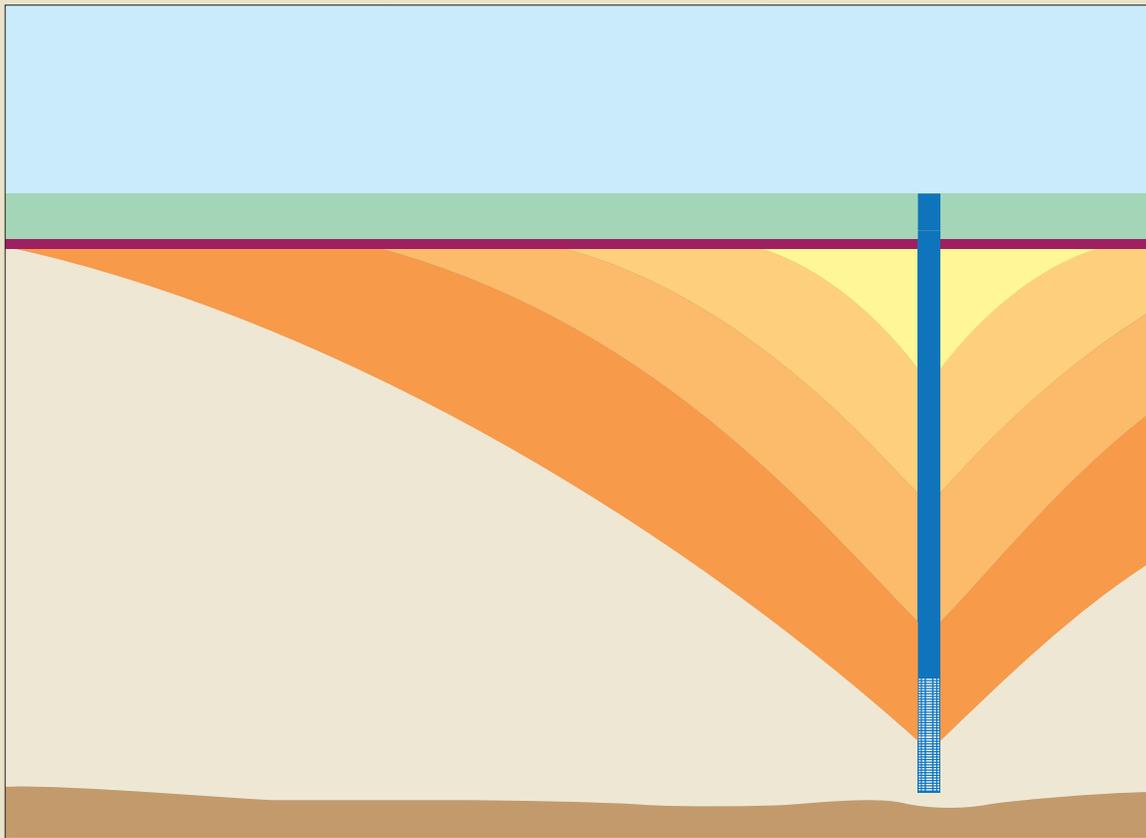


Prepared in cooperation with the U.S. Fish and Wildlife Service

Historical and Potential Groundwater Drawdown in the Bruneau Area, Owyhee County, Southwestern Idaho



Scientific Investigations Report 2012–5119

Cover: Diagrammatic representation of cones of depression produced by a pumping well.

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By Candice B. Adkins and James R. Bartolino

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Scientific Investigations Report 2012–5119

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

U.S. Department of the Interior
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U.S. Geological Survey, Reston, Virginia: 2012

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Conversion Factors and Datums

Conversion Factors

Multiply	By	To obtain
Length		
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Area		
acre	4,047	square meter (m ²)
square mile (mi ²)	2.590	square kilometer (km ²)
Volume		
gallon (gal)	0.003785	cubic meter (m ³)
cubic foot (ft ³)	0.02832	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)
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) may be converted to degrees Fahrenheit (°F) as follows:

$$^{\circ}\text{F}=(1.8\times^{\circ}\text{C})+32.$$

*Transmissivity: The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness [(ft³/d)/ft²]ft. In this report, the mathematically reduced form, foot squared per day (ft²/d), is used for convenience.

Datums

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

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

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

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Historical and Potential Groundwater Drawdown in the Bruneau Area, Owyhee County, Southwestern Idaho

By Candice B. Adkins and James R. Bartolino

Abstract

Geothermal seeps and springs in the Bruneau area in southwestern Idaho provide a vital but disappearing habitat for the Bruneau hot springsnail (*Pyrgulopsis bruneauensis*). In order to aid in conservation efforts, a two-part study was conducted (1) to determine trends in groundwater levels over time and (2) to simulate drawdown in aquifers that contribute to the geothermal seeps and springs along the Bruneau River.

Seasonal and Regional Kendall tests for trends were used to determine water-level trends over a 20-year monitoring (1990–2010) period. Seasonal Kendall tests were used to calculate trends in groundwater-levels in 22 monitoring wells and indicated statistically significant changes in water level with trends ranging from 0.21 to 1.0 feet per year. Regional Kendall tests were used to calculate drawdown in categories of wells based on five criteria (well depth, distance from Indian Bathtub Spring, geologic unit, regional topographic valley, and temperature). Results from Regional Kendall tests indicate that slope of the trend (in feet per year) increased as a function of well depth; trends in water level as a function of other categories did not exhibit an obvious pattern based on distance from Indian Bathtub Spring, geologic unit, topographic valley, or temperature.

Analytical solutions were used to simulate drawdown and recovery in wells using the Theis equation and a range of hydraulic parameters. Drawdown effects were determined by changing the storativity, transmissivity, and flow values over a hypothetical timeline. For example, estimates projected that after 20 years of pumping (at an assumed storativity of 0.002, a transmissivity of 980,000 feet squared per day, and a flow of 100 acre-feet per year), 1 foot of drawdown in the volcanic-rock aquifers would not be detected; however, other estimates using the same time frame but different hydraulic parameters (storativity of 0.001, transmissivity of 13,000 feet squared per day, and 610 acre-feet per year) determined 1 foot of drawdown to be detected as far as 29 miles from the hypothetical pumping well. A sensitivity analysis was performed to determine the effect of changing one hydraulic parameter while keeping the others constant. Many assumptions had to be made about properties of the aquifer in order to calculate effects of drawdown on geothermal seeps and springs. These analyses estimate pumping effects over time; the recovery of groundwater levels would likely take significantly longer to observe than the effects from pumping.

Introduction

The Bruneau hot springsnail (*Pyrgulopsis bruneauensis*) is a small endangered gastropod found only in geothermal seeps and springs along a 5 mile (mi) length of the Bruneau River and a tributary, Hot Creek, in southwestern Idaho. The Bruneau hot springsnail inhabits exposed surfaces along geothermal seeps and springs in which water temperature ranges from 60.3 to 98.4 °F. The U.S. Fish and Wildlife Service (USFWS) has determined that the principal threat to the Bruneau hot springsnail is “the reduction and/or elimination of their geothermal springs habitat as a result of agricultural groundwater withdrawals” (U.S. Fish and Wildlife Service, 2007); furthermore, the species was listed as endangered by the USFWS in 1998 (Federal Register, 1998). Research was conducted to better understand declines in groundwater levels and their effects on springs and seeps in the Bruneau study area.

The regional geothermal aquifers that feed the seeps and springs along the Bruneau River are used for irrigation in the Bruneau, Little, and Sugar Valleys that compose the Bruneau study area (Berenbrock, 1993). Historical decreases in discharge from geothermal seeps and springs along the Bruneau River and Hot Creek have been associated with groundwater declines due to pumping of groundwater for irrigation (Berenbrock, 1993). This decrease in geothermal discharge has caused the hot springsnail habitat to decline (USFWS, 2007); the total number of geothermal seeps and springs located upstream of Hot Creek on the western side of the Bruneau River decreased from 84 (in 1991) to 54 (in 2010) (Hopper and Burak, 2011). Similarly, the number of springs decreased on the eastern side of the Bruneau River upstream of Hot Creek from 62 (in 1991) to 23 (in 2010) (Hopper and Burak, 2011).

A recovery plan adopted by the USFWS in 2002 for the Bruneau hot springsnail suggests implementing conservation measures to protect groundwater in the geothermal aquifer (U.S. Fish and Wildlife Service, 2002). A groundwater-flow model of the Bruneau study area could aid these stabilization efforts but an effort conducted by the U.S. Geological Survey (USGS) in the early 1990s to develop a model was unsuccessful because of a lack of data for this highly complex aquifer system (Berenbrock, 1993). However, information collected in previous studies can still be used to help guide future conservation efforts. This study incorporates previously collected data with statistical and analytical techniques to increase understanding of current groundwater conditions.

Purpose and Scope

In 2010, the USGS, in cooperation with the USFWS, conducted a two-part study to address concerns about recent groundwater trends and to help guide future groundwater conservation efforts. The first part of the study completed in 2010, analyzed groundwater levels in 22 wells over a 20-year period to determine trends over time. The second part of the study, completed in 2012, used analytical solutions of the Theis equation (Theis, 1935) to approximate the extent, timing, and magnitude of drawdown from continuous groundwater pumping by a hypothetical single well within the study area. These estimates required simplifications of, and assumptions about, actual conditions based on limited data. However, these estimates provide information on how pumping from wells in certain locations of the Bruneau area has affected spring flows.

This report describes methods, results, and conclusions about trends in groundwater drawdown from 1990 to 2010 and estimated future drawdown as determined by this study. Previous studies are used to substantiate findings from this report. Conclusions from this report and suggestions for future studies include determinations from both components of this study.

Previous Investigations

Several studies have been made on the occurrence, use, and chemistry of groundwater in and around the Bruneau study area. These studies have been supplemented by geological information from previous studies on the Bruneau Plateau and adjacent eastern Snake River Plain.

Early reports by Piper (1924) and Stearns and others (1937) examined groundwater resources and estimated annual withdrawal of groundwater from wells. Littleton and Crosthwaite (1957) identified multiple aquifer systems; artesian aquifers were suggested as sources for future water supply. The quantity and quality of water was estimated; chemical analyses of water samples revealed high sodium and fluoride concentrations in some groundwater (Littleton and Crosthwaite, 1957). Ralston and Chapman (1969) studied both availability and conditions of groundwater in northern Owyhee County.

An audio-magnetotelluric (AMT) survey conducted by Jackson (1974) examined resistivities along a cross section including the study area. Thermal fluids were speculated to rise along basement faults and then be transported laterally

into permeable layers. Blackwell (1975) logged temperatures in 41 wells to determine a geothermal gradient and described heat flow for commercial geothermal development. This study produced temperature data, geothermal gradients, and heat flow data for wells in north-central Owyhee County, Idaho. Blackwell (1975) discovered that geothermal gradients are higher in the Bruneau area than in the neighboring areas around Grand View; variations in geothermal gradients were speculated to be due to higher heat flow from basement rocks or lateral heat transport by water.

Young and Whitehead (1975) inventoried and sampled 94 wells and springs in the Bruneau-Grand View area to assess the geothermal system and probable sources of recharge and their report described areal extent of the Bruneau geothermal system. As part of a follow-up study, Young and Lewis (1982) analyzed water from 12 wells and 9 springs in north-central Nevada and southwestern Idaho. Stable isotopes indicated that climate during recharge was 5–9 °F cooler than 1975 temperatures and carbon-14 dating indicated geothermal waters had an age of 18,000 to 25,000 years. Age dating suggested water in this area circulates for thousands to tens of thousands of years.

Moffat and Jones (1984) investigated sources of groundwater and surface water available in the Bruneau area, as well as agricultural demand for water resources, and concluded that the demand on water resources was higher than the sustainable amount of groundwater withdrawal. Chemical analyses were conducted on water samples from selected wells and results indicated that water from some wells exceeded the U.S. Environmental Protection Agency's recommended drinking water limits for dissolved solids, pH, fluoride, chloride, or sulfate. Recharge was determined to be from precipitation, leakage from unlined canals, percolation of excess irrigation water, groundwater inflow across the southern boundary of the study area, upward leakage of water from the geothermal system, and downward leakage from the overlying perched system. Young and others (1990) described eight test holes and selected thermal-water wells for hydrologic monitoring. Data from their report included well-completion, lithologic, and gamma log information for the eight test holes. This report also included hydrographs of geothermal water springs as well as chemical and isotopic analyses of water from six of the eight test holes.

Berenbrock (1993) performed a groundwater resource investigation in the greater Bruneau area for the purpose of better understanding the habitat and groundwater available for the Bruneau hot springsnail. Groundwater resources

were mapped and water use, areas of recharge, history of groundwater discharge, groundwater movement, and trends in water levels were discussed. A geothermal aquifer was identified throughout the region in both sedimentary and volcanic rocks. Four larger-scale cones of depression in the potentiometric surface were identified in both the sedimentary-rock and volcanic-rock aquifers and were attributed to pumping. Changes in spring discharge corresponded with changes in hydraulic head throughout the region. This report also included calculations of hydraulic properties of the aquifer (such as transmissivity and hydraulic conductivity, specific capacity, and storativity) as determined by aquifer tests.

Harrington and Bendixsen (1999) reviewed the hydrologic condition of the Grandview-Bruneau Groundwater Management Area and determined that the overall groundwater system was relatively stable. As part of a follow-up study, the Idaho Department of Water Resources (IDWR) reviewed data collected from 18 monitoring wells throughout the Grand View-Bruneau Groundwater Management Area (McVay, 2012). Water levels in monitoring wells were examined for changes over a 10-year time period (2000–2010) and 20-year time period (1990–2010). McVay (2012) concluded that groundwater levels declined in 16 of 17 wells over the 10-year time period and groundwater levels declined in 15 of 17 wells over the 20-year time period. These wells showed seasonal fluctuation and exhibited declining groundwater levels at an average rate of 0.76 feet per year (ft/yr) from 2000 to 2010.

Description of Study Area

The Bruneau study area ([fig. 1](#)) is located in southwestern Idaho, near the towns of Bruneau and Grand View, about 65 mi southeast of Boise. It is bounded by the Snake River to the north, the Owyhee Mountains and Chalk Hills to the west, the Jarbidge Mountains to the south, and the Bruneau Plateau to the east. The study area lies on the southern margin of the northwest-trending western Snake River Plain and on the northern margin of the Bruneau-Jarbidge eruptive center. Berenbrock (1993) defined the Bruneau study area as extending from 42° 45' latitude north to the Snake River and east from the drainage divide of Little Jacks Creek and Shoofly Creek to the drainage divide between the Bruneau River and Sailor Creek, an area of about 600 square miles (mi²).

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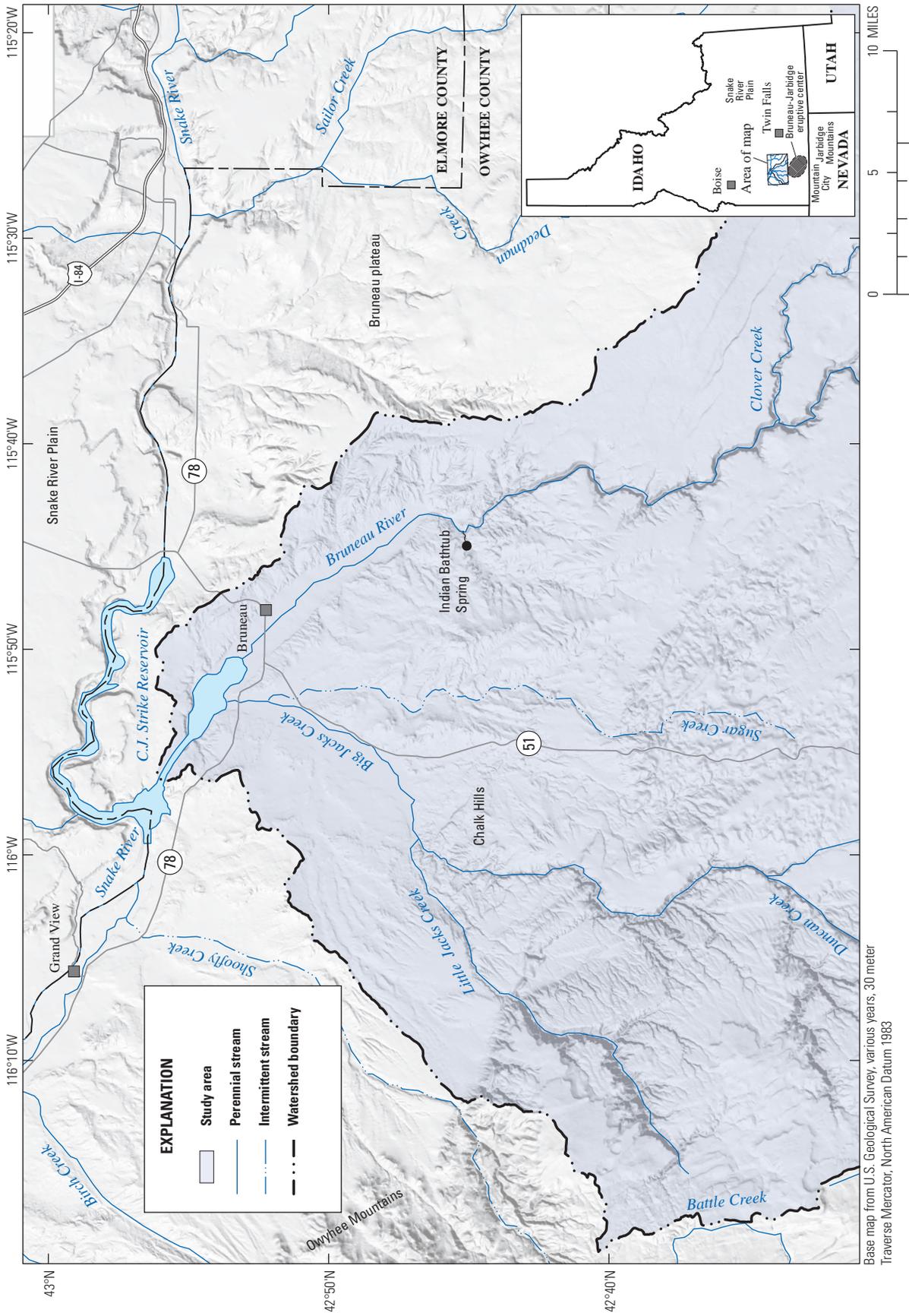


Figure 1. Location of Bruneau study area, southwestern Idaho.

Climate

Most of the study area is classified as BSk under the modified Köppen climate classification system in which B indicates a dry climate with annual evaporation greater than precipitation; S specifies a semiarid steppe with annual precipitation ranging between 15 and 30 inches (in.); and k indicates a dry and cold climate with a mean annual temperature below 64°F (Critchfield, 1983; Godfrey, 2000; Peel and others, 2007). The National Weather Service (NWS) currently (2012) has four active weather stations within 25 mi of the town of Bruneau: Bruneau, Mountain Home, Grand View 4 NW, and Glenns Ferry. An additional nine weather stations are either inactive, including the Mountain City, Nevada, station, or the NWS has not received any observation data (U.S. Department of Commerce, 2011). As of 2011, there were two active AgriMet stations located in or within 25 mi of the study area: Grand View (GDVI) and Glenns Ferry (GFRI) (Bureau of Reclamation, 2011). More information about these stations is provided in [table 1](#).

The four active NWS stations provide sufficient data for calculation of long-term mean temperatures ([table 2](#)). Mean annual temperatures at the four stations ranged from 50.5°F at Mountain Home to 54.7°F at Bruneau ([table 2](#)). The coldest month in the area typically is January, with mean low temperatures ranging from 20.3°F at Glenns Ferry to 23.4°F at Bruneau. The warmest month typically is July, with mean high temperatures ranging from 93.2°F at Mountain Home to 96.0°F at Glenns Ferry. Mean first-freeze dates range from September 23 at Glenns Ferry to October 5 at Bruneau; mean last-freeze dates range from May 7 at Bruneau to May 19 at Glenns Ferry. Mean annual precipitation ranges from 6.91 in. at Grand View 4 NW to 9.98 in. at Mountain Home. July and August typically are the driest months; November, December, and January are the wettest (Western Regional Climate Center, 2011). The inactive Mountain City station provides historical precipitation and temperature data of the area upstream of the Bruneau study area; historical mean annual precipitation was 13.53 in. during the data-collection period.

Table 1. National Weather Service and AgriMet stations near the Bruneau study area, southwestern Idaho.

[Latitude and longitude in decimal degrees. Horizontal coordinate system is North American Datum of 1983; vertical coordinate information is North American Vertical Datum of 1988]

Station name	Station or identification No.	Elevation (feet)	Latitude (north)	Longitude (west)	Dates in operation	
					Starting date	Ending date
National Weather Service stations ¹						
Bruneau	101195	2,530	42.88	-115.80	01-01-37	Present
Glenns Ferry	103631	2,466	42.93	-115.32	08-01-48	Present
Grand View 4 NW	103760	2,400	43.02	-116.18	08-01-48	Present
Mountain Home	106174	3,140	43.13	-115.72	08-01-48	Present
Mountain City	265392	5,620	41.78	-115.97	02-11-55	11-30-99
AgriMet stations ²						
Glenns Ferry	GFRI	3,025	42.87	-115.35	04-13-93	Present
Grand View	GDVI	2,580	42.91	-116.06	02-10-93	Present

¹Data from Western Regional Climate Center (2011).

²Data from Bureau of Reclamation (2011).

Table 2. Summary of data from selected weather stations in and near the Bruneau study area, southwestern Idaho.

[Data from Western Regional Climate Center (2011). Summary values are through December 31, 2005, for active stations. Mean total precipitation includes melted snow. **Abbreviations:** °F, degrees Fahrenheit; in., inch; ND, no data]

Station name	Mean temperature (°F)			Mean annual total precipitation (in.)	Mean annual snowfall (in.)	Mean freeze date		Period of record used for summary
	July maximum	January minimum	Annual			Last	First	
Bruneau	93.4	23.4	54.7	7.44	4.0	May 7	Oct. 5	June 1, 1962 – Dec. 31, 2005
Glenns Ferry	96.0	20.3	52.2	9.45	11.3	May 19	Sept. 23	Aug. 3, 1948 – Dec. 31, 2005
Grand View 4 NW	94.2	20.6	51.3	6.91	5.4	May 8	Sept. 28	Apr. 1, 1933 – Dec. 31, 2005
Mountain Home	93.2	20.6	50.5	9.98	10.7	May 14	Sept. 24	Aug. 1, 1948 – Dec. 31, 2005
Mountain City (inactive)	83.3	9.7	36.9	13.53	38.0	ND	ND	Feb. 11, 1955 – Nov. 30, 1999

Land Cover, Management, and Use

The Bruneau study area lies within the Intermountain Sagebrush Province/Sagebrush Steppe ecosystem of the Bailey-Kuchler classification (Bureau of Land Management, 2009). By the Level IV ecoregion classification, land in the study area falls into two classes: valley bottoms are classified as Treasure Valley ecoregion and uplands are classified as Unwooded Alkaline Foothills ecoregion (McGrath and others, 2002).

Most of the land in the study area is federally owned and is under the control of the Bureau of Land Management, which leases the land for grazing. In the vicinity of Bruneau, much of the low-lying land along Little Jacks and Sugar Creeks and the Bruneau River is privately owned and under cultivation. Alfalfa is the major crop along with corn, oats, potatoes, dry beans, and sugar beets (National Agricultural Statistics Service, 2011). Irrigation water for these crops is mostly supplied by groundwater, although some land is irrigated by surface-water diversions.

The first European settlers in the Bruneau area arrived around 1870 to establish cattle ranches. Farming began in the 1880s with irrigation water diverted from streams and rivers in the area (Idaho State Historical Society, 1964, 1975). Currently (2012), three irrigation companies divert surface water for irrigation: Bruneau Buckaroo Cooperative Ditch Company, Hot Springs Ditch Company, and the South Side Bruneau Canal Company. Groundwater development began in 1896, and by 1922 slightly more than 100 flowing irrigation wells were in use (Berenbrock, 1993). In 1954, the use of groundwater for irrigation accelerated; by 1982, about 220 irrigation wells had been drilled (Berenbrock, 1993). This increase in pumping led to declines in groundwater levels and spring discharges, and in response, the Bruneau-Grand View Groundwater Management Area was established by the Idaho Department of Water Resources in 1982 (Idaho Department of Water Resources, 2011).

The main community in the study area is the unincorporated town of Bruneau. The Bruneau census county division (CCD) encompasses about the eastern one-third of Owyhee County, and it had a 2010 census population of 629 (U.S. Census Bureau, 2011).

Geologic Setting

The oldest rocks in or near the study area are rhyolitic ash-flow tuffs correlated to Eocene Challis Volcanics. These rocks are overlain by Miocene rhyolite flows of the Idavada Volcanics which, along with the faulting that created the western Snake River Plain, are related to the track of the Yellowstone hot spot. This volcanism transitioned to bimodal

volcanism with the eruption of basaltic shield volcanoes and continued rhyolite flows. By Pliocene time, volcanism had completed the transition to basalt with the eruption of additional shield volcanoes and basalts erupted in a subaqueous environment beneath the paleo Lake Idaho (Jenks and others, 1998; Wood and Clemens, 2002).

Lake Idaho probably formed in the late Miocene as rhyolitic volcanism ended. At its greatest extent, Lake Idaho probably extended from the present city of Twin Falls, Idaho, to the present Idaho-Oregon border. As the lake subsided, it was filled with thick sequences of sediment interbedded with basalt, together forming the Idaho Group. This lake persisted into the Pleistocene, although its extent fluctuated with changes in climate and tectonism, causing cycles of erosion and redeposition of lake deposits. Lake Idaho was finally breached as the ancestral Snake River established its current course and tributary streams in the area formed. These post-Lake Idaho volcanic rocks and interbedded sediment associated with the through-flowing Snake River compose the Pleistocene Snake River Group. Deposits of Quaternary alluvium overlie the older rocks along streams and alluvial fans, and localized areas of eolian sediment are present (Malde and Powers, 1962; Jenks and others, 1998).

The area is heavily faulted, and most faults apparently occurred after Lake Idaho drained. Faults trend in two directions: (1) northwest-trending faults that parallel the western Snake River Plain, and (2) apparently older north- to northeast-trending faults that control the spatial distribution of most of the tributary valleys in the area, as well as some, if not most, of the springs (Jenks and others, 1998).

Groundwater Occurrence

Young and Whitehead (1975) defined two primary aquifer types in the study area based on lithology: sedimentary-rock aquifers and underlying volcanic-rock aquifers. Geothermal water occurs in both aquifer types. Sedimentary-rock aquifers are composed of unconsolidated and consolidated sediments and interbedded volcanic rocks of the Miocene to Pleistocene Idaho Group and Pleistocene Snake River Group. Although the Idaho Group sediments primarily are fine-grained sands, silts, and clays typical of lacustrine deposition, coarser grained sand and gravel units were deposited under deltaic or alluvial conditions as lake levels fluctuated (Young and Whitehead, 1975). Snake River Group sediments range from gravels deposited by the Snake River and its tributaries to fine-grained sediment deposited between lava flows. The sedimentary-rock aquifers are about 2,000 ft thick in the Bruneau study area. Interbedded fine- and coarse-grained sediment and volcanic rocks create confined or semiconfined conditions in the sedimentary rock aquifer and well yields vary considerably.

Recharge to the sedimentary-rock aquifers probably is from infiltration of precipitation onto the surrounding Bruneau Plateau and Owyhee and Jarbidge Mountains (Young and Whitehead, 1975). Newton (1991) included the sedimentary-rock aquifers near Bruneau as part of the western Snake River Plain regional aquifer system.

The volcanic-rock aquifers are composed of the Pliocene Banbury Basalt of the Idaho Group underlain by Miocene rhyolite flows of the Idavada Volcanics, and they may be about 2,500 ft thick in the study area. Groundwater is under confined conditions with fine-grained sediments or dense volcanic rocks acting as confining beds; well yields range from poor to excellent. Recharge primarily is from infiltration of precipitation on volcanic-rock outcrops in the Owyhee and Jarbidge Mountains (Young and Whitehead, 1975).

Locally, unconsolidated Quaternary alluvium along stream channels yields water to wells and springs. The alluvium is less than 100 ft thick and groundwater is under unconfined conditions. Recharge is from infiltration of precipitation, losing stream reaches, excess irrigation water, and possible upwelling of deeper groundwater (Berenbrock, 1993).

Many springs and wells in the study area produce geothermal water. Groundwater temperatures ranged from 59 to 109°F in the sedimentary-rock aquifers, and from 49 to 181°F in the volcanic rock aquifers; a sole temperature measurement from alluvium was 52°F (Young and Whitehead, 1975). Young and Whitehead (1975) concluded that volcanic rock aquifers were the source of geothermal water because of high water temperatures. Berenbrock (1993) stated that several lines of evidence presented by previous studies suggested that most of the springs in the study area discharge water from the volcanic-rock aquifers.

Groundwater/Surface-Water Interaction

Surface water in the Bruneau study area loses water to and gains water from groundwater. Spring discharge in the Bruneau study area provided about 10,100 acre feet per year (acre-ft/yr) prior to extensive groundwater development (Littleton and Crosthwaite, 1957) and geothermal seeps and springs along the Bruneau River still support an important ecological area. The cold-water aquifer receives recharge from infiltration of precipitation, streamflow, and applied irrigation water (Berenbrock, 1993). Due to the lack of data about the hydrologic connection between the cold-water

and geothermal-water aquifers, we are currently unable to determine the interaction between surface water with the underlying geothermal aquifer.

Limited information is available about the quantity of groundwater recharge from surface water. It is difficult to locate areas where surface water may be recharging groundwater because no gain/loss studies have been conducted along the Bruneau River to date (2012). Limited information suggests that the majority of flow from Little and Big Jacks Creeks infiltrates to the groundwater system (Kjelstrom, 1986). Due to the uncertain connection between the geothermal aquifers and surface water, interactions between the two were not included in the estimated drawdown portion of this study.

Methods

Analysis of Trends in Historical Drawdown

Starting in 2010, the USGS, in cooperation with the USFWS, performed a statistical analysis of historical water-level data in the Bruneau study area to determine trends in groundwater levels between 1990 and 2010. Previous studies suggested that water levels had declined and that discharge from geothermal seeps and springs had decreased with time (Hopper and Burak, 2011; McVay, 2012). A statistical analysis was conducted to determine if there was a statistically significant change in water levels in recent history. A trend test was performed on water-level data from monitoring wells with ten or more years of data over the period of record. Water level data from selected wells were analyzed individually, and in groups recommended by USFWS in order to determine if groundwater levels had significantly declined over a 20-year monitoring period.

Data were trend-tested using variations of the nonparametric Kendall test, a statistical test for trends over time (Helsel and Hirsch, 2002). Kendall tests generally are used to determine whether data (in this case, water levels) demonstrate a monotonic trend during a given time period. The test computes a Kendall's *tau* nonparametric correlation coefficient as its test of significance, along with a slope and intercept indicating the direction and magnitude of the trend (Helsel and others, 2006). A positive slope indicates increasing depth to water, or increasing drawdown.

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Two methods of Kendall tests were used for this study: a Seasonal Kendall test for individual wells and a Regional Kendall test for multiple wells in one category. Monitoring wells in the area respond seasonally to groundwater pumping and recharge (McVay, 2012); the effect of seasonal irrigation pumping is evident in hydrographs of individual wells (fig. 2). To compensate for this seasonal variation and to better discern the trend in water levels over time, a Seasonal Kendall test was used. Seasonal Kendall tests correct for seasonality by performing a Kendall test on each season separately (defined here as irrigation and non-irrigation season, or approximately May-September and October-April) and then combining the results to determine the overall trend in the data, if any. Individual wells were trend-tested using a Seasonal Kendall test to determine if there was a statistically significant change in water levels over the period of study. Precipitation data from weather stations were also analyzed by a Seasonal Kendall test to determine trends in precipitation over time.

Regional Kendall tests allow for wells with similar attributes to be analyzed for an overall trend; this study used Regional Kendall tests to calculate trends among five categories of wells with similar attributes (table 3). For a Regional Kendall test, a Kendall test is performed on data from individual wells and results are combined into an overall test to determine a consistent trend among that category of wells. Categories of wells were defined based on well depth, distance from Indian Bathtub Spring, geologic unit (in which the well was completed), regional topographic valley, and water temperature (at the time of well completion [table 3]). There is limited information about some wells, such as completion information, water temperature, and geologic information. This lack of data led to some wells not being categorized and thus excluded from the analysis, resulting in small datasets that gave less power to statistical tests.

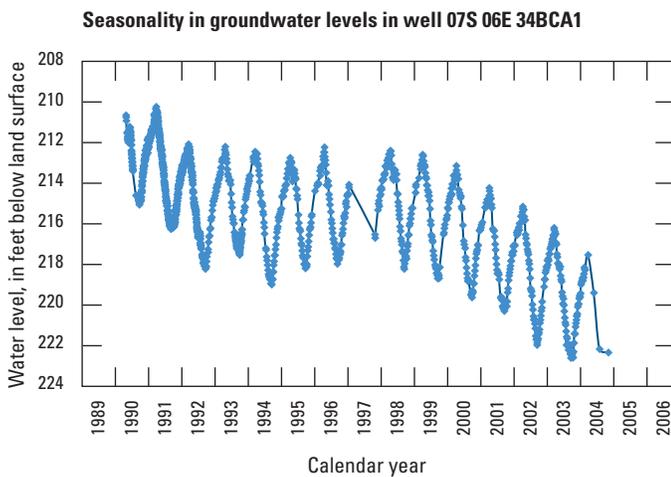


Figure 2. Seasonal fluctuations of water levels from well 07S 06E 34BCA1, typical of seasonal fluctuation in response to groundwater pumping and recharge, Bruneau area, southwestern Idaho.

Table 3. Categories of wells for Regional Kendall analysis as suggested by U.S. Fish and Wildlife Service, March 2010.

[Abbreviations: BLS, below land surface; °C, degrees Celsius; <, less than; >, greater than]

Categories	
Well depth (in feet BLS)	
	0–200
	201–500
	501–1,000
	1,001–1,500
	1,501–2,000
Distance from Indian Bathtub Spring (in miles)	
	<1
	1.01–3
	3.01–10
	10.01–15
	15.01–20
Geologic unit	
	Idaho Group
	Idavada Group
	Banbury Group
Regional topographic valley	
	Bruneau Valley
	Sugar Valley
	Little Valley
Temperature (°C)	
	< 30
	30–40
	> 40.01

Data Selection

Records of measurements from monitoring wells located throughout the Bruneau study area provide water-level data from various aquifers from 1950 to present (2012). Multiple agencies recorded water levels in wells throughout the study area for various purposes. For this study, 22 monitoring wells in the Bruneau study area were selected for statistical analysis ([table 4](#)) based on length and consistency of record. These wells were measured by the USGS, private consultants, or IDWR. Water-level data were obtained from the USGS National Water Information System (NWIS) (U.S. Geological Survey, 2011) and the IDWR groundwater-level database hydro.online (Idaho Department of Water Resources, 2010); information about well completion is available in drillers' logs archived by IDWR (2012). Monitoring wells penetrate both the unconfined alluvium and geothermal (volcanic-rock and sedimentary-rock) aquifers. Therefore, observed trends in monitoring wells may not reflect water levels from only the geothermal system.

Precipitation data were obtained from two NWS weather stations representing the area—Bruneau and Mountain City. These weather stations collected rain and snow precipitation data from 1962 to 2009 (Bruneau) and from 1955 to 1999 (Mountain City). The Mountain City, Nevada, station is topographically upgradient of the Bruneau River basin and was used to represent possible recharge [this is representative of the upstream area defined by Berenbrock (1993) that may be a recharge area]. Average annual precipitation over the period of record ranges from 7.44 in. at Bruneau to 13.53 in. at Mountain City (U.S. Department of Commerce, 2011).

Computation of Tests

A DOS executable computer program for the Kendall trend tests developed by Helsel and others (2006) was used to perform the Kendall tests. Test statistics generated by this

program included Kendall's τ , the Kendall test statistic S , and the p -value for significance of trend. For examples of input or output files for the program, see Helsel and others (2006).

Refining Data for Analysis

Many measurements were available from the years of observation; these data were edited for input into the computer program for the Kendall family of trend tests (Helsel and others, 2006). To create a two-season seasonal Kendall-test, the program required each calendar year to contain two values representing water levels from the irrigation and non-irrigation seasons. One data point was selected from each season to represent seasonal water levels; this data point was automatically generated by the DOS executable computer program by selecting the median seasonal value from a list of water level measurements and decimal dates.

To verify that two-season seasonal Kendall tests were appropriate, four-season Kendall-test analyses also were run, but the tests were not as statistically robust (as evidenced by higher p -values) as two-season Kendall tests. Seasonal values also were manually selected and input into the program and results similar to the automated tests were generated.

Regional Kendall tests were performed on data from wells grouped into each of the five categories described in [table 3](#) to determine trends in water levels over time. Program input required one value per year for each well to represent annual water levels. The selected value was chosen to represent conditions as unaffected by irrigation pumping as possible. Due to the varied amount of available data from each well and desire to not produce error or bias by calculating an aggregate value, a water level from early March (before the start of the irrigation season) was selected as the representative value from each well.

Table 4. Location, record, and completion information for monitoring wells in topographically defined regions and weather stations that were used for statistical trend analysis, Bruneau study area, southwestern Idaho.

[Well information was obtained from well driller's logs and water-level measurements were obtained from U.S. Geological Survey and Idaho Department of Water Resources web sites. **Well No.:** Location of well Nos. are shown in [figure 5](#). **Latitude** and **longitude** in decimal degrees. Horizontal coordinate system is North American Datum of 1983; vertical coordinate information is North American Vertical Datum of 1988. **Agency measuring:** IDWR, Idaho Department of Water Resources; USGS, U.S. Geological Survey. **Abbreviations:** ft, feet; BLS, below land surface; °C, degrees Celsius; -, data not available]

Well No.	USGS site identification No.	Latitude	Longitude	Elevation (ft)	Geologic unit completed in	Well depth (ft BLS)	Screened interval (ft BLS)	Temperature (°C)	Years of data	Total readings over period of record	Period of record	Agency measuring
Other												
06S 03E 14BCB1	425414116043301	42.904	-116.076	2,643	Idaho	1,342	373-1,342	-	20	63	1990-2009	USGS
Little Valley												
06S 04E 14ABC1	425425115563801	42.907	-115.944	2,665	Idaho	1,905	1,600-1,905	55	20	102	1990-2009	USGS
07S 05E 18BCD1	424855115543701	42.815	-115.910	2,643	Banbury	517	254-517	25.4	21	152	1990-2009	USGS, IDWR, Consultant
07S 05E 19CCC1	424737115544501	42.794	-115.913	2,720	Idavada	760	309-760	35.6	8	55	1994-2000	USGS
07S 04E 27BCC1	424709115582301	42.786	-115.973	2,770	Idavada	1,390	19-1,390	27	21	171	1990-2009	USGS, IDWR, Consultant
Sugar Valley												
06S 05E 33DBB1	425127115515501	42.858	-115.865	2,540	Unknown	142	-	17	20	116	1990-2009	USGS
06S 05E 35CBD1	425117115495501	42.855	-115.832	2,620	Idaho	476	230-476	22	20	121	1990-2009	USGS
07S 05E 13CBB1	424853115485401	42.815	-115.815	2,771	Banbury	1,954	180-1,680	36	21	165	1990-2009	USGS, IDWR, Consultant
07S 05E 21CCA1	424738115514001	42.794	-115.861	2,775	Idavada	1,135	406-1,135	40	18	146	1990-2007	USGS, IDWR, Consultant
07S 06E 29BBA1	424734115462801	42.793	-115.774	2,832	Banbury	760	415-760	39.8	21	1,732	1990-2009	USGS, IDWR
07S 06E 29BBA2	424734115462802	42.793	-115.774	2,832	Banbury	348	250-365	-	21	285	1990-2009	USGS, IDWR, Consultant
08S 05E 16AAA1	424420115512201	42.739	-115.856	3,010	Banbury	410	-	43.2	12	100	1990-2001	USGS, IDWR, Consultant
Bruneau Valley												
07S 06E 09BAD2	425004115445302	42.834	-115.748	2,578	Idaho	960	80-960	49.5	21	149	1990-2009	USGS, IDWR, Consultant
07S 06E 26BDA1	424718115422801	42.788	-115.708	2,655	Banbury	-	-	33.8	21	293	1990-2009	USGS, IDWR, Consultant
07S 06E 34BCA1	424620115440301	42.772	-115.734	2,889	Banbury	681	322-681	38.8	16	1,531	1990-2004	USGS
07S 06E 34BCA2	424620115440302	42.772	-115.734	2,890	Banbury	323	302-323	-	11	294	1990-2009	USGS, IDWR, Consultant
07S 06E 34BCA3	424620115440303	42.772	-115.734	2,890	Banbury	679	659-679	-	21	184	1990-2009	USGS, IDWR, Consultant
07S 06E 34DAD1	424607115430701	42.769	-115.719	2,675	Banbury	300	46-300	35.5	13	71	1990-2002	USGS, IDWR, Consultant
08S 06E 03BDC1	424540115442201	42.761	-115.739	2,754	Banbury	480	194-480	35.7	21	1,613	1990-2009	USGS, IDWR
08S 06E 03BDC2	424540115442202	42.761	-115.739	2,754	Banbury	90	80-90	34	15	1,718	1990-2004	USGS
08S 06E 03BDC3	424540115442203	42.761	-115.739	2,754	Banbury	140	120-140	34.5	21	1,743	1990-2009	USGS, IDWR
08S 06E 04DCD1	424523115451201	42.756	-115.753	2,837	Banbury	600	170-600	30.4	21	1,775	1990-2009	USGS, IDWR
Weather stations												
Bruneau		42.883	-115.800	2,530	N/A	N/A	N/A	N/A	47	558	1962-2009	NWS
Mountain City		41.783	-115.967	5,620	N/A	N/A	N/A	N/A	44	523	1955-99	NWS

Estimated Drawdown

The Theis equation and the principle of superposition of solutions were used to estimate drawdown and recovery. Effects of drawdown from pumping and recovery of a well after pumping has ceased can be projected on a specified area using the superposition principle (Reilly and others, 1987). Analytical solutions describe the response of an aquifer in an idealized representation of the real world. Therefore, the drawdown calculations generated by analytical methods must be viewed as idealized estimates of the response of an aquifer to assumed parameters.

Various pumping rates and times were used to estimate the effects of pumping on groundwater levels. Published hydraulic information was used to calculate the timing and magnitude of drawdown conditions from continuous groundwater pumping. Drawdown, as calculated by the Theis equation, is affected by the amount of water being removed from an aquifer, the permeability of the aquifer, and the ability of the aquifer to store or release water. Such hydraulic parameters were determined from single-well (well-performance and slug) tests and multiple-well aquifer tests.

Groundwater movement in an aquifer is controlled by hydraulic parameters. The measure of the water-transmitting characteristic of a material, termed the hydraulic conductivity, is controlled by the size and arrangement of water-transmitting pores or fractures, as well as the dynamic characteristics of water itself (Heath, 1987). Transmissivity is the hydraulic conductivity of an aquifer multiplied by the saturated thickness (or vertical extent of water-bearing material) of an aquifer (Heath, 1987). Storativity (or storage coefficient) is the volume of water that an aquifer releases from storage per unit of surface area per unit decrease in hydraulic head (Freeze and Cherry, 1979). The Theis equation allows for the calculation of drawdown from a pumping well if flow, transmissivity, and storativity are known. The range of values used to estimate idealized drawdown is presented in [table 5](#). Because the analytical approach used in this investigation

cannot incorporate variations in hydraulic parameters, a range of values were taken from the literature and analyzed for different combinations of flow, transmissivity, and storativity.

The Theis equation assumes an idealized version of an aquifer. This idealized aquifer is a confined aquifer, or an aquifer that is bounded above and below by impermeable beds and is completely saturated (Heath, 1987). The idealized aquifer has the same hydraulic parameters throughout, properties referred to as homogeneity and isotropy (Freeze and Cherry, 1979). All calculations made here incorporate these assumptions; it is likely these assumptions do not reflect real-world conditions.

Values Used in Drawdown Estimation

The Theis equation uses values of storativity, transmissivity, and flow (rate of groundwater pumping) to calculate drawdown effects. Values of hydraulic parameters were taken from Berenbrock (1993); they encompass the full range of storativity and transmissivity values found in sedimentary-rock and volcanic-rock aquifers ([table 5](#)). The sedimentary-rock and volcanic-rock aquifers had differing ranges of hydraulic parameters; analyses were made of both types of aquifer to represent a range of possible conditions that may be found in the study area. Groundwater from the unconfined alluvium (cold-water aquifer) was not included in the analysis because of its assumed lack of influence on geothermal seeps and springs. Transmissivity values included the span of values calculated by two different methods used by Berenbrock (1993, table 3) (where transmissivity was calculated by multiplying specific capacity by 267 or by multiplying thickness of the aquifer by hydraulic conductivity). Because of the large range of values, the geometric means of transmissivity and storativity values were used as a mid-range value between the high and low values. The geometric mean was selected to prevent extreme numbers from skewing the estimate of the mean (Helsel and Hirsch, 2002).

Table 5. Range of hydraulic parameters used in this study, Bruneau study area, southwestern Idaho.

[Transmissivity and storativity values taken from Berenbrock (1993, table 3). Flow was calculated as described in text.
Abbreviations: ft²/d, foot squared per day; acre-ft/yr, acre-feet per year; –, data not available]

Parameter	Low value	Well	High value	Well	Geometric mean
Sedimentary aquifers					
Transmissivity (T , in ft ² /d)	300	6S 5E 23DDD1	33,000	6S 4E 35ACC1	3,730
Flow (Q , in acre-ft/yr)	100	–	610	–	250
Storativity (S , dimensionless)	0.0004	–	0.002	–	0.0009
Volcanic aquifers					
Transmissivity (T , in ft ² /d)	300	11S 7E 25ACA1	980,000	7S 4E 23CBB1	13,000
Flow (Q , in acre-ft/yr)	100	–	610	–	250
Storativity (S , dimensionless)	0.001	–	0.003	–	0.002

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Due to uncertainty about aquifer properties and geometry in the Bruneau study area, the drawdowns calculated in this report should be considered estimates. It was assumed that the range of published values in Berenbrock (1993) represents the range of values present in the Bruneau study area.

Flow was calculated as the amount of estimated annual groundwater pumpage based on irrigation demand using a multi-step process. Crop types were identified from land-cover maps (National Agricultural Statistics Service, 2011) and it was assumed that pumpage was equivalent to evapotranspiration and rates were estimated for each crop using the ETIdaho web site (Allen and Robison, 2009) which incorporates the standardized Penman-Monteith reference equation at a number of weather stations throughout Idaho. For this analysis, calculations were made for 2009 conditions observed at the Bruneau NWS station.

Irrigated crops in the study area identified by land-cover data include dry beans, alfalfa, field corn, grain, and grass pasture. Evapotranspiration rates ranged from 9.92 to 58.15 inches per year (in/yr). The volume of evapotranspiration (in acre-ft/yr) was calculated by multiplying irrigated acreage by evapotranspiration rate. Calculations assumed that each well would supply a 0.25 mi long pivot section, irrigating roughly 125 acres, typical of irrigation practices in the area. The resulting values were 100 and 610 acre-ft/yr (table 5). A mid-range flow value was assigned to represent the median value of all evapotranspiration estimates (250 acre-ft/yr). All calculations are rounded to two significant figures.

Analysis of Data

Three locations were used to represent the habitat for the Bruneau hot springsnail (fig. 3). Two points along the Bruneau River represented the upstream (HS2) and downstream (HS1) limit of geothermal seeps and springs and one location was at Indian Bathtub Spring (HS3), located along Hot Creek (table 6). All estimates are applicable to any of these three points.

A spreadsheet was used to calculate drawdown using the Theis equation and combinations of hydraulic parameters in table 5 (Halford, 2005). Extent of groundwater drawdown was calculated by assuming a single well was pumping. The distance drawdown value generated represents the radial distance of the cone of depression given the assumptions used.

This program uses the Theis equation (1), rearranged to solve for s :

$$s = (Q / 4\pi T)W(u) \quad (1)$$

where:

s = drawdown (change in hydraulic head at a point since the beginning of pumping),

Q = flow, or the discharge rate for a pumping well (at the origin),

T = transmissivity of the aquifer,

$W(u)$ = well function that is derived from the location where the Theis curve meets $1/u$, where u is calculated using the following equation (2):

$$u = (r^{2s}) / 4Tt \quad (2)$$

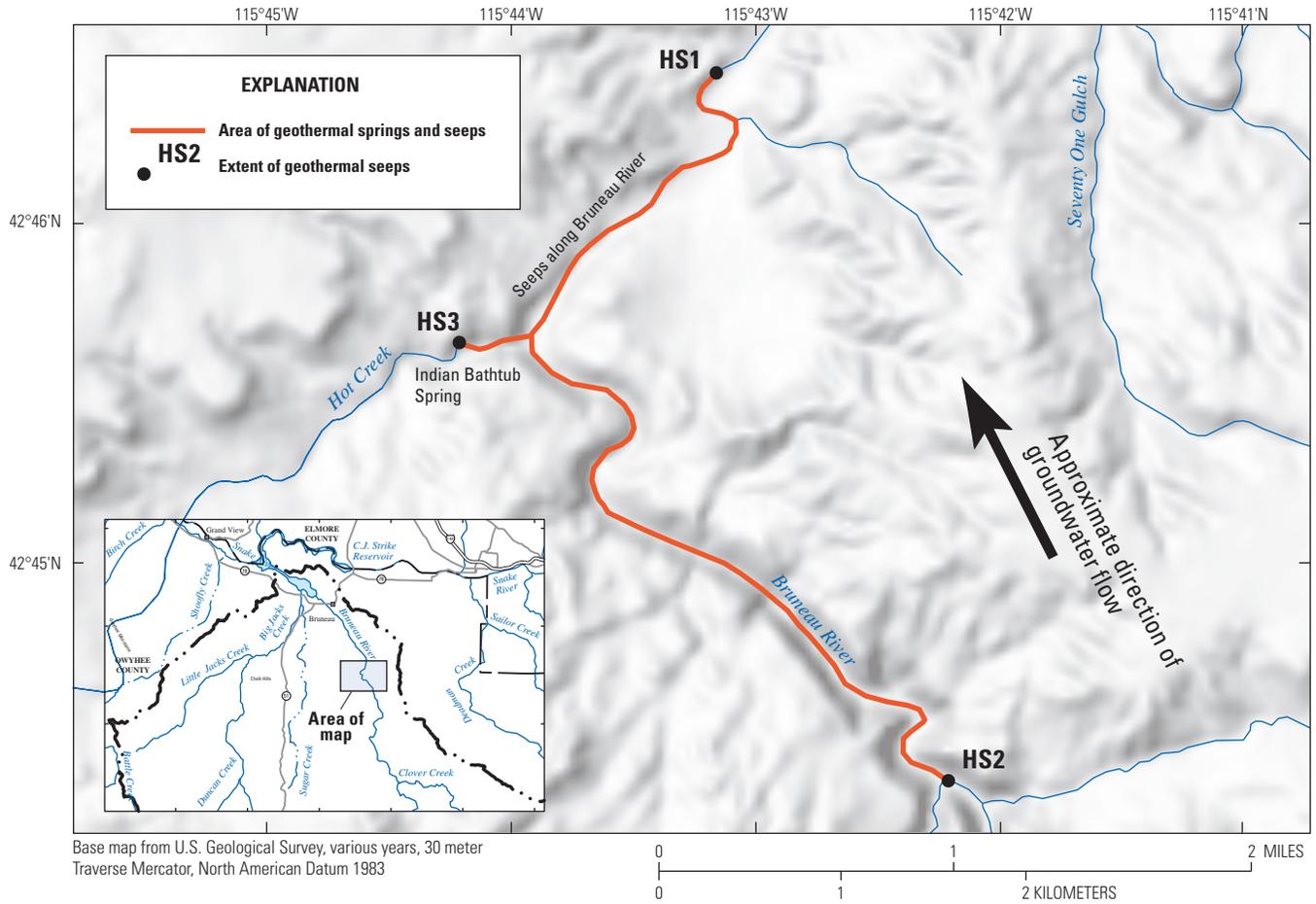
where:

u = dimensionless time parameter,

r = radial distance from the pumping well to the point where drawdown is observed,

T = transmissivity of the aquifer,

t = time since pumping began.



Base map from U.S. Geological Survey, various years, 30 meter Traverse Mercator, North American Datum 1983

Figure 3. Three locations representing the geothermal inflow stretch along the Bruneau River, southwestern Idaho. Two locations represent the upstream (HS2) and downstream (HS1) limit of geothermal seeps and springs and one location is at the Indian Bathhtub Spring (HS3), located along Hot Creek.

Table 6. Extent of geothermal seeps and springs along the Bruneau River, southwestern Idaho.

[Latitude and longitude in decimal degrees. Coordinate system: North American Datum of 1983. Actual locations of geothermal seeps as reported by U.S. Fish and Wildlife Service]

Name	Site name	Latitude	Longitude
Downstream extent of geothermal seeps	HS1	42.776	-115.718
Beginning of geothermal seeps	HS2	42.741	-115.702
Indian Bathhtub Spring	HS3	42.762	-115.734

Trends in Historical Drawdown

A measure of the level of significance of a statistical test, also known as a *p*-value, was generated by the Kendall tests and used to determine the presence or absence of trends in groundwater levels. A *p*-value is a result of a test on the null hypothesis; in this study examining groundwater levels, the null hypothesis was that groundwater levels did not change over time. If the data failed to support the null hypothesis, the *p*-value generated by the test was small and the null hypothesis was rejected (Ott and Longnecker, 2001). The lower the *p*-value was, the more significant the trend. Tests generating small *p*-values ($p < 0.10$) indicate a significant trend in groundwater levels over the period of assessment. A *p*-value of less than 0.10 indicates with at least 90 percent certainty that the null hypothesis is rejected, or that there is a significant trend in the data.

Seasonal Kendall Results

Results from Seasonal Kendall tests from 22 wells are presented in [table 7](#). The results show slopes (describing the overall trend) and *p*-values (including those seasonally adjusted) for both automated tests. Seven wells have a period of record of less than 20 years ([table 4](#)); such limited data give less power to the tests on these wells and limits the amount of information that can be derived about long-term trends.

Seasonal Kendall tests indicated that most wells showed statistically significant downward trends in groundwater levels. The *p*-values for statistically significant Seasonal Kendall tests ranged from <0.001 to 0.081. Seasonal Kendall analyses of statistically significant individual wells generated positive slopes, indicating that these wells experienced statistically significant declining water levels during the period of record ([fig. 4](#)). Statistically significant tests had slopes ranging from 0.21 to 1.0 in individual wells.

Wells with seasonally adjusted *p*-values greater than 0.10 indicate that water levels did not undergo a significant monotonic change over time. Four wells (06S 04E 14ABC1, 07S 05E 18BCD1, 07S 05E 19CCC1, and 07S 06E 09BAD2) had adjusted *p*-values that were greater than the specified *p*-value limit (0.10) and were not considered to show a significant trend over time. Wells without a significant trend in water levels could indicate a relatively constant water level or exhibit too much variation to discern a trend.

Seasonal Kendall tests for the Bruneau and Mountain City weather station precipitation data generated seasonally adjusted *p*-values of 0.737 and 0.258, indicating that no significant trend in precipitation was apparent over the time period examined. A comparison between trends indicate that declines in groundwater levels are not linked with recent precipitation. Historical trends in precipitation prior to the period of record could not be determined and their effects on groundwater could not be accounted for.

Table 7. Results from Seasonal Kendall trend analysis of water levels in monitoring wells and weather stations, Bruneau study area, southwestern Idaho.

[Seasonal Kendall trend analysis performed on DOS executable program. Numbers in **bold** represent a *p*-value greater than 0.10; slopes generated from these tests are not statistically significant. Positive slopes indicate increasing depth to water. **Abbreviations:** USGS, U.S. Geological Survey; ft/yr, feet per year]

USGS site identification No.	Seasonal Kendall test: Automated		
	Trend slope (ft/yr)	<i>p</i> -value	Adjusted <i>p</i> -value (seasonally adjusted)
08S 05E 16AAA1	0.49	0.002	0.012
08S 06E 04DCD1	0.55	<0.001	<0.001
08S 06E 03BDC1	0.91	<0.001	<0.001
08S 06E 03BDC2	0.40	<0.001	0.000
08S 06E 03BDC3	0.32	<0.001	<0.001
07S 06E 34DAD1	0.38	0.000	0.002
07S 06E 34BCA1	0.44	<0.001	0.000
07S 06E 34BCA2	0.29	0.057	0.048
07S 06E 34BCA3	0.56	<0.001	<0.001
07S 04E 27BCC1	0.51	0.000	0.000
07S 06E 26BDA1	0.53	<0.001	<0.001
07S 06E 29BBA1	0.56	<0.001	<0.001
07S 06E 29BBA2	0.30	<0.001	<0.001
07S 05E 19CCC1	0.32	0.440	0.412
07S 05E 21CCA1	0.35	0.004	0.004
07S 05E 13CBB1	1.01	<0.001	0.000
07S 05E 18BCD1	-0.22	0.996	0.966
07S 06E 09BAD2	0.18	0.377	0.439
06S 05E 35CBD1	1.10	0.113	0.047
06S 05E 33DBB1	0.21	0.081	0.051
06S 03E 14BCB1	0.85	0.000	0.003
06S 04E 14ABC1	0.75	0.568	0.554
Weather stations			
Bruneau	0.00	0.709	0.737
Mountain City	0.00	0.253	0.258

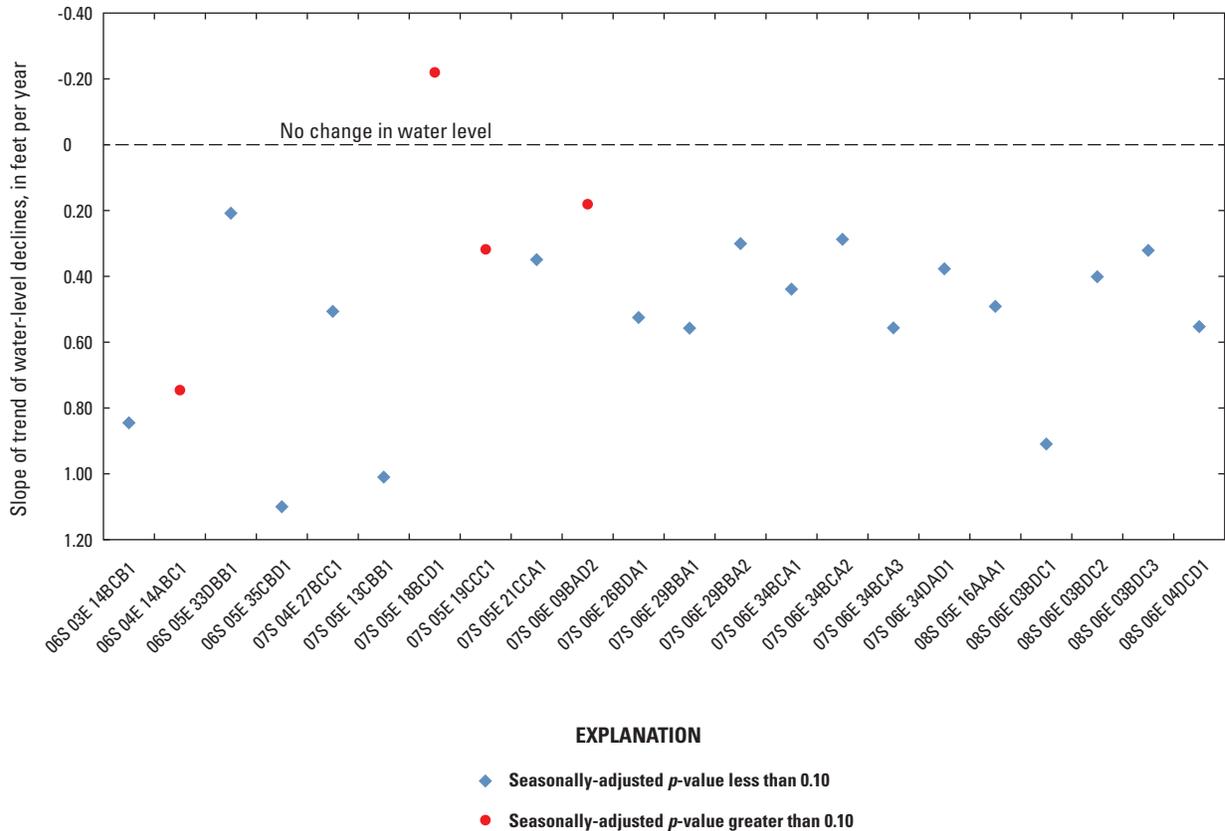


Figure 4. Slopes of trends of groundwater decline by monitoring well, generated by Seasonal Kendall test, Bruneau study area, southwestern Idaho.

Regional Kendall Results

Regional Kendall tests were performed to determine if one particular group of wells appeared to have significant water-level declines. Wells were grouped by depth, distance from Indian Bathtub Spring, geologic unit, and water temperature (table 3). In addition, wells were assigned to regional topographic valleys (fig. 5) and divided into the Bruneau, Sugar, and Little Valleys.

All Regional Kendall tests yielded p -values less than 0.10 and indicated a significant change in slope over time; slope values varied by category (table 8). Groups categorized by distance from the Indian Bathtub Spring generated slopes that ranged from 0.37 to 0.5 ft/yr and did not seem to exhibit any discernible pattern based on distance from the spring. Wells categorized by geologic unit had relatively similar slopes (ranging from 0.45 ft/yr in the Banbury Basalt to 0.56 ft/yr in the Idaho Group). Wells grouped by water temperature had slopes from 0.28 to 0.48 ft/yr and did not indicate a pattern of one-directional change with increasing

temperature gradient. Water temperature was measured at the time of drilling and may represent water from the unconfined alluvium, geothermal aquifer, or a mix of both due to long screen lengths. The slopes of wells categorized by regional topographic valley ranged from 0.35 ft/yr in Sugar Valley to 0.51 ft/yr in Little Valley and did not show a significantly larger slope than the Bruneau Valley (0.48 ft/yr).

Perhaps the most informative of the Regional Kendall tests is the test by depth (fig. 6). Slopes of the overall trend increased with depth from 0.27 ft/yr (in the 0–200 ft range) to 0.62 ft/yr (in the 1,501–2,000 ft range). An increase of slope with increasing well depth indicates that water-level decreases are more apparent as completion depth increases. This may be due to small sample size (only one well in the 501–1,000 ft and 1,501–2,000 ft categories), but it may indicate an actual trend with depth. Decreases in water level may be most evident in deep wells due to the limited amount of recharge affecting deep wells or other factors that influence the deep parts of the regional aquifer.

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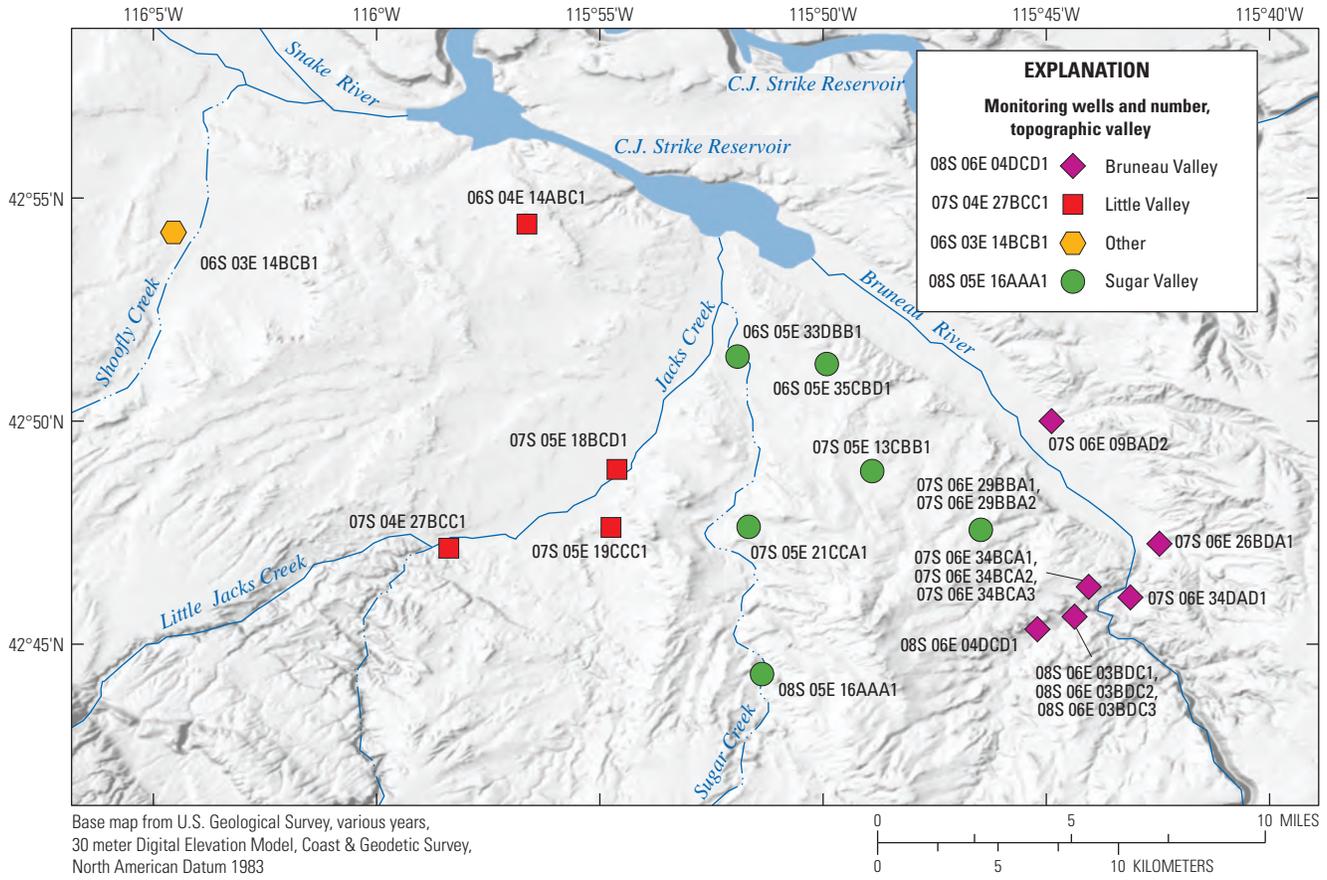


Figure 5. Map showing groups of monitoring wells by regional topographic valley, Bruneau study area, southwestern Idaho.

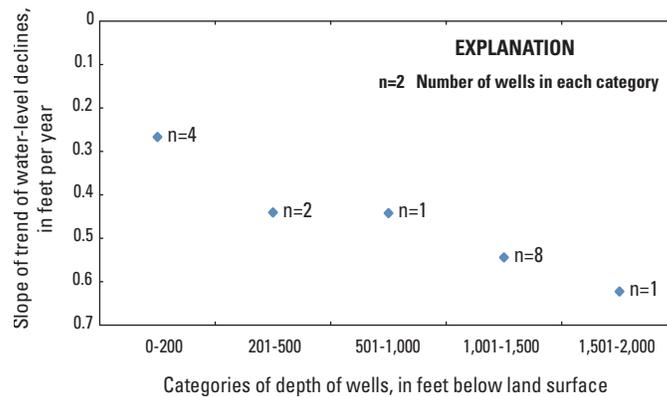


Figure 6. Slopes of trends of groundwater decline as calculated by the Regional Kendall test by depth of wells, Bruneau study area, southwestern Idaho.

Table 8. Results from Regional Kendall trend analyses of water levels by categories, Bruneau study area, southwestern Idaho.

[Seasonal Kendall trend analysis run on DOS executable program. No *p*-value was greater than 0.10. **Abbreviations:** ft/yr, feet per year; °C, degrees Celsius; BLS, below land surface, <, less than; >, greater than]

Category of wells	Slope (drawdown in ft/yr)	<i>p</i> -value	Number of wells in each category (n)
Completion depth (in feet BLS)			
0–200	0.27	0.0000	4
200–500	0.44	0.0000	2
500–1,000	0.44	0.0000	1
1,000–1,500	0.54	0.0000	8
1,500–2,000	0.62	0.0339	1
Distance from Indian Bathtub (in miles)			
< 1	0.48	0.0000	1
1–3	0.37	0.0000	2
3–10	0.50	0.0000	3
10–15	0.38	0.0000	5
15–20	0.48	0.0266	1
Geologic unit			
Idaho	0.56	0.0042	2
Idavada	0.41	0.0000	5
Banbury	0.45	0.0000	7
Regional topographic valley			
Bruneau	0.48	0.0000	1
Sugar	0.35	0.0000	3
Little	0.51	0.0002	9
Temperature (°C)			
< 30	0.45	0.0000	5
30–40	0.48	0.0000	6
> 40	0.28	0.0147	3

Statistically Significant Water Level Decreases in the Bruneau Study Area

The majority of results from the Seasonal Kendall and Regional Kendall tests indicate that groundwater in monitoring wells showed statistically significant changes in water levels during the period of record. The overall trend of significant water-level decline ranged from 0.21 to 1.0 ft/yr during the study period. Significant declines in water levels may be a

regional trend that is apparent throughout the Bruneau study area. This would confirm the results published by McVay (2012), indicating that on average, wells in the Grand View-Bruneau Groundwater Management Area exhibit water level declines. However, not all monitoring wells used in this study were completed in the geothermal aquifer. Therefore, the results of this study indicate increasing depth to water in both the geothermal aquifers and unconfined alluvium.

Factors not Accounted for in Statistical Analysis

These statistical tests determined general drawdown trends; however, there was no attempt to correlate the effects due to pumping, land-use change, and other variables that could be impacting water levels in the Bruneau study area. Groundwater withdrawals for irrigation are most likely a significant contributor to water-level declines. Historical pumping estimates are available in Berenbrock (1993). However, not enough information is available to determine the effect of pumping on groundwater levels in specific monitoring wells to incorporate into this statistical analysis. Analysis of data on regional pumping histories, changes in land use, and drawdown relations between pumping wells and monitoring wells could produce a more powerful statistical analysis of regional trends in the Bruneau study area.

Estimated Drawdown

Drawdown was estimated for wells completed in the sedimentary-rock (table 9) and volcanic-rock (table 10) aquifers. Results show the radial distance at which drawdown (or recovery) of 1 and 5 ft would be detected at a time intervals of 1, 5, 10, and 20 years for specified values of transmissivity, storativity, and flow (table 5). Recovery effects may take longer than those of drawdown, depending on recharge conditions.

Drawdown and recovery effects are greatest in estimates of small drawdown increments and with increasing time. After 20 years of pumping from the sedimentary-rock aquifers, 1 ft of drawdown was simulated as much as 65 mi away from the pumping well, assuming a medium transmissivity, the highest flow, and the lowest storativity values. Using different hydraulic parameters (highest transmissivity and lowest flow values), drawdown was less than one foot during the 20-year time period. Estimations projecting drawdown at the same time period range between these values.

18 Historical and Potential Groundwater Drawdown in the Bruneau Area, Owyhee County, Southwestern Idaho

Similarly, results from estimates in the volcanic-rock aquifer also had a large range. A drawdown of 1 ft in the volcanic-rock aquifers was seen after 20 years as far as 29 mi away (assuming the medium transmissivity and storativity values and the highest flow value). Estimations using the highest transmissivity value for the volcanic-rock aquifers showed that 1 ft of drawdown was less than one foot. Using the same time period while varying hydraulic parameters, drawdown estimates fall between these two extreme values.

Different values of hydraulic parameters changes the projected effects of pumping or recovery. According to the Theis equation, an increase in the flow (pumping rate) will proportionately increase the vertical drawdown and lateral extent of the cone of depression. A decrease in the storativity value increases radial groundwater drawdown. An increase in

transmissivity value decreases vertical drawdown but the cone of depression increases in radius. Therefore, a decrease in the transmissivity value increases drawdown at the pumping well, making a cone that is deeper with a tighter radius. Because of the way hydraulic parameters interact, sometimes mid-range values of transmissivity may paradoxically produce more drawdown or a greater radius of drawdown than low values of transmissivity.

The closer a well is to a given geothermal seep or spring, the more likely that pumping of the well will affect drawdown or recovery of the aquifer. The shape of a cone of depression demonstrates that drawdown is greater closer to the pumping center. If all Theis assumptions are valid, pumping near the geothermal seeps or springs would have the greatest effect on drawdown in the area.

Table 9. Estimated distance of specified drawdowns and times in the sedimentary-rock aquifers, Bruneau study area, southwestern Idaho.

[Results generated from the Theis equation and associated assumptions. **Abbreviations:** acre-ft/yr, acre-feet per year; ft²/d, foot squared per day; –, target drawdown was not achieved in this simulation]

Flow (acre-ft/yr)	Transmissivity (ft ² /d)	Storativity (dimensionless)	1-foot drawdown				5-foot drawdown			
			1 year	5 years	10 years	20 years	1 year	5 years	10 years	20 years
			Distance from pumping well (in miles)							
100	300	0.0004	5.6	12	18	25	2.3	5.1	7.2	10
	300	0.0009	3.7	8.3	12	17	1.5	3.4	4.8	6.8
	300	0.002	2.5	5.6	7.9	11	1.0	2.3	3.2	4.5
	3,730	0.0004	2.3	5.2	7.4	10	–	–	–	–
	3,730	0.0009	1.6	3.5	4.9	7.0	–	–	–	–
	3,730	0.002	–	–	–	–	–	–	–	–
	33,000	0.0004	–	–	–	–	–	–	–	–
	33,000	0.0009	–	–	–	–	–	–	–	–
	33,000	0.002	–	–	–	–	–	–	–	–
250	300	0.0004	7.3	16	23	33	4.2	9.4	13	19
	300	0.0009	4.8	11	15	22	2.8	6.2	8.8	12
	300	0.002	3.3	7.3	10	15	1.9	4.2	5.9	8.4
	3,730	0.0004	8.1	18	25	36	0.33	0.73	1.0	1.5
	3,730	0.0009	5.4	12	17	24	0.22	0.49	0.69	0.97
	3,730	0.002	3.6	8.1	11	16	0.15	0.33	0.46	0.65
	33,000	0.0004	0.05	0.11	0.15	0.21	–	–	–	–
	33,000	0.0009	–	–	–	–	–	–	–	–
	33,000	0.002	0.02	0.05	0.07	0.09	–	–	–	–
610	300	0.0004	8.8	20	28	39	6.0	13	19	27
	300	0.0009	5.8	13	18	26	4.0	8.9	13	18
	300	0.002	3.9	8.8	12	18	2.7	6.0	8.4	12
	3,730	0.0004	15	33	46	65	3.3	7.5	11	15
	3,730	0.0009	9.7	22	31	44	2.2	5.0	7.1	10
	3,730	0.002	6.5	15	21	29	1.5	3.3	4.7	6.7
	33,000	0.0004	2.9	6.4	9.0	13	–	–	–	–
	33,000	0.0009	1.9	4.3	6.0	8.5	–	–	–	–
	33,000	0.002	1.3	2.9	4.0	5.7	–	–	–	–

Visualization of Estimated Drawdown

The distance drawdown calculated by analytical methods represents the radial distance of equal water-table decline; this radius could be used to create a circle with a perimeter showing equal drawdown, representing the cone of depression. Estimates of the effects of a pumping well as pumping and drawdown continue throughout time are shown in [figure 7](#). Drawdown circles centered around Indian Bathtub Spring (HS3) demonstrate the area experiencing 1 ft of drawdown at various times given a set of conditions (pumping from the volcanic-rock aquifers at the highest flow, mid-range transmissivity, and mid-range storativity values). On this map,

drawdown is centered on Indian Bathtub Spring; however, circles of drawdown can be placed on any point along the geothermal reach to indicate impacts on that location. [Figure 7](#) implies that if a well is located within the extent of drawdown, it will affect the geothermal system in that area given those hydraulic parameters.

A diagrammatic side-view representation of a pumping well and its cones of depression with increasing time ([fig. 8](#)) present another way to conceptualize simulations. In this figure, the cones of depression created from different pumping estimates are shown from a cross-sectional side view. As the cone of depression expands with time, 1 ft of drawdown is seen farther from the well and may potentially affect spring flow if the cone of depression intersects geothermal flows.

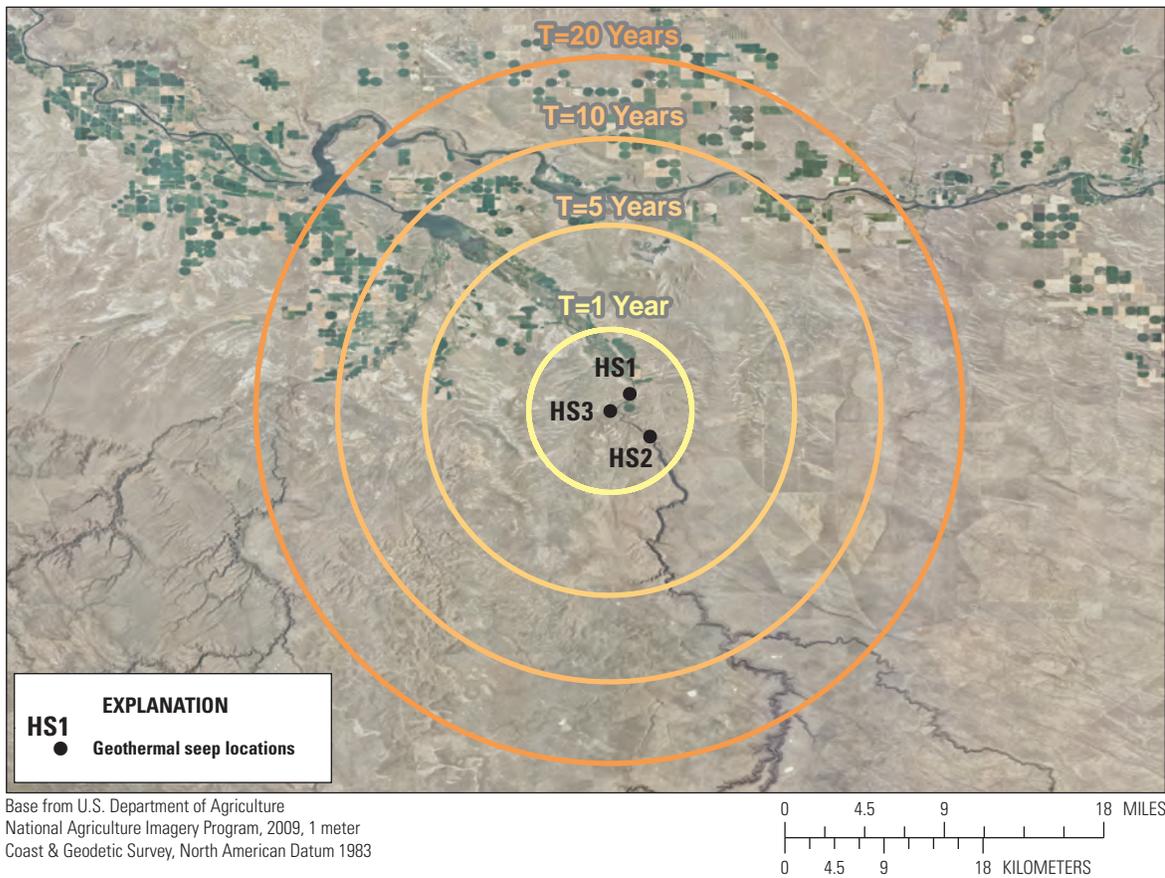


Figure 7. Extent of cone of depression of 1 foot of drawdown with increasing time (1, 5, 10, and 20 years) assuming highest flow, mid-range transmissivity, and highest storativity values in the volcanic-rock aquifers, Bruneau area, southwestern Idaho. Drawdown is centered on Indian Bathtub Spring (HS3).

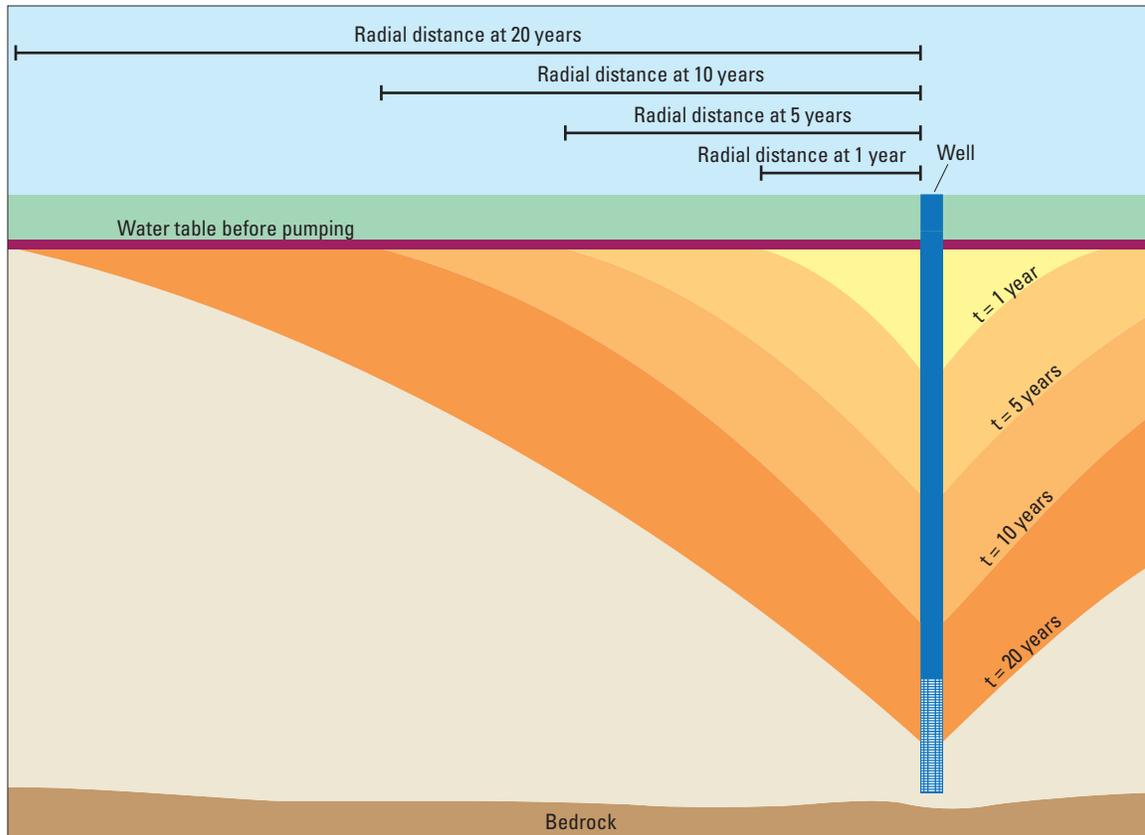


Figure 8. Representation of cones of depression produced by a pumping well. The drawdown caused by continuous pumping increases radially as time progresses.

Assumptions of Analytical Methods

The estimates presented here incorporate assumptions that may not be valid in the study area. The Theis equation assumes a homogeneous, isotropic aquifer with known hydraulic parameters. In reality, the geothermal aquifer is most likely not homogeneous or isotropic; the range of hydraulic parameters used in this study indicate that the aquifers probably have varying characteristics throughout. In addition, calculations assumed a confined, horizontal aquifer of infinite extent. Varying geology and a confining unit of unknown extent may limit the validity of these assumptions on a large scale.

Simplifying assumptions were made for this study. Elevation differences between wells and the geothermal seeps and springs along the Bruneau River were not accounted for, thus estimates assume a flat potentiometric surface. Estimates

assumed that pumping did not induce flow from the Bruneau River or Snake River, or account for other forms of recharge. In actuality, recharge has been determined to contribute to the geothermal aquifers (Berenbrock, 1993). Calculations were made for the effects of one pumping well; in reality, many wells in the area are pumping and drawdown may increase with multiple pumping wells. Estimates also assumed unfractured and uniform geology, and did not account for lateral changes in stratigraphy or faults that may affect the aquifer.

Ideally, the assumptions made in this study could be tested by measuring drawdown near a well with known hydraulic parameters. However, there is no location in the study area where a monitoring well is close to a single pumping well. All monitoring wells, and therefore, areas where drawdown could be monitored, are in areas that could potentially be affected by multiple pumping wells.

Sensitivity Analysis

To compensate for the unknown hydraulic parameters at the location of a pumping well, drawdown calculations were made using combinations of hydraulic parameters. The range of distance-drawdown values demonstrates how the uncertainty about hydraulic properties in an exact area can generate substantially different drawdown results using the Theis equation. The effect of changing one hydraulic parameter (fig. 9), such as storativity, can be quite large. In figure 9, the aquifer type, flow, transmissivity, time, and amount of drawdown remain constant while only the assumed storativity value changes. The uncertainty associated with such a large range of hydraulic parameters indicates that drawdown may range over an order of magnitude or more from the calculated results.

Suggestions for Further Study

All calculations in this study were made using existing data. Future studies could benefit from additional data collection and assumption testing. The statistical analysis would be more robust if additional data regarding well completion and water temperature were available. Future studies would benefit by examining more than 20 years of data and by the addition of more monitoring wells to the network, especially near geothermal seeps and springs of interest. The comparison of results from this study with trends from other monitoring wells in the western Snake River Plain may give insight into trends specific to the Bruneau study area.

The estimated drawdown portion of this study was based on many assumptions and more robust results could be achieved with additional knowledge of aquifer properties near the area of interest. A large range of hydraulic parameters and pumping rates generated varying drawdown estimates.

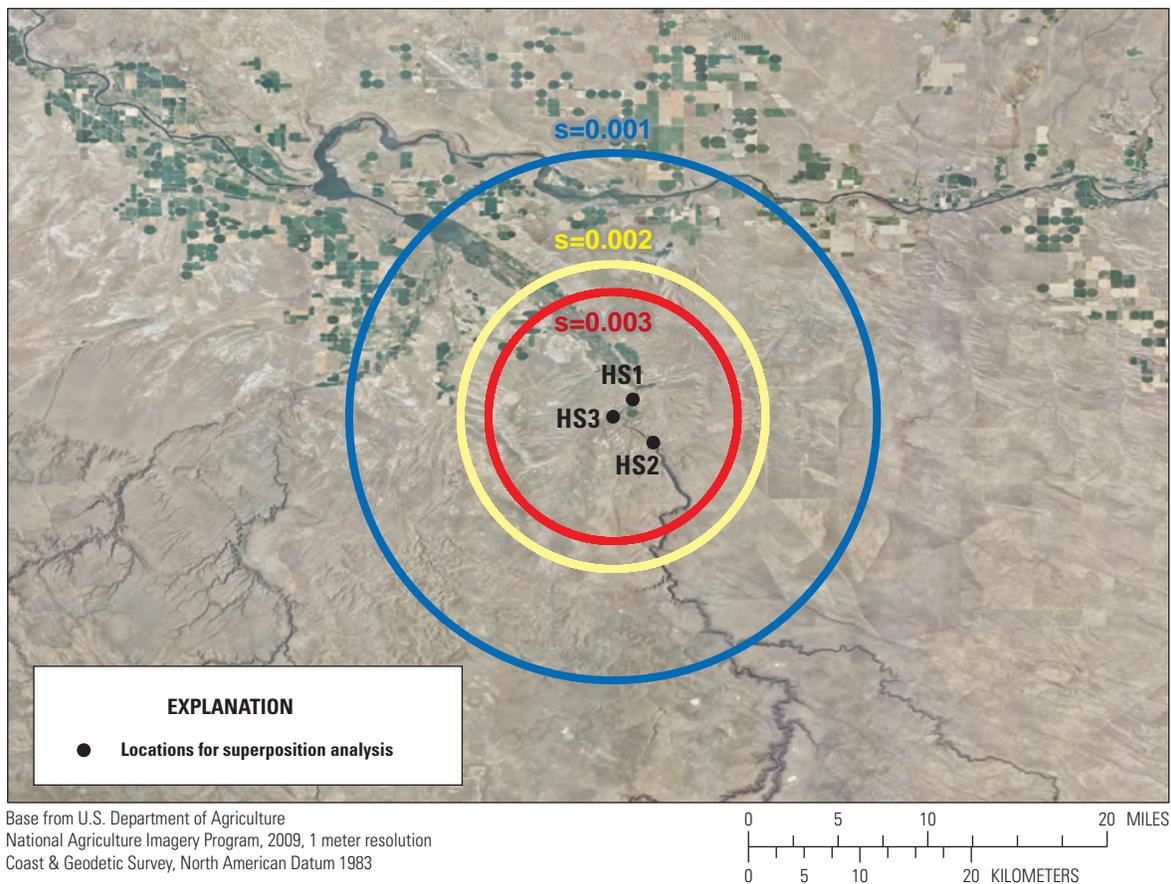


Figure 9. Cones of depression based on different values of storativity. Circles representing the radial distance experiencing 1 ft drawdown in the volcanic-rock aquifers after 5 years of pumping at a highest flow and mid-range transmissivity values, Bruneau area, southwestern Idaho. Drawdown is centered on Indian Bathtub Spring (site HS3).

The same method of estimating drawdown used in this study could be applied at specific wells to generate better estimates of the effects of conservation efforts; drawdown estimates for a specific well could be generated using the exact hydraulic parameters and pumping information for that particular well.

The assumptions in this study could be applied to a simple numerical model study using the superposition principle. Such a study would require many simplifying assumptions to create a model that has a transmissive layer, correct geometric positions of any surface-water features including springs and streams, and locations of wells of interest. This type of model could calculate capture by specific wells. Previous efforts to model the area were unsuccessful (Berenbrock, 1993) and a simplified model would involve many assumptions.

As conservation efforts move forward, it is important to increase localized water level monitoring and include hydrologic studies in future plans. Closely monitored changes to pumping could generate a greater knowledge of the hydrogeology of the Bruneau study area and effectiveness of conservation efforts. Greater numbers of monitoring wells, especially those installed near wells with decreased pumping, would provide extensive data that could be used in future studies.

Summary and Conclusions

As part of a two phase study, existing data were used to determine trends in water levels, and groundwater drawdown was estimated to inform conservation efforts aimed at preserving the habitat of the Bruneau hot springsnail. The two components of this study increase the understanding of the possible effects of groundwater withdrawal on geothermal seeps and springs that are vital to the Bruneau hot springsnail habitat. Historical water levels indicate that groundwater levels have significantly decreased in the Bruneau study area. The historical impacts of groundwater drawdown need to be taken into account as conservation efforts seek to maintain the geothermal inflows to the Bruneau River. Both historical and estimated drawdowns imply that water levels, and potentially springs and seeps are affected by pumping.

Water-level data from 22 monitoring wells collected over a 20-year period were analyzed statistically using variations of the Kendall test. Results from a Seasonal Kendall test on individual wells indicated statistically significant (p -value < 0.10) declines in groundwater levels have occurred for

18 of the 22 wells evaluated. Slopes of the trend of water-level declines in individual wells ranged from 0.21 to 1.01 feet per year. Water levels from four wells in the study area had p -values greater than 0.10, indicating that they did not experience a significant change in water level over time.

Regional Kendall tests for trends were performed on various categories of wells. Wells were categorized based on well depth, distance from Indian Bathtub Spring, geologic unit, topographical valley, and temperature. The only discernible trend in well categories was seen in wells increasing in depth that had increasing depth to water measurements. All Regional Kendall tests were statistically significant and generated positive slopes, indicating declines in groundwater levels. The general pattern of increasing depth to water throughout the study area as seen in data from monitoring wells indicate that water-level declines may be a regional trend throughout the entire Bruneau study area.

Drawdown, or recovery, was calculated using the Theis equation, a range of hydraulic parameters, and theory of superposition analysis. Estimates were performed for units of the geothermal-bearing aquifers (sedimentary-rock and volcanic-rock). The Theis equation was used to estimate drawdown using different combinations of transmissivity, storativity, and flow (pumping rates). Estimated drawdown varied substantially based on assumptions of hydraulic parameters. For example, by using the mid-range value of transmissivity, the lowest value of storativity, and the highest value of flow, 1 foot of drawdown could be seen in the volcanic-rock aquifer as far as 29 miles away in a 20-year time span. However, by increasing transmissivity to the highest value and using the same values of storativity, flow, and time, estimated results show less than 1 foot of drawdown during the same time period.

A range of values estimating pumping effects at different times and various pumping conditions was generated and presented in two tables. Many assumptions that implied an idealized aquifer were made for these calculations and more accurate estimations of pumping effects could be made with an improved understanding of the aquifer systems. If all Theis assumptions apply, decreasing pumping closer to the geothermal reach would be the most effective groundwater conservation effort. Future studies would benefit from additional collection of water-level measurements. As future conservation efforts are made, it is important to monitor the nearby groundwater system and geothermal seeps and springs to refine hydrological models and to improve understanding of the groundwater system.

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