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Prepared in cooperation with the Rural Water Authority of Douglas County

Groundwater Levels in the Denver Basin Bedrock Aquifers of Douglas County, Colorado, 2011–2013

Scientific Investigations Report 2014–5172

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

Cover: Photographs showing *top*, domestic well in Douglas County; *bottom left*, rural Douglas County looking northwest over Parker, Colorado; and *bottom right*, development south of Castle Rock, Colorado. All photographs by Rhett Everett, U.S. Geological Survey.

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SALLY JEWELL, Secretary

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Pressure	
atmosphere, standard (atm)	101.3	kilopascal (kPa)
pound per square foot (lb/ft^2)	0.04788	kilopascal (kPa)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8×°C)+32$$

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

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

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

Abbreviations and Acronyms

ARAP	Arapahoe aquifer
CDWR	Colorado Division of Water Resources
CWCB	Colorado Water Conservation Board
DENV	Denver aquifer
ft	feet
GPS	global positioning system
LARA	Laramie-Fox Hills aquifer
LDAW	lower Dawson aquifer
LSD	land surface datum
mi^2	square mile
MP	measuring point
NAD83	North American Datum 1983
NAVD88	North American Vertical Datum 1988
NWIS	National Water Information System
OPUS	Online Positioning User Service
PPR	parameter prediction
RTK	real-time kinematic
RWADC	Rural Water Authority of Douglas County
UDAW	upper Dawson aquifer
USGS	United States Geological Survey
UTC	Coordinated Universal Time

Groundwater Levels in the Denver Basin Bedrock Aquifers of Douglas County, Colorado, 2011–2013

By Rhett R. Everett

Abstract

More than 70 percent of the municipal water supply in the south Denver metropolitan area is provided by groundwater, and homeowners in rural areas depend solely on self-supplied groundwater for water supply. Increased groundwater withdrawal to meet the demand of the rapidly growing population is causing water levels to decline. The U.S. Geological Survey, in cooperation with the Rural Water Authority of Douglas County, began a study in 2011 to assess the groundwater resources of the Denver Basin aquifers within Douglas County, Colorado. The primary purpose of this study was to monitor changes in the groundwater levels of the bedrock aquifers of the Denver Basin within rural Douglas County. To better assess the water resources of the Denver Basin bedrock aquifers, a groundwater monitoring network was established in 2011. More than 500 manual and 213,900 automated water-level measurements collected from the 36 domestic-well network between April 2011 and June 2013 showed water-level declines in all aquifers.

Manual and automated (time-series) water-level data collection from these sites between 2011 and 2013 showed water level declines in 36 wells. Over the 2-year monitoring period, average declines of approximately 0.4 foot per year were observed in the upper Dawson aquifer, declines of over 2.6 feet per year were observed in the lower Dawson aquifer, declines of about 3.2 feet per year were observed in the Denver aquifer, declines of about 1.9 feet per year were observed in the Arapahoe aquifer, and declines of about 9.9 feet per year were observed in the Laramie-Fox Hills aquifer.

Introduction

Groundwater from Denver Basin bedrock aquifers (fig. 1) provides more than 70 percent of the municipal water supply in the south Denver metropolitan area, and some water providers consider groundwater availability in this area insufficient for long-term demand (South Metro Water Supply Study Board, written commun., 2003; Colorado Water Conservation Board, 2004a). Domestic groundwater use is less than municipal use but is widespread throughout the basin, and residents in rural areas depend solely on self-supplied groundwater for water supply (Paschke, 2011). Some Douglas County municipal water providers have water rights to the South Platte River and its tributaries Cherry Creek and Plum Creek (fig. 1), but their allocations do not provide enough water to satisfy the renewable supplies necessary to fulfill the existing water demands of the county (South Metro Water Supply Study Board, written commun., 2003). In 1990, the population of Douglas County, Colorado (Colo.) (fig. 1), was just over 60,000 people (U.S. Census Bureau, 2011). Between 2000 and 2008, the population had increased by about 60 percent from 175,766 to 280,621 residents occupying more than 101,000 housing units. The Douglas County Planning Commission estimates the population will grow to more than 444,000 by 2030 (Douglas County 2030 Comprehensive Master Plan, undated). Increased groundwater withdrawal is causing large water-level declines, especially along the western edge of the Denver Basin and in parts of Douglas County. This raises concerns that the groundwater supply may be depleted much faster than previously thought (Nichols and others, 2001; Moore and others, 2007).

In October 2008, the Rural Water Authority of Douglas County (RWADC) was created to assist county residents in developing water resources and systems for the benefit of all water users and landowners within the county. The RWADC's mission is to assist the more than 8,000 rural well-water users and 14 small (fewer than 500 taps) water districts by evaluating current and future water supplies and demand, determining services and(or) facilities that are of benefit to them, and advising and assisting other agencies on rural water issues (*http://www.rwadc.org/home.html* accessed September 2012). The RWADC collaborates with other local, regional, and statewide water-supply agencies in the development of water-supply plans and conservation of water resources; educates and informs water users as to issues affecting an adequate, sustainable, and reliable water supply; and provides services or functions related to the provision of an adequate, sustainable, and reliable water supply to rural water users. The U.S. Geological Survey (USGS), in cooperation with the RWADC, began a study in 2011 to assess the groundwater resources of the Denver Basin aquifers within Douglas County. The primary purpose of this study was to monitor changes in the groundwater levels of the bedrock

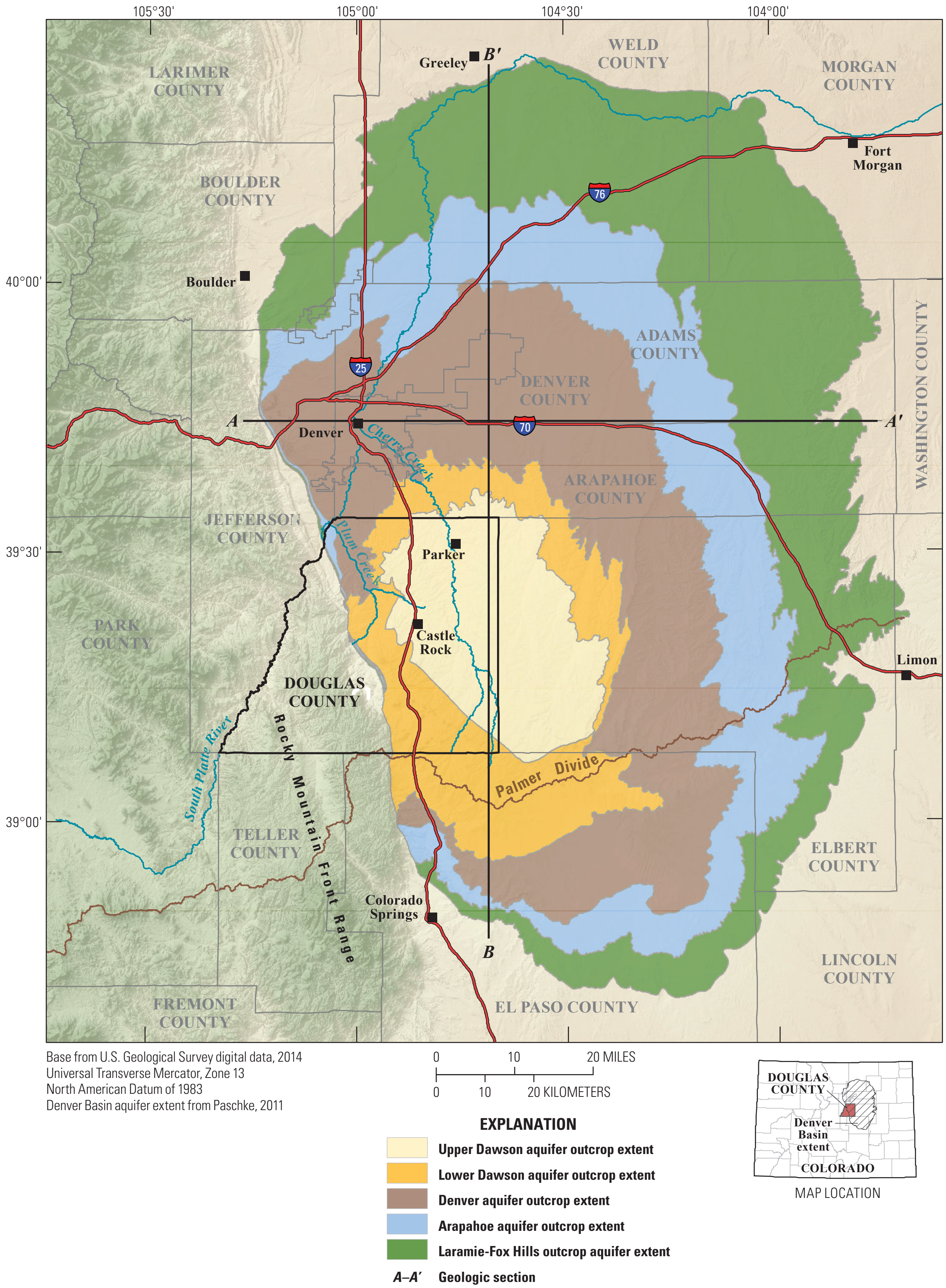


Figure 1. Location of the Denver Basin bedrock aquifer system, Colorado.

aquifers of the Denver Basin within rural Douglas County. To accomplish this, a county-wide groundwater-level monitoring network for the long-term monitoring of the water resources was established. Water levels measured from wells in the network provide an assessment of the current water resource and provide the basis from which to monitor long-term changes of the hydrologic system.

Purpose and Scope

The purpose of this report is to describe changes in the groundwater level of the bedrock aquifers of the Denver Basin within rural Douglas County, Colo. Currently (2014), 36 existing well sites throughout the county are included in the monitoring network and water-level measurements are being made bi-monthly (every 2 months) (fig. 2). In addition to manual measurements, 15 of the wells are equipped with vented pressure transducers and data loggers set to record water levels on an hourly basis (fig. 2). This report presents a summary of the well-selection process, data collected between April 2011 and June 2013, and limited discussion of the preliminary observations.

Previous Work

Since Cross and others (1884) first described the artesian groundwater conditions of the Denver Basin in 1884, extensive work has been conducted to describe the geologic history, structural geology, stratigraphy, natural resources, and hydrologic conditions of the Denver Basin and surrounding area. Wireman and Romero (1989) published a bibliography of geology and groundwater geology for the Denver Basin containing over 160 references, and Paschke (2011) cited over 190 references in a detailed description of previous work. The following discussion of previous work is a brief summary that focuses on work directly related to groundwater and this report.

Systematic hydrogeologic characterization of the Denver Basin aquifers began in the 1970s as part of developing nontributary groundwater rules established by Colorado Senate Bill 213 (Graham and Van Slyke, 2004). The Colorado Division of Water Resources (CDWR) and the USGS collaborated through the 1970s and 1980s by mapping and characterizing the primary aquifers of the Denver Basin. This collaboration resulted in multiple reports (Romero and Hampton, 1972; Romero, 1976; Robson and Romero, 1981a, 1981b; Robson, Romero, and Zawistowski, 1981; Robson, Wacinski, and others, 1981; and Robson, 1983), and culminated in the construction of a groundwater flow model of the Denver Basin aquifers (Robson, 1987). Using additional available data, the CDWR then created maps of geologic structure, silt-plus-sand thickness, and areas of nontributary groundwater for each of the bedrock aquifers (Van Slyke and others, 1988a, 1988b, 1988c, 1988d). This work formed the basis for defining aquifer boundaries in the basin (Graham and Van Slyke, 2004). More recently, the USGS, in cooperation with the CDWR and the Colorado Water Conservation Board (CWCB), developed a fully three-dimensional groundwater flow model of the Denver Basin aquifer system (Paschke, 2011).

Historical water-level data collection for Denver Basin bedrock aquifers has been irregular, and water-level monitoring efforts have decreased since the 1980s (Colorado Water Conservation Board, 2004b, 2006). Initial water-level monitoring in the Denver Basin completed by Emmons and others (1896) included wells located in downtown Denver. The first basin-wide assessment of water levels was done by the USGS from 1956 to 1963 (McConaghy and others, 1964). Major and others (1983) included a comprehensive set of water-level data for the bedrock and alluvial aquifers through 1981. In the 1980s, the CDWR established a water-level monitoring network of approximately 278 wells and water-level data collected therefrom are published in annual reports (Pottorff and Horn, 2013). The South Platte Decision Support System published a compilation and bibliography of all available water-level data for bedrock and alluvial aquifers through 2004 (Colorado Water Conservation Board, 2004b, 2006).

Studies within Douglas County that contributed to understanding the hydrologic resources include Hillier and others (1978), who examined the hydrology and water quality of the Arapahoe aquifer in the Englewood–Castle Rock area, and the Castle Pines core hole that fully penetrated the Arapahoe aquifer (Raforth and Jehn, 1990; Robson and Banta, 1990; Robson and Banta, 1993; Robson, 1995). Moore and others (2007) examined groundwater use and population growth and summarized the problems associated with groundwater development in Douglas County. The CDWR monitoring network presently measures water levels in about 89 municipal and domestic wells within Douglas County on an annual basis (Pottorff and Horn, 2013). Since 2009, the USGS has measured water levels in 19 domestic wells in a subdivision near Parker, Colo., in the northeastern corner of Douglas County.

Description of the Study Area

Douglas County, Colo., is located midway between Denver and Colorado Springs (fig. 1). The county encompasses 842 square miles (mi^2) and is bounded by Jefferson County and the South Platte River to the west, Arapahoe County to the north, Teller and El Paso Counties to the South, and Elbert County to the east. Elevations in Douglas County range from a low of about 5,400 feet (ft) in the northwest corner to over 9,800 ft in the southwest corner. The varied topography is characterized by mountains, foothills, ridgelines, mesas, and plains. Vegetation varies with topography. Pine, spruce, and fir trees cover the mountains; gamble oak, mountain mahogany, and chokecherry are predominate in the foothills; cottonwood trees, willows, and lush grasses are found in the riparian zones; and blue grama, switch grass, and winter wheat grasses are prevalent in plains (Douglas County 2030 Comprehensive Master Plan, undated). Douglas County is drained by the South Platte River and Cherry and Plum Creeks that flow north into the South Platte (fig. 1).

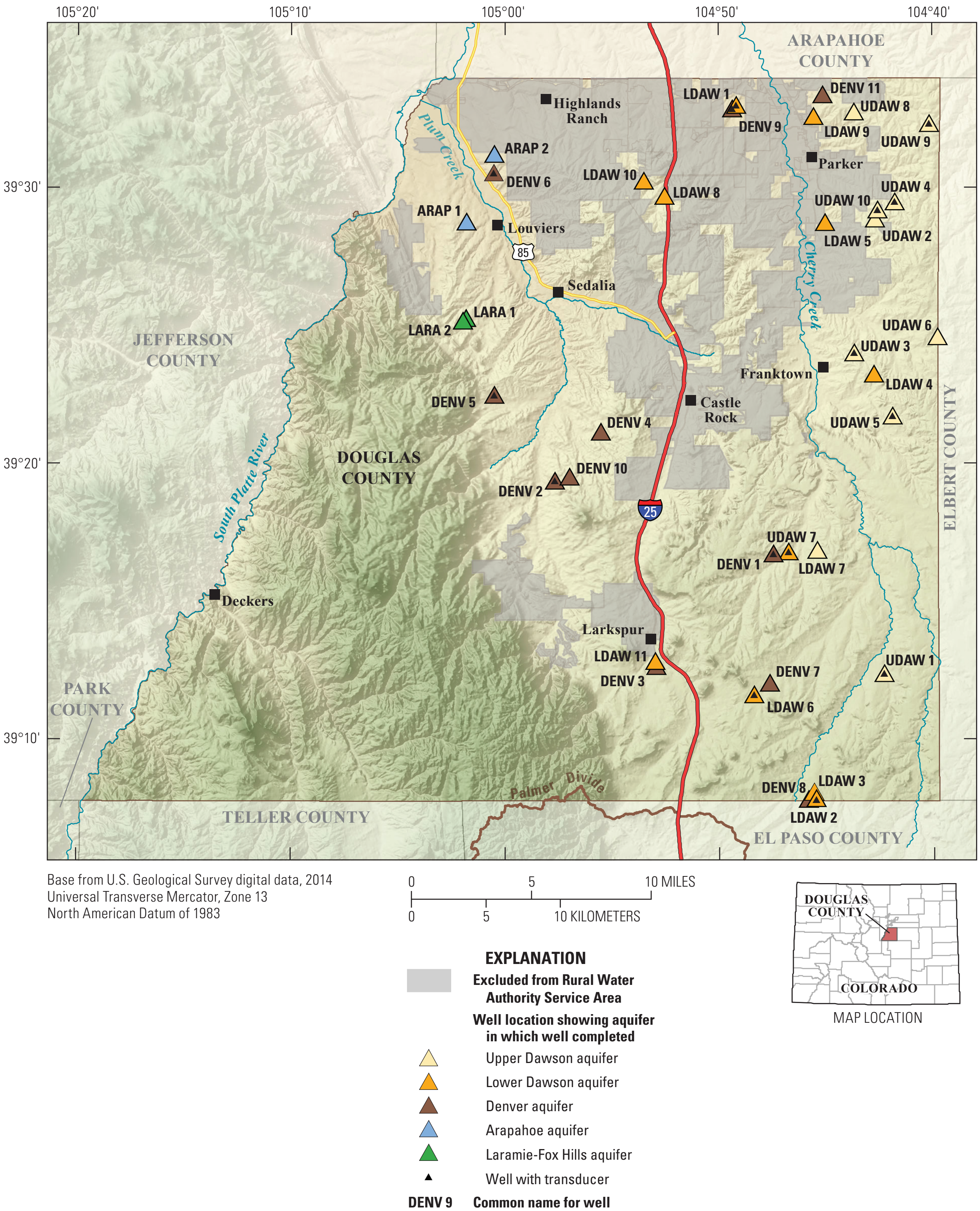


Figure 2. Location of water-level monitoring network well sites, Douglas County, Colorado.

In 2010, the county population was 285,465; a 62.4 percent increase since the 2000 census (U.S. Census Bureau, 2011), making Douglas County the fastest growing county in the Front Range urban corridor. Douglas County has a diverse land use. In addition to its urban centers of Castle Rock, Parker, and unincorporated Highlands Ranch, Douglas County has several smaller rural communities, housing developments, ranches, and open spaces.

The western one-third of the county is underlain by the granitic bedrock of the Rocky Mountain Front Range (fig. 1), and private well owners withdraw their water from fractures in the bedrock. The eastern two-thirds overlie the Denver Basin, and private well owners withdraw their water from one of the principal aquifers, depending on well location and use. Douglas County reports the total number of domestic private wells increased from 1,124 in 1970 to 7,957 by 2009 (Douglas County, 2009).

The Denver Basin aquifer system is a synclinal structure composed of Late Cretaceous to Tertiary-age sandstone bedrock aquifers separated by claystone confining units that underlie about 7,000 mi^2 of the Great Plains along the eastern edge of the Rocky Mountain Front Range (Fenneman, 1931; Robson, 1987; Paschke, 2011). The Denver Basin extends north to Greeley; south to near Colorado Springs; west to the base of the Front Range; and east to the eastern edge of Adams, Arapahoe, and Elbert Counties (fig. 1). The lowest part of the Denver Basin bedrock aquifer system is located in Douglas County just north of Parker, Colo., at an elevation of approximately 3,410 ft. The total thickness of the aquifer system reaches a maximum of approximately 3,200 ft beneath the topographic high of the Palmer Divide (fig. 1). Surface-water drainage in the Denver Basin is split by the Palmer Divide, with the northern three-quarters draining into the South Platte River Basin and the southern one-quarter draining into the Arkansas River Basin.

The bedrock aquifers, from oldest to youngest, are the Laramie–Fox Hills, Arapahoe, Denver, and Dawson aquifers (Robson, 1987) and are composed of the Fox Hills Sandstone, Laramie Formation, Arapahoe Formation, Denver Formation, and Dawson Formation, respectively (fig. 3). The Arapahoe and Dawson aquifers are divided into lower and upper units in parts of the basin. The Cretaceous Pierre Shale confining layer underlies the bedrock aquifers throughout the basin, while alluvial sand, gravel, and clay deposits overlie the bedrock aquifers primarily along the stream channels of the South Platte and Arkansas River drainage systems. All of the bedrock aquifer units crop out at some point in the Denver Basin. The oldest rocks of the Laramie-Fox Hills aquifer, are exposed around the outer margins of the basin, and the outcrop area of each younger unit is smaller in size and contained within the boundaries of the older unit that it overlies (fig. 1). Generally, confined groundwater conditions exist in the bedrock aquifers where they are overlain by younger units, and unconfined groundwater conditions exist in outcrop areas and in alluvial deposits.

The Laramie-Fox Hills aquifer is the oldest, most extensive, and deepest of the bedrock aquifers in the Denver Basin. The Laramie–Fox Hills aquifer is composed of the basal sandstone layers of the Cretaceous Laramie Formation, composed of very fine to medium-grained sandstone with interstitial silt and clay, and the underlying Fox Hills Sandstone, composed of very fine grained silty sandstone and shaly siltstone with interbedded shale (Romero, 1976; Schneider, 1980; Robson, Wacinski, and others, 1981; Robson, 1987). The Laramie-Fox Hills aquifer underlies the entire extent the of the Denver Basin, approximately 7,000 mi^2 (543 mi^2 within Douglas County) and ranges in thickness from tens of feet near the edges of the basin to between 300 and 400 ft near the central part of the basin where the average water-yielding thickness is about 150 ft (Robson, 1987; Paschke, 2011). The Laramie-Fox Hills aquifer is confined by the Cretaceous upper Laramie Formation. Composed of a gray to black shale, coal seams, and minor amounts of siltstone and sandstone, the confining layer ranges in thickness from as much as 700 ft near the Front Range to less than 100 ft on the eastern edge of the basin.

The Arapahoe aquifer is composed of Cretaceous-age sequences of interbedded conglomerate, sandstone, siltstone, and shale. The aquifer underlies approximately 4,700 mi^2 of the Denver Basin (540 mi^2 within Douglas County) and is generally 400 to 700 ft thick with an average water-yielding thickness of 200 to 300 ft thick (Romero, 1976; Robson, Romero, and Zawistowski, 1981; Robson, 1987). In the northern one-third of its extent, where shale is more prevalent, the Arapahoe aquifer is divided into upper and lower aquifers with an intervening shale confining unit. In the southern two-thirds of the aquifer, extensive lens-shaped conglomerate and coarse-grained sandstone beds up to 40 ft thick are present (Robson, 1987). In some areas, particularly in Douglas and El Paso Counties, the lenses are so closely spaced they form a single hydrologic unit that can be up to 300 ft thick (Robson, 1987; Paschke, 2011). The elevation of the base of the lower Arapahoe aquifer ranges from 4,100 ft at the basin center just north of Parker, Colo., to approximately 6,200 ft along the southwest basin margin, and the maximum depth to the base of the aquifer is approximately 2,600 ft below land surface at the Palmer Divide (Paschke, 2011). The Arapahoe aquifer is confined by fine-grained deposits in the upper portion of the Arapahoe Formation. Averaging about 90 ft thick, this unit ranges from 0 ft to a maximum thickness of about 250 ft near the center of the confining-unit extent in southwest Adams County (Paschke, 2011).

The Denver aquifer is composed of Late Cretaceous- to Tertiary-age interbedded shale, claystone, siltstone, sandstone, coal, and volcanic ash and rocks (Romero, 1976; Robson, Wacinski, and others, 1981; Robson, 1987). The aquifer underlies approximately 3,200 mi^2 of the Denver Basin (532 mi^2 within Douglas County) and is generally 600 to 1,200 ft thick with an average water-yielding thickness between 100 to 300 ft (Robson, 1987; Paschke, 2011). In general, sandstone beds, derived from alluvial fan deposits, are more predominant along the mountain front (Crifasi, 1992; Kirkham and Ladwig, 1979), and finer grained sediments and coal beds, derived from overbank and swamp deposits, increase in predominance farther from the mountain front (Kirkham and Ladwig, 1979). The water-bearing sandstone and siltstone units in the Denver aquifer occur in lens-shaped beds ranging in thickness from as little

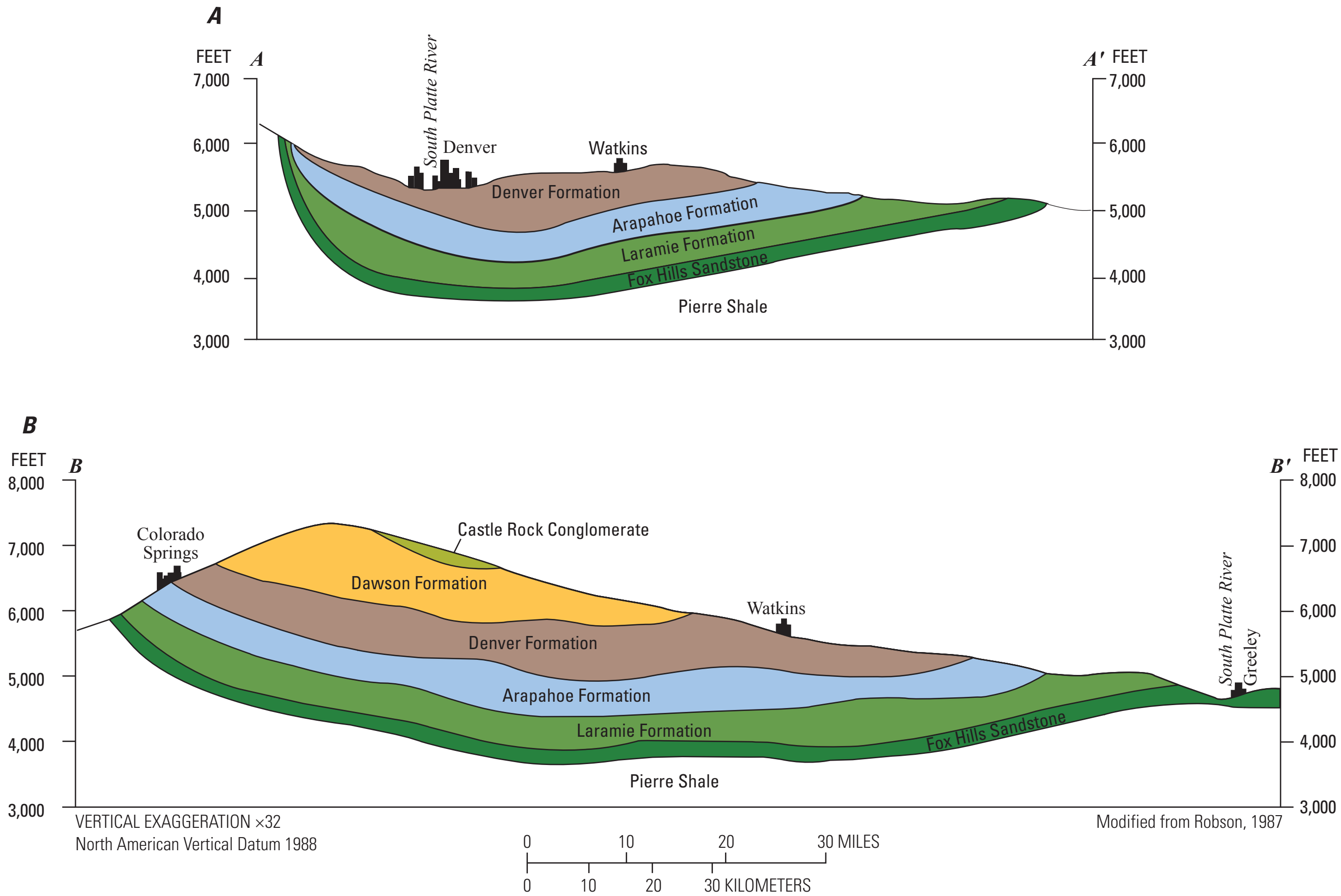


Figure 3. Generalized geologic cross sections through the Denver Basin. *A*, east to west cross section; *B*, north to south cross.

as a few inches to as much as 50 ft that are dispersed within relatively thick sequences of claystone and shale. Therefore, the thickness of water-yielding materials is much less than the overall thickness of the aquifer, which generally ranges from 100 to 300 ft (Robson, 1987). The greatest water-bearing thickness in the Denver aquifer (400 to 600 ft) occurs along the western basin margin in southern Douglas County (Paschke, 2011). Due to the heterogeneity of the Denver Formation, the extent and thickness of the confining unit is difficult to map on a regional scale (Raynolds, 2002, 2004). Administratively, the Denver stratigraphic interval is divided into three sections: a lower confining unit, an aquifer, and an upper confining unit (Paschke, 2011). Total thickness of the lower confining unit ranges from 0 to as much as 300 ft with a mean of about 50 ft. Thickness of the upper confining unit ranges from 0 to as much as 200 ft, with a mean of about 50 ft and the unit has a smaller extent than that of the Denver aquifer (Paschke, 2011).

The Dawson aquifer is composed of interbedded fluvial conglomerate, sandstone, siltstone, and shale (Romero, 1976; Robson, Romero, and Zawistowski, 1981; Robson, 1987). The aquifer underlies approximately 1,400 mi^2 of the Denver Basin (488 mi^2 within Douglas County) and ranges from 100 to 1,100 ft thick with an average water-yielding thickness between 100 and 400 ft (Robson, 1987; Paschke, 2011). In the northern two-thirds of its extent, a clay and shale confining layer is present in the Dawson, and the aquifer is separated into the upper Dawson aquifer, which has an extent of 600 mi^2 (298 mi^2 within Douglas County) and lower Dawson aquifer, which has an extent of 1,400 mi^2 (488 mi^2 within Douglas County). In the southern part of the Dawson aquifer, the confining layer is difficult to identify, and the entire 600-ft-thick sequence of sediment in this area is assigned to the lower Dawson aquifer (Paschke, 2011). The greatest water-bearing thickness (200 to 375 ft) is located in the west-central part of the basin along the Douglas-El Paso County line, similar to the Denver and Arapahoe aquifers (Paschke, 2011).

The alluvial aquifer is composed of unconsolidated, coarse-grained sand and gravel deposits, with interbedded clays present in some areas (Scott, 1963). The aquifer overlies approximately 2,352 mi^2 of the Denver Basin (33 mi^2 within Douglas County), primarily along present-day stream channels, and is generally 3 to 376 ft thick (Paschke, 2011). Alluvial deposits along the main channel of the South Platte River and tributaries draining directly from the Front Range tend to be coarser grained than alluvial deposits in tributaries draining from the Palmer Divide, because streams draining from the mountains receive coarser-grained source materials from steeper terrain than streams draining the sedimentary rocks of the Denver Basin (Paschke, 2011).

Study Methods

This section presents an overview of the methods used to assess groundwater levels in the study area.

Identifying Target Areas

Statistical analysis and predictive simulation results of the USGS groundwater model presented by Paschke (2011) were used to ascertain areas of potential interest with respect to groundwater levels. In addition, anecdotal information provided by residents was used to identify areas of known problems that were of interest.

Parameter-prediction (PPR) statistics quantify the decrease in prediction uncertainty caused by improved information for a parameter, and Observation-Prediction (OPR) statistic quantifies the decrease in prediction uncertainty caused by addition or omission of an observation (Hill and Tiedeman, 2007). The program OPR–PPR (Tonkin and others, 2007) is a model-analysis tool designed to calculate the OPR and PPR statistics. OPR–PPR also calculates the Observation-Parameter (OPA) statistic, which quantifies the relation of observations and their uncertainties to parameter uncertainty. Maps of the OPA statistic values for a selected parameter can be used to identify areas where parameter uncertainty would be most effectively decreased by adding an observation; in this case, a head observation (Paschke, 2011). The OPA values, calculated from Paschke (2011), for the potentiometric surface parameter for each bedrock aquifer were grouped together and overlaid on a map (fig. 4). The darkest colors on the map of PPR statistics identify areas where additional water-level data would most effectively decrease prediction uncertainty; therefore, additional data collected in these areas would be most beneficial in improving the groundwater model. Thus, these areas were targeted for additional water-level data collection.

While they are not definitive predictors of future conditions, predictive groundwater model simulations lend insight to long-term effects of groundwater withdrawal on water levels. The 50-year (yr) (December 31, 2003 to December 31, 2053) predictive simulations of groundwater-level declines done by Paschke (2011) were used for this purpose. For each bedrock aquifer, results indicated areas within Douglas County that had the potential for more than 100 ft of drawdown at the end of the prediction period (fig. 4). The areas of predicted 100-ft water-level declines were located mostly in northern Douglas County (fig. 4).

Conversations with RWADC board members and residents indicated several areas where well owners were experiencing problems. While these problems were broad in scope, reports of declining water quality and the need to lower a pump or replace a well were noted and given a higher priority. In general, these reports were associated with areas along the outer edge of a given aquifer or wells that were more than 30 yr old. In an attempt to quantify the problems, these areas were identified as areas of reported problems (fig. 4).

Well Selection

Once the areas of interest (OPA statistics, predicted drawdown, and reported problems) with respect to groundwater levels were identified, an effort was made to find existing wells in those areas that could be incorporated into a water-level monitoring network. Well selection was completed in several steps including: creation of a database of domestic wells in Douglas County, field visits, solicitation of volunteers, and final site selection.

A database of domestic wells in Douglas County was created to access the spatial distribution of wells within a given aquifer. First, all well-permit applications within Douglas County were retrieved from the Colorado Division of Water Resources well permit database (accessed February 2011). This dataset contained more than 16,300 records. The list was then filtered to remove the records for abandoned and non-completed wells and all wells outside of the RWADC service area, leaving a dataset of more than 13,800 wells. The dataset was then filtered again to remove all wells with an incomplete construction record; this included records that were missing completion aquifer, well depth, screen interval, or construction date, and resulted in a dataset of about 7,450 well records. These remaining wells were then cross referenced with the USGS groundwater model (Paschke, 2011) to verify the aquifer of completion. Finally, only wells that showed agreement between the State database and the USGS model with respect to aquifer of completion were selected for inclusion in the dataset. This process resulted in a final dataset of approximately 6,260 domestic wells with about 2,350 in the upper Dawson aquifer, about 1,670 in the lower Dawson aquifer, about 1,900 in the Denver aquifer, approximately 240 in the Arapahoe aquifer, and about 100 in the Laramie-Fox Hills aquifer (fig. 5).

After creation of the database, field visits and solicitation of volunteers began. In February and March 2011, RWADC held meetings in each of its five districts to inform local residents of its role in the community and to increase public awareness. Concerned citizens that attended these meetings were informed about the monitoring program and asked to volunteer. More than 50 well owners volunteered to have their wells considered for the study. From March through June 2011, door-to-door solicitation was conducted. The primary focus of this task was to obtain access to wells located in the previously identified areas of interest or in areas that would provide a more even spatially-distributed network. While all attempts were made to select wells that would provide data representative of the aquifer in a given area, final selection of the wells was mainly driven by the willingness of residents to participate in the study.

Presently (2014) the network consists of 36 wells: 10 in the upper Dawson aquifer, 11 in the lower Dawson aquifer, 11 in the Denver aquifer, 2 in the Arapahoe aquifer, and 2 in the Laramie-Fox Hills (fig. 2) aquifer. The initial round of water-level measurements, made between May and June 2011, included 31 wells. An additional four wells were added to the network in August 2011, and one additional well was added in August 2012. Pressure transducers were installed in 15 of the wells between

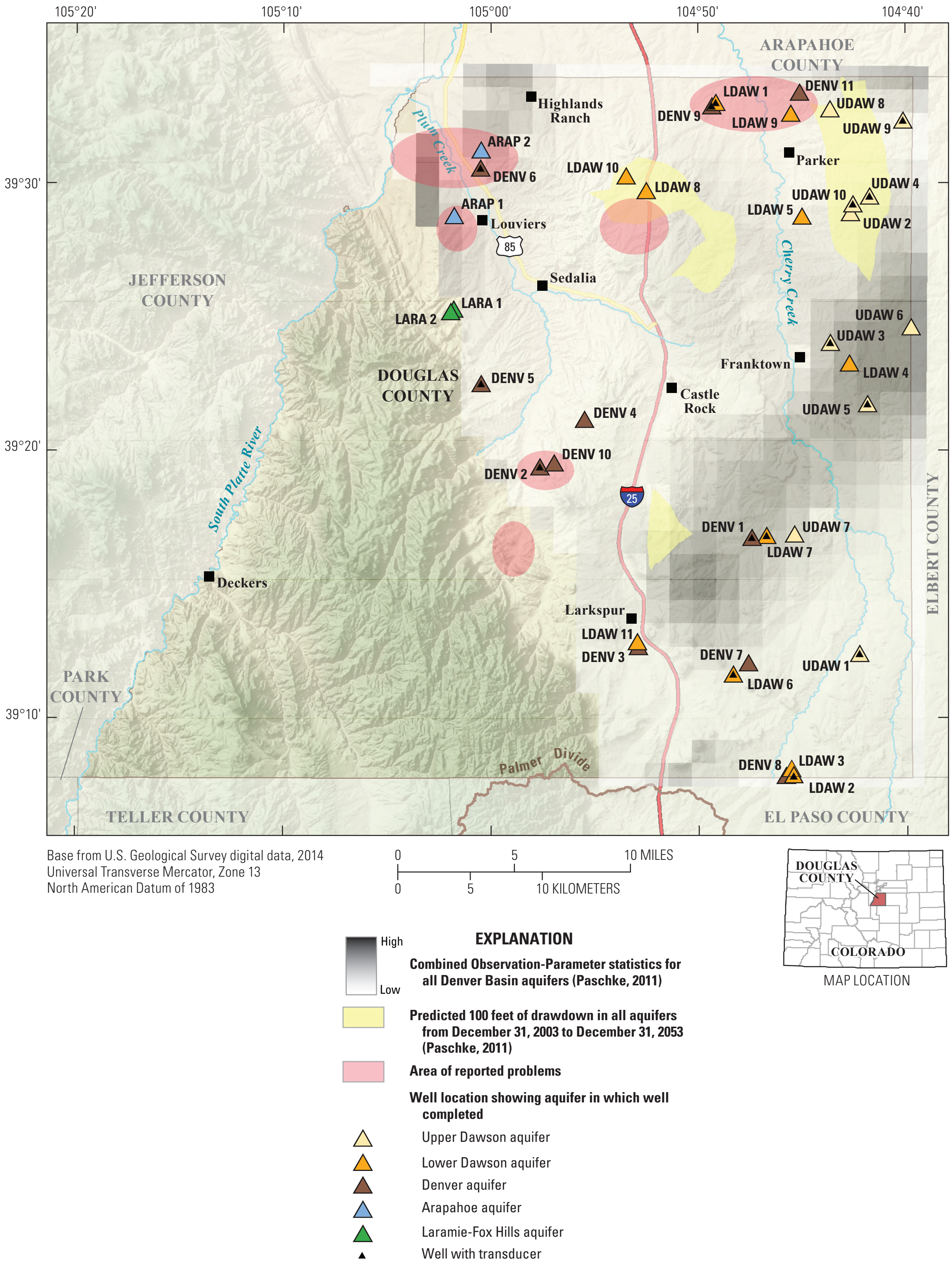
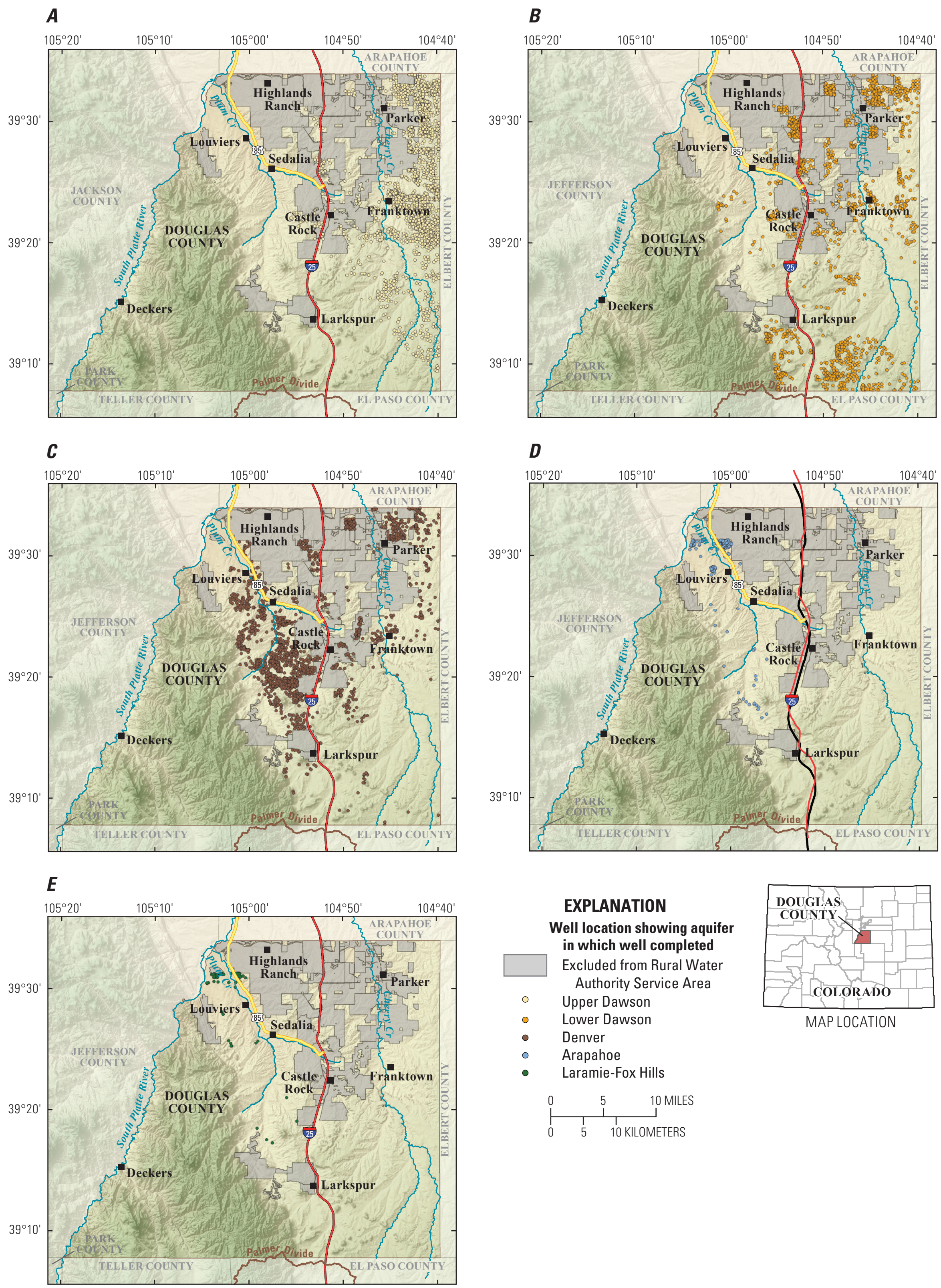


Figure 4. Areas identified as being of interest for groundwater monitoring, Douglas County, Colorado.



Base from U.S. Geological Survey digital data, 2014
Universal Transverse Mercator, Zone 13
North American Datum of 1983

Figure 5. Distribution of domestic wells in Douglas County, Colorado, for *A*, the upper Dawson aquifer; *B*, the lower Dawson aquifer; *C*, the Denver aquifer; *D*, the Arapahoe aquifer; and *E*, the Laramie Fox-Hills aquifer.

August 2011 and April 2012 to automatically measure and record the depth to water at regular time intervals (fig. 2). Six pressure transducers were installed in August 2011, four in October 2011, four in December 2011, and one in April 2012.

For quality control purposes, five of the selected wells (UDAW 2, LDAW 3, LDAW 8, DENV 10, LARA 2) are completed in the same aquifer and in close proximity to other selected wells. These wells were selected to provide additional water-level measurements that could be used to determine if a well was representative of the local aquifer system.

GPS Survey

To accurately compare water-level data across the county, the land surface elevation at each well was determined using a real-time kinematic (RTK) global positioning system (GPS) following procedures described by Rydlund and Densmore (2012). The survey was performed with a global navigation satellite system RTK GPS receiver, radio modem, and a controller with a vertical and horizontal precision, as rated by the manufacturer, of plus or minus 0.066 ft and plus or minus 0.033 ft, respectively (Trimble Navigation Limited, 2009). The RTK GPS setup consisted of a base station, which included a receiver and radio, and a rover, which consisted of a receiver and controller. The base station was located at a fixed position and allowed to collect data for over 2 hours (hr). The rover communicates with the base station and is used to collect and record individual data points throughout the study area based on the position of the base station. Data from the base station collected throughout the study were submitted to the National Geodetic Survey's Online Positioning User Service (OPUS) Web site for processing (*http://www.ngs.noaa.gov/OPUS/*, accessed June 2013). All survey data collected by the rover were recomputed to reflect the OPUS solution correction. All survey data were collected with a common coordinate system, geoid, ellipsoid, and datum. The coordinate system used was Universal Transverse Mercator, zone 12 north, the horizontal datum was the North American Datum of 1983 (NAD 83), and the vertical datum was the North American Vertical Datum of 1988 (NAVD 88), Geoid 03, ellipsoid World Geodetic System 1984 (WGS 84).

At each well, the measuring point (MP) was surveyed and the elevation of the land surface was calculated by subtracting the height of the measuring point from the measuring point elevation. The elevation of the land-surface datum at each well is given in table 1.

Water-Level Measurements

Water levels, measured as depth to water below land surface, were routinely measured in all 36 wells in the network (table 1). The water-level measurements in this report are given in feet with reference to land-surface datum (LSD). LSD is a datum plane that is approximately at land surface at each well. Measurements times in this report are given in reference to Coordinated Universal Time (UTC), which is synonymous with the antiquated Greenwich Mean Time. Local time can be calculated from UTC by subtracting 7 hr for Mountain Standard Time or by subtracting 6 hr for Mountain Daylight Time.

Manual water-level measurements were made bi-monthly in all wells in the network between April 2011and June 2013 (fig. 2). In 2011, water levels were made in April, June, August, October, and December. In 2012, water levels were made in February, April, June, August, October, and December. In 2013, water levels were made in February, April, and June. Additional water-level measurements were recorded in some wells for various reasons, such as non-static water levels or additional site visits. Water levels were measured and recorded to within 0.01 ft by using a calibrated steel tape, whenever possible, following procedures outlined by Cunningham and Schalk (2011) (with the exception that a break-away weight was not used because of the concern the weight could become tangled in the pump wiring). When conditions such as inclement weather or the presence of condensation within the well casing prohibited the use of a steel tape, a calibrated electric tape was used instead. Depth-to-water measurements were made from the measuring point, typically the top of the steel surface casing or well cap.

To verify that the water level in the well was under static conditions, consecutive measurements were made until two measurements were within 0.02 ft of one another or the reason for lack of agreement was determined. If consecutive measurements indicated the water level was rising, or recovering, the shallowest measurement was used and marked with a status of "R" for recently pumped. If consecutive measurements indicated the water level was slowly falling, or declining, the shallowest measurement was used and marked with a status of "S" for nearby pumping. If no trend was determined, the average of the measurements was used. If a pump was operated during a visit, the water level was allowed to recover for approximately 10 minutes until a measurement was made. If a pump was cycling during a visit, the tape was held in place during the recovery period until the pump turned on again and this single highest level was recorded. Depth to water below land surface was calculated by subtracting the measuring point (MP) height from the depth to water below the MP. Groundwater elevations were calculated by subtracting depth to water below land surface from the land surface elevation. A summary of the available manual water-level measurements, including land-surface elevation, period of record, number of measurements, and the minimum and maximum observed water levels is presented in the Groundwater Levels in the Denver Basin Bedrock Aquifers of Douglas County section. For the hydrographs presented in this report (Appendix 1), the water-level measurements with a status of "R" or "S," which are known to be lower than the static level, are shown as upward-pointing triangles.

Pressure transducer instrumentation in 15 of the wells included a vented 30 pound per square inch pressure transducer with an accuracy, as rated by the manufacturer, of plus or minus 0.05 percent of the full scale at 15 °C and a built in data logger (In-Situ Inc., 2014). The transducers were suspended in the well on a vented communication cable that allowed downloading the data without disturbing the probe. Once the transducer was in place, it was calibrated to the manual depth to water below land

Table 1. Identification, location, and construction information for wells located in the Rural Water Authority monitoring network, Douglas County, Colorado.

[Site identification numbers in this table are hyperlinked directly to the data on NWISWeb. See figure 2 for well locations. Abbreviations: NAD83, North American datum 1983;°, degrees; ', minutes; ", seconds; LSD, land surface datum; ft, feet; NAVD 88, North American Vertical Datum of 1988; bls, below land surface]

Common name	Site identification number	Latitude (NAD83) (degrees, minutes, seconds)	Longitude (NAD83) (degrees, minutes, seconds)	Elevation of LSD (ft above NAVD88)	Depth to top of perforations (ft bls)	Depth to bottom of perforations (ft bls)	Depth to bottom of hole (ft bls)
UDAW 1	391229104421901	39° 12' 22.40"	104° 42' 18.79"	6934.52	260	320	320
UDAW 2	392856104424101	39° 28' 51.12"	104° 42' 41.81"	6284.27	210	310	310
UDAW 3	392412104434201	39° 24' 00.07"	104° 43' 41.47"	6414.87	193	283	283
UDAW 4	392934104414901	39° 29' 28.68"	104° 41' 45.98"	6267.98	240	300	300
UDAW 5	392149104415501	39° 21' 42.84"	104° 41' 53.47"	6501.66	250	350	350
UDAW 6	392441104394901	39° 24' 35.49"	104° 39' 46.81"	6590.31	280	400	400
UDAW 7	391658104453101	39° 16' 51.02"	104° 45' 25.37"	6808.79	202	302	302
UDAW 8	393252104434701	39° 32' 44.61"	104° 43' 40.56"	6195.89	170	213	213
UDAW 9	393226104394401	39° 32' 18.18"	104° 40' 09.34"	6285.29	215	314	314
UDAW 10	392916104423601	39° 29' 10.65"	104° 42' 34.58"	6288.97	240	320	320
LDAW 1	393259104491001	39° 32' 59.62"	104° 49' 11.40"	5816.50	220	260	280
LDAW 2	390756104453801	39° 07' 50.15"	104° 45' 35.11"	7278.15	100	180	200
LDAW 3	390811104453801	39° 08' 05.45"	104° 45' 36.86"	7308.07	220	300	320
LDAW 4	392318104424601	39° 23' 13.64"	104° 42' 46.06"	6501.52	623	723	723
LDAW 5	392851104450101	39° 28' 44.38"	104° 45' 02.28"	6021.79	340	530	530
LDAW 6	391143104482501	39° 11' 37.67"	104° 48' 22.89"	7085.07	125	205	205
LDAW 7	391654104464501	39° 16' 48.55"	104° 46' 46.54"	6676.78	125	345	345
LDAW 8	392949104523401	39° 29' 41.31"	104° 52' 33.56"	6235.80	348	388	468
LDAW 9	393239104452901	39° 32' 34.88"	104° 45' 33.98"	5908.71	243	285	285
LDAW 10	393021104533101	39° 30' 14.61"	104° 53' 30.83"	6324.88	460	620	640
LDAW 11	391257104530201	39° 12' 49.86"	104° 53' 00.55"	6799.61	100	240	240
DENV 1	391656104473001	39° 16' 43.87"	104° 47' 28.54"	6783.59	480	600	600
DENV 2	391929104574101	39° 19' 22.18"	104° 57' 40.27"	6268.94	120	300	300
DENV 3	391245104525501	39° 12' 38.72"	104° 52' 56.68"	6822.46	485	665	665
DENV 4	392115104553501	39° 21' 09.46"	104° 55' 32.44"	6376.53	380	480	480
DENV 5	392235105003001	39° 22' 29.42"	105° 00' 30.46"	6317.29	280	380	380
DENV 6	393040105003201	39° 30' 32.91"	105° 00' 32.78"	5716.55	200	320	320
DENV 7	391212104473801	39° 12' 02.73"	104° 47' 39.07"	7003.66	780	900	900
DENV 8	390755104454001	39° 07' 50.14"	104° 45' 40.26"	7265.13	910	1300	1300
DENV 9	393252104492101	39° 32' 51.83"	104° 49' 23.15"	5864.18	383	463	463
DENV 10	391936104570101	39° 19' 31.13"	104° 57' 00.44"	6410.74	304	404	404
DENV 11	393330104450701	39° 33' 22.42"	104° 45' 07.66"	6058.29	575	610	610
ARAP 1	392853105015001	39° 28' 46.00"	105° 01' 48.83"	5789.08	450	730	730
ARAP 2	393120105003101	39° 31' 12.83"	105° 00' 30.08"	5750.03	355	735	735
LARA 1	392522105015001	39° 25' 15.92"	105° 01' 49.28"	6169.43	361	601	601
LARA 2	392522105015401	39° 25' 15.20"	105° 01' 53.18"	6155.85	140	480	500

surface measurement and programmed to record a water level every hour. Bi-monthly manual water-level measurements are used to calibrate the time-series data and correct for instrument drift. Graphs of the time-series data presented in this report include the daily maximum groundwater elevation (blue line, Appendix 1) which is the highest of a given day's 24 observations. The daily maximum groundwater elevation most often occurs when nearby pumping is at its lowest (usually during the early morning hours) and is most representative of the static water level. In some cases, the manual measurement (circle or triangle) plotted along with the time-series data is lower than the time-series daily maximum value (blue line). This slight difference observed on the graphs occurs because the instantaneous manual measurement is not always the daily maximum observation recorded by the data logger.

Accessing Data

Users of the data presented in this report are encouraged to access information through the USGS National Water Information System (NWIS) web page (NWISWeb) at *http://waterdata.usgs.gov/nwis*. NWISWeb serves as an interface to a database of site information and groundwater, surface-water, and water-quality data collected throughout the United States and elsewhere. NWISWeb is updated from the database on a regularly scheduled basis. Data can be retrieved by category and geographic area, and the retrieval can be selectively refined by a specific location or parameter field. NWISWeb can output water-level and water-quality graphs, site maps, and data tables (in HTML and ASCII format) and can be used to develop site-selection lists. All manual water-level measurements and the daily maximum, minimum, and median values for all time-series water-level data for these sites are available through the USGS NWISWeb. Updates to data presented in this report after publication will be made to NWISWeb. In digital copies of this report, the site identification numbers presented in the tables are hyperlinked directly to the data on NWISWeb. Formal requests for specific data may be directed to the U.S. Geological Survey Colorado Water Science Center, in Lakewood, Colo.

Groundwater Levels in the Denver Basin Bedrock Aquifers of Douglas County

More than 500 manual and 213,900 automated water-level measurements were collected between April 2011 and June 2013. Hydrographs, plots of water levels over time, for each well are shown in Appendix 1.

Historical Water Levels

Historical water-level data available for the wells used in this study were reported on the Well Completion and Pump Installation Report (“driller’s logs”) submitted to the State by the driller or pump installer immediately after the well was constructed. A comparison of water levels reported on driller’s logs with the initial manual water level measured by USGS indicate water levels had risen in 9 of the 36 wells, 5 wells in the lower Dawson aquifer (LDAW 2, LDAW 3, LDAW 6, LDAW 7, and LDAW 11) and 4 wells in the Denver aquifer (DENV 1, DENV 4, DENV 8, and DENV 9) and had declined in the remaining 27 wells (table 2). This does not consider seasonal fluctuations in water levels, time between measurements, well-development conditions, or methods of measurement, all of which could introduce uncertainty and skew the results. In some cases, the driller’s depth to water may be estimated, as the values are reported to the tens of feet; this could introduce error into the calculated change when compared with water levels measured to the hundredth of a foot. However, water-level measurements reported by the Colorado Division of Water Resources show that a rise in water level has occurred in some wells in Douglas County in the past (Pottorff and Horn, 2013). This suggests that this study’s observed rise in water level is possible. There does not appear to be any spatial correlations between wells with rising water levels in this study.

Two wells had available water-level data prior to the start of this study. Bi-monthly water-level measurements were made in LDAW 1 and DENV 9 beginning in January 2009 (table 3). A comparison of the highest water levels observed each year indicate water levels in LDAW 1 rose about 7.5 ft between 2009 and 2010, declined about 6.6 ft between 2010 and 2011, and rose about 1.1 ft between 2011 and 2012. Water levels in DENV 9 rose about 18.8 ft between 2009 and 2010, declined about 4.9 ft between 2010 and 2011, and declined about 4.0 ft between 2011 and 2012. Water levels in DENV 9 during January and March 2009 were lower than the water levels observed in July. This suggests that the initial water levels may have been affected by local pumping and therefore may not have been truly representative of static conditions.

Manual Water-Level Measurements

In general, water levels in the monitored domestic wells were lowest during the summer and fall (July to October; Appendix 1) and recovered during the winter months, with the highest levels being observed during the winter and spring months (December to April). Water levels measured during the summer months are expected to be less than those measured during other seasons because of increased groundwater pumping for lawn irrigation. Differences between the highest and lowest observed water levels ranged from less than 1 ft (DENV 3 and UDAW 7) to about 79 ft (LARA 1) (table 3).

Comparison of February (representing the seasonal high) manual water-level measurements in 2012 and 2013 shows that water levels declined in 33 of the wells. While the amount of the decline varied by aquifer and well location, declines in all wells in all aquifers averaged about 2.1 ft (table 4). The greatest decline of about 12 ft was observed in DENV 9, while the least decline of 0.02 ft was observed in DENV 3. The only observed rise in water level, about 18.2 ft in LDAW 4, may be attributed to the fact the well was recently pumped before the February 2012 measurement. Pumping would temporarily lower the water level; therefore, the water level would not be representative of the static conditions and the year-to-year change may not be representative of the true change. Data concerning water-level change between February 2012 and February 2013 were not available for two of the wells (LDAW 11 and DENV 8). The average change in water-level measurements from February 2012 to 2013 for each aquifer show declines of about 0.9 ft per year in the upper Dawson aquifer, about 0.3 ft per year in the lower Dawson aquifer, about 3.9 ft per year in the Denver aquifer, about 5.6 ft per year in the Arapahoe aquifer, and about 5.4 ft in the Laramie-Fox Hills aquifer (table 4).

Comparison of all year-to-year changes in manual water-level measurements for all wells in all aquifers indicates an average decline of about 2.6 ft for all months compared between June 2011 and 2013 (table 4). Average year-to-year change in all water levels for the wells in the upper Dawson aquifer ranged from a rise of about 3.5 ft (UDAW 5) to a decline of about 1.2 ft (UDAW 9) and on average declined about 0.4 ft. Average year-to-year change in all water levels for the wells in the lower Dawson aquifer ranged from a decline of about 0.9 ft (LDAW 6) to a decline of about 5.4 ft (LDAW 1) and on average declined about 2.6 ft. Average year-to-year decline in

Table 2. Summary of water level measurements reported on Well Completion and Pump Installation Reports and initial water levels measured in 2011 including rate of change for selected wells, Douglas County, Colorado.

[See figure 2 for well locations. Abbreviations: UDAW, upper Dawson well; LDAW, lower Dawson well; DENV, Denver well; ARAP, Arapahoe well; LARA, Laramie Fox–Hills well; ft, feet; M, month; D, day; YYYY, year]

Common name common name	Reported on Well Completion Report		Measured by USGS		Change in water level (ft)	Rate of change (ft per year)
	Year of reported water level	Reported depth to water (ft)	Date of measured water level (M/D/YYYY)	Measured depth to water (ft)		
UDAW 1	2007	80	5/26/2011	90.55	–10.55	–2.6
UDAW 2	1983	81	5/27/2011	140.79	–59.79	–2.1
UDAW 3	1981	110	5/26/2011	154.44	–44.44	–1.5
UDAW 4	1999	111	5/27/2011	120.37	–9.37	–0.8
UDAW 5	1994	100	8/13/2011	165.3	–65.3	–3.8
UDAW 6	1994	200	5/26/2011	214.95	–14.95	–0.9
UDAW 7	1998	140	6/12/2011	154.44	–14.44	–1.1
UDAW 8	1968	123	6/12/2011	167.69	–44.69	–1
UDAW 9	1978	154	5/27/2011	208.94	–54.94	–1.7
UDAW 10	1982	103	5/27/2011	112.78	–9.78	–0.3
					Average:	–1.6
LDAW 1	1979	50	5/23/2011	50.15	–0.15	0.0
LDAW 2	1991	91	5/25/2011	66.58	24.42	1.2
LDAW 3	1986	132	5/25/2011	123.25	8.75	0.4
LDAW 4	1992	510	5/26/2011	548.52	–38.52	–2
LDAW 5	1995	185	6/12/2011	222.38	–37.38	–2.3
LDAW 6	1994	70	5/26/2011	39.69	30.31	1.8
LDAW 7	1997	110	5/26/2011	84.16	25.84	1.8
LDAW 8	2005	330	8/12/2011	387.6	–57.6	–9.6
LDAW 9	1972	126	6/12/2011	163.86	–37.86	–1
LDAW 10	1983	436	6/3/2011	478.5	–42.5	–1.5
LDAW 11	1995	95	7/30/2012	91.61	3.39	0.2
					Average:	–1.0
DENV 1	1988	290	5/27/2011	147.76	142.24	6.2
DENV 2	1989	90	6/3/2011	102.4	–12.4	–0.6
DENV 3	2006	435	5/25/2011	442.46	–7.46	–1.5
DENV 4	1997	230	4/16/2011	229.17	0.83	0.1
DENV 5	1991	134	4/16/2011	207.53	–73.53	–3.7
DENV 6	1988	185	5/24/2011	222.09	–37.09	–1.6
DENV 7	1995	347	5/25/2011	399.76	–52.76	–3.3
DENV 8	1998	560	5/25/2011	249.22	310.78	23.9
DENV 9	1997	170	5/23/2011	129.06	40.94	2.9
DENV 10	1978	225	6/3/2011	232.37	–7.37	–0.2
DENV 11	1972	320	5/27/2011	343.39	–23.39	–0.6
					Average:	2.0
ARAP 1	1986	420	8/12/2011	542.59	–122.59	–4.9
ARAP 2	2007	315	8/12/2011	368.2	–53.2	–13.3
					Average:	–9.1
LARA 1	1999	87	5/24/2011	102.9	–15.9	–1.3
LARA 2	1999	75	5/24/2011	89.25	–14.25	–1.2
					Average:	–1.25

all water levels for the wells in the Denver aquifer ranged from about 0.3 ft (DENV 3) to almost 6.9 ft per year (DENV 7) and averaged about 3.2 ft. Average year-to-year decline in all water levels for the wells in the Arapahoe aquifer ranged from about 1.1 ft (ARAP 2) to almost 2.8 ft (ARAP 1) and averaged about 1.9 ft. Average year-to-year decline in all water levels for the wells in the Laramie-Fox Hills aquifer ranged from about 7.3 ft (LARA 2) to about 12.6 ft (LARA 1) and averaged about 9.9 ft. The average year-to-year changes for all wells in a given aquifer are shown in figure 6 (table 5).

Time-Series Water-Level Measurements

Time-series measurements collected by the transducers provided a greater level of detail that allowed for additional analysis. Hydrographs for each well are shown in Appendix 1. The daily maximum groundwater elevations were used to determine the highest levels observed throughout the year, which were then used to calculate year-to-year change in water level. Hydrographs of the time-series data were also examined for trends or notable hydrologic activity.

Table 3. Summary of manual water level measurements including period of record, number of measurements, and minimum and maximum observed water levels for selected wells, Douglas County, Colorado.

[See figure 2 for well locations. Abbreviations: UDAW, upper Dawson well; LDAW, lower Dawson well; DENV, Denver well; ARAP, Arapahoe well; LARA, Laramie Fox-Hills well; LSD, land surface datum; ft, feet; NAVD 88, North American Vertical Datum of 1988; M, month; D, day; YYYY, year]

Common name common name	Elevation of LSD (ft above NAVD88)	Period of record		Total number of observations	Minimum water level below LSD (ft)	Maximum water level below LSD (ft)	Minimum water level elevation (NAVD88) (ft)	Maximum water level elevation (NAVD88) (ft)	Range in water level (ft)
		Begin date (M/D/YYYY)	End date (M/D/YYYY)						
UDAW 1	6934.52	5/26/2011	6/4/2013	19	90.55	94.63	6839.89	6843.97	4.08
UDAW 2	6284.27	5/27/2011	6/5/2013	13	136.71	152.77	6131.50	6147.56	16.06
UDAW 3	6414.87	5/26/2011	6/5/2013	16	154.44	156.35	6258.52	6260.43	1.91
UDAW 4	6267.98	5/27/2011	6/5/2013	15	114.37	131.05	6136.93	6153.61	16.68
UDAW 5	6501.66	8/13/2011	6/5/2013	14	126.72	170.35	6331.31	6374.94	43.63
UDAW 6	6590.31	5/26/2011	6/5/2013	13	214.95	217.63	6372.68	6375.36	2.68
UDAW 7	6808.79	6/12/2011	6/5/2013	13	154.07	155.04	6653.75	6654.72	0.97
UDAW 8	6195.89	6/12/2011	6/7/2013	13	167.34	170.26	6025.63	6028.55	2.92
UDAW 9	6285.29	5/27/2011	6/7/2013	16	208.85	212.04	6073.25	6076.44	3.19
UDAW 10	6288.97	5/27/2011	6/5/2013	16	112.58	120.10	6168.87	6176.39	7.52
LDAW 1	5816.50	1/10/2009	6/7/2013	27	43.59	64.64	5751.86	5772.91	21.05
LDAW 2	7278.15	5/25/2011	6/4/2013	17	66.58	71.12	7207.03	7211.57	4.54
LDAW 3	7308.07	5/25/2011	6/4/2013	13	117.94	127.72	7180.35	7190.13	9.78
LDAW 4	6501.52	5/26/2011	6/5/2013	13	547.36	579.70	5921.82	5954.16	32.34
LDAW 5	6021.79	6/12/2011	6/5/2013	13	191.44	233.23	5788.56	5830.35	41.79
LDAW 6	7085.07	5/26/2011	6/4/2013	13	39.69	41.40	7043.67	7045.38	1.71
LDAW 7	6676.78	5/26/2011	6/5/2013	15	84.16	91.37	6585.41	6592.62	7.21
LDAW 8	6235.80	8/12/2011	6/7/2013	12	380.29	394.66	5841.14	5855.51	14.37
LDAW 9	5908.71	6/12/2011	6/7/2013	13	158.10	184.95	5723.76	5750.61	26.85
LDAW 10	6324.88	6/3/2011	6/7/2013	13	475.50	485.19	5839.69	5849.38	9.69
LDAW 11	6799.61	7/30/2012	6/4/2013	6	89.96	91.61	6708.00	6709.65	1.65
DENV 1	6783.59	5/27/2011	6/5/2013	16	147.33	153.28	6630.31	6636.26	5.95
DENV 2	6268.94	6/3/2011	6/3/2013	17	101.42	107.99	6160.95	6167.52	6.57
DENV 3	6822.46	5/25/2011	6/4/2013	13	442.46	443.35	6379.11	6380.00	0.89
DENV 4	6376.53	4/16/2011	6/3/2013	14	224.58	235.88	6140.65	6151.95	11.30
DENV 5	6317.29	4/16/2011	6/3/2013	17	190.15	214.76	6102.53	6147.14	24.61
DENV 6	5716.55	5/24/2011	6/3/2013	14	222.09	225.55	5491.00	5494.46	3.46
DENV 7	7003.66	5/25/2011	6/4/2013	13	397.97	413.51	6590.15	6605.69	15.54
DENV 8	7265.13	5/25/2011	6/4/2013	13	249.22	315.00	6950.13	7015.91	65.78
DENV 9	5864.18	1/10/2009	6/7/2013	28	113.44	158.38	5705.80	5750.74	44.94
DENV 10	6410.74	6/3/2011	6/3/2013	13	232.37	234.70	6176.04	6178.37	2.33
DENV 11	6058.29	5/27/2011	6/7/2013	13	337.22	384.83	5673.46	5721.07	47.61
ARAP 1	5789.08	8/12/2011	6/3/2013	12	541.79	546.40	5242.68	5247.29	4.61
ARAP 2	5750.03	8/12/2011	6/3/2013	12	359.89	369.49	5380.54	5390.14	9.60
LARA 1	6169.43	5/24/2011	6/3/2013	15	102.90	182.05	5987.38	6066.53	79.15
LARA 2	6155.85	5/24/2011	6/3/2013	13	86.96	129.23	6026.62	6068.89	42.27

Table 4. Summary of year-to-year changes in manual water level measurements, Douglas County, Colorado.

[See figure 2 for well locations. Abbreviations: UDAW, upper Dawson well; LDAW, lower Dawson well; DENV, Denver well; ARAP, Arapahoe well; LARA, Laramie Fox-Hills well; LSD, land surface datum; ft, feet; NAVD 88, North American Vertical Datum of 1988; --, data not available]

Common name	Elevation of LSD (ft above NAVD88)	Water level change - Jun 2011 to Jun 2012 (ft)	Water level change - Aug 2011 to Aug 2012 (ft)	Water level change - Oct 2011 to Oct 2012 (ft)	Water level change - Dec 2011 to Dec 2012 (ft)	Water level change - Feb 2012 to Feb 2013 (ft)	Water level change - April 2012 to April 2013 (ft)	Water level change - June 2012 to June 2013 (ft)	Average year to year change for each month compared (ft)
UDAW 1	6934.52	–2.64	–1.61	–0.37	–2.46	–0.14	0.18	0.08	–0.99
UDAW 2	6284.27	–6.05	–1.72	4.55	–1.60	–2.18	3.28	–2.06	–0.83
UDAW 3	6414.87	–1.01	–0.57	–0.42	–0.11	–0.44	–0.46	–0.34	–0.48
UDAW 4	6267.98	–4.31	–1.87	1.93	–1.84	–0.44	0.95	0.69	–0.70
UDAW 5	6501.66	--	–5.05	16.52	–1.68	–2.23	0.02	13.52	3.52
UDAW 6	6590.31	–1.45	–1.34	–0.78	–0.52	–0.59	0.22	–0.27	–0.68
UDAW 7	6808.79	–0.37	–0.18	–0.02	–0.33	–0.17	–0.07	–0.20	–0.19
UDAW 8	6195.89	–0.96	–1.11	–0.72	–0.77	–0.68	–0.65	–0.09	–0.71
UDAW 9	6285.29	–1.62	–1.78	–0.82	–1.08	–1.01	–1.08	–0.67	–1.15
UDAW 10	6288.97	–4.63	–0.44	4.13	–1.04	–0.91	–3.03	–0.41	–0.90
	Average:	–2.56	–1.57	2.4	–1.14	–0.88	–0.06	1.03	–0.37
LDAW 1	5816.50	–6.45	–5.65	–3.20	–5.73	–7.39	–5.83	–3.33	–5.37
LDAW 2	7278.15	–2.85	–1.67	–1.09	–1.75	–1.46	–0.96	–1.68	–1.64
LDAW 3	7308.07	–4.47	–8.62	0.40	–1.57	–1.44	–0.44	0.56	–2.23
LDAW 4	6501.52	0.99	–1.95	–7.04	–6.75	18.19	–4.55	–14.41	–2.22
LDAW 5	6021.79	2.51	–16.43	–5.57	–5.00	–2.26	0.58	–0.47	–3.81
LDAW 6	7085.07	–0.83	--	--	–0.77	–0.82	–1.01	–0.88	–0.86
LDAW 7	6676.78	–3.73	–3.29	0.23	–0.70	–0.43	1.01	0.30	–0.94
LDAW 8	6235.80	--	–6.56	–1.40	–3.15	–2.60	0.02	–3.47	–2.86
LDAW 9	5908.71	–4.41	–15.45	–5.06	–4.25	–2.37	–2.16	1.63	–4.58
LDAW 10	6324.88	–2.32	–3.00	1.16	–2.33	–2.01	–1.06	–1.08	–1.52
LDAW 11	6799.61	--	--	--	--	--	--	--	--
	Average:	–2.40	–6.96	–2.40	–3.20	–0.26	–1.44	–2.28	–2.65
DENV 1	6783.59	–0.93	–3.34	–2.88	–2.51	–2.00	–0.74	–0.92	–1.90
DENV 2	6268.94	–2.37	–4.90	–2.94	–1.50	–1.02	–0.60	–2.17	–2.21
DENV 3	6822.46	–0.45	--	–0.02	–0.41	–0.02	–0.45	–0.42	–0.30
DENV 4	6376.53	–8.74	–1.57	1.27	–1.94	–1.80	1.68	–0.80	–1.70
DENV 5	6317.29	–14.53	–11.27	0.00	–25.02	–5.31	–2.28	10.47	–6.85
DENV 6	5716.55	–1.25	–0.99	–0.25	–2.41	–0.27	1.39	–0.88	–0.67
DENV 7	7003.66	–9.75	–6.34	–1.58	–12.41	–8.63	–5.89	–3.61	–6.89
DENV 8	7265.13	–4.29	--	–3.66	–4.41	--	–3.03	–3.77	–3.83
DENV 9	5864.18	–11.42	–7.65	–4.72	1.25	–12.02	–0.92	0.70	–4.97
DENV 10	6410.74	–0.65	1.27	–0.67	–0.09	–1.00	–1.06	–0.87	–0.44
DENV 11	6058.29	–18.39	–7.13	–6.62	–10.11	–6.81	1.55	8.58	–5.56
	Average:	–6.62	–4.66	–2.01	–5.41	–3.89	–0.94	0.57	–3.23
ARAP 1	5789.08	--	–2.81	–3.15	–2.81	–2.63	–2.66	–2.45	–2.75
ARAP 2	5750.03	--	6.57	7.62	1.58	–8.54	–8.51	–5.40	–1.11
	Average:	--	1.88	2.24	–0.62	–5.59	–5.59	–3.93	–1.93
LARA 1	6169.43	–42.05	–68.61	16.10	–12.98	–7.73	9.04	18.30	–12.56
LARA 2	6155.85	–33.59	–12.63	3.67	–5.91	–3.02	1.92	–1.22	–7.25
	Average:	–37.82	–40.62	9.89	–9.45	–5.38	5.48	8.54	–9.91

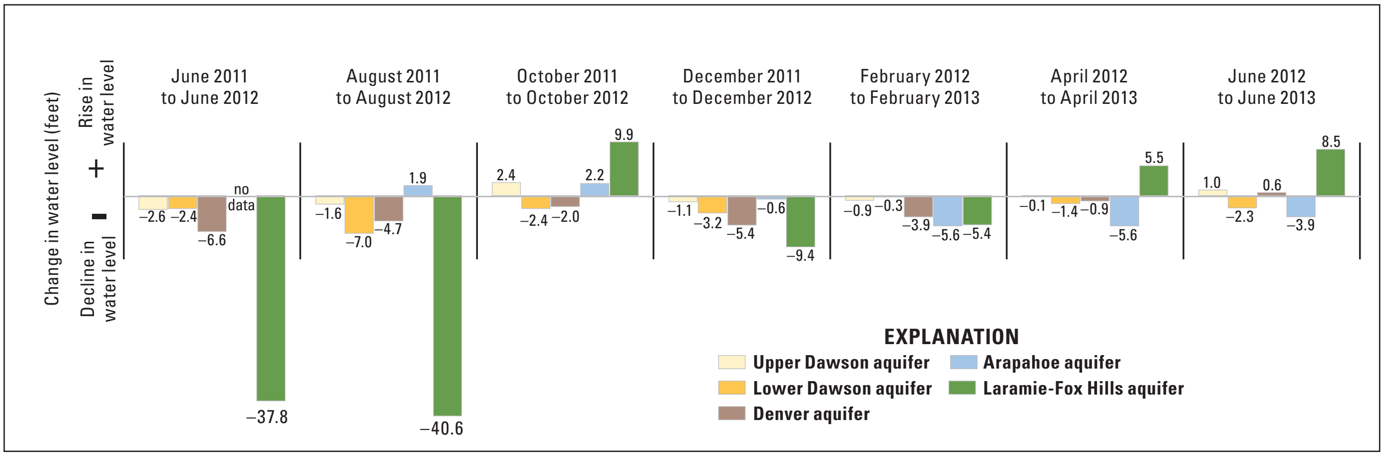


Figure 6. Bar graph showing average year-to-year changes in manual water-level measurements, Douglas County, Colorado.

The highest and lowest observed water levels and the date on which they occurred were calculated. During 2012, the highest observed water levels occurred between late January and late April and most often occurred in mid-March, whereas the lowest levels were observed between late June and late October and most often occurred in mid to late September (table 6). During 2013, the highest observed levels occurred between mid-January and mid-May and most often occurred in April (table 6).

The year-to-year change in water levels for the time-series sites, calculated from the highest observed levels in each calendar year, showed declines in water levels in all 15 wells. The declines ranged from about 0.2 ft (LDAW 7) to about 8.4 ft (DENV 9) and averaged about 1.8 ft (table 6). Declines in the upper Dawson aquifer ranged from about 0.3 ft (UDAW 1) to about 1.2 ft (UDAW 9) and averaged almost 0.7 ft. Declines in the lower Dawson aquifer ranged from about 0.2 (LDAW 7) to about 5.7 ft (LDAW 1) and averaged about 2.1 ft. Declines in the Denver aquifer ranged from about 1.0 (DENV 1 and DENV 2) to over 8.4 ft (DENV 9) and averaged about 3.1 ft (table 6).

During the seasonal decline of 2012, April through August, a relative rise in water levels was observed multiple times in several of the wells (fig. 7). Most rises in water level were less than 2 ft and typically occurred over several days to a week. In some cases, the timeframe of the rise correlated with rises in other wells in the same aquifer or, occasionally, with other wells in the other aquifers. In early July 2012, a relative rise in water levels was observed in 12 (all except UDAW 10, LDAW 6, DENV 6) of the 15 wells (light blue vertical bar, fig. 7). Almost 8 ft of rise was observed in UDAW 5, over 5 ft of rise was observed in LDAW 1, and about 3 ft of rise was observed in DENV 9. Although the exact cause of this increase is not known, decreased pumping or natural and induced recharge are possible factors. Regardless of cause, this observed rise demonstrates that water levels in the aquifers can respond quickly to changes in the hydrologic system and that there generally is good lateral hydraulic connection within each aquifer.

Potentiometric-Surface and Difference Maps

Potentiometric-surface maps illustrate the distribution of hydraulic heads in an aquifer at a given time using contour lines of equal hydraulic head. Groundwater flow can be inferred from potentiometric-surface maps from areas of high hydraulic head to areas of low hydraulic head, in a direction generally perpendicular to contours on the potentiometric-surface maps. To show the hydraulic-head distribution for the upper and lower Dawson and the Denver aquifers, potentiometric-surface maps were created from the manual water-level measurements collected during February, April, and June 2012 and 2013. The Inverse Distance Weighting and contour functions in ArcGIS software (Environmental Systems Research Institute, Inc., 1999–2010) were used to interpolate the six potentiometric-surface maps. There was little difference between potentiometric-surface maps for the six time periods due to the steep gradient across Douglas County, in comparison to the relatively small seasonal and annual changes in water level, and the distance between wells. The potentiometric-surface map for the upper Dawson aquifer in February 2013 (fig. 8) shows that groundwater flows generally from south to north from an elevation of approximately 6,800 ft to approximately 6,100 ft. The potentiometric-surface maps for the lower Dawson aquifer in February 2013 (fig. 9) and April 2013 (fig. 10) show that groundwater flows generally from south to north from an elevation of approximately 7,100 to 5,800 ft. The potentiometric-surface map for the Denver aquifer in February 2013 (fig. 11) shows that groundwater flow generally is to the west and northwest in the southern half of Douglas County, northward in the northern half of the county, and westerly near Louviers.

Difference maps illustrate the change in a parameter over time. Regional changes can be inferred by interpolation of individual points. To show the changes in water level for the upper and lower Dawson aquifer and the Denver aquifers, difference maps were created from the February 2012 and February 2013 manual water-level measurements using the Inverse Distance Weighting and contour functions in ArcGIS software. The

Table 5. Average year-to-year changes in manual and time-series water level measurements, Douglas County, Colorado.

[See figure 2 for well locations. Abbreviations: ft, feet; --, data not available]

Aquifer name	Average water level change - Jun 2011 to Jun 2012 (ft)	Average water level change - Aug 2011 to Aug 2012 (ft)	Average water level change - Oct 2011 to Oct 2012 (ft)	Average water level change - Dec 2011 to Dec 2012 (ft)	Average water level change - Feb 2012 to Feb 2013 (ft)	Average water level change - April 2012 to April 2013 (ft)	Average water level change - June 2012 to June 2013 (ft)	Average change of all year-to-year measurements (ft)	Average change in maximum observed water level elevation from time-series data, 2012 to 2013 (ft)
Upper Dawson	–2.56	–1.57	2.40	–1.14	–0.88	–0.06	1.03	–0.37	–0.68
Lower Dawson	–2.40	–6.96	–2.40	–3.20	–0.26	–1.44	–2.28	–2.65	–2.06
Denver	–6.62	–4.66	–2.01	–5.41	–3.89	–0.94	0.57	–3.23	–3.12
Arapahoe	--	1.88	2.24	–0.62	–5.59	–5.58	–3.92	–1.93	--
Laramie-Fox Hills	–37.82	–40.62	9.89	–9.45	–5.38	5.48	8.54	–9.91	--

Table 6. Summary of highest and lowest observed water levels and date of observation at time-series data sites, Douglas County, Colorado.

[See figure 2 for well locations. Abbreviations: UDAW, upper Dawson well; LDAW, lower Dawson well; DENV, Denver well; ARAP, Arapahoe well; LARA, Laramie Fox-Hills well; LSD, land surface datum; ft, feet; NAVD 88, North American Vertical Datum of 1988; M, month; D, day; YYYY, year; --, data not available]

Common name Common name	Elevation of LSD (ft above NAVD88)	Period of record		Calendar year 2012				Calendar year 2013				Change in maximum water level elevation from time-series data, 2012 to 2013 (ft)
		Begin Date (M/D/YYYY)	End Date (M/D/YYYY)	Maximum water level elevation (NAVD88) (ft)	Date of observation (M/D/YYYY)	Minimum water level elevation (NAVD88) (ft)	Date of observation (M/D/YYYY)	Maximum water level elevation (NAVD88) (ft)	Date of observation (M/D/YYYY)	Minimum water level elevation (NAVD88) (ft)[1]	Date of observation (M/D/YYYY)[1]	
UDAW 1	6934.52	8/26/2011	6/4/2013	6844.33	3/11/2012	6839.40	6/25/2012	6844.06	3/21/2013	--	--	–0.27
UDAW 3	6414.87	10/14/2011	6/5/2013	6260.88	3/18/2012	6258.19	9/14/2012	6260.37	4/13/2013	--	--	–0.51
UDAW 4	6267.98	10/14/2011	6/5/2013	6154.41	3/17/2012	6133.81	9/3/2012	6154.01	3/9/2013	--	--	–0.40
UDAW 5	6501.66	10/14/2011	6/5/2013	6375.62	3/12/2012	6339.07	7/23/2012	6374.63	3/21/2013	--	--	–0.99
UDAW 9	6285.29	10/14/2011	6/7/2013	6077.12	3/18/2012	6072.94	9/7/2012	6075.97	4/8/2013	--	--	–1.15
UDAW 10	6288.97	8/27/2011	6/5/2013	6176.99	1/22/2012	6167.74	10/22/2012	6176.22	4/13/2013	--	--	–0.77
LDAW 1	5816.50	12/8/2011	6/7/2013	5768.79	3/11/2012	5746.17	9/11/2012	5763.13	5/11/2013	--	--	–5.66
LDAW 2	7278.15	8/11/2011	6/4/2013	7211.28	1/22/2012	7206.25	7/6/2012	7209.77	2/10/2013	--	--	–1.51
LDAW 6	7085.07	8/26/2011	6/4/2013	7045.10	4/15/2012	7043.92	9/22/2012	7044.18	4/8/2013	--	--	–0.92
LDAW 7	6676.78	8/26/2011	6/5/2013	6592.86	3/15/2012	6583.50	8/5/2012	6592.70	4/20/2013	--	--	–0.16
DENV 1	6783.59	4/3/2012	6/5/2013	6637.04	4/27/2012	6628.95	8/19/2012	6636.02	5/16/2013	--	--	–1.02
DENV 2	6268.94	8/27/2011	6/3/2013	6167.72	1/20/2012	6161.39	7/31/2012	6166.73	3/9/2013	--	--	–0.99
DENV 5	6317.29	12/6/2011	6/3/2013	6136.70	3/19/2012	6108.93	9/10/2012	6133.00	5/10/2013	--	--	–3.70
DENV 6	5716.55	12/6/2011	6/3/2013	5494.80	1/22/2012	5492.48	9/8/2012	5493.32	1/11/2013	--	--	–1.48
DENV 9	5864.18	12/8/2011	6/7/2013	5743.45	3/7/2012	5704.41	9/6/2012	5735.04	4/27/2013	--	--	–8.41

[1]The minimum water level for 2013 did not occur before the date of the last measurement presented in this report, July, 7, 2013.

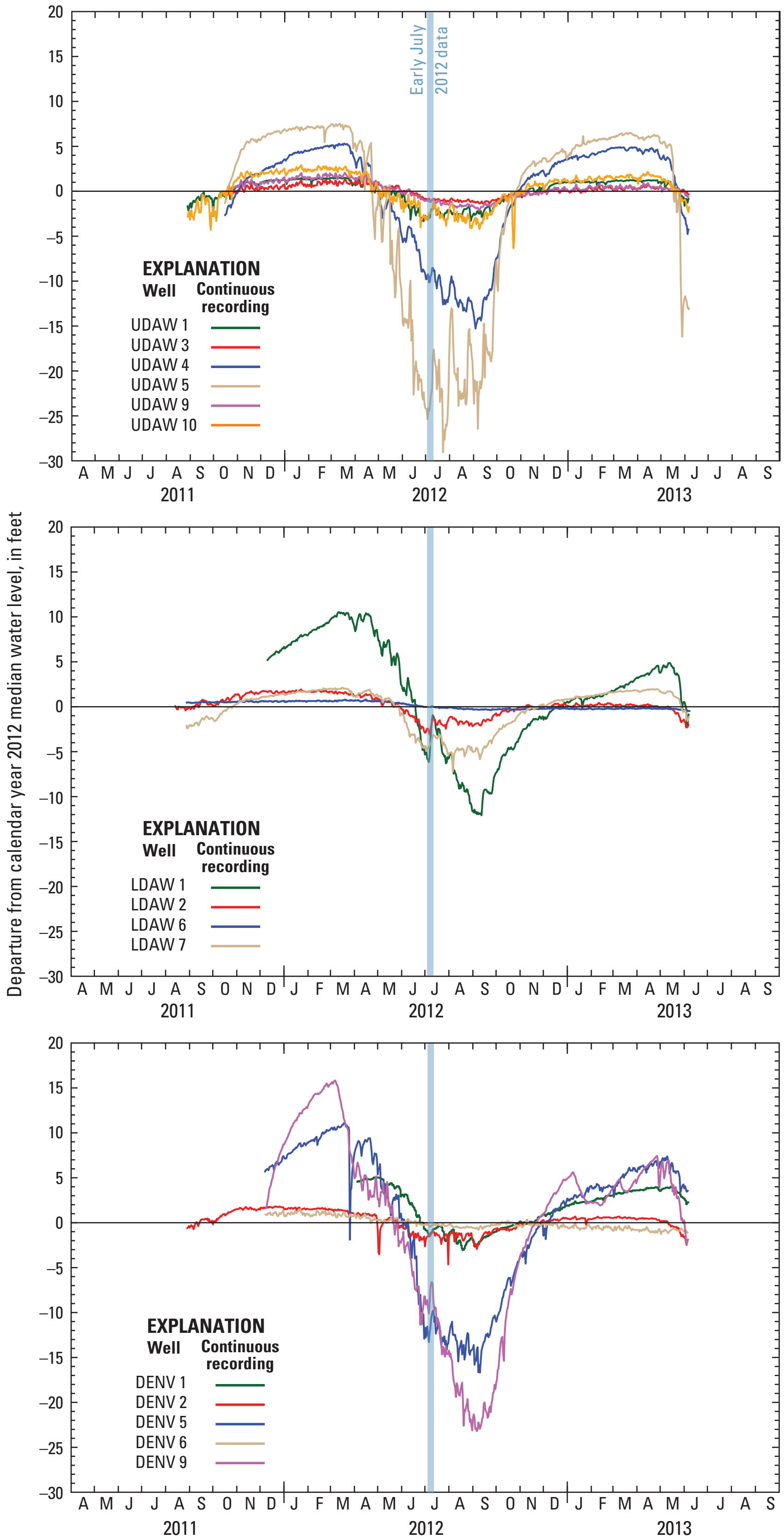


Figure 7. Departure from calendar year 2012 median water level in wells, Douglas County, Colorado.

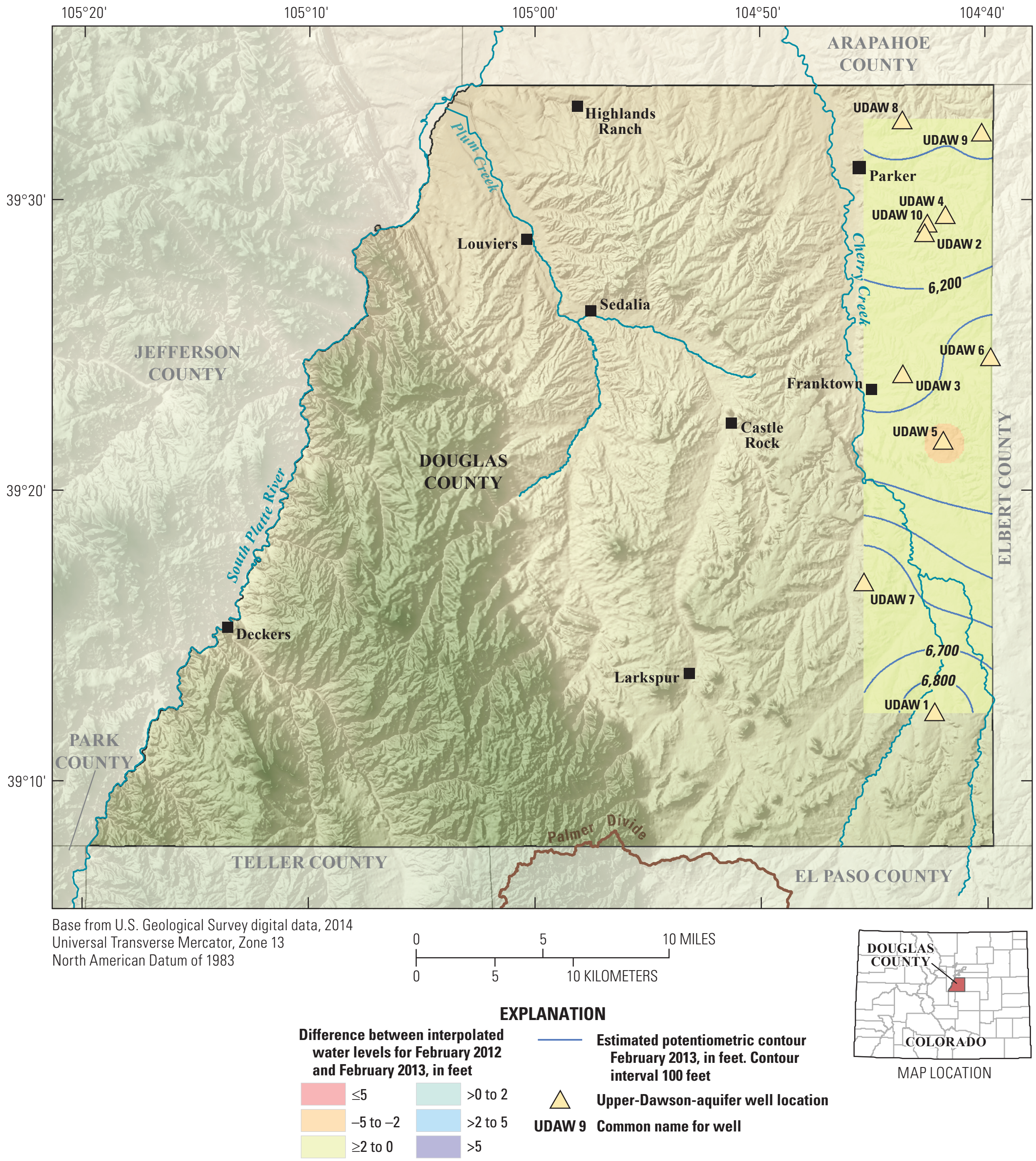


Figure 8. Estimated potentiometric surface of the upper Dawson aquifer for February 2013 and change in head from February 2012, Douglas County, Colorado. (≤, less than or equal to; ≥, greater than or equal to; >, greater than)

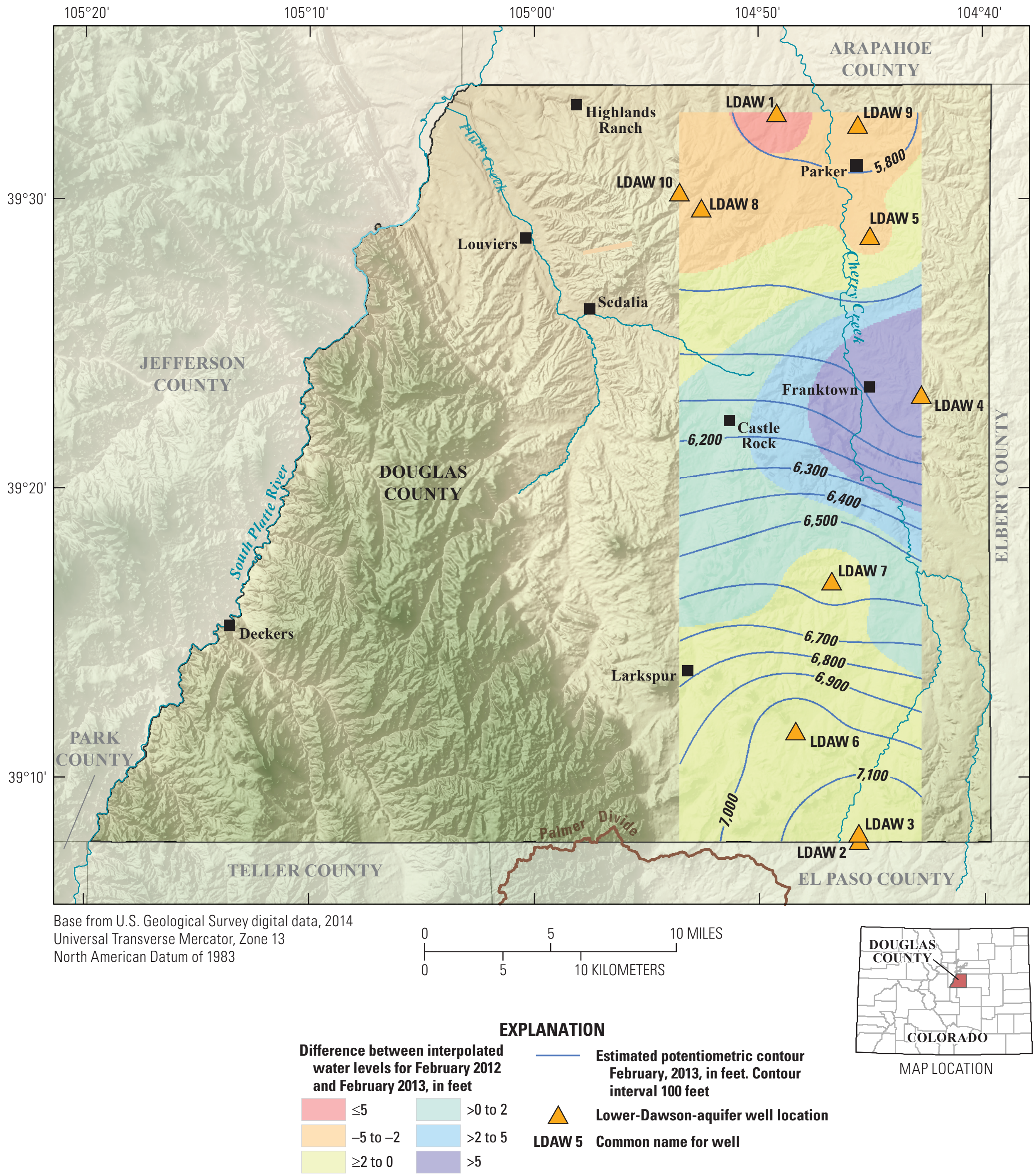


Figure 9. Estimated potentiometric surface of the lower Dawson aquifer for February 2013 and change in head from February 2012, Douglas County, Colorado. (≤, less than or equal to; ≥, greater than or equal to; >, greater than)

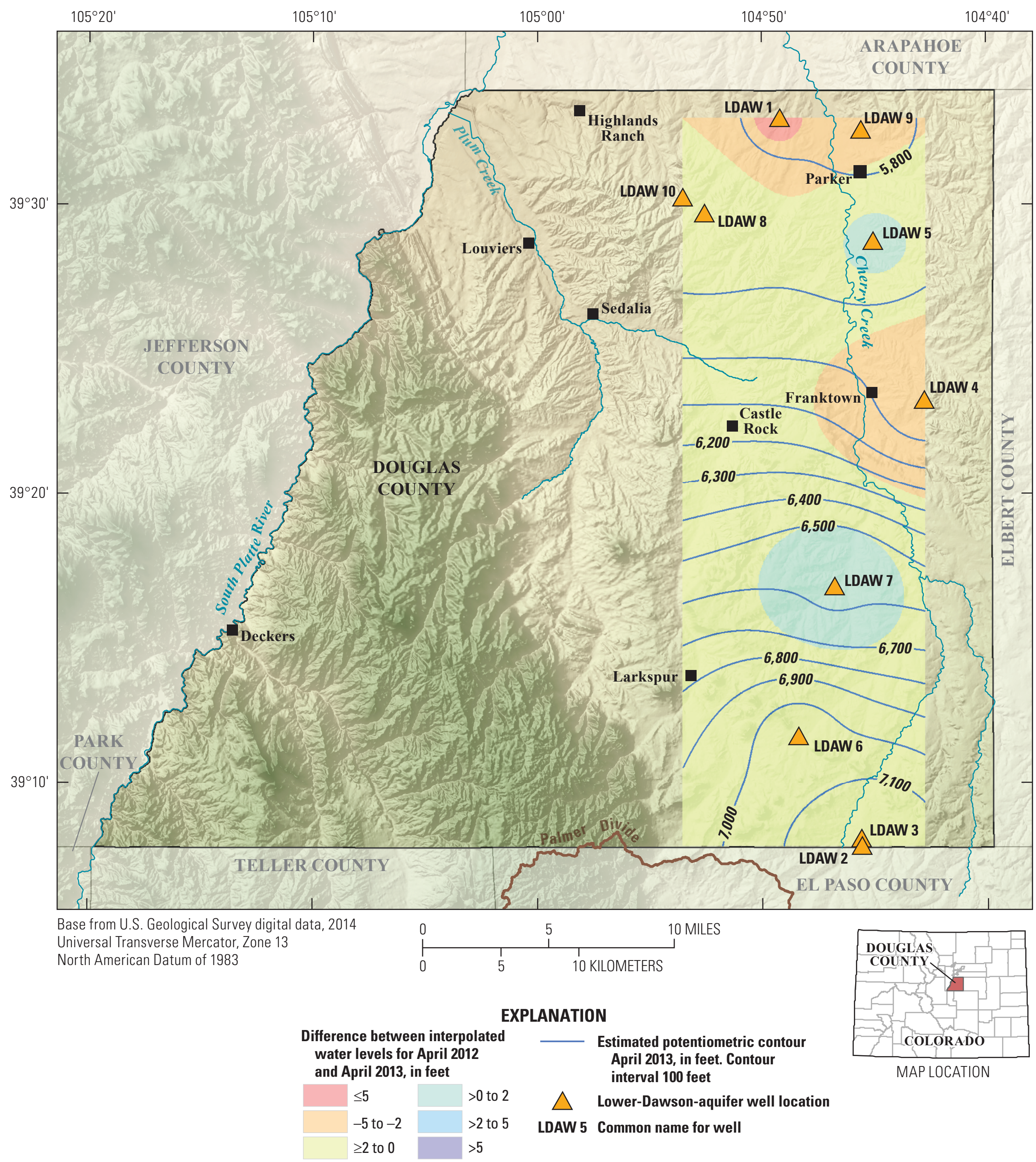


Figure 10. Estimated potentiometric surface of the lower Dawson aquifer for April 2013 and change in head from April 2012, Douglas County, Colorado. (≤, less than or equal to; ≥, greater than or equal to; >, greater than)

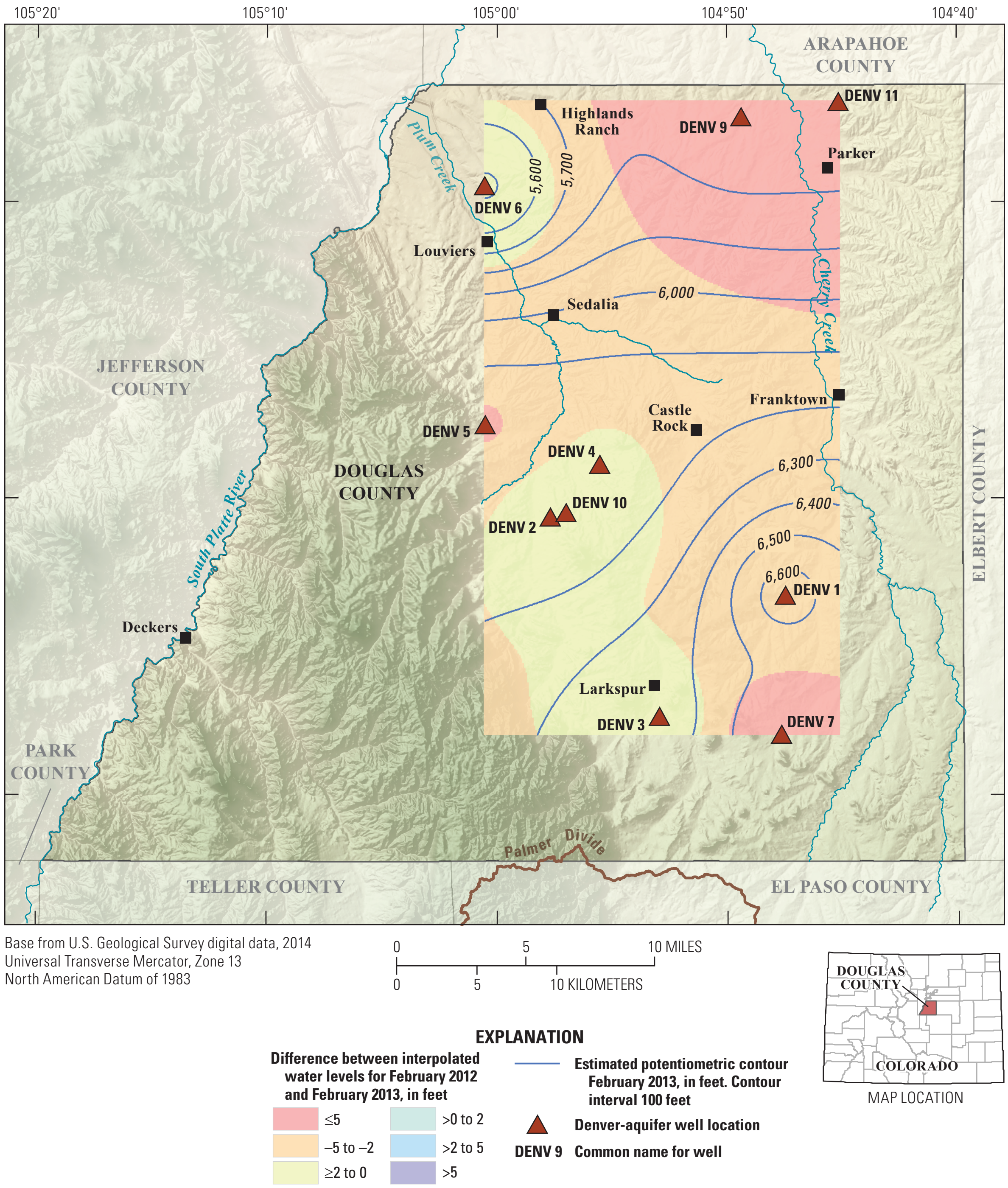


Figure 11. Estimated potentiometric surface of the Denver aquifer for February 2013 and change in head from February 2012, Douglas County, Colorado. (≤, less than or equal to; ≥, greater than or equal to; >, greater than)

results are plotted on the potentiometric-surface maps (figs. 8–11). The difference map for the upper Dawson aquifer shows that declines ranging between 0 and 2 ft are uniform across the county with a small area of greater decline (2 to 5 ft) centered around UDAW 5 (fig. 8). The difference map for the lower Dawson aquifer shows water level declines are greater in the northern portion of the county and less in the southern with a rise in water levels located near Franktown (fig. 9). This rise, centered on LDAW 4, may be attributed to the fact that the well was recently pumped before the February 2012 measurement (as previously described) and that the seasonal high is not reached until later in the year; therefore, the February measurements may not be representative of the static conditions at this location. For comparison, a difference map from the April 2012 and April 2013 measurements for the lower Dawson aquifer was plotted (fig. 10). The map shows that declines are greater in the northern portion of the county and less in the southern, but with a decline in Franktown area (fig. 10). The difference map for the Denver aquifer shows that the largest area of decline is located in the northeastern section of the county around Parker (fig. 11).

Summary and Conclusions

More than 70 percent of the municipal water supply in the south Denver metropolitan area is provided by groundwater, and homeowners in rural areas depend solely on self-supplied groundwater for water supply. Increased groundwater withdrawal to meet the demand of the rapidly growing population is causing water levels to decline. The U.S. Geological Survey, in cooperation with the Rural Water Authority of Douglas County, began a study in 2011 to assess the groundwater resources of the Denver Basin aquifers within Douglas County, Colorado. The primary purpose of this study was to monitor changes in the groundwater levels of the bedrock aquifers of the Denver Basin within rural Douglas County. To better assess the water resources of the Denver Basin bedrock aquifers, a groundwater monitoring network was established in 2011. More than 500 manual and 213,900 automated water-level measurements collected from the 36 domestic-well network between April 2011 and 2013 showed water-level declines in all aquifers.

The average change in water-level measurements from February 2012 to February 2013 for each aquifer shows declines of about 0.9 feet (ft) per year in the upper Dawson aquifer, about 0.3 ft per year in the lower Dawson aquifer, about 3.9 ft per year in the Denver aquifer, about 5.6 ft per year in the Arapahoe aquifer, and about 5.4 ft in the Laramie-Fox Hills aquifer. The average of all year-to-year changes in manual water-level measurements shows declines of about 0.4 ft per year in the upper Dawson aquifer, over 2.6 ft per year in the lower Dawson aquifer, about 3.2 ft per year in the Denver aquifer, about 1.9 ft per year in the Arapahoe aquifer, and about 9.9 ft in the Laramie-Fox Hills aquifer. Year-to-year change in the highest observed water level recorded at the time-series sites show declines of about 0.7 ft in the upper Dawson aquifer, about 2.1 ft in the lower Dawson aquifer, and about 3.1 ft in the Denver aquifer. The difference maps for the lower Dawson and Denver aquifers show declines are greatest in the northeastern section of the county around Parker.

Continued monitoring is needed to determine if the declines in the groundwater levels observed between 2012 and 2013 are representative of the long-term year-to-year changes in the Denver Basin bedrock aquifers. Regions showing the greatest decline in water level require close monitoring. Wells located in these regions will be the first affected by declining water levels if the higher rates of decline continue from year to year.

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Appendix 1. Hydrographs of Wells in the Douglas County Water-Level Monitoring Network, Douglas County, Colorado

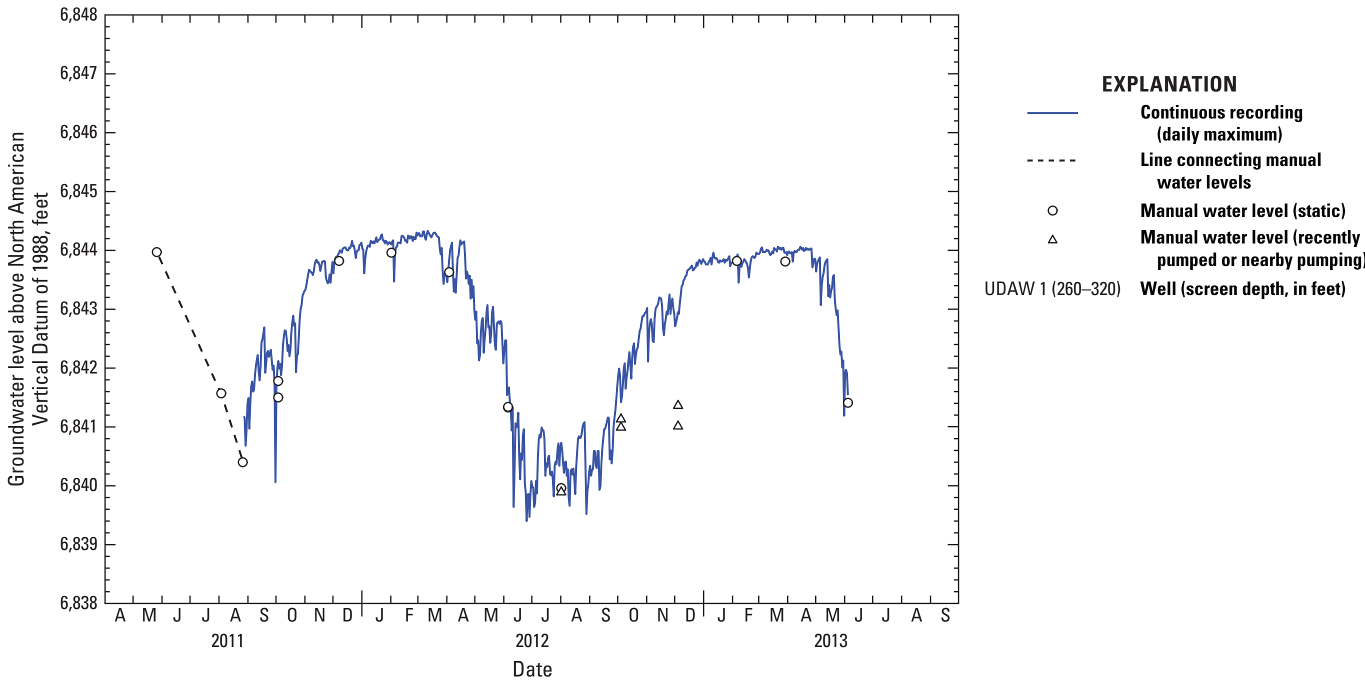

Figure 1–1. Water-level hydrograph from UDAW 1, from May 26, 2011, to June 04, 2013, Douglas County, Colorado.

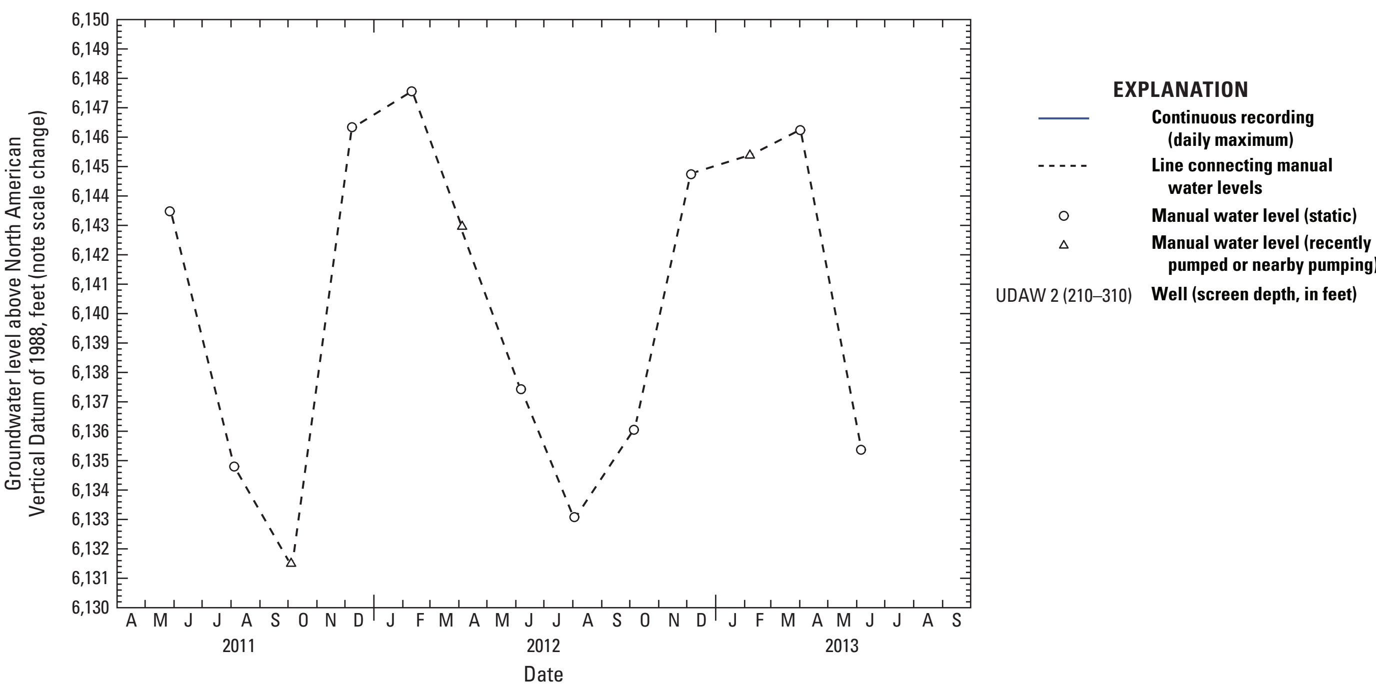

Figure 1–2. Water-level hydrograph from UDAW 2, from May 27, 2011, to June 05, 2013, Douglas County, Colorado.

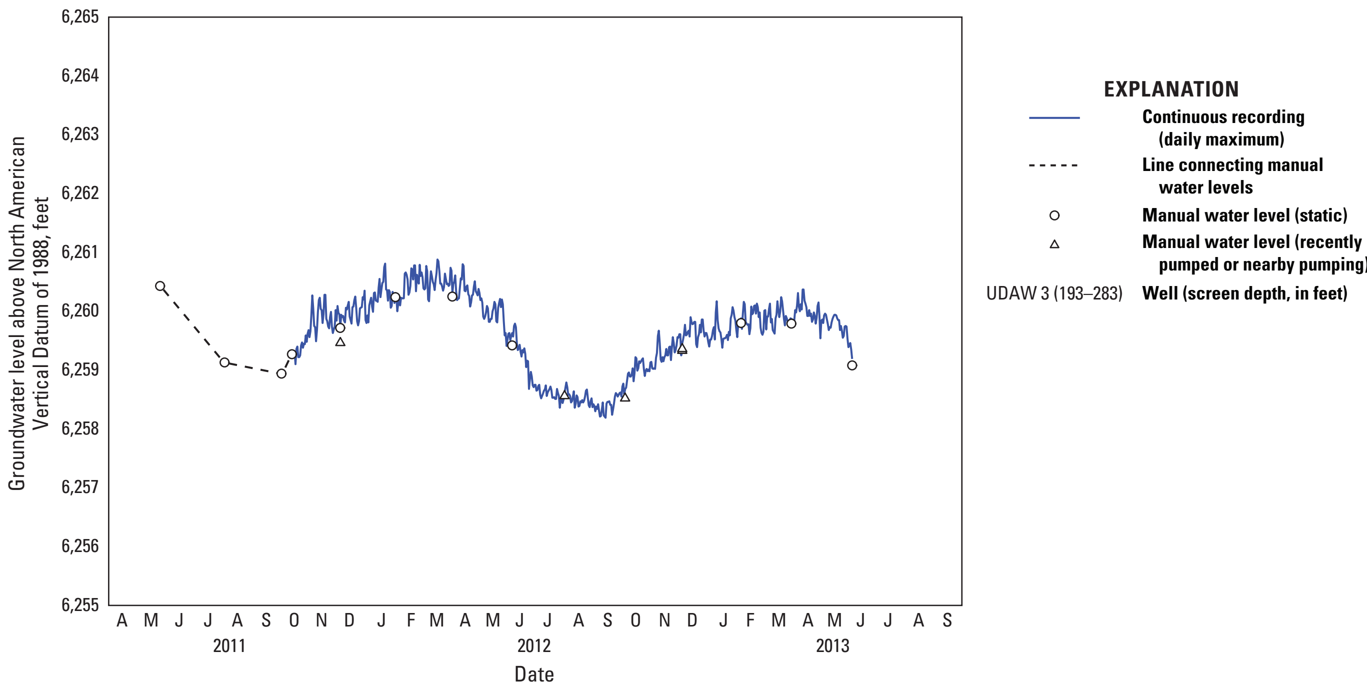

Figure 1–3. Water-level hydrograph from UDAW 3, from May 26, 2011, to June 05, 2013, Douglas County, Colorado.

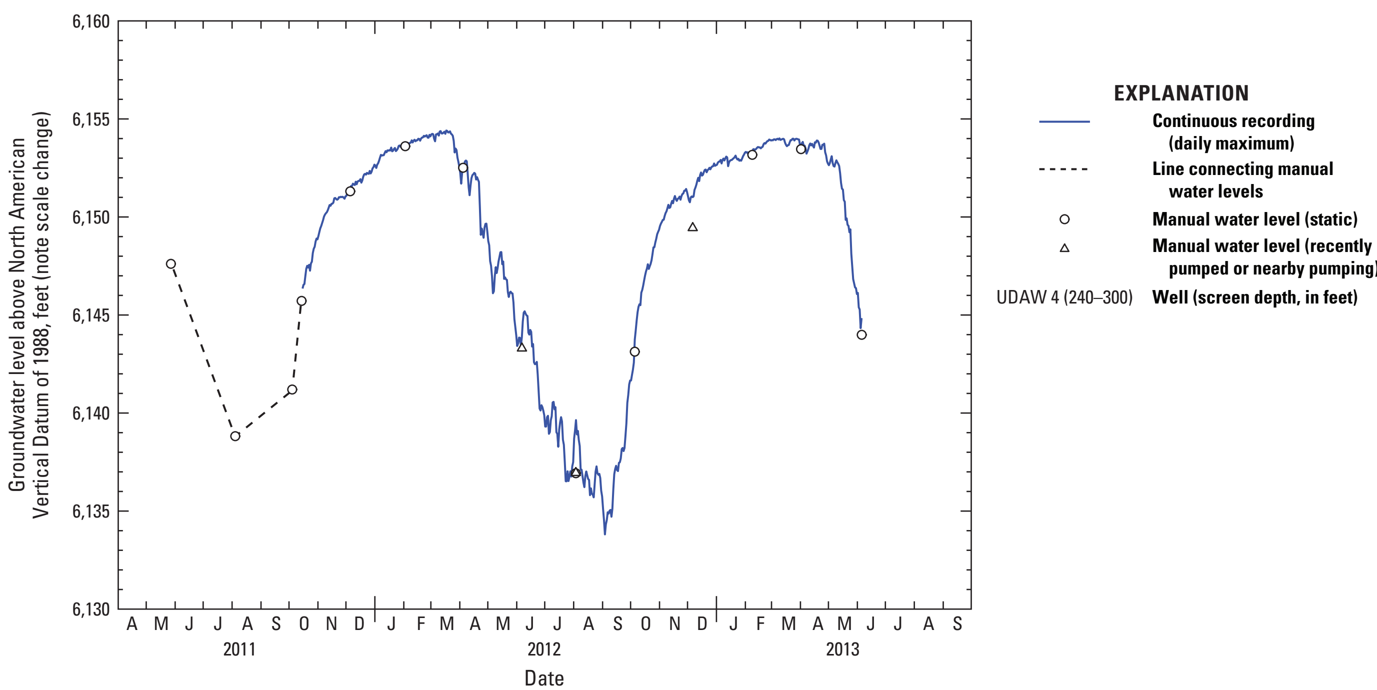

Figure 1–4. Water-level hydrograph from UDAW 4, from May 27, 2011, to June 05, 2013, Douglas County, Colorado.

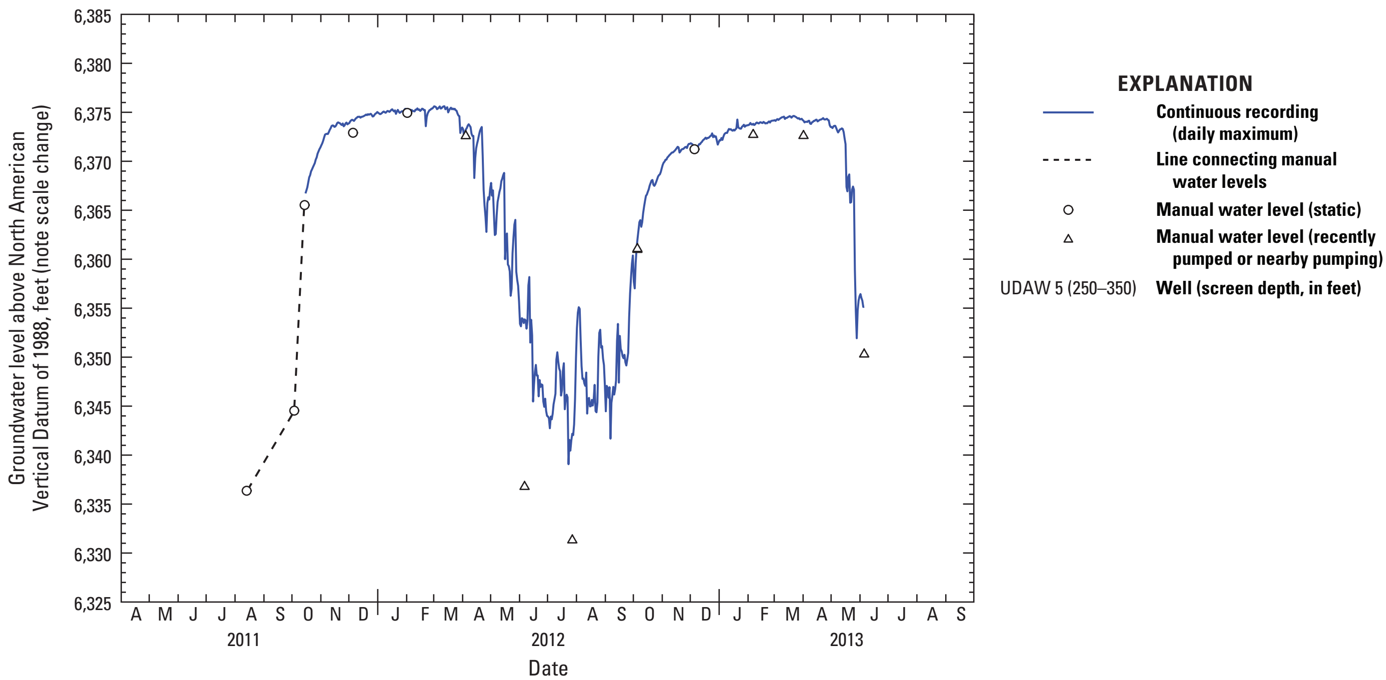

Figure 1–5. Water-level hydrograph from UDAW 5, from August 13, 2011, to June 05, 2013, Douglas County, Colorado.

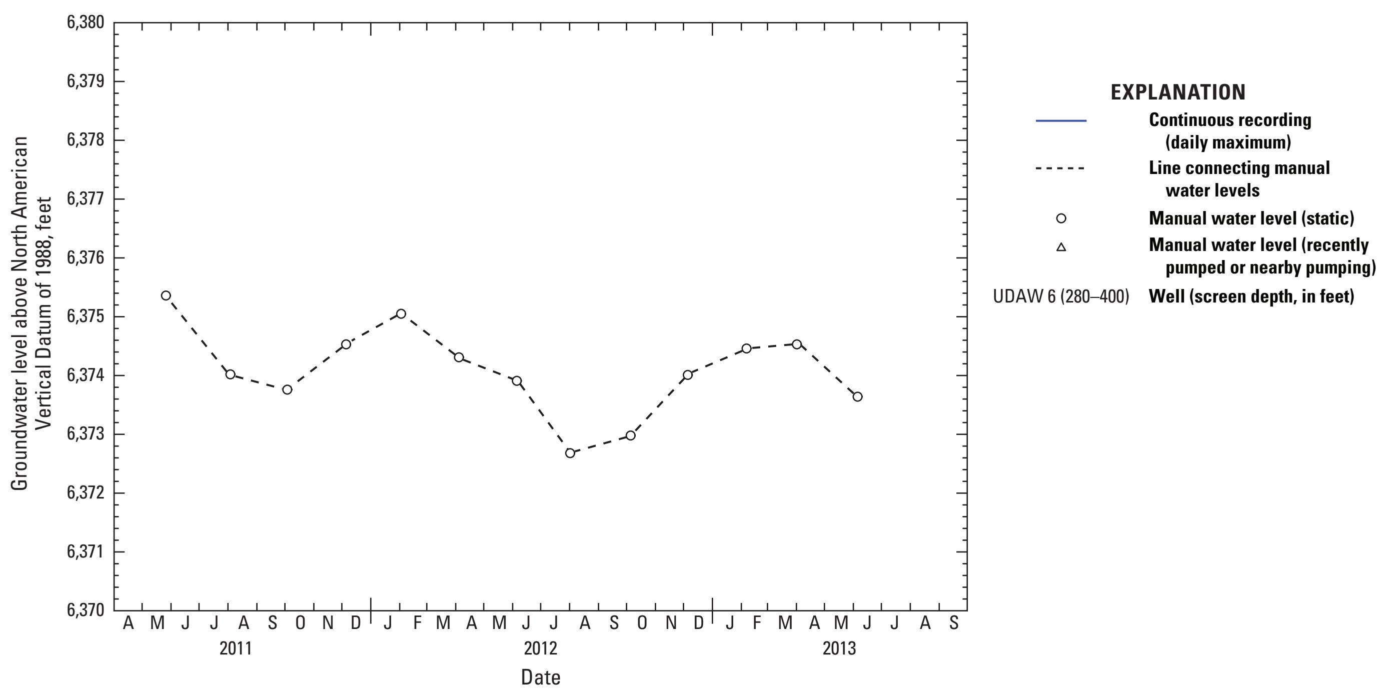

Figure 1–6. Water-level hydrograph from UDAW 6, from May 26, 2011, to June 05, 2013, Douglas County, Colorado.

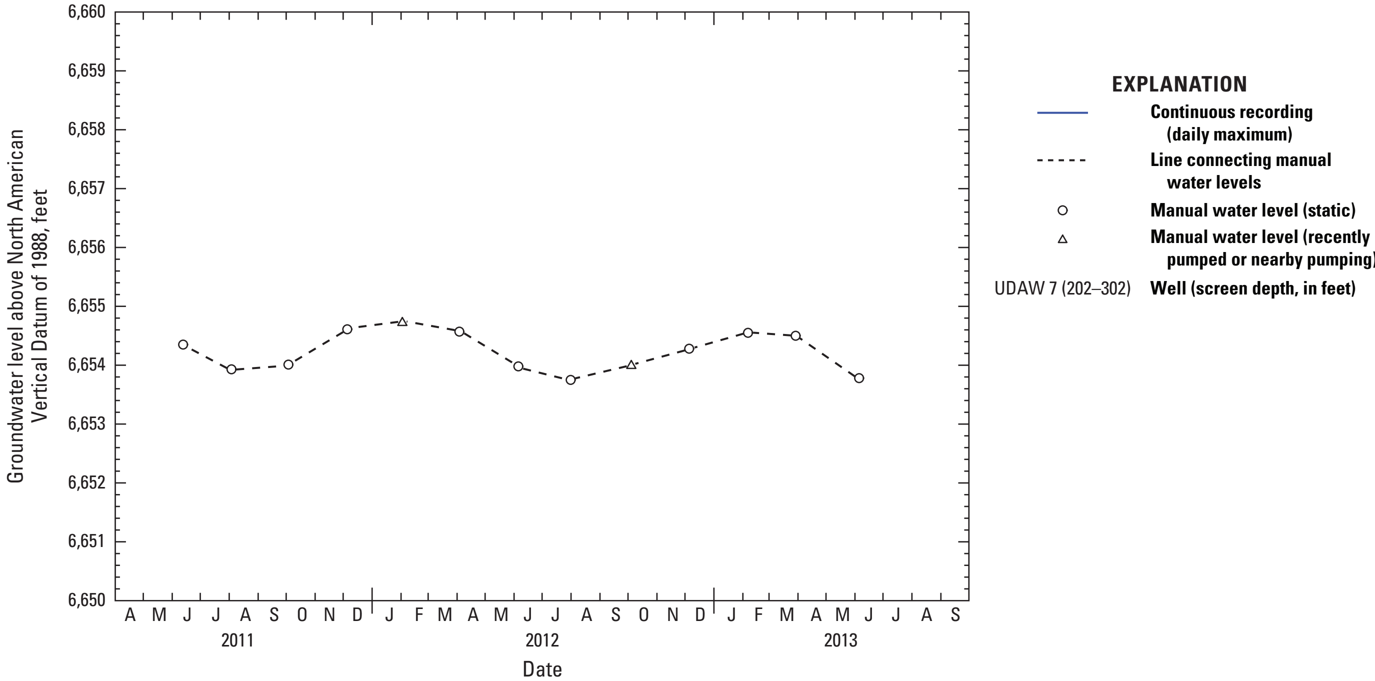

Figure 1–7. Water-level hydrograph from UDAW 7, from June 12, 2011, to June 05, 2013, Douglas County, Colorado.

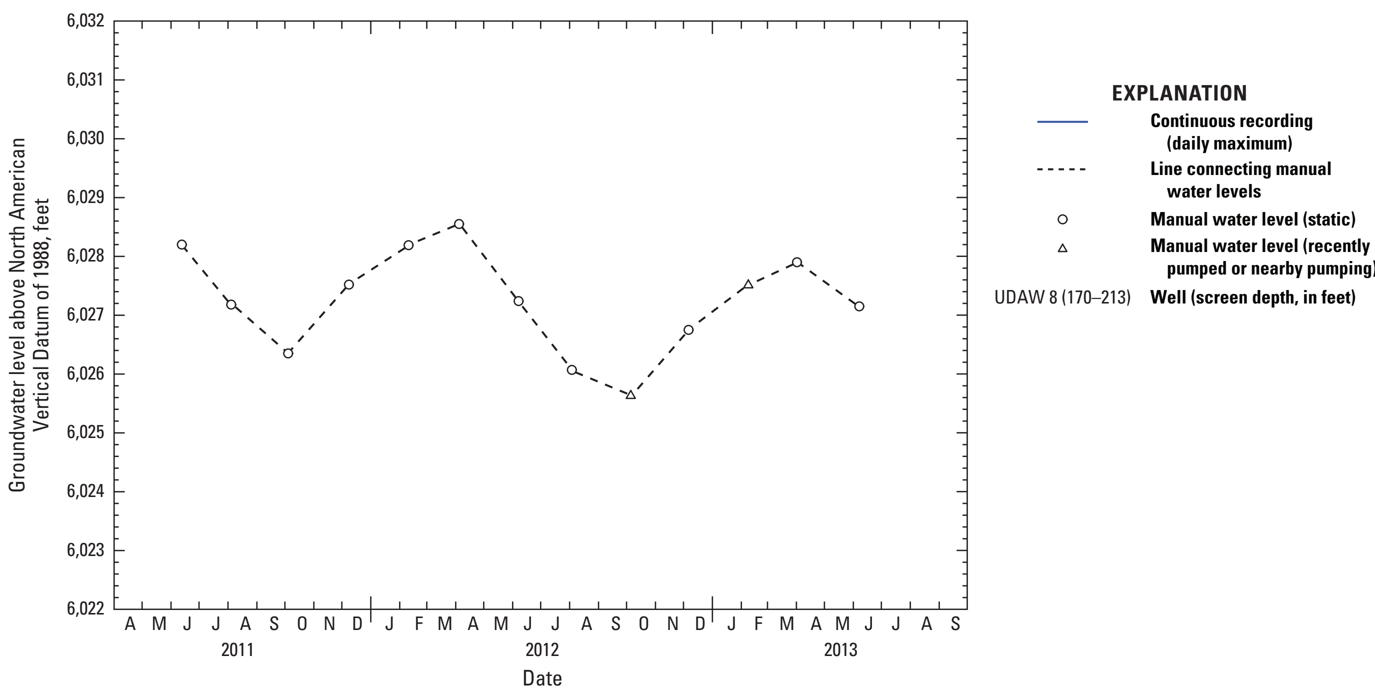

Figure 1–8. Water-level hydrograph from UDAW 8, from June 12, 2011, to June 07, 2013, Douglas County, Colorado.

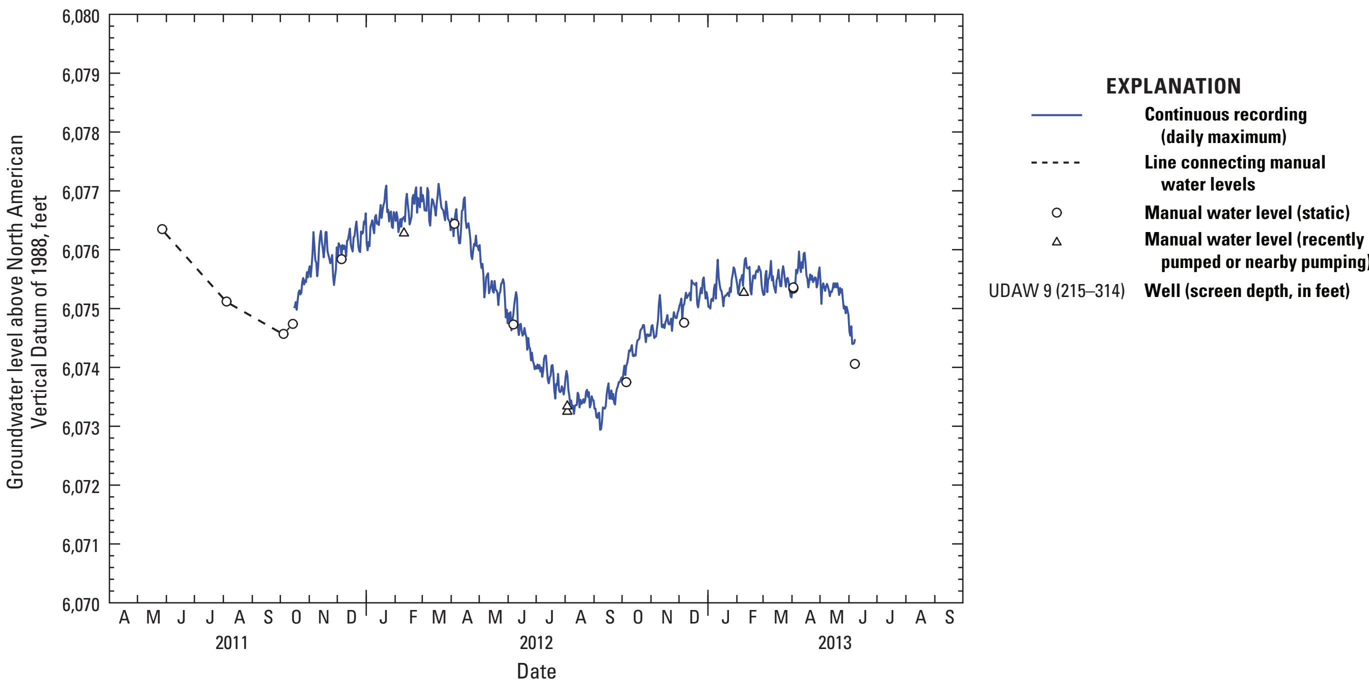

Figure 1–9. Water-level hydrograph from UDAW 9, from May 27, 2011, to June 07, 2013, Douglas County, Colorado.

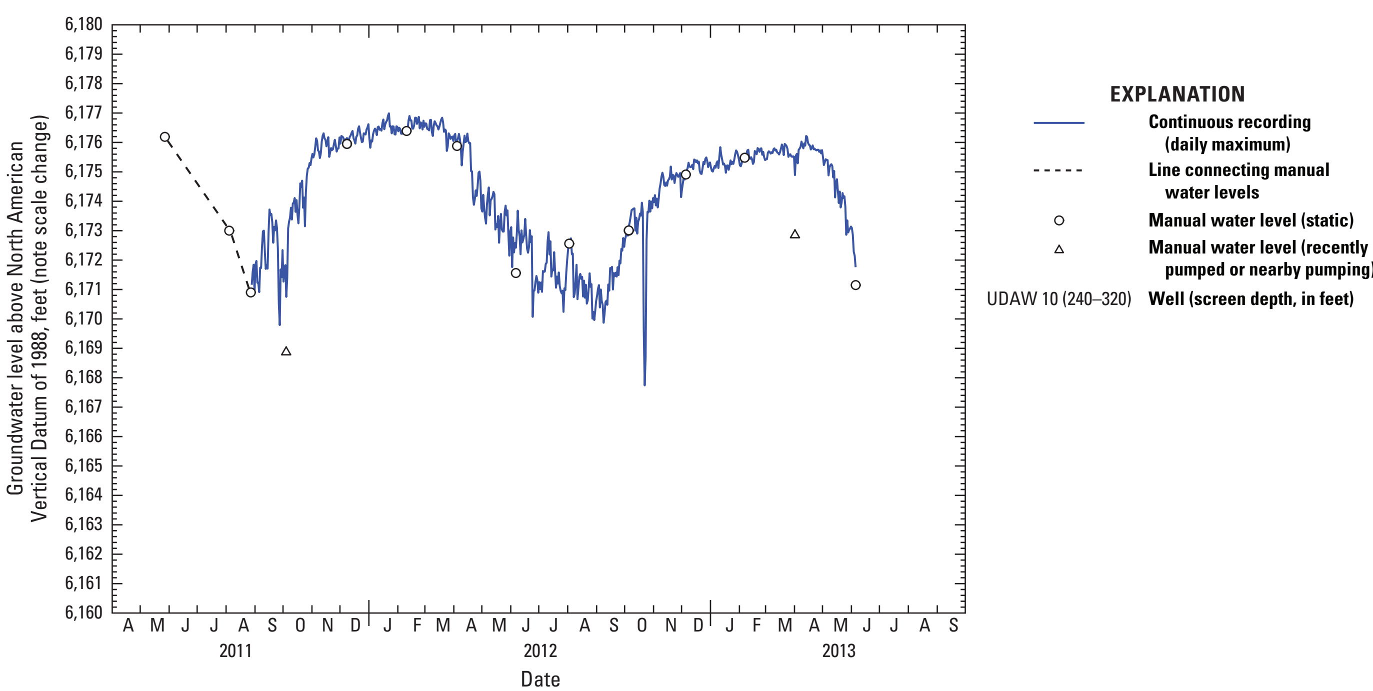

Figure 1–10. Water-level hydrograph from UDAW 10, from May 27, 2011, to June 05, 2013, Douglas County, Colorado.

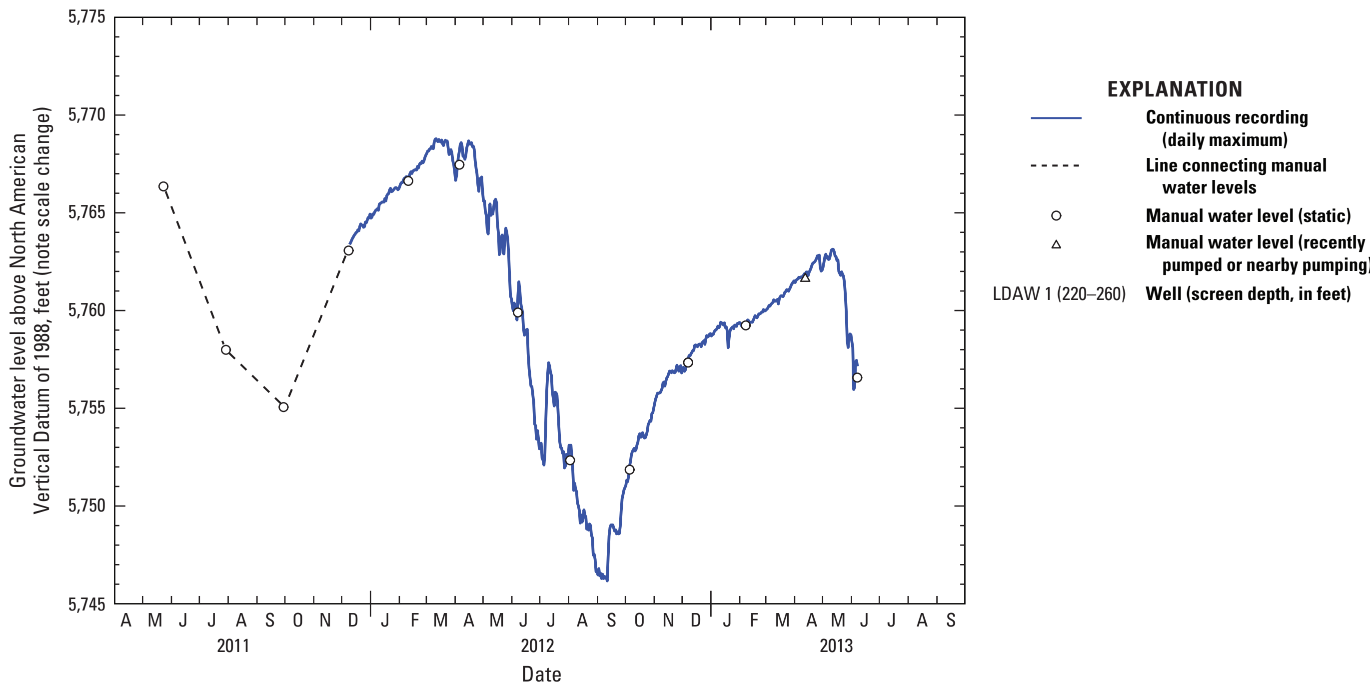

Figure 1–11. Water-level hydrograph from LDAW 1, from May 23, 2011, to June 06, 2013, Douglas County, Colorado.

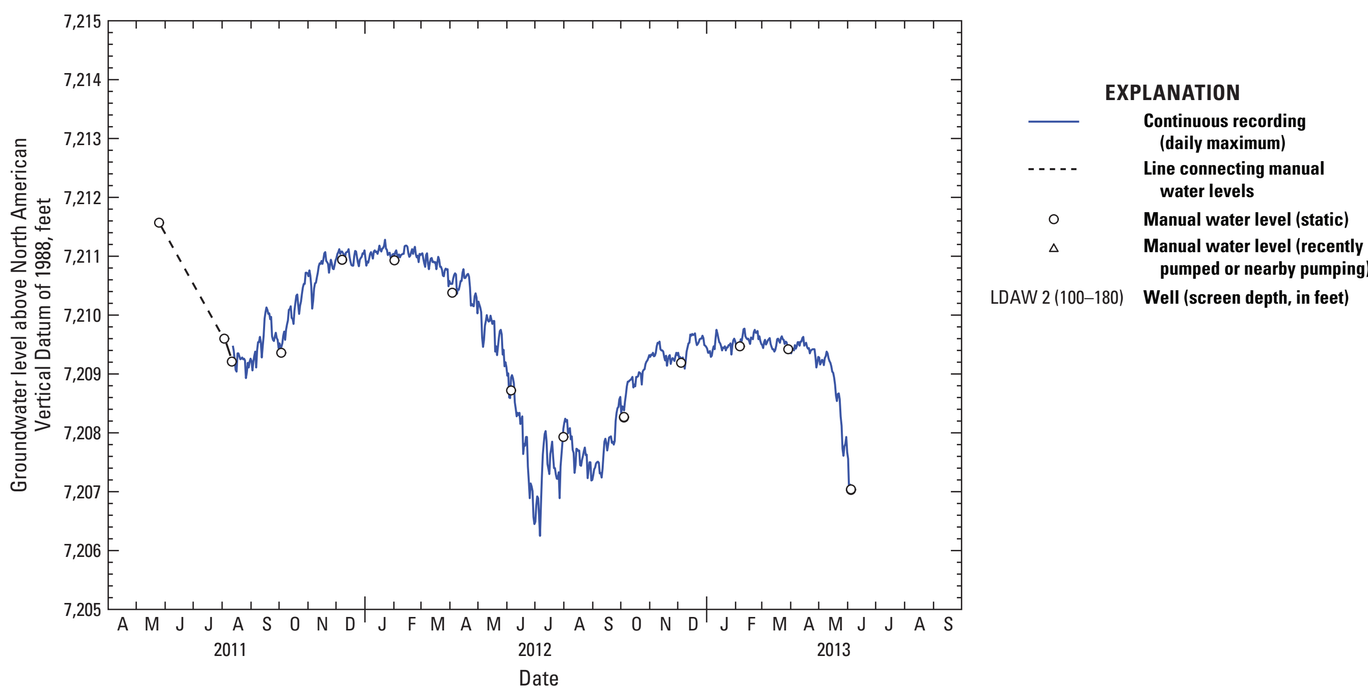

Figure 1–12. Water-level hydrograph from LDAW 2, from May 25, 2011, to June 04, 2013, Douglas County, Colorado.

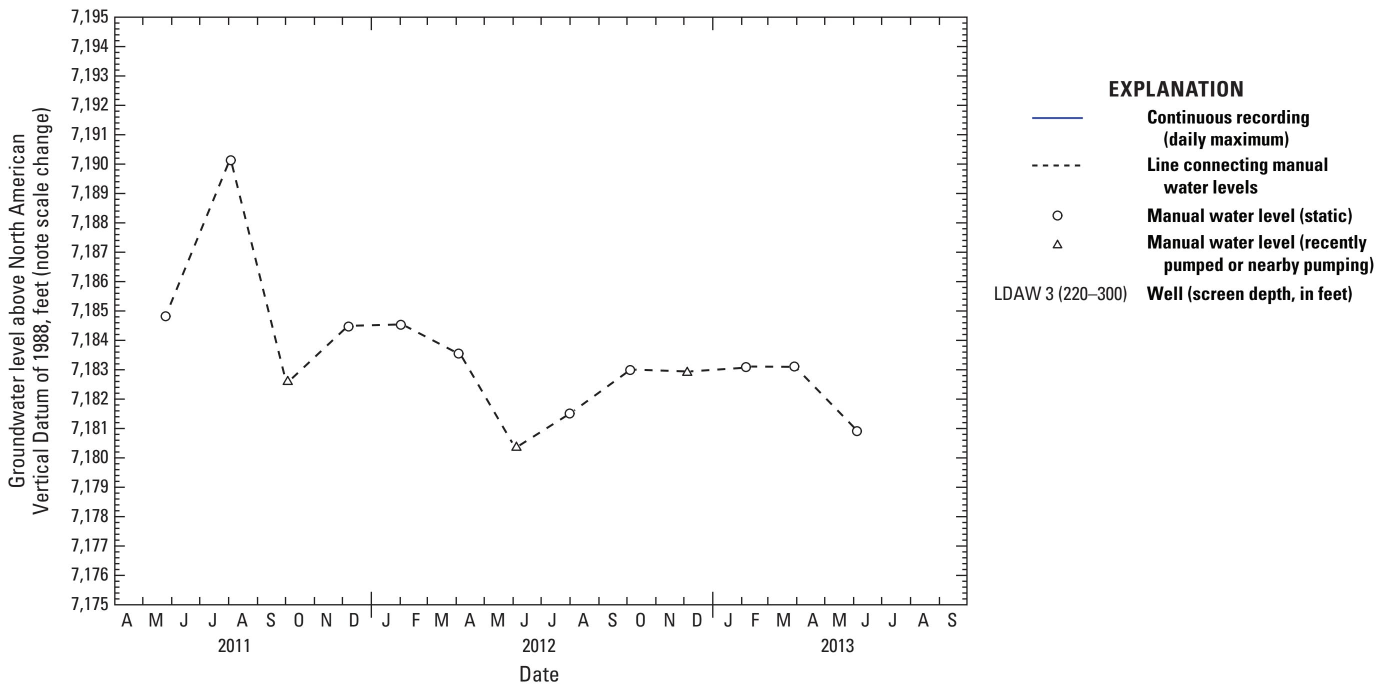

Figure 1–13. Water-level hydrograph from LDAW 3, from May 25, 2011, to June 04, 2013, Douglas County, Colorado.

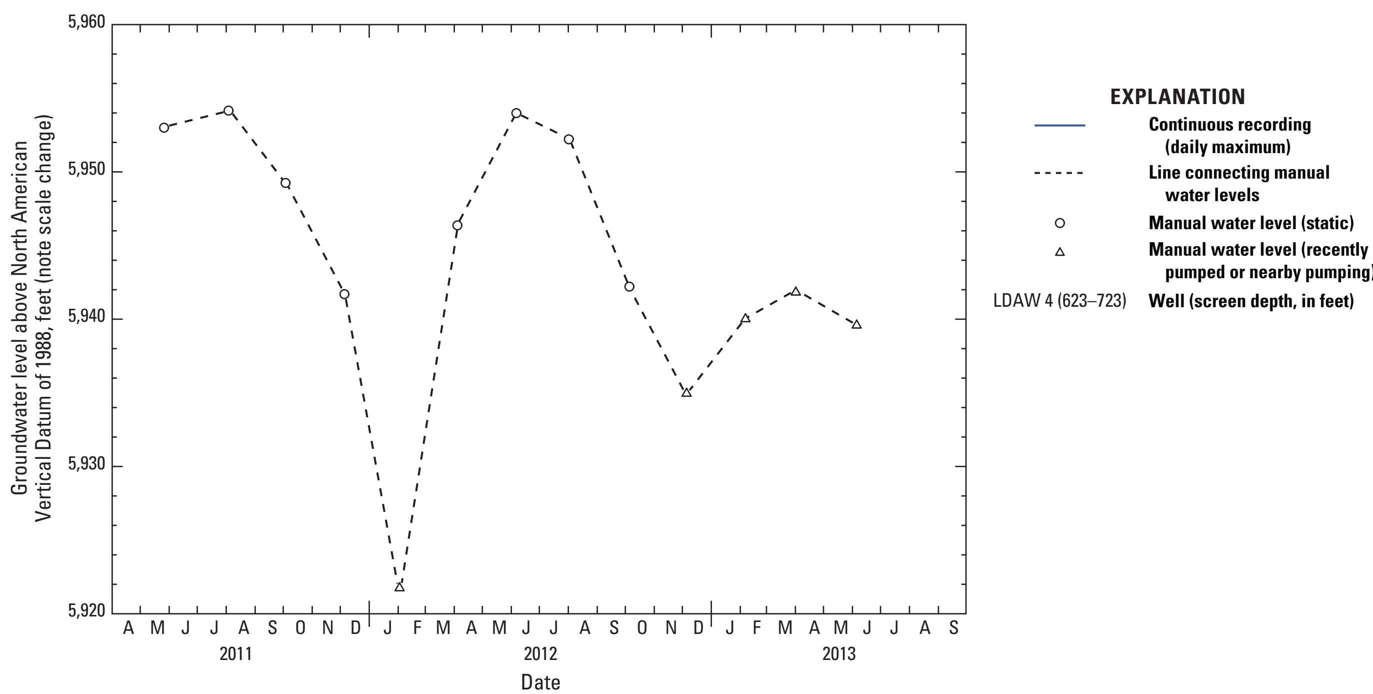

Figure 1–14. Water-level hydrograph from LDAW 4, from May 26, 2011, to June 07, 2013, Douglas County, Colorado.

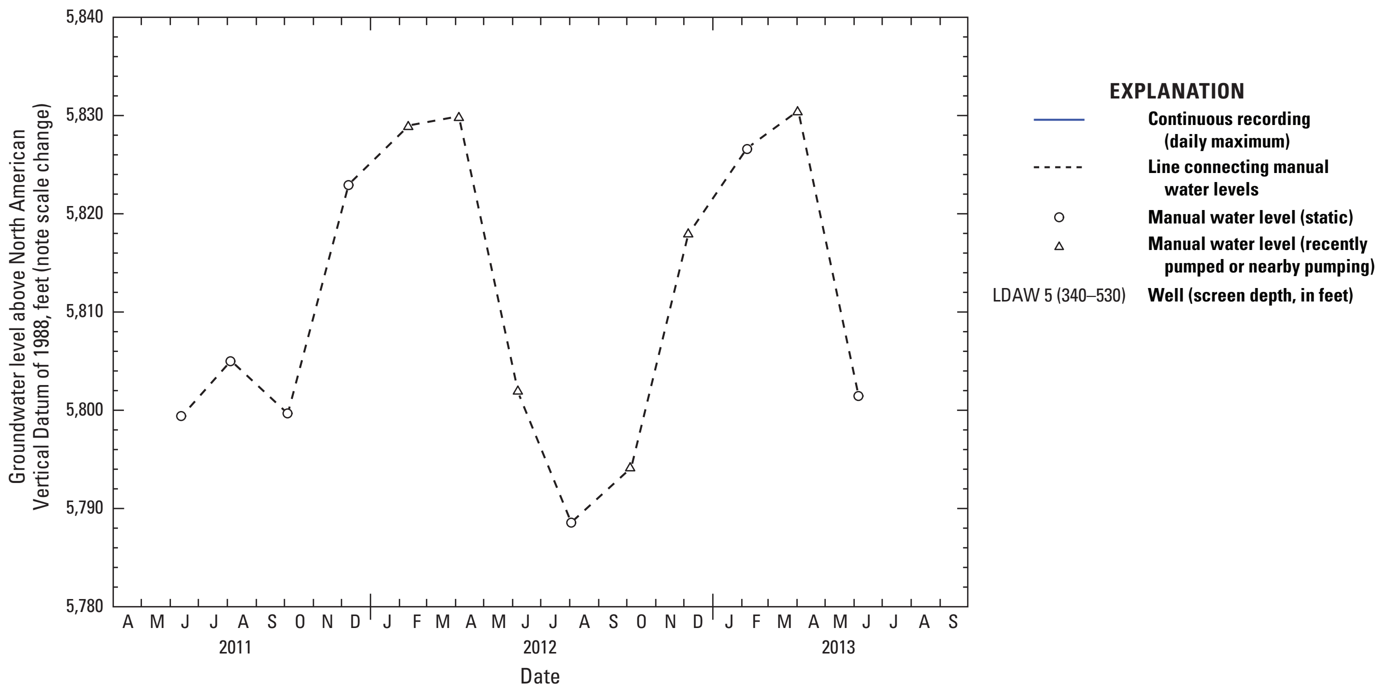

Figure 1–15. Water-level hydrograph from LDAW 5, from June 06, 2011, to June 05, 2013, Douglas County, Colorado.

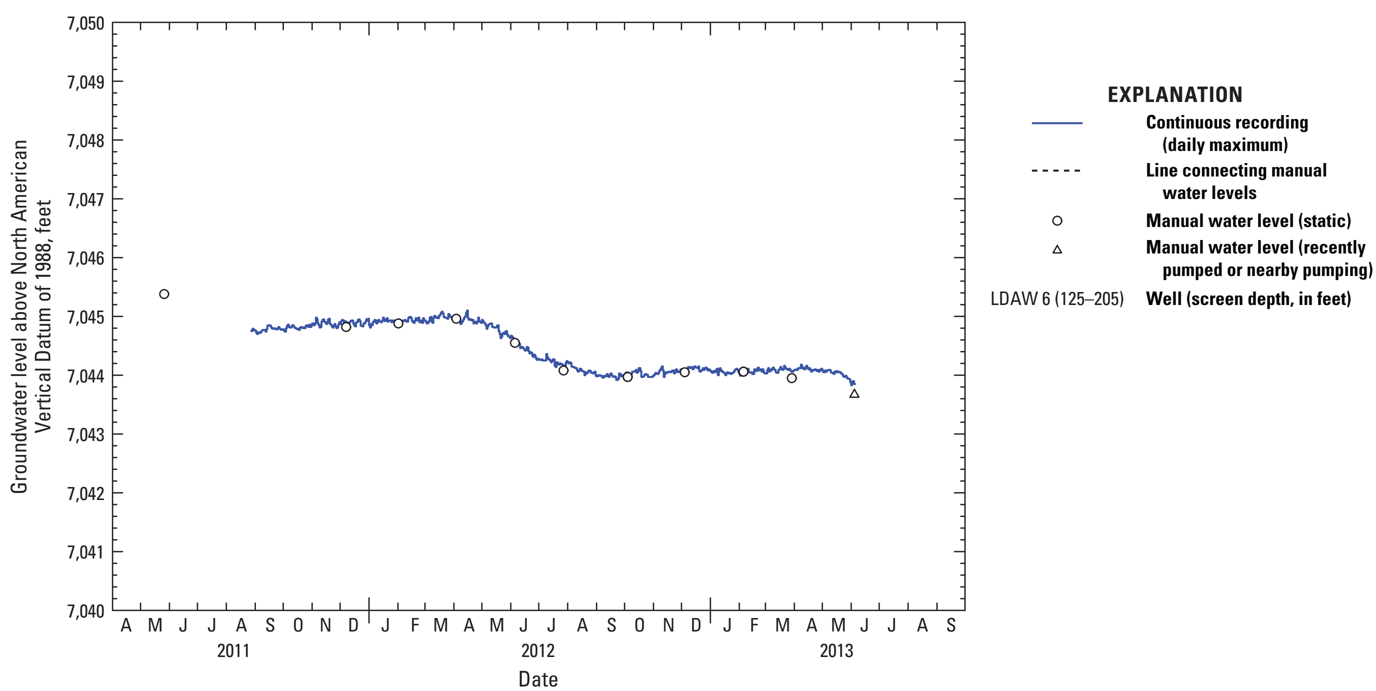

Figure 1–16. Water-level hydrograph from LDAW 6, from May 26, 2011, to June 04, 2013, Douglas County, Colorado.

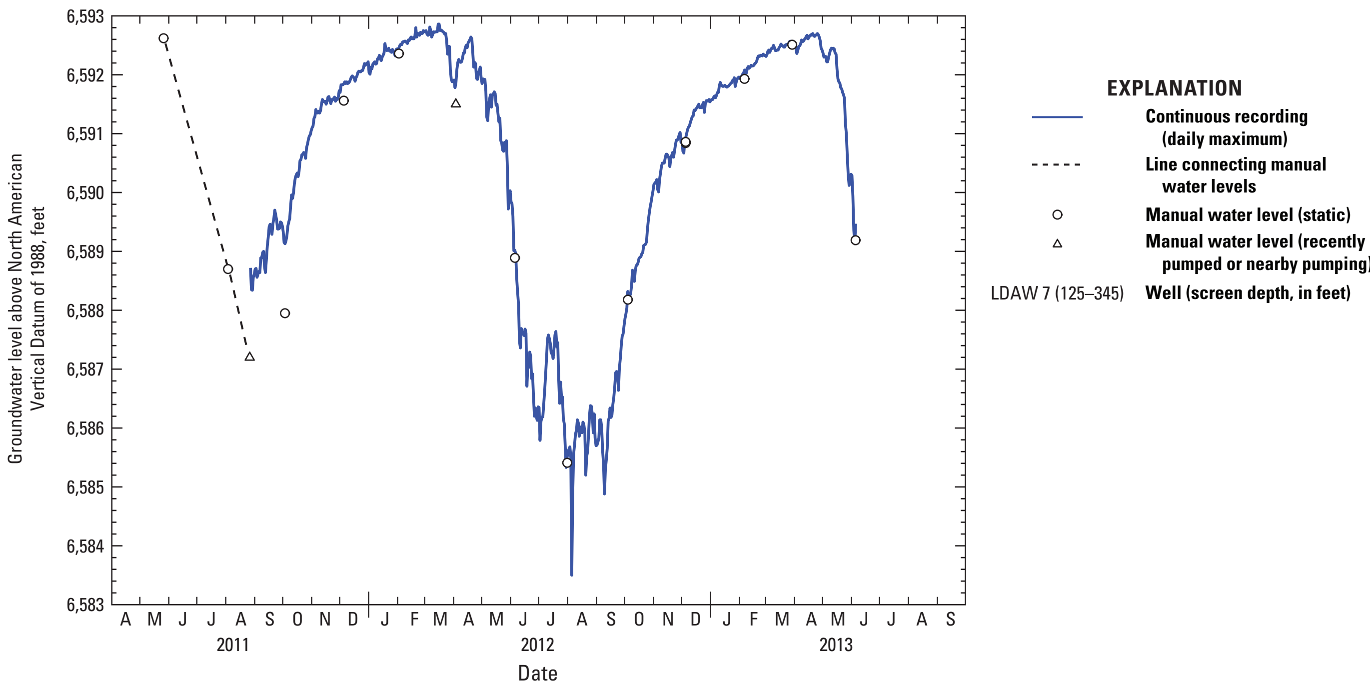

Figure 1–17. Water-level hydrograph from LDAW 7, from May 26, 2011, to June 05, 2013, Douglas County, Colorado.

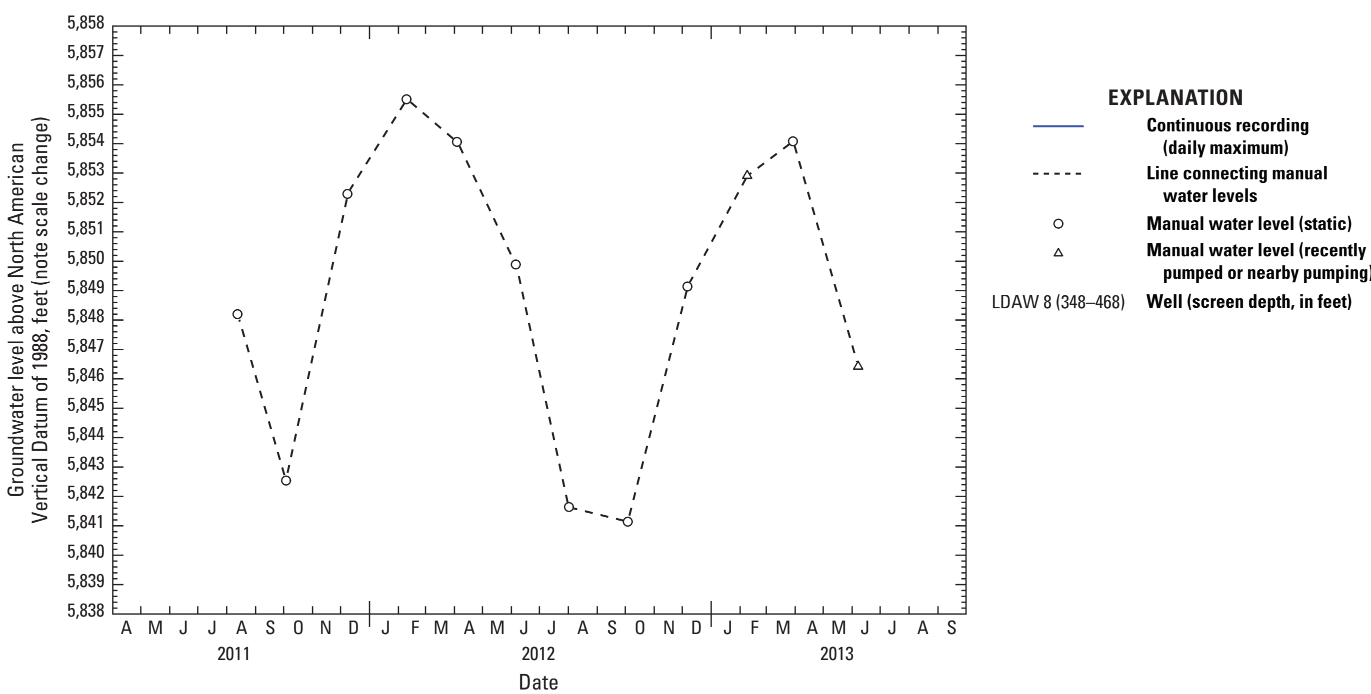

Figure 1–18. Water-level hydrograph from LDAW 8, from August 12, 2011, to June 07, 2013, Douglas County, Colorado.

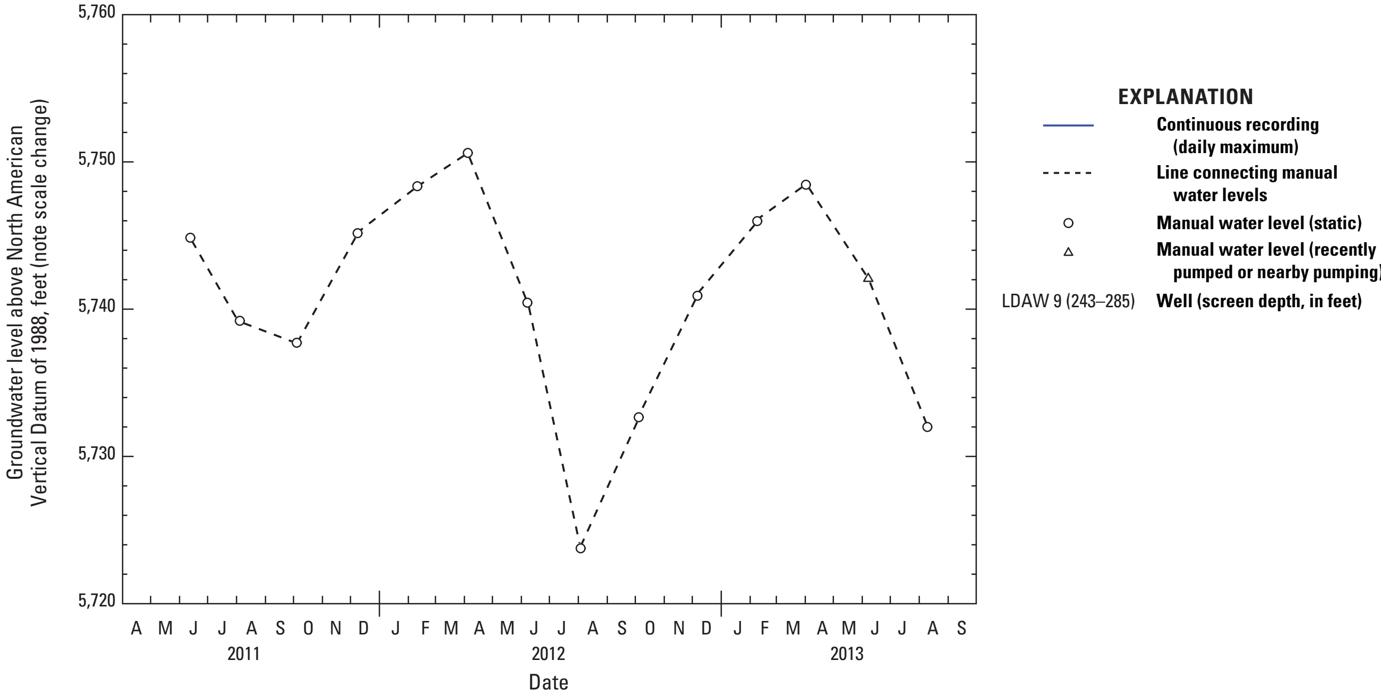

Figure 1–19. Water-level hydrograph from LDAW 9, from June 12, 2011, to June 07, 2013, Douglas County, Colorado.

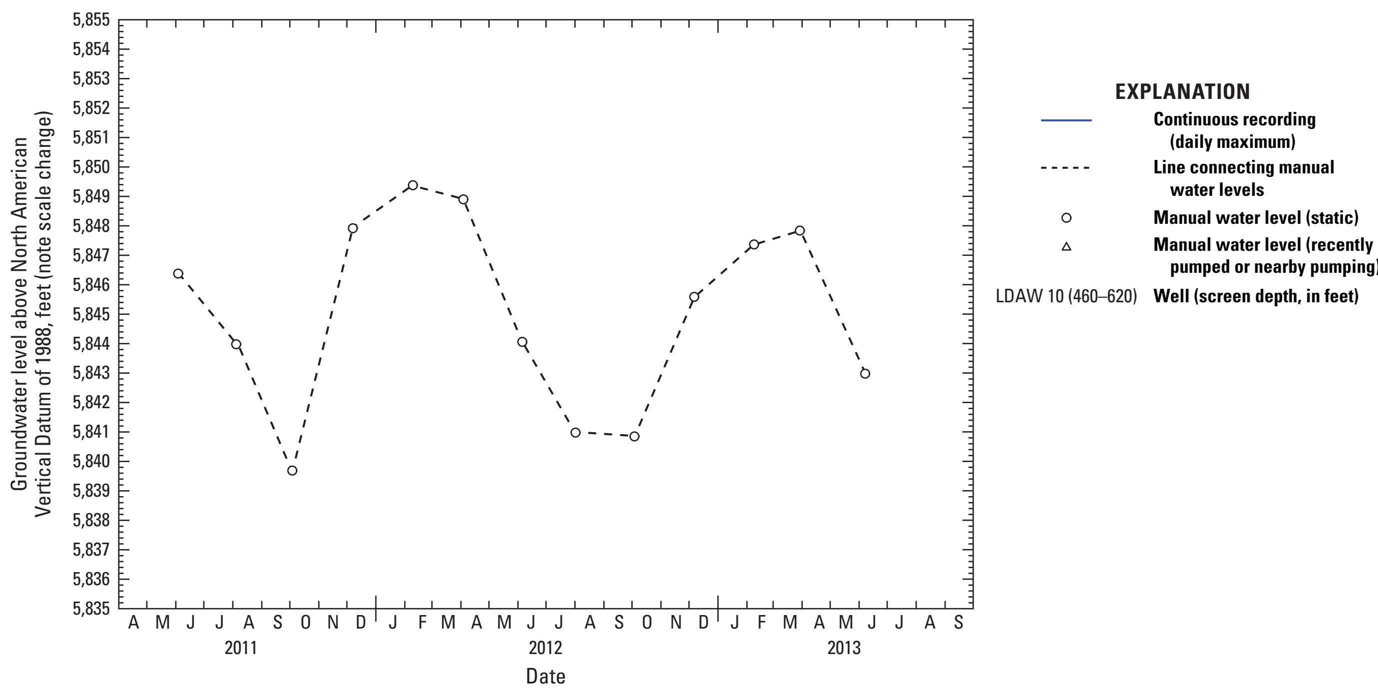

Figure 1–20. Water-level hydrograph from LDAW 10, from June 03, 2011, to June 07, 2013, Douglas County, Colorado.

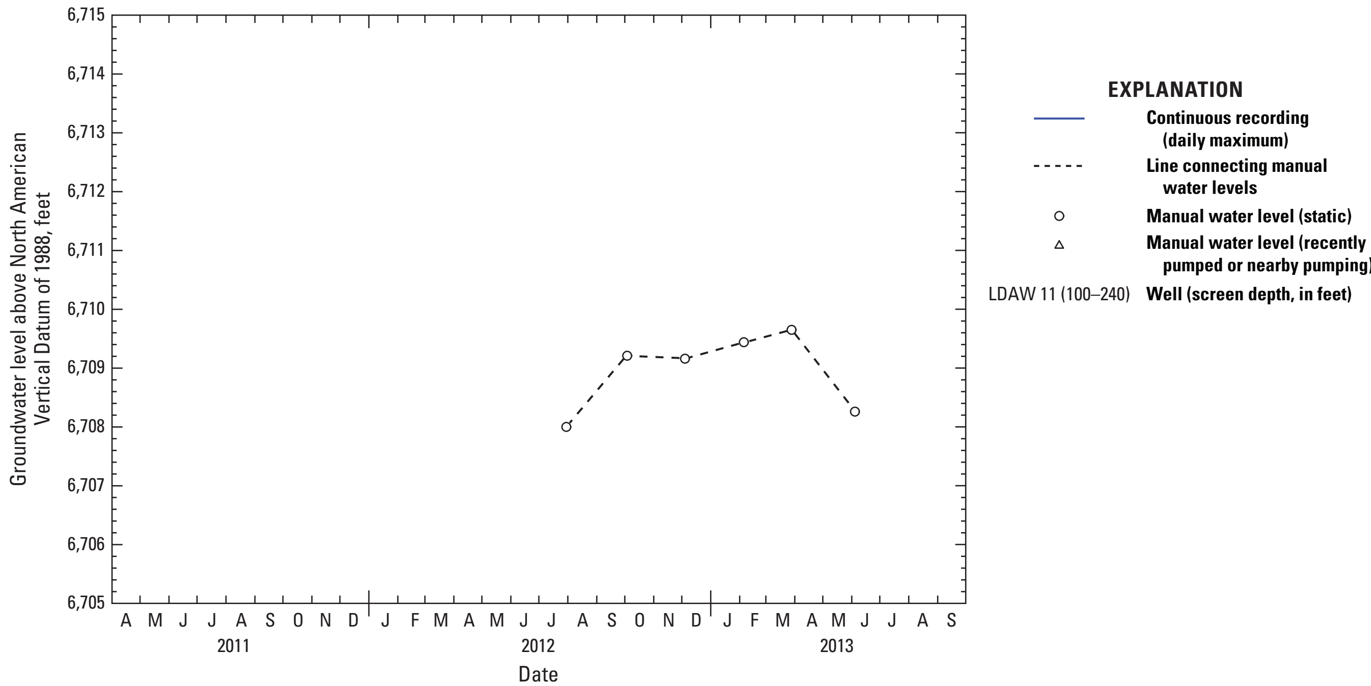

Figure 1–21. Water-level hydrograph from LDAW 11, from July 30, 2011, to June 04, 2013, Douglas County, Colorado.

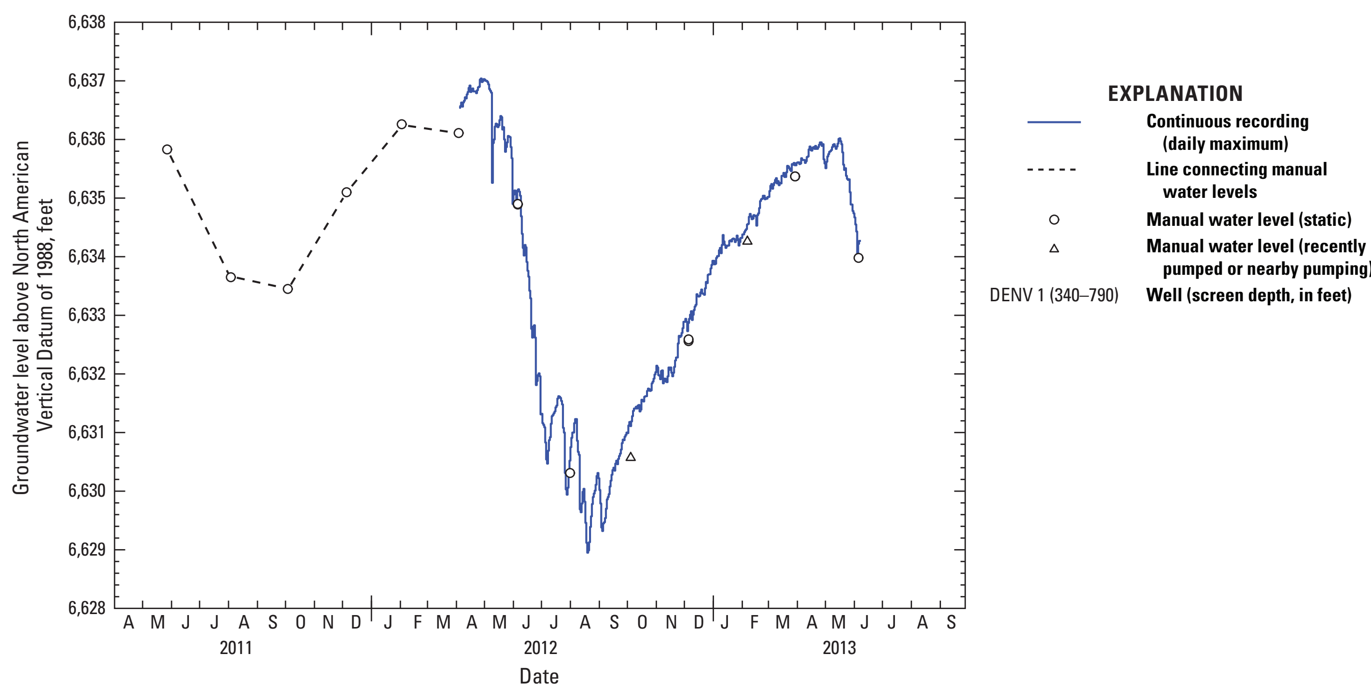

Figure 1–22. Water-level hydrograph from DENV 1, from May 27, 2011, to June 05, 2013, Douglas County, Colorado.

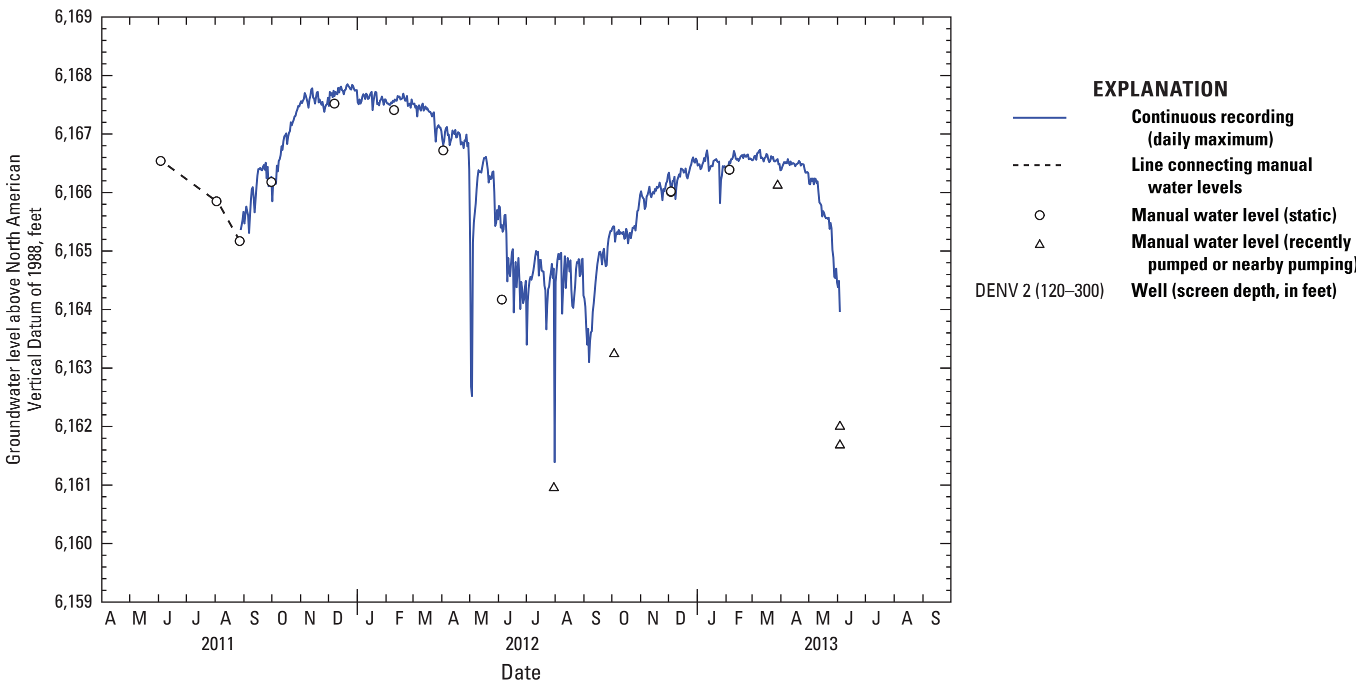

Figure 1–23. Water-level hydrograph from DENV 2, from June 03, 2011, to June 03, 2013, Douglas County, Colorado.

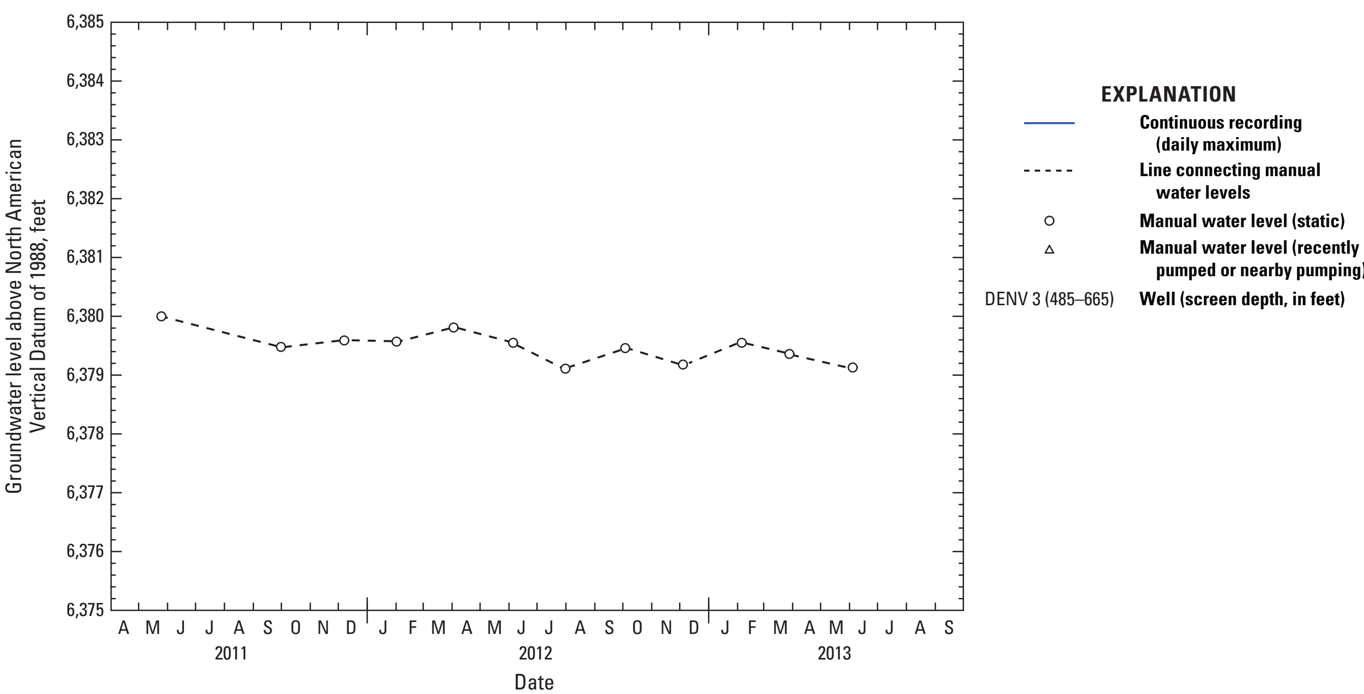

Figure 1–24. Water-level hydrograph from DENV 3, from May 25, 2011, to June 04, 2013, Douglas County, Colorado.

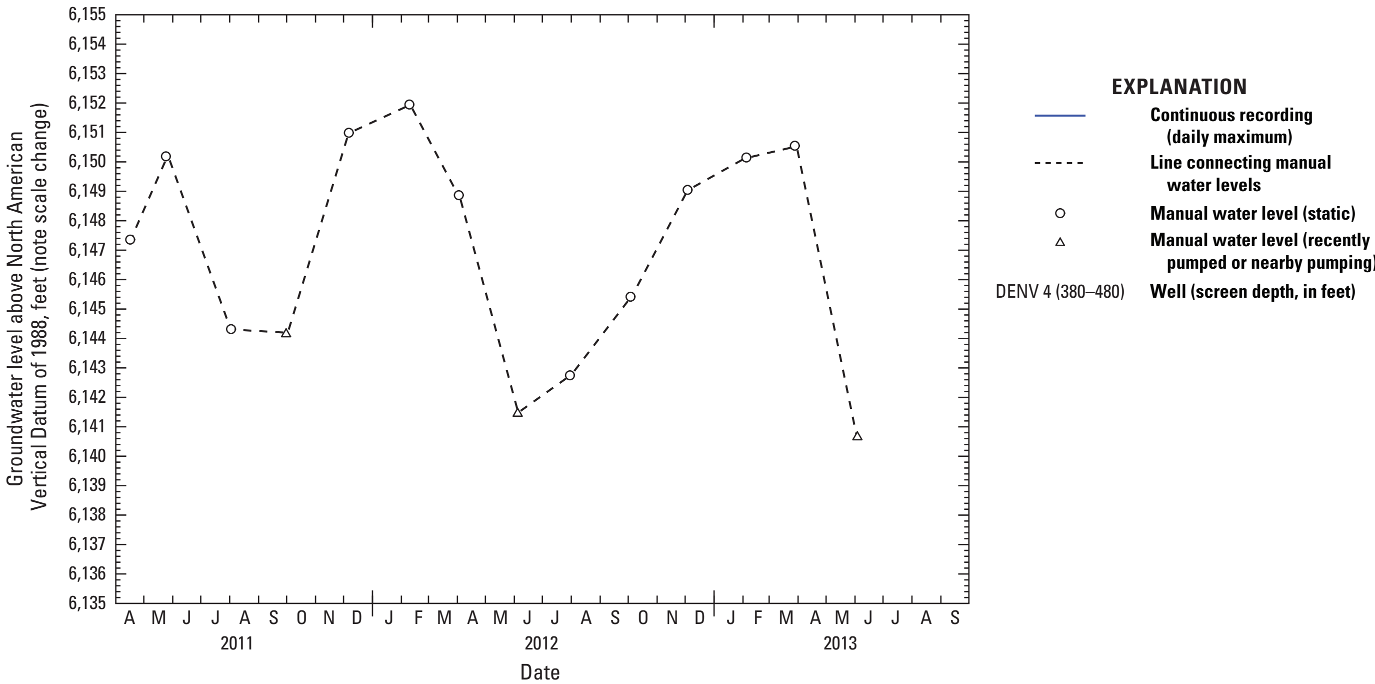

Figure 1–25. Water-level hydrograph from DENV 4, from April 16, 2011, to June 03, 2013, Douglas County, Colorado.

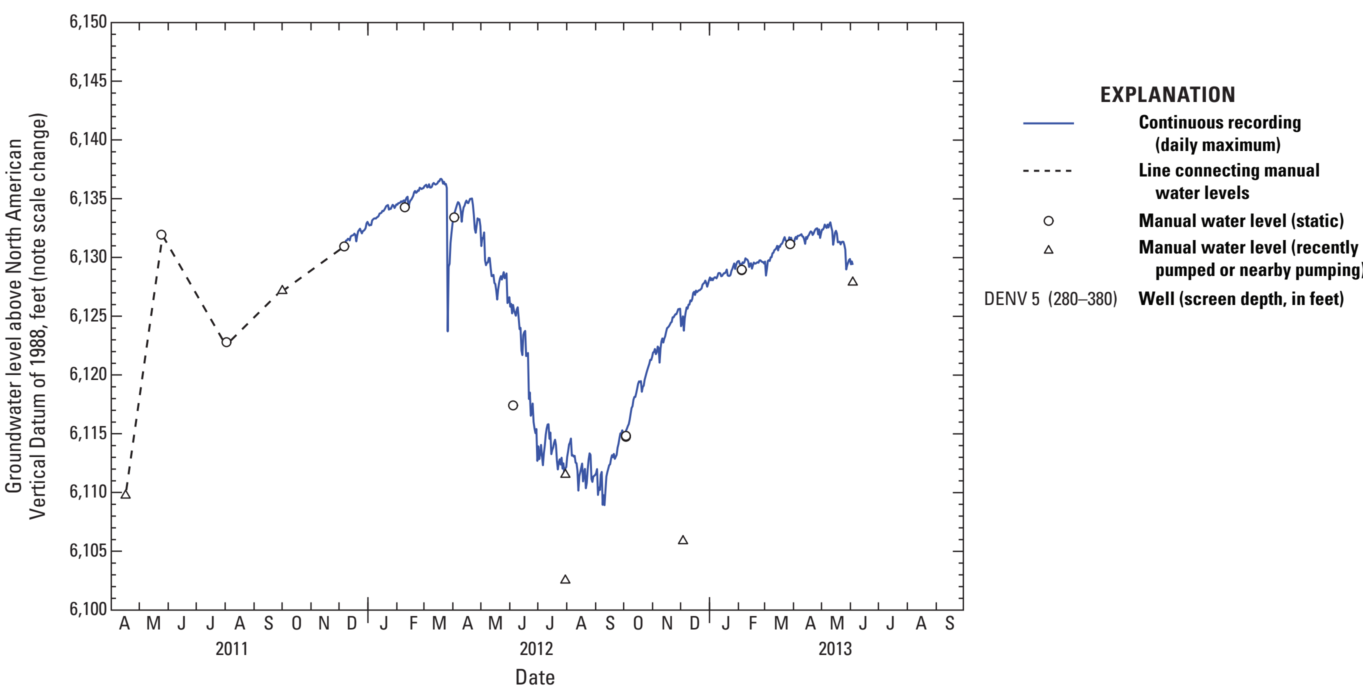

Figure 1–26. Water-level hydrograph from DENV 5, from April 16, 2011, to June 03, 2013, Douglas County, Colorado.

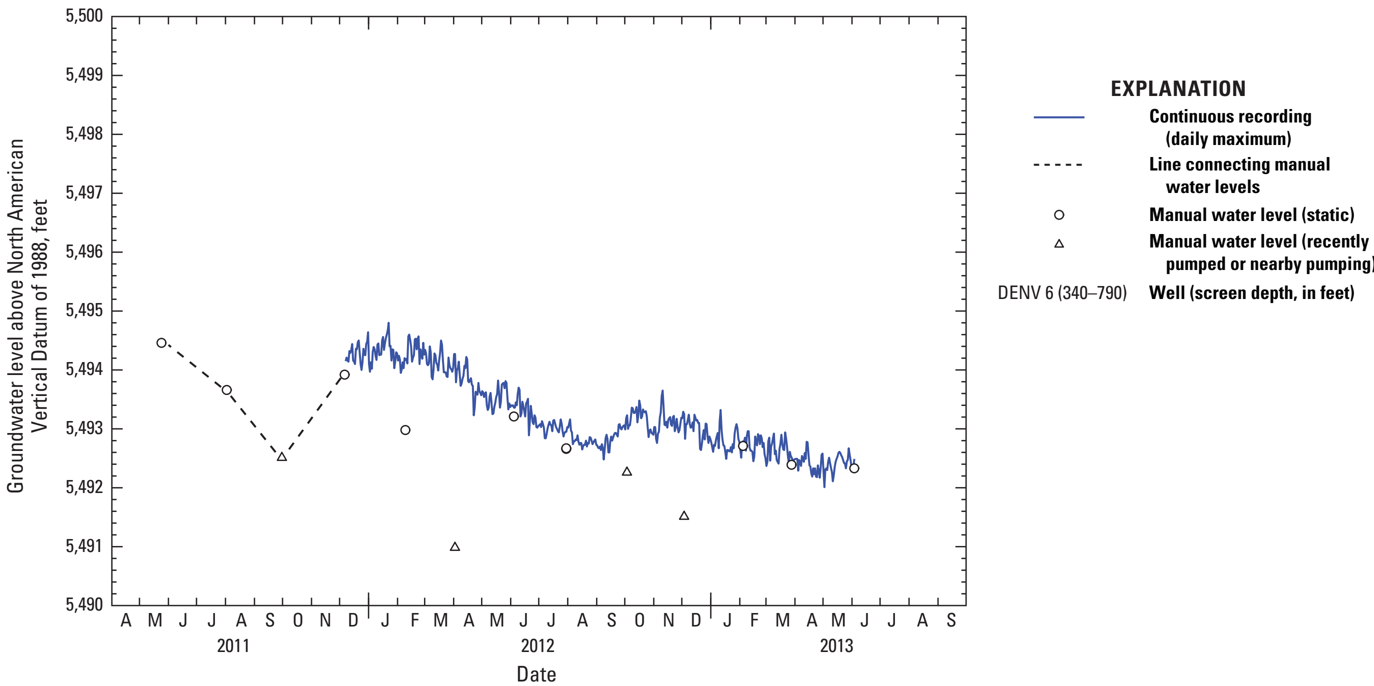

Figure 1–27. Water-level hydrograph from DENV 6, from May 24, 2011, to June 03, 2013, Douglas County, Colorado.

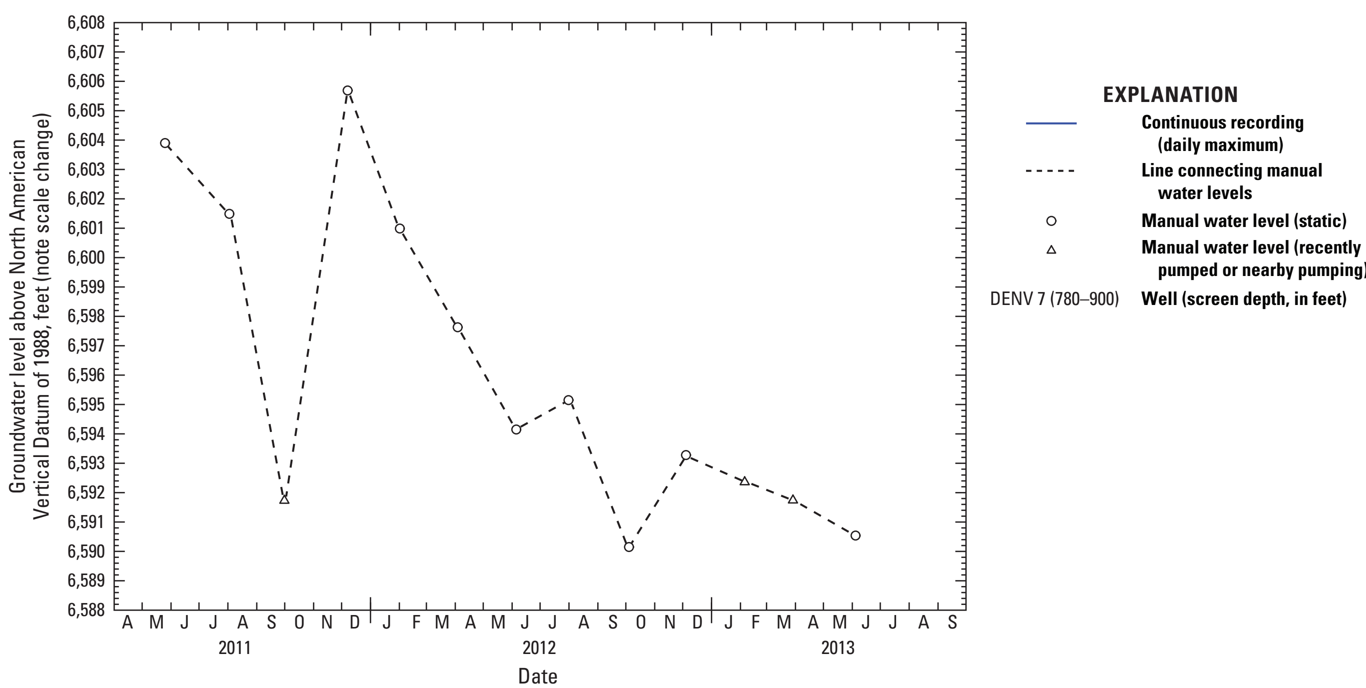

Figure 1–28. Water-level hydrograph from DENV 7, from May 25, 2011, to June 04, 2013, Douglas County, Colorado.

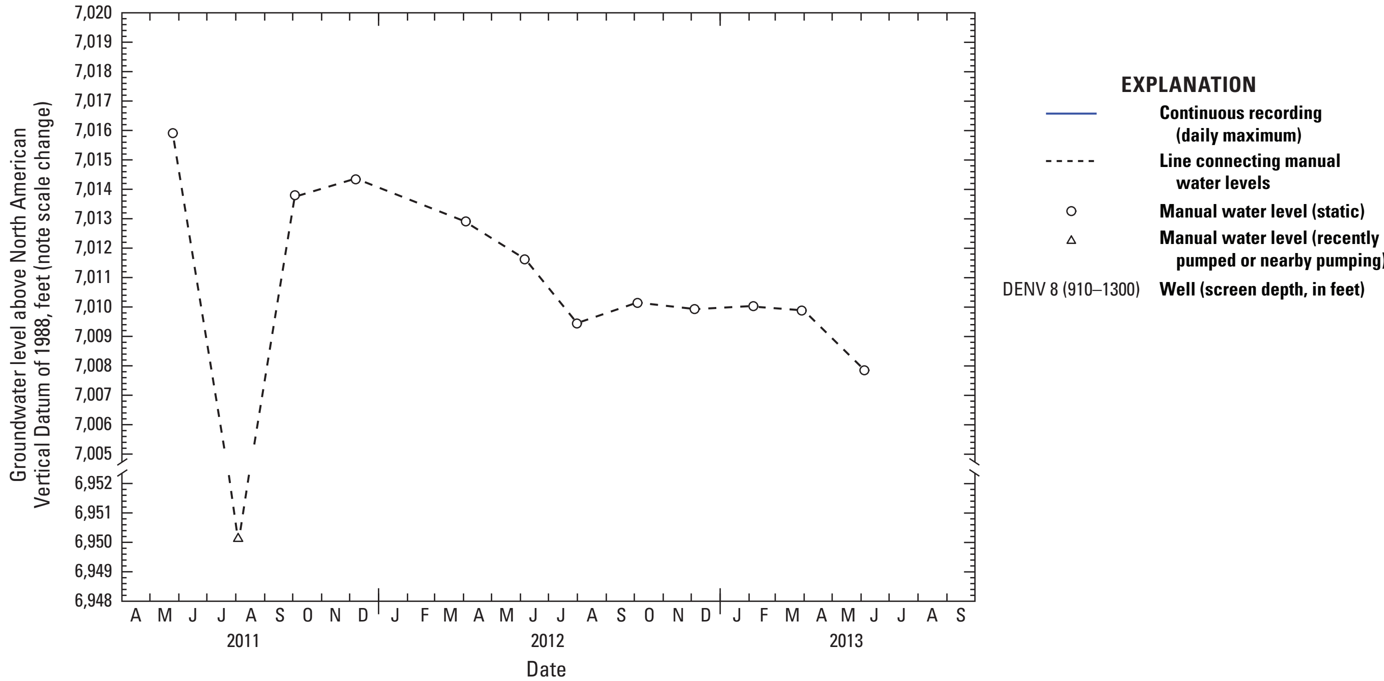

Figure 1–29. Water-level hydrograph from DENV 8, from May 25, 2011, to June 04, 2013, Douglas County, Colorado.

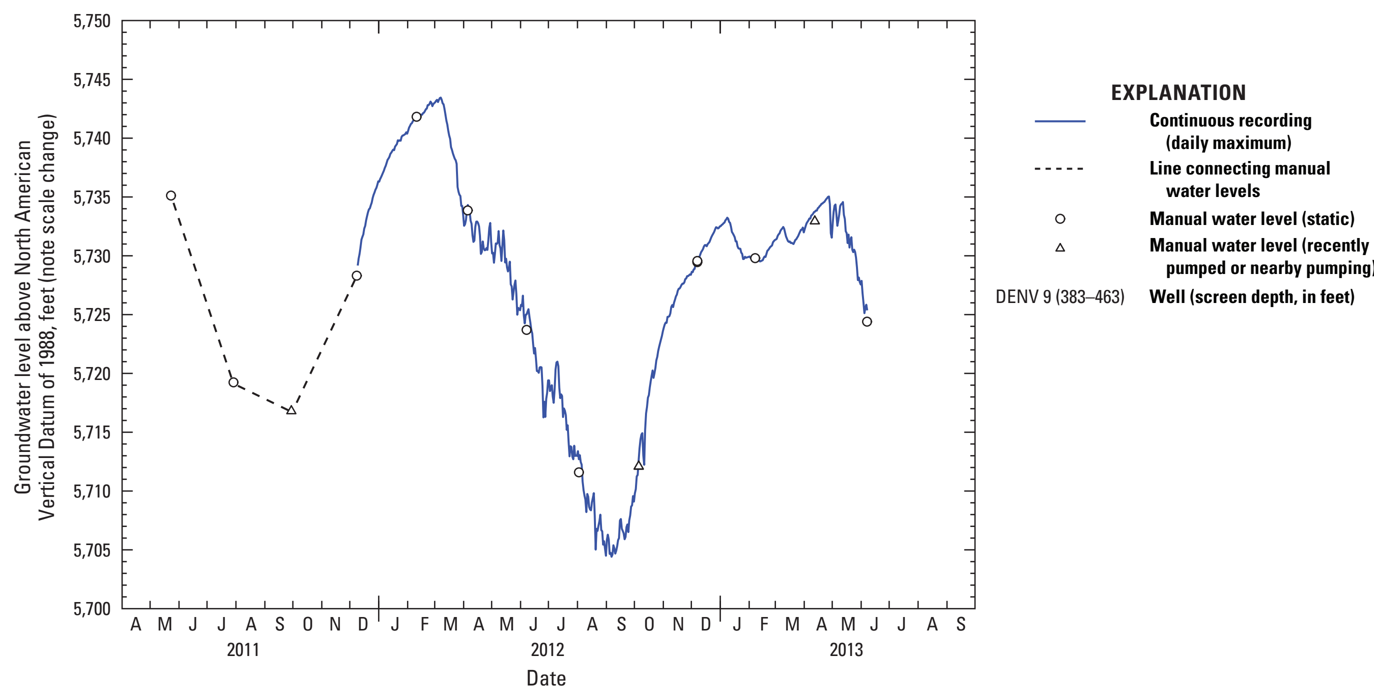

Figure 1–30. Water-level hydrograph from DENV 9, from March 18, 2011, to June 06, 2013, Douglas County, Colorado.

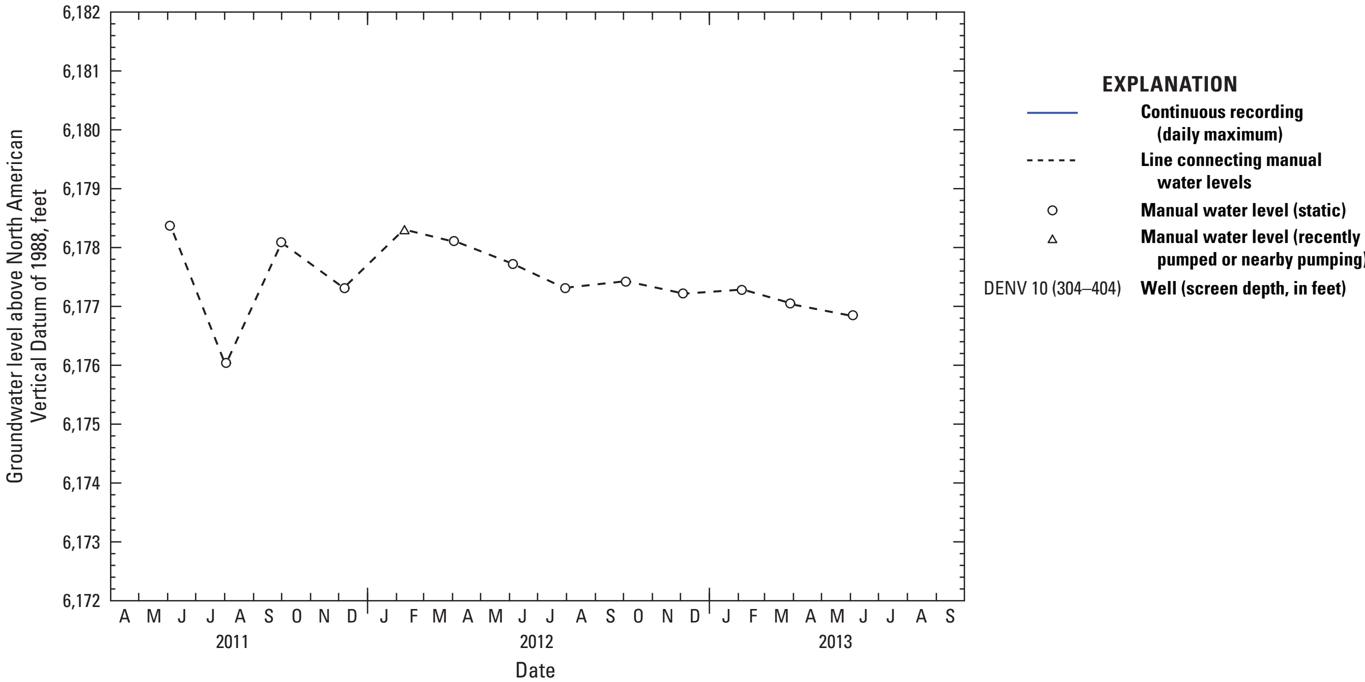

Figure 1–31. Water-level hydrograph from DENV 10, from June 03, 2011, to June 03, 2013, Douglas County, Colorado.

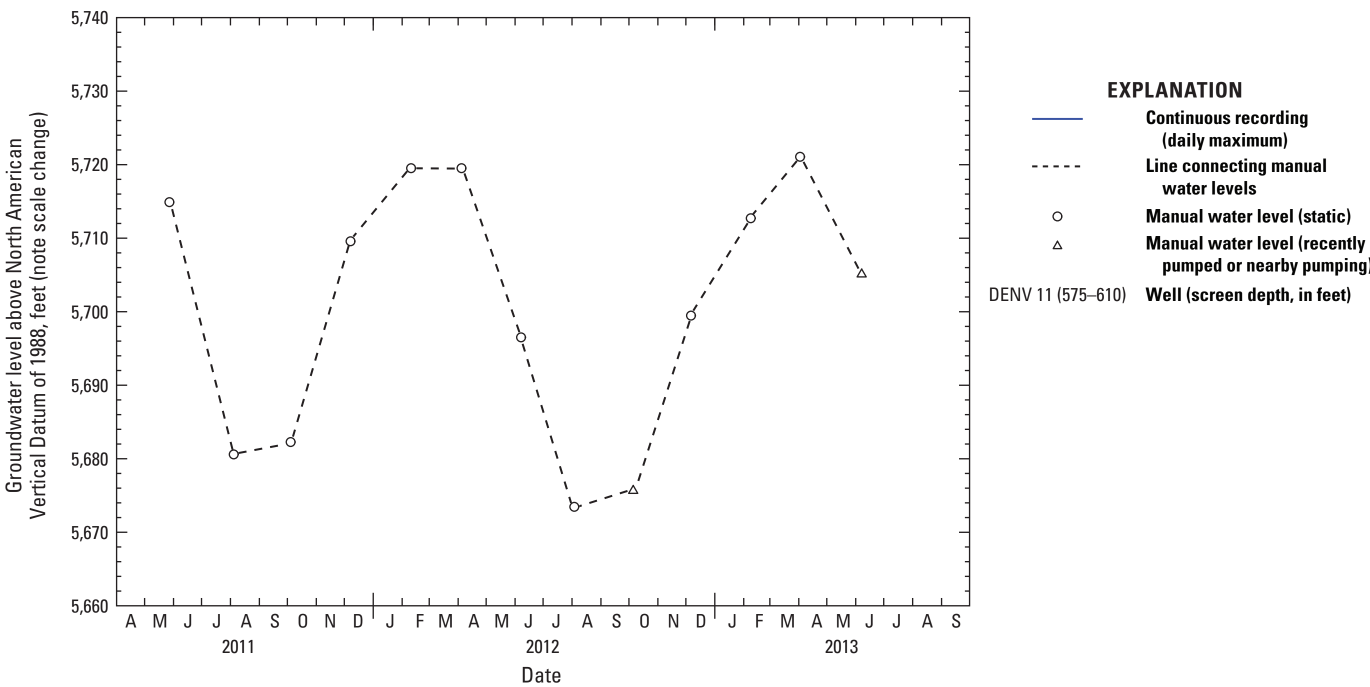

Figure 1–32. Water-level hydrograph from DENV 11, from May 27, 2011, to June 07, 2013, Douglas County, Colorado.

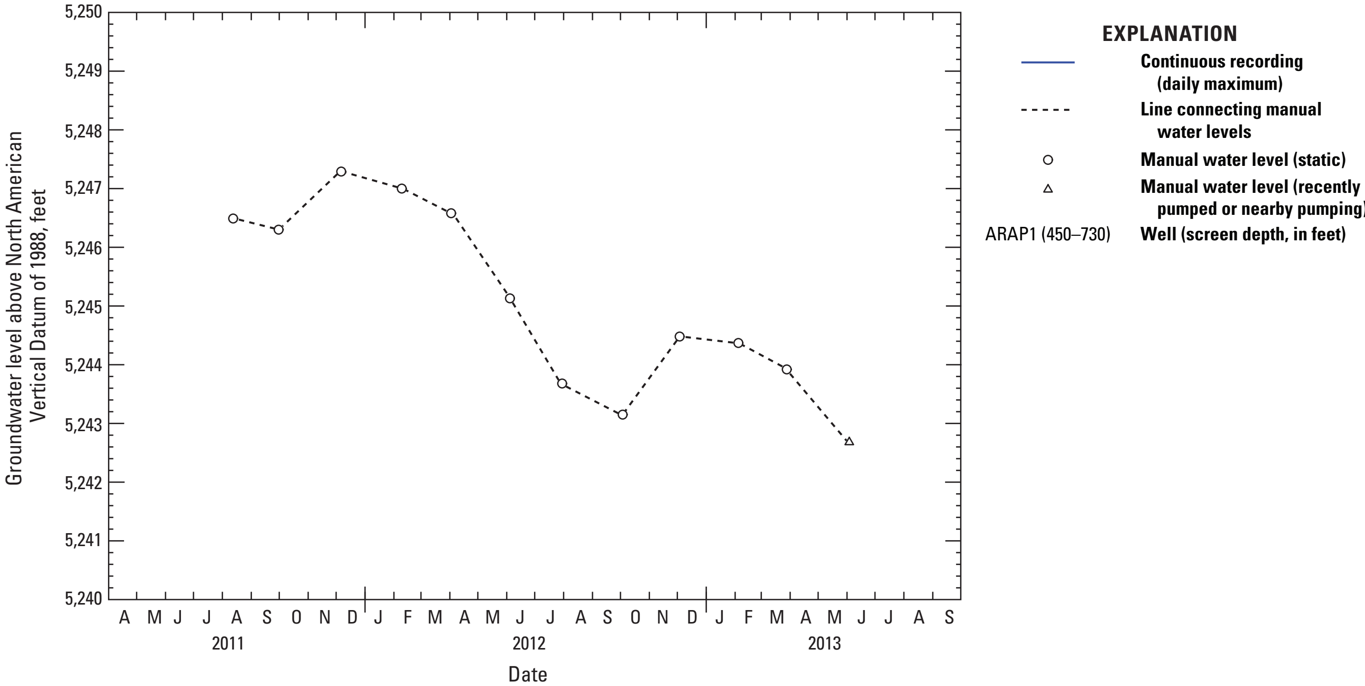

Figure 1–33. Water-level hydrograph from ARAP 1, from August 12, 2011, to June 03, 2013, Douglas County, Colorado.

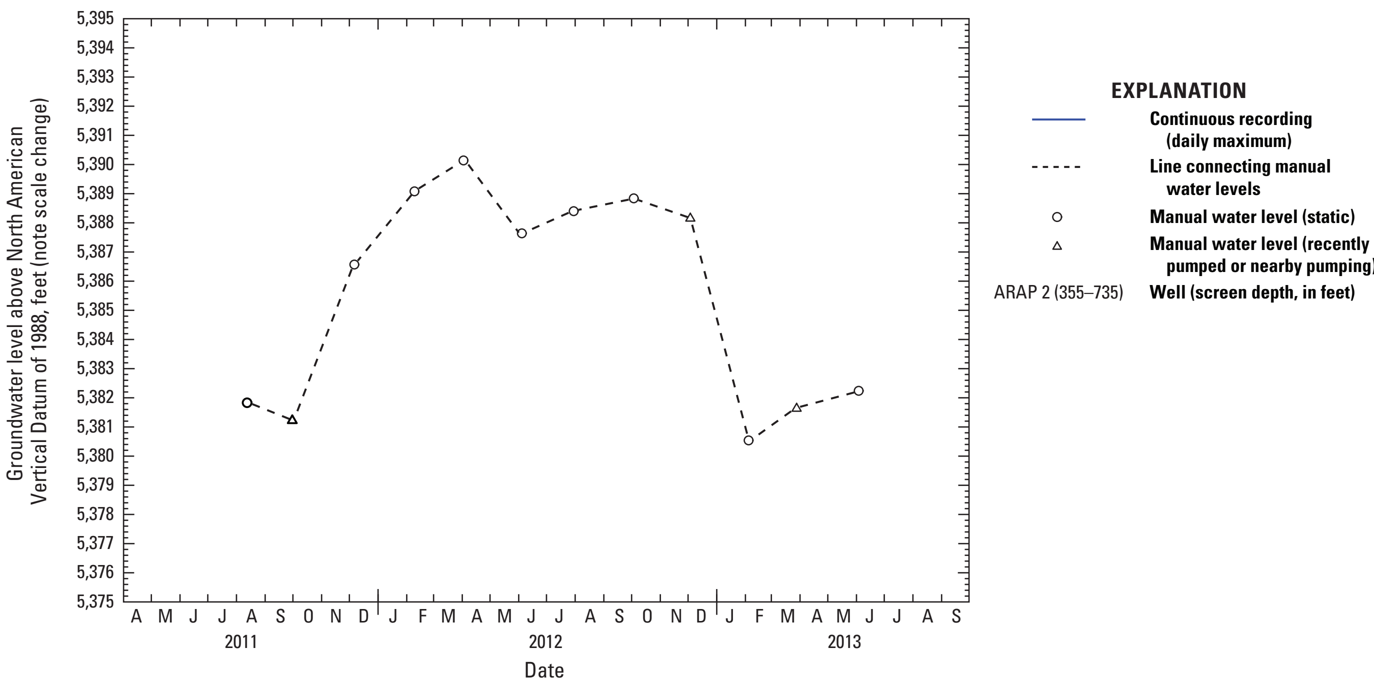

Figure 1–34. Water-level hydrograph from ARAP 2, from August 12, 2011, to June 03, 2013, Douglas County, Colorado.

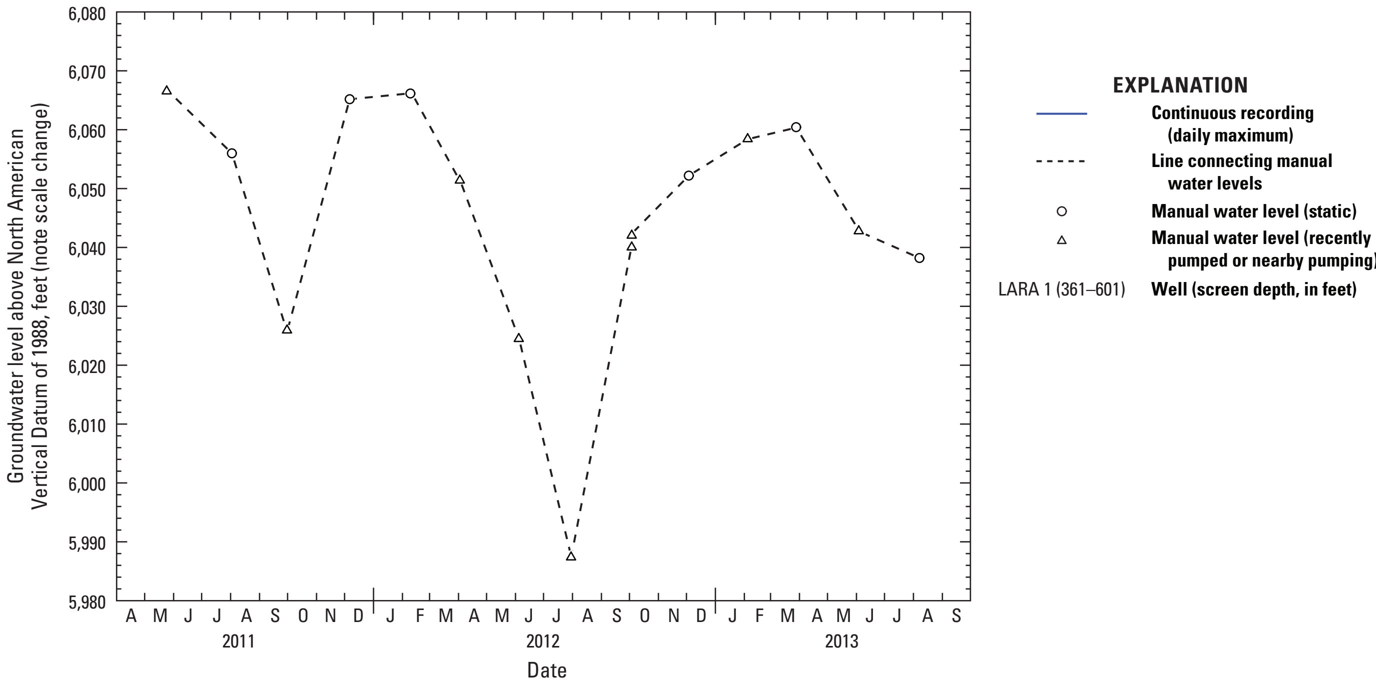

Figure 1–35. Water-level hydrograph from LARA 1, from May 24, 2011, to June 03, 2013, Douglas County, Colorado.

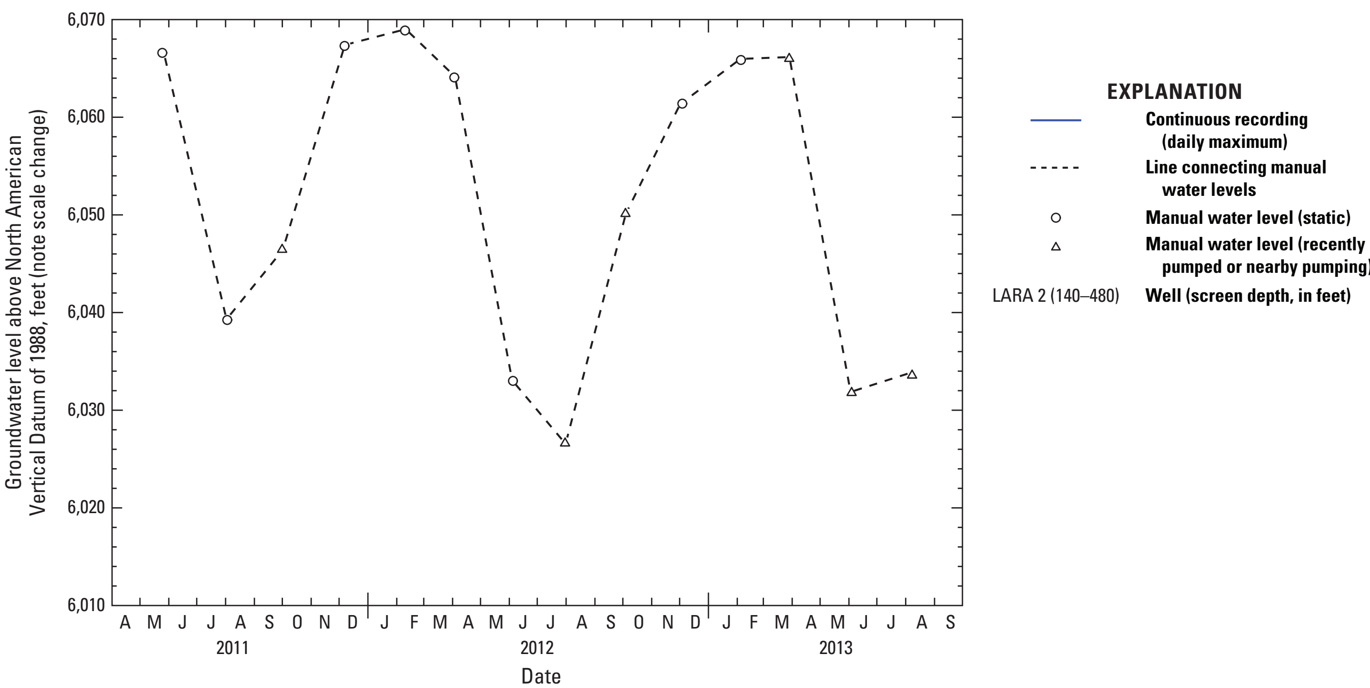

Figure 1–36. Water-level hydrograph from LARA 2, from May 24, 2011, to June 03, 2013, Douglas County, Colorado.

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