in the Great Basin region of Nevada, Utah, and adjacent states—summary report: U.S. Geological Survey Professional Paper 1409–A, 66 p.

Heilweil, V.M., and Brooks, L.E., eds., 2011, Conceptual model of the Great Basin carbonate and alluvial aquifer system: U.S. Geological Survey Scientific Investigations Report 2010–5193, 191 p.

Heilweil, V.M., Sweetkind, D.S., and Susong, D.D., 2011, Introduction, chapter A, *in* Heilweil, V.M. and Brooks, L.E., eds., Conceptual model of the Great Basin carbonate and alluvial aquifer system: U.S. Geological Survey Scientific Investigations Report 2010–5193, p. 3–14.

Hevesi, J.A., Flint, A.L., and Flint, L.E., 2003, Simulation of net infiltration and potential recharge using a distributed-parameter watershed model of the Death Valley region, Nevada and California: U.S. Geological Survey Water-Resources Investigations Report 03–4090, 161 p.

Hood, J.W., and Rush, F.E., 1965, Water-resources appraisal of the Snake Valley area, Utah and Nevada: Nevada Department of Conservation and Natural Resources Water Resources Reconnaissance Report 34, 43 p.

Kirby, S., and Hurlow, H., 2005, Hydrogeologic setting of the Snake Valley hydrologic basin, Millard County, Utah, and White Pine and Lincoln Counties, Nevada—Implications for possible effects of proposed water wells: Utah Geological Survey Report of Investigation 254, 22 p.

Leake, S.A., Reeves, H.W., and Dickinson, J.E., 2010, A new capture fraction method to map how pumpage affects surface water flow: Ground Water, v. 48, p. 690–700, doi: 10.1111/j.1745-6584.2010.00701.x.

Masbruch, M.D., Heilweil, V.M., Buto, S.G., Brooks, L.E., Susong, D.D., Flint, A.L., Flint, L.E., and Gardner, P.M., 2011, Estimated groundwater budgets, chapter D, *in* Heilweil, V.M. and Brooks, L.E., eds., Conceptual model of the Great Basin carbonate and alluvial aquifer system: U.S. Geological Survey Scientific Investigations Report 2010–5193, p. 73–125.

Moreo, M.T., Laczniak, R.J., and Stannard, D.I., 2007, Evapotranspiration rate measurements of vegetation typical of ground-water discharge areas in the Basin and Range carbonate-rock aquifer system, Nevada and Utah, September 2005–August 2006: U.S. Geological Survey Scientific Investigations Report 2007–5078, 36 p.

Plume, R.W., and Carlton, S.M., 1988, Hydrogeology of the Great Basin region of Nevada, Utah, and adjacent states: U.S. Geological Survey Hydrologic Investigations Atlas HA–694–A, 1 sheet, scale 1:1,000,000.

Prudic, D.E., Harrill, J.R., and Burbey, T.J., 1995, Conceptual evaluation of regional ground-water flow in the Carbonate Rock Province of the Great Basin Nevada, Utah, and adjacent states: U.S. Geological Survey Professional Paper 1409–D, 102 p.

San Juan, C.A., Belcher, W.R., Laczniak, R.J., and Putnam, H.M., 2010, Hydrologic components for model development, chapter C *in* Belcher, W.R., ed., Death Valley regional ground-water flow system, Nevada and California—Hydrogeologic framework and transient ground-water flow model: U.S. Geological Survey Professional Paper 1711, p. 99–132.

Southern Nevada Water Authority (SNWA), 2011, Southern Nevada Water Authority Clark, Lincoln, and White Pine Counties groundwater development project conceptual plan of development, 152 p., available on the Southern Nevada Water Authority website at *http://www.snwa.com/assets/pdf/wr_gdp_concept_plan_2011.pdf*, accessed on July 31, 2012

Sweetkind, D.S., Knochenmus, L.A., Ponce, D.A., Wallace, A.R., Scheirer, D.S., Watt, J.T., and Plume, R.W., 2007, Hydrogeologic framework, *in* Welch, A.H., Bright, D.J., and Knochenmus, L.A., eds., Water resources of the Basin and Range carbonate-rock aquifer system, White Pine County, Nevada and adjacent areas in Nevada and Utah: U.S. Geological Survey Scientific Investigations Report 2007–5261, p. 11–36.

Sweetkind, D.S., Cederberg, J.R., Masbruch, M.D., and Buto, S.G., 2011a, Hydrogeologic framework, chapter B, *in* Heilweil, V.M., and Brooks, L.E., eds., Conceptual model of the Great Basin carbonate and alluvial aquifer system: U.S. Geological Survey Scientific Investigations Report 2010–5193, p. 15–50.

Sweetkind, D.S., Masbruch, M.D., Heilweil, V.M., and Buto, S.G., 2011b, Groundwater flow, chapter C, *in* Heilweil, V.M., and Brooks, L.E., eds., Conceptual model of the Great Basin carbonate and alluvial aquifer system: U.S. Geological Survey Scientific Investigations Report 2010–5193, p. 51–72.

Thomas, J.M., Mason, J.L., and Crabtree, J.D., 1986, Groundwater levels in the Great Basin region of Nevada, Utah, and adjacent states: U.S. Geological Survey Hydrologic Investigations Atlas HA–694–B, 2 sheets, scale 1:1,000,000.

Thomas, J.M., Welch, A.H., and Dettinger, M.D., 1996, Geochemistry and isotope hydrology of representative aquifers in the Great Basin region of Nevada, Utah, and adjacent states: U.S. Geological Survey Professional Paper 1409–C, 100 p.

Utah Geological Survey, 2009, Snake Valley ground-water monitoring-well project: Snake Valley and adjacent areas, available on the Utah Geological Survey website at *http://geology.utah.gov/esp/snake_valley_project/index.htm*, accessed on August 6, 2012.

Welborn, T.L., and Moreo, M.T., 2007, Irrigated acreage within the Basin and Range carbonate-rock aquifer system, White Pine County, Nevada, and adjacent areas in Nevada and Utah: U.S. Geological Survey Data Series 273, 18 p.

Welch, A.H., Bright, D.J., and Knochenmus, L.A., eds., 2007, Water resources of the Basin and Range carbonate-rock aquifer system, White Pine County, Nevada, and adjacent areas in Nevada and Utah: U.S. Geological Survey Scientific Investigations Report 2007–5261, 96 p.

Wilkowske, C.D., Allen, D.V., and Phillips, J.V., 2003, Drought conditions in Utah during 1999–2002—a historical perspective: U.S. Geological Survey Fact Sheet 037–03, 6 p.

Appendix 1

Table 1-1 is a Microsoft Excel® file available at *http://pubs.usgs.gov/of/2014/1176*.

1-1. Simulated drawdowns of the water table resulting from existing groundwater withdrawals and proposed groundwater withdrawals at Bureau of Land Management water-rights sites and springs of interest.

Appendix 2

Table 2-1 is a Microsoft Excel® file available at *http://pubs.usgs.gov/of/2014/1176*.

2-1. Simulated capture of natural discharge resulting from existing groundwater withdrawals and proposed groundwater withdrawals at Bureau of Land Management water-rights sites and other springs of interest.

Masbruch and Gardner—**Potential Effects of Existing and Proposed Groundwater Withdrawals on Water Levels and Natural Groundwater Discharge in Snake Valley, Juab and Millard Counties, Utah, White Pine County, Nevada, and Surrounding Areas in Utah and Nevada**—OFR 2014-1176

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