# HYDROGEOLOGY AND WATER MANAGEMENT OF THE CLEAR LAKE AQUIFER, WITH EMPHASIS ON THE SOUTH MEDICINE LAKE MANAGEMENT AREA

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*Cover:Sun setting over Medicine Lake. Photo by Kevin Chandler, MBMG.*

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# TABLE OF CONTENTS

## FIGURES

## TABLES

# PREFACE

The Ground Water Investigation Program (GWIP) at the Montana Bureau of Mines and Geology (MBMG) investigates areas prioritized by the Ground-Water Assessment Steering Committee (2-15-1523 MCA) based on current and anticipated growth of industry, housing, commercial activity, or agriculture. Additional program information and project ranking details are available at http://www.mbmg.mtech.edu/WaterEnvironment/GWIP/main.asp. GWIP also collects and compiles groundwater and surface-water data for each study area. These data are used to interpret how groundwater has responded to past stresses and to project future responses.

The final products of the Clear Lake aquifer study include:

> An **Interpretive Report** (this report) that presents data interpretations and summarizes the project results. This report's main focus is potential effects to surface water and groundwater from increased use of the Clear Lake aquifer, and whether water development or other land uses have impacted water quality in the Clear Lake aquifer.
>
> A **Groundwater Modeling Report** (Chandler and Reiten, 2019) documents development of groundwater flow models, including a detailed description of the procedures, assumptions, and results of the models. Groundwater modelers and other qualified individuals can evaluate and use the models as a starting point to test additional water-use scenarios and for site-specific analyses. The MBMG website includes the model files (http://www.mbmg.mtech.edu/gwip/gwip.html).
>
> MBMG's Groundwater Information Center (GWIC) online database (http://mbmggwic.mtech.edu/) provides a permanent archive for the data from this study.

# ABSTRACT


The Clear Lake aquifer of northeast Montana is contained in a buried valley underlying broad topographic swales associated with the ancestral Missouri River and glacial meltwater. The aquifer consists of the alluvial gravel of the ancestral Missouri and overlying glacial outwash gravel. These deposits form distinctive zones in the aquifer with varying connectivity.

Local precipitation and snowmelt recharges the aquifer, which replenishes lakes and wetlands. Evapotranspiration removes from 3 to 5 ft of water annually from the lakes and wetlands, creating gradients in the groundwater flow system.

This project focused on the South Medicine Lake management area, where the alluvial gravel of the Clear Lake aquifer is not continuous with the lower alluvial zone of the aquifer east of Medicine Lake. A groundwater divide underlying an area of sand hills southeast of Medicine Lake separates the flow system. Precipitation falling on the sand hills recharges the aquifer. As a result, good-quality irrigation water in the alluvial aquifer is restricted to an area within about 5 to 6 mi of the sand hills. Water level, water quality, and aquifer test results all indicate a hydraulic barrier to groundwater flow between this segment of the Clear Lake aquifer and the surface water of Medicine Lake.

Extensive monitoring and pumping volume estimates from irrigation wells provided the background for conceptual and numeric model development. Steady-state and transient finite difference numerical models simulate conditions in the aquifer. The transient model was calibrated to water-level fluctuations resulting from pumping at four existing irrigation wells in 2015. Predictive simulations evaluate changes in the flow system from increased pumping, including simulations doubling the number of wells and increasing pumping withdrawals by a factor of five. A simulation with twice the number of irrigation wells and pumping rates similar to 2015 indicated no change in water levels near Big Muddy Creek. The simulation with eight wells pumping nearly continuously indicated groundwater-level declines near Big Muddy Creek. Predictive model simulations can be used to assess additional pumping from proposed wells as new permits are requested.

Water quality in the upper outwash gravel zone is generally acceptable for irrigation, while much of the alluvial gravel zone is not. High concentrations of sodium and elevated dissolved minerals in the Fort Union aquifer locally degrade water quality in the Clear Lake aquifer, predominately in the lower alluvial zone.

# INTRODUCTION

## Background

The Clear Lake aquifer is an important water resource in northeastern Montana. The aquifer contains (1) sand and gravel (Wiota Gravel) deposited as alluvium by the ancestral Missouri River and (2) glacial outwash sand and gravel deposited by meltwater streams. The aquifer, in eastern Sheridan and Roosevelt Counties, Montana, extends from Westby along the state line southwest to Big Muddy Creek (fig. 1). These deposits form a complex aquifer system, with some areas capable of supporting high-yield irrigation wells. Groundwater flow is to the southwest from the North Dakota border to the Big Muddy Creek Valley. In some locations, the aquifer units are hydraulically connected, but elsewhere, confining beds separate them. Precipitation recharges the aquifer, but estimates of the amount and distribution of recharge vary widely. The aquifer discharges to wells, lakes, wetlands, and the alluvium and outwash underlying the Big Muddy Creek Valley. The volume of water that discharges from the aquifer is not well defined. For example, groundwater reaches surface sloughs and lakes where it evaporates, and phreatophytes, plants with roots tapping the water table, consume groundwater through transpiration.

Area lakes and wetlands are important habitat for migratory birds and other wildlife. The U.S. Fish and Wildlife Service (USFWS) manages many of these lakes and wetlands as part of the Medicine Lake Wildlife Refuge (fig. 2). The USFWS is concerned that irrigation withdrawals will deplete water from the wetlands, thereby adversely affecting the habitat (S. Lofgren, oral commun., 2017). The USFWS is also concerned with impacts of hydrocarbon development to groundwater and surface water in these areas.

The Sheridan County Conservation District (SCCD) has a reserved groundwater right for irrigation from the Clear Lake aquifer under the Sheridan County Water Reservation (SCWR). The Montana Bureau of Mines and Geology (MBMG) has monitored and evaluated the effects of irrigation development in the Clear Lake aquifer since the 1980s, providing hydrogeologic data that support aquifer management. Currently, the combined irrigation authorizations from the pre-reservation State permits and the SCWR permits total about 13,737 acre-ft of water per year. Developing additional irrigation wells and appropriating more groundwater could potentially affect existing water-rights holders and could affect water levels in area wetlands.

## Purpose and Scope

The project purpose is to provide data, analyses, and interpretations to support management of the Clear Lake aquifer. To meet this purpose, the MBMG addressed two objectives:

1. Determine how much groundwater withdrawal from the Clear Lake aquifer is possible without detrimental effects to surface water or excessive water-level declines in wells.

2. Determine if groundwater or energy development have affected water quality in the Clear Lake aquifer.

Major tasks to accomplish these objectives include:

i. *Evaluate data from previous geologic and hydrogeologic reports along with other data.*

Data collection by the MBMG and SCCD since the 1980s have included exploratory test drilling, monitoring well construction, aquifer testing, water-level monitoring, and water-quality sampling. These data combined with data collected during this project (2013–2015) provided information to construct a conceptual hydrogeologic model of the Clear Lake aquifer and support calibration of the South Medicine Lake numerical model.

ii. *Develop a conceptual model for the South Medicine Lake focus area.*

This project focused on the South Medicine Lake area because of concerns that irrigation withdrawals were affecting water levels in Medicine Lake, decreasing flows in Big Muddy Creek, and creating detrimental well interference. The conceptual model includes information on the geologic framework and groundwater flow system for the Clear Lake aquifer. The conceptual model provided the basis for construction of the numerical groundwater flow model.

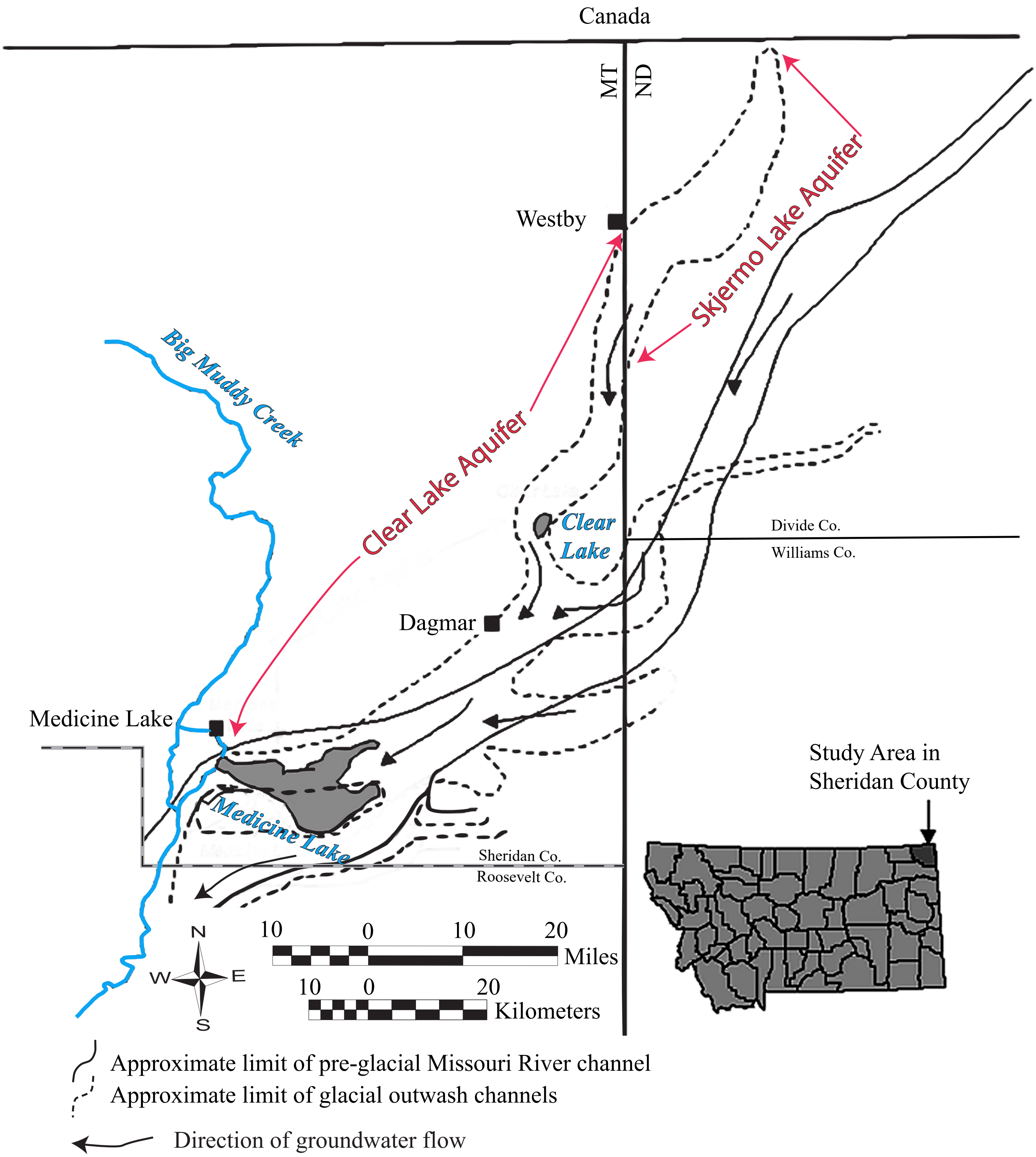


Figure 1. Sand and gravel deposits in buried valleys of the ancestral Missouri River and glacial outwash channels form the Clear Lake aquifer in Montana. The outwash part of the aquifer is called the Skjermo Lake aquifer in North Dakota (modified from Donovan, 1988).

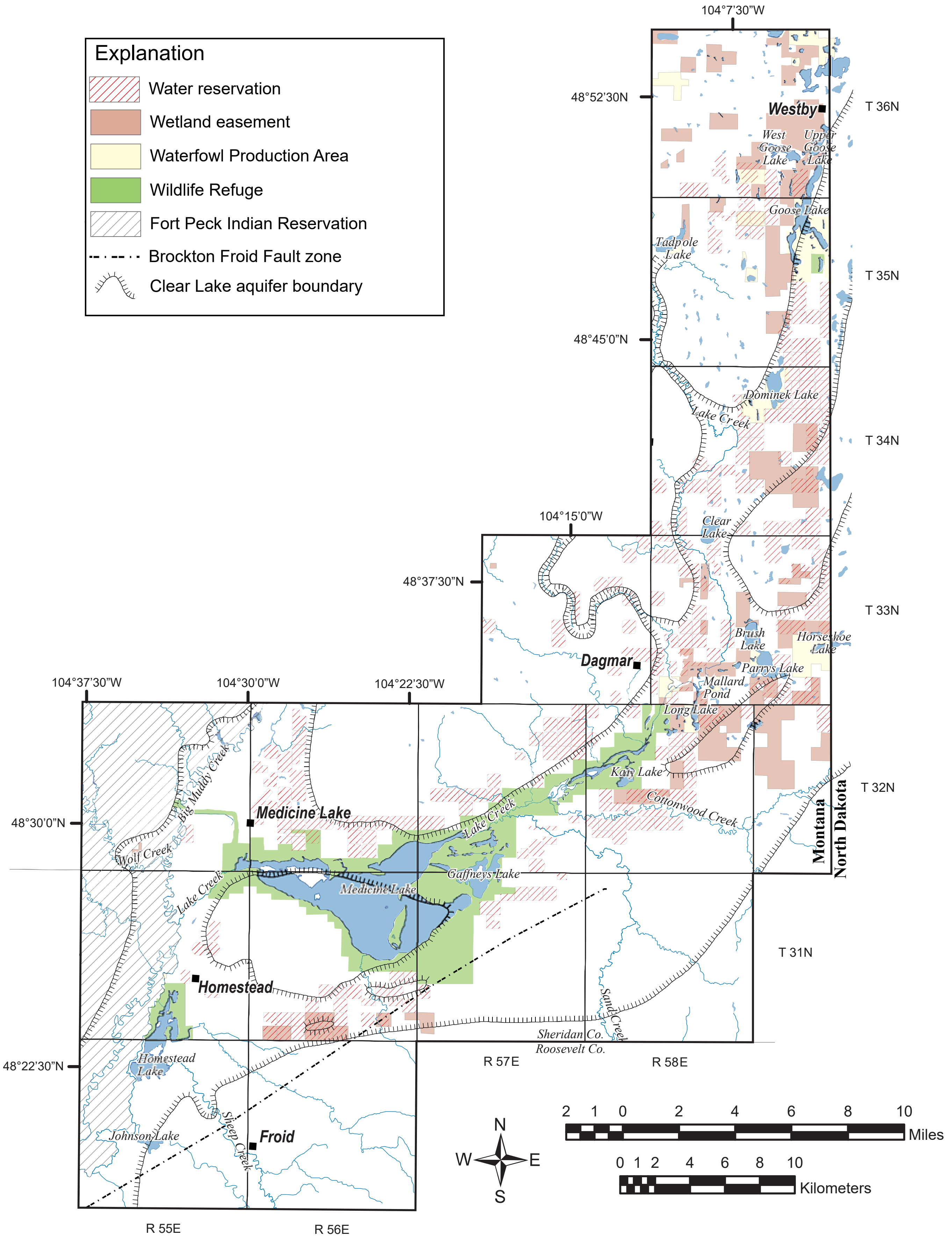


Figure 2. The Clear Lake aquifer is located in northeastern Montana. This map displays the aquifer extent, SCCD water reservation, and USFWS properties.

*iii. Develop a numerical groundwater flow model of the South Medicine Lake focus area.*

The numerical model provides a tool to guide water-management decisions by simulating increased water use from potential new wells. Detailed information on model construction, calibration, and water-use scenario results are presented in the companion report by Chandler and Reiten (2019).

*iv. Model water-use scenarios in the South Medicine Lake focus area.*

The five water-use scenarios simulated with the groundwater flow model included pumping at 2015 volume, no pumping, and three increased pumping scenarios.

*v. Evaluate variability of water quality with respect to irrigation development and potential impacts of releases associated with hydrocarbon extraction.*

Not all of the groundwater in the Clear Lake aquifer is suitable for irrigation. In some areas naturally elevated sodium produces high salinity hazards for irrigation, and clay soils exacerbate these problems, reducing crop production. Historic releases of chloride brines coproduced with hydrocarbons plus hydrocarbon compounds have been detected in samples from lakes, wetlands, streams, and groundwater associated with the Clear Lake aquifer. Identifying contaminated areas and those with elevated salinity will help guide future development.

## Project Location

The Clear Lake aquifer study area encompasses 586 $mi^2$ in northeastern Montana (fig. 2). The numerical model area comprises 73 $mi^2$, mostly in the South Medicine Lake management area (fig. 3).

## Resource Management

A Technical Advisory Committee (TAC) made up of representatives from the SCCD, MBMG, Department of Natural Resources and Conservation (DNRC), USFWS, Fort Peck Tribes, Natural Resource Conservation Service (NRCS), and Sheridan County Planning Board was established to review requests for new appropriations and their potential effect on water resources. The SCCD through the TAC manages irrigation development to reduce or eliminate potential detrimental effects resulting from new groundwater use. Detrimental effects include well interference, which may reduce the performance of nearby irrigation wells or make them unusable. Such impacts have not been observed as of 2016.

In the management process, SCCD has conducted or contracted test drilling, water-level monitoring, water-use monitoring, water-quality analyses, data compilation, mapping, and hydrogeologic interpretation required to assess irrigation development from the Clear Lake aquifer. The scrutiny applied to permitting irrigation wells is much greater now than prior to establishment of the SCWR.

The development of the South Medicine Lake groundwater model (Chandler and Reiten, 2019) through this project added another management tool. The model is useful to simulate hydrologic conditions associated with additional irrigation development in the South Medicine Lake focus area. The TAC, assisted by hydrogeologists, will be able to simulate new groundwater withdrawals using the model, and evaluate potential impacts. The USFWS may use project results to evaluate their water rights and to assess how releases from hydrocarbon extraction may affect water quality of wetlands and lakes. The Fort Peck Tribes may use information from this report and model to assess effects from irrigation to flows in Big Muddy Creek.

### *Sheridan County Water Reservation*

Irrigation development of the Clear Lake aquifer started in the mid-1970s under pre-SCWR Montana water permits. Groundwater levels declined during the 1980s, evoking concern among resource managers that the new groundwater withdrawals caused these declines. The 1980s also coincided with a period of drought. To address these concerns, negotiations among the SCCD, USFWS, and DNRC resulted in the creation of the SCWR in 1995. Administered by the SCCD, the SCWR reserved 15,479 acre-ft of water for irrigation purposes, with initial development limited to 5,809 acre-ft. In addition to managing water developed under the SCWR, the SCCD monitors and evaluates water use at wells supplying 26 pre-reservation water permits. By 2002 the pending applications and developed water authorizations had approached the 5,809 acre-ft cap of the SCWR. At a 10-yr review in 2004, the SCCD requested (and DNRC raised) the water development cap to 10,000 acre-ft.

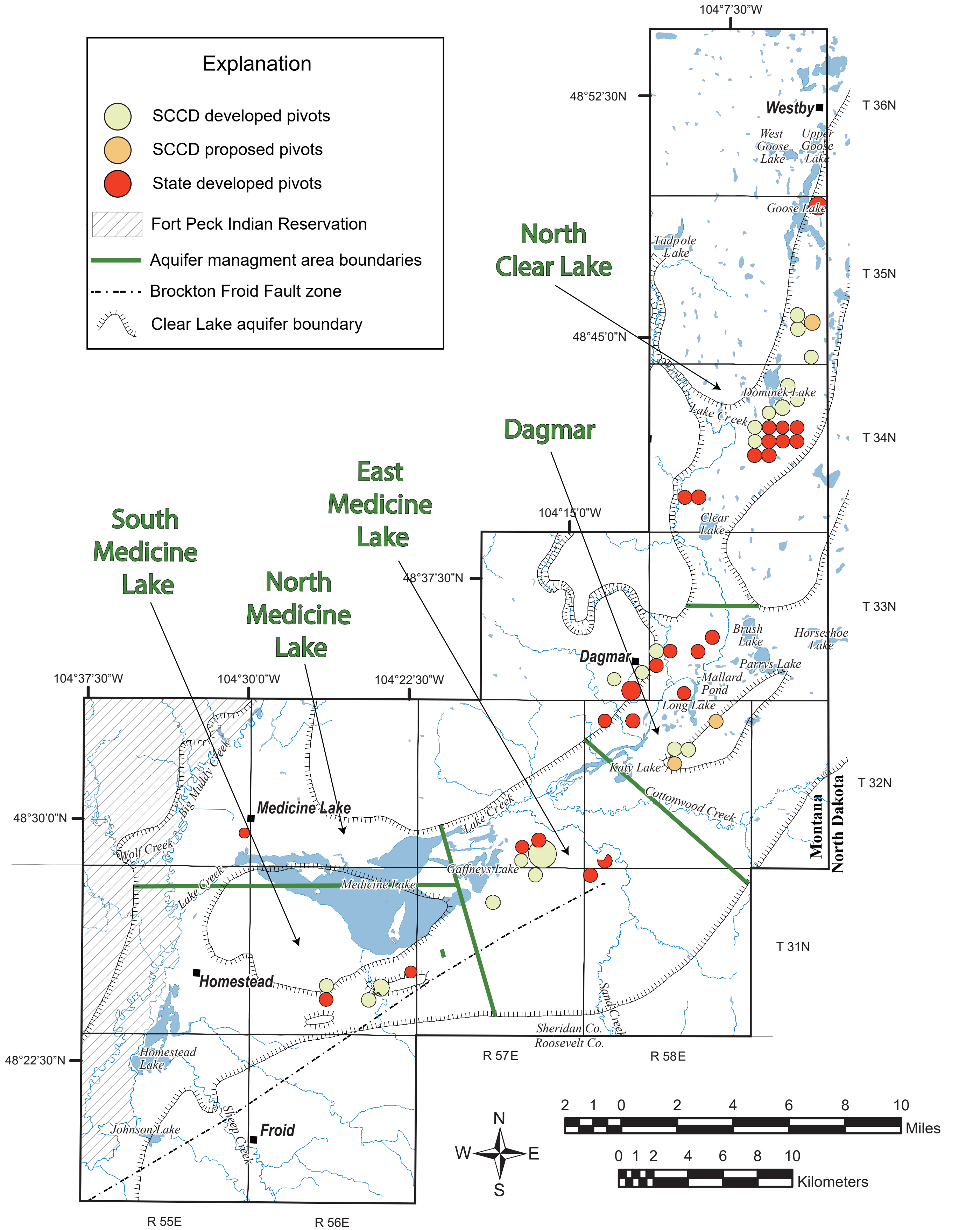


Figure 3. The Clear Lake aquifer is divided into five management areas based on irrigation development patterns, general aquifer conditions, and proximity to locations of recharge and discharge. The pivot symbol sizes approximate the acreage irrigated.

Data requirements for each permit application have tempered the growth in water development. Applicants must document that water quantity, water quality, and soil types are adequate for the proposed irrigation project and that the project is technically feasible. Hydrogeologists from the MBMG assist the TAC review of applications. Hydrographs from nearby monitoring wells are used to determine water-level trends and to assess potential impacts of irrigation projects on wetlands, which are classified by USFWS regarding their significance for habitat and the local environment.

The initial hydrogeologic investigation program started with test-hole drilling, water-level monitoring, water-quality sampling, aquifer testing, water-use monitoring, and numeric modeling. These efforts provided scientific data for the water reservation proposal and initial hydrogeologic report (Donovan, 1988). Monitoring efforts were limited until 1995 when the SCCD, DNRC, and USFWS realized that continued water-level and water-quality monitoring were essential to evaluate the effects of increased irrigation development. The MBMG reestablished monitoring for the SCWR and stored the water-level and water-quality data in the MBMG Groundwater Information Center (GWIC) database. State and Federal funding have periodically allowed additional test drilling to delineate aquifer extent and thickness, and expand the monitoring network.

*Water Use in the SCWR*

Figure 3 shows the aquifer management areas and status of irrigation development in the Clear Lake aquifer. The map displays irrigation pivots permitted under State water rights and the SCWR-permitted pivots. Each irrigation water right includes a point of diversion (irrigation well or wells) and a point of use (pivot or pivots). The sizes of the pivots on the map indicate the approximate areas permitted for irrigation. Groundwater use increased from about 600 acre-ft/yr when first reported in 1980 to nearly 6,000 acre-ft/yr in 1998. Although the volume of water authorized has increased since 1998, the annual use has not exceeded the 1998 volume (Reiten, 2002). Because power costs to run the irrigation system are large, producers only irrigate to supplement precipitation when needed. Therefore, the timing and volume of rainfall during a growing season affects irrigation groundwater withdrawals. The SCWR typically authorizes 2 ft annually, but farmers rarely apply over 1 ft of water even in dry years.

*Aquifer Management Areas*

We divided the Clear Lake aquifer into five distinct management areas based on development patterns, general aquifer conditions, and proximity to recharge and discharge (fig. 3). The management areas from northeast to southwest (downgradient) are designated North Clear Lake, Dagmar, East Medicine Lake, North Medicine Lake, and South Medicine Lake. There are 26 State water permits in these management areas authorizing 7,889 acre-ft, and 21 SCWR permits authorizing 5,848 acre-ft of withdrawal each year.

## Previous Investigations

Members of the Lewis and Clark expedition recorded the first geologic observations in this region in 1805–1806 as they traveled along the Missouri River. They described general geologic/geomorphic features including coalbeds, clinker, salts, burning coalbeds, erosional features, and glacial erratics along with descriptions of the region's physiography and topography. In the late 1800s and early 1900s, additional field studies described the physiography and geology of northeast Montana (Warren, 1868; Upham, 1904; Leonard, 1916). At about the same time, Beekly (1912), Bauer (1914), Collier and Thom (1918), and Alden (1924) published on topics ranging from regional mapping (emphasizing Quaternary geology) to coal resource investigations. The first published observations of the ancestral Missouri River Valley and its buried valley alluvial deposits came from this phase of geologic field studies. Researchers also described the Flaxville gravel and its relation to other terrace deposits in the region.

Mapping of glacial deposits since the early 1900s has progressively improved the understanding of the numerous advances and retreats of continental glaciers during the Pleistocene. Calhoun (1906) developed the first map depicting the extent of glaciation in northeastern Montana. Alden (1932) mapped glacial geology of eastern Montana and surrounding areas. Howard (1960) mapped Cenozoic deposits emphasizing the Pleistocene in Montana and North Dakota, centered on the confluence of the Yellowstone and Missouri Rivers. Colton and others (1961) mapped glacial geology in eastern Montana. As researchers incorporated new regional information, they developed a better chronology of glacial advances. Mapping by Clayton and others (1980) in North Dakota emphasized the Quaternary geology, glacial chronology, and landforms associated with glacial deposits. Fullerton and Colton (1986) interpreted the glacial geology and chronology of the Montana plains. Bergantino (1986) compiled a map of the Quaternary geology covering the study area. Fullerton and Colton (1986), Colton and others (2006a,b), and Fullerton and others (2007) developed Quaternary geologic maps and the current accepted chronology of glaciation in the region.

Geologic and hydrologic investigations in the Medicine Lake area resulted from proposed water-resource development associated with reservoir construction in the late 1940s. Wilson (1948) proposed the first reservoir on Big Muddy Creek. A proposal to construct a reservoir at Medicine Lake soon followed (Kirchen, 1949) and included an electrical resistivity study to identify the buried valley aquifer (Edwards, 1951). Witkind (1959) published a geologic map covering most of the present study area as part of these reservoir investigations.

During the 1950s and 1960s, groundwater research emphasized county or provincial studies of aquifers to determine water availability. In Montana, research focused on groundwater resources in the Missouri River Valley (Swenson, 1955). Levings (1986) investigated groundwater conditions in the Plentywood area as a result of proposed water use for a newly constructed coal power plant in Canada. The new water reservation for the Clear Lake aquifer required detailed hydrogeologic data and interpretations as reported in Donovan and Bergantino (1987) and Donovan (1988). Schuele (1998) produced a groundwater model to evaluate the water balance and impacts of irrigation development on lakes and wetlands. Both the Donovan (1988) and Schuele (1998) models simulated the entire aquifer system to forecast aquifer response to climate and land-use changes. Although the models provided water-budget estimates, they were too simplistic to serve as management models and did not evaluate the impacts of increased use at specific locations.

Donovan and Rose (1994) modeled the water chemistry of lakes and concluded that the flow of shallow and intermediate groundwater from the Clear Lake aquifer into the lakes explains the lakes' water chemistry. The lake water chemistry ranges from fresh water to highly concentrated brines.

In North Dakota, research focused on Divide and Williams Counties along Montana's northeast border. Armstrong (1965, 1967) mapped the geology and evaluated the hydrology of buried valley aquifers. Hansen (1967) and Freers (1970) mapped the geology of Divide and Williams counties bordering Montana. The Skjermo Lake aquifer is the continuation of the Clear Lake aquifer into North Dakota. A series of annual reports by Wanek (1983–1996), in addition to a groundwater model (Wanek, 1984), describe the Skjermo Lake aquifer and water use. Shaver and Pusc (1992) described longitudinal and transverse hydraulic barriers in buried valley aquifers and their ability to alter groundwater flow and availability.

In Canada, aquifers associated with buried valleys of the ancestral Missouri and Yellowstone Rivers have experienced extensive water withdrawals, monitoring, and modeling (Cummings and others, 2012). Christianson and Parizek (1961) summarized studies of these aquifers near Estevan, Saskatchewan. van der Kamp and Maathuis (2012) evaluated excessive drawdown in buried valley aquifers of the Estevan Valley. Smerdon and others (2005) investigated and modeled the hydraulic connection between a buried valley aquifer and a large irrigation reservoir.

Since the early 1980s the MBMG has provided hydrogeologic data and interpretations to the SCCD. MBMG hydrogeologists have served on the SCCD (TAC) since 1995. Responsibilities include assisting with the maintenance of the monitoring program, interpreting water-level data, conducting and interpreting aquifer tests on new irrigation well applications, and coordinating with the USFWS and Fort Peck Tribes on SCWR activities. The SCCD and MBMG collect, annually compile, and enter monitoring data into the MBMG GWIC system. These data provide background for the water permit application process (SCCD, unpublished file data). Reiten (2002) summarized the results of the monitoring program. The TAC determined that dividing the aquifer into separate management areas would improve development decisions. Reiten (2002) included hydrographs from monitoring and irrigation wells that demonstrate short- and long-term trends in groundwater levels, a discussion of aquifer conditions, effects of pumping on groundwater levels and surface-water resources, and potential for additional development for each management area.

## Regional Setting

*Physiography*

Big Muddy Creek and its tributaries overlie the Clear Lake aquifer and flow into the Missouri River 26 mi south of Medicine Lake. An exception is the Brush Lake internally drained area located northeast of Dagmar (plate 1). This area has poorly defined surface drainage, and many of the lakes and wetlands have no surface inlets or outlets. Big Muddy Creek is the largest stream in the area and forms the study area western boundary. Other streams that overlie the aquifer include Lake Creek, Cottonwood Creek, and Sand Creek.

Numerous lakes and wetlands overlie the Clear Lake aquifer area. Several of the larger named lakes (from north to south) are Goose Lake, Dominek Lake, Clear Lake, Brush Lake, Mallard Pond, Long Lake, Katy Lake, Gaffney Lake, Medicine Lake, and Homestead Lake. Medicine Lake is the largest of these, covering an area of about 8,214 acres at the full pool level (1,933 ft above mean sea level as reported by the USFWS). At this level, Medicine Lake holds 48,580 acre-ft of water. It is shallow, with a maximum depth of about 10 ft at full stage. Artificial controls regulate water levels in Medicine Lake. Big Muddy Creek is diverted to the lake during high streamflows to increase lake stage.

The topography of the study area is one of relatively low relief. Elevations range from 2,100 ft in the northern area near Westby to about 1,930 ft in the southwest, where the aquifer underlies Big Muddy Creek. Most of the modern streams are underfit and occupy relatively broad valleys derived from glacially diverted streams or meltwater channels.

*Geology and Drainage Development*

The landscape of northeastern Montana has evolved with Tertiary (Flaxville) and Quaternary (Wiota) deposition and erosion by rivers that flowed to the northeast in the geologic past. These fluvial systems formed a series of gravel-capped terraces that step down in elevation from the northwest to the southeast. The terraces slope towards the northeast, where they underlie glacial till. Plate 2 depicts the regional geology, physiography, and drainage in the Wolf Point quadrangle in northeast Montana. The Flaxville plateaus are highly dissected and their edges show distinct dendritic erosional patterns exposing underlying fine-grained bedrock. While the Clear Lake aquifer occupies a relatively small part of this area, this view aids in placing the aquifer within the regional geologic setting and landscape.

During Miocene–Oligocene time, the ancestral Missouri River flowed to the northeast down the regional paleo-slope from just north of the Canadian border towards Hudson Bay and ultimately the Labrador Sea (fig. 4; Cummings and others, 2012). Tectonic uplifting in Canada and stream piracy south of the border forced the channel to the southeast. Alluvial terrace deposits formed at each new stream position (fig. 5). The Cypress Hills gravel (1 in fig. 5) is a remnant of the oldest fluvial deposit (Eocene–early Miocene). The river system shifted south into Montana during the Oligocene and Pliocene, depositing successive lower terraces of the Flaxville Formation (2). During the Pleistocene, several terraces developed as the alluvial system migrated southeast (Donovan and Bergantino, 1987). These ancestral Missouri River alluvial deposits are referred to as the Wiota gravel (3) in this report. Green and blue lines show the approximate locations of buried scarps of the Wiota gravel. Although the Wiota gravel as described by Jensen and Varnes (1964) was not projected into the subsurface, we use this name to describe subsurface deposits of the basal gravel in the buried valley (4). The gravel is identical to higher terrace deposits and it forms the final "Wiota" deposition in the buried valley (5). The Brockton–Froid Fault zone appears to have tectonically controlled the southeast migration of the ancestral Missouri River.

The limits of Quaternary glacial ice advance as described by Fullerton and others (2004) are also featured in plate 2. The unglaciated areas associated with the Flaxville terraces are notable by the relatively high elevation and flat surfaces. Plate 2 also identifies several broad swales: these are defined by areas of low relief within topographic lowlands. The Manning Lake swale and the Medicine Lake swale trend southwest to northeast and delineate the preglacial Missouri River Valley. These swales are 6–8 mi wide and are filled by alluvium and glacial deposits, including outwash, lake sediment, and till. The north- to south-trending Clear Lake swale is 1–4 mi wide, and is filled by glacial deposits, including outwash, lake sediment, and till.

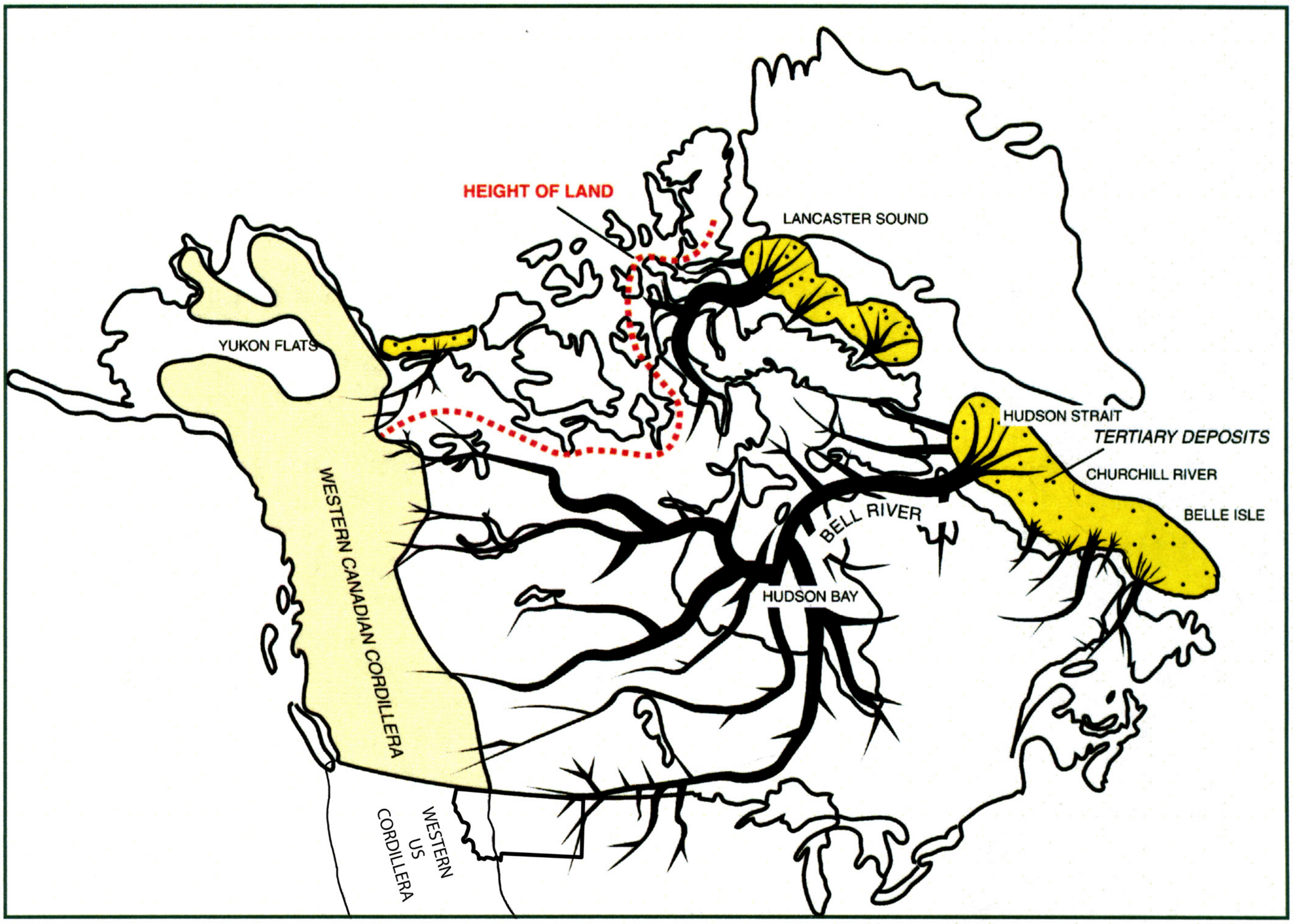


Figure 4. Conceptual depiction of Tertiary (preglacial) drainage in northern United States and Canadian prairies. Adapted from Cummings and others (2012) with permission.

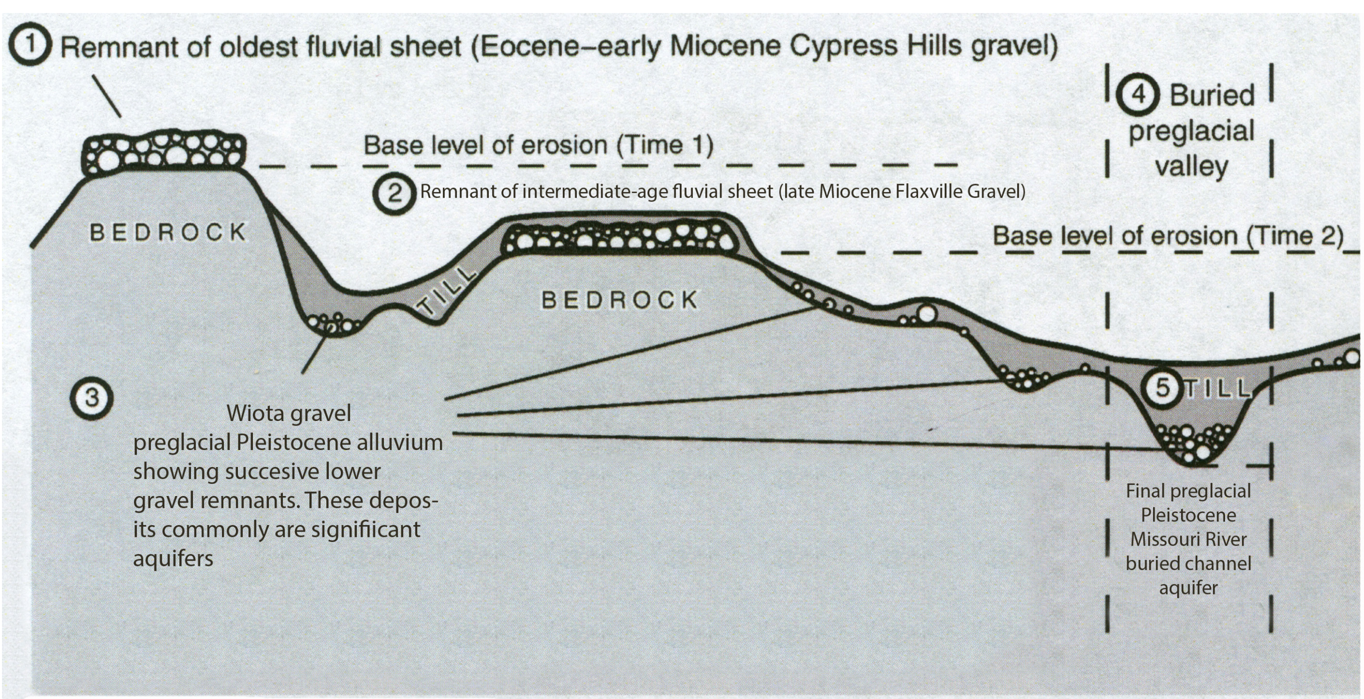


Figure 5. Illustration depicting the stratigraphic position, relative age, and relative position of Rocky Mountain derived quartzite-rich gravel during Tertiary erosion in the Great Plains of northern Montana and Canada. Adapted from Cummings and others (2012) with permission.

Quaternary glaciers dammed and eventually diverted the Missouri to its present course (Cummings and others, 2012). These diversions commonly occupied the low-lying swales, but flow was generally opposite the regional paleo-slope or around the margins of glacial ice. Multiple advances and retreats of glacial ice buried the alluvial gravels beneath glacial till, preglacial lake clays, fine-grained deltaic deposits, and coarse-grained glacial outwash. Glacial meltwater deposited outwash in these low-lying swales multiple times. Meltwater incised channels 200 to 300 ft deep into some of the larger drainages, and these channels were subsequently filled with glacial sediments.

Advancing glaciers diverted several of these drainages at a variety of scales (plate 2). A large-scale diversion of the Missouri River east of Culbertson blocked the river, forming the Bainville diversion, leaving the Bainville swale in the former river position. The Antelope diversion and swale result from a medium-scale diversion. Numerous smaller scale diversions appear on the map, including the Coalridge channel near Dagmar, and the unnamed channel west of the Big Muddy near Plentywood, which trends generally southwest crossing Wolf Creek and Smoke Creek.

The Clear Lake aquifer is composed of two zones: (1) the lower pre-glacial alluvium (Wiota gravel) deposited by the northeast-flowing ancestral Missouri River in the Medicine Lake swale, and (2) upper glacial outwash sand and gravel deposited by southwest-flowing meltwater streams in the Clear Lake swale and adjacent part of the Medicine Lake swale. The outwash deposits overlie the alluvial deposits, older glacial deposits, and Fort Union bedrock depending on the specific location. In some places, locally extensive aquitards composed of fine-grained glacial till and lake clay separate the aquifer zones. In other locations the upper outwash and lower alluvial zones are hydraulically connected. The aquifer in our study area extends from Westby to the southwest where it directly contacts alluvial and outwash sand and gravel underlying Big Muddy Creek. Groundwater flow in the Clear Lake aquifer is generally towards the south or southwest.

*Climate*

Eastern Sheridan and Roosevelt Counties have a semiarid continental climate, characterized by cold, dry winters; cool, moist springs; moderately hot, dry summers; and cool, dry autumns. January is generally the coldest month with an average low temperature of -2°F and July the warmest month with an average high temperature of 84°F (based on 1960–2015 data). At Westby, near the northern extent of the aquifer, the average precipitation is about 14.2 in per year, with most of the precipitation falling during the growing season from May through August (fig. 6; WRCC, 2018, Westby, Montana Station 248777).

Near the southern extent of the aquifer at Medicine Lake, the average precipitation is about 13.8 in per year (WRCC, 2015 Medicine Lake, Montana Station 245572). During the 11-yr period from 1979 to 1990, an extended drought (1980s drought) affected water resources in northeastern Montana. In 9 of the 11 drought years, the annual precipitation was below the 1960–2015 average (fig. 7). Extreme drought, defined here by annual precipitation less than 10 in, occurred during 7 of these 11 years. Shallow wetlands dried and lake levels declined. Likewise, aquifer recharge was diminished, resulting in groundwater-level declines.

Although potential evaporation typically exceeds precipitation in this area, estimates of evaporation vary widely. The Medicine Lake 3 SE weather station (48.29°, -104.27°) reports a long-term pan evaporation average of 39.30 in for the period of record 1911–2005 (WRCC). A comparable station with a long-term Class A evaporation pan at Sidney, 50 mi south, was used in previous studies. Long-term data from the Sidney site report average annual evaporation of 33.14 in, period of record 1910–2005 (WRCC). Evaporation from a Class A pan at the U.S. Department of Agriculture research farm near Froid indicated 53% higher evaporation rates than at Sidney. The average evaporation at the Froid station was 52 in/yr from 1984 to 1988, during extreme drought conditions. In contrast, the Sidney station reported 34 in of annual evaporation over the same time period (Donovan, 1988). Wind and hot temperatures contribute to an average of 6 to 12 in of monthly evaporation from May to August at the Froid site. For the modeling effort conducted as part of this study, Chandler and Reiten (2019) assumed a potential evapotranspiration rate of approximately 3 ft/yr.

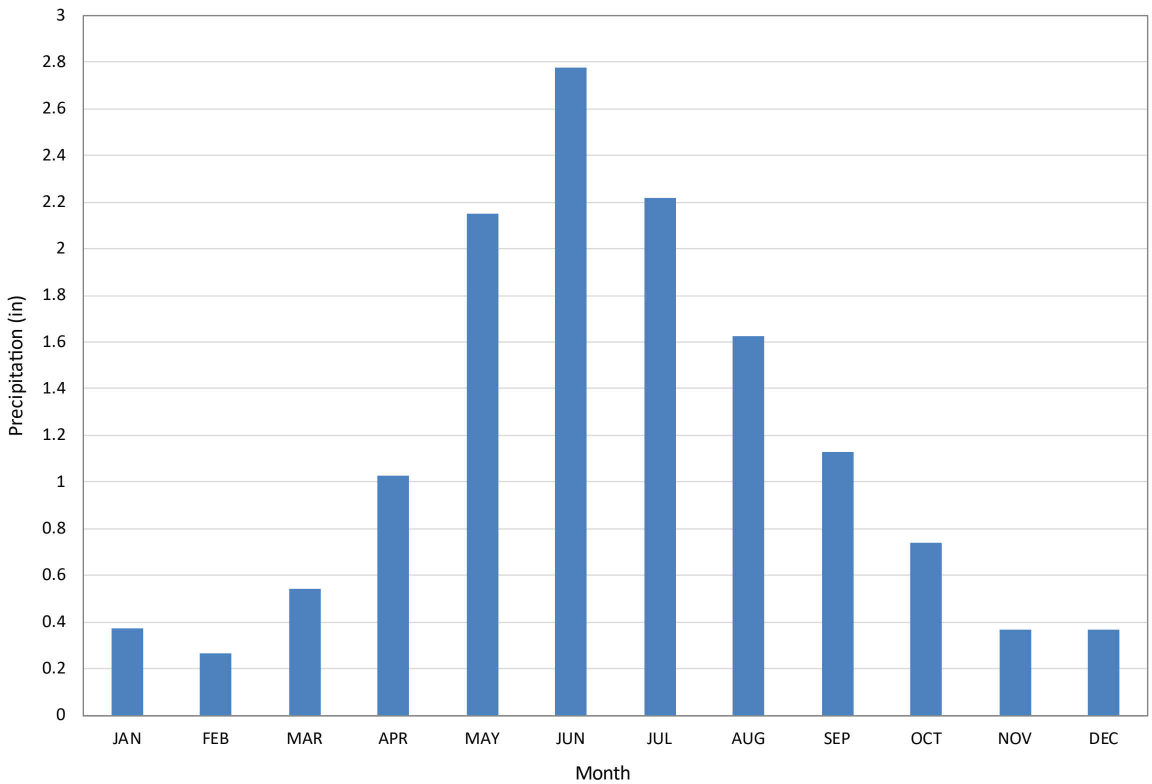


Figure 6. Average monthly precipitation for Medicine Lake Based on the period 1960–2015. http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?mt5572 [Accessed March 1, 2016].

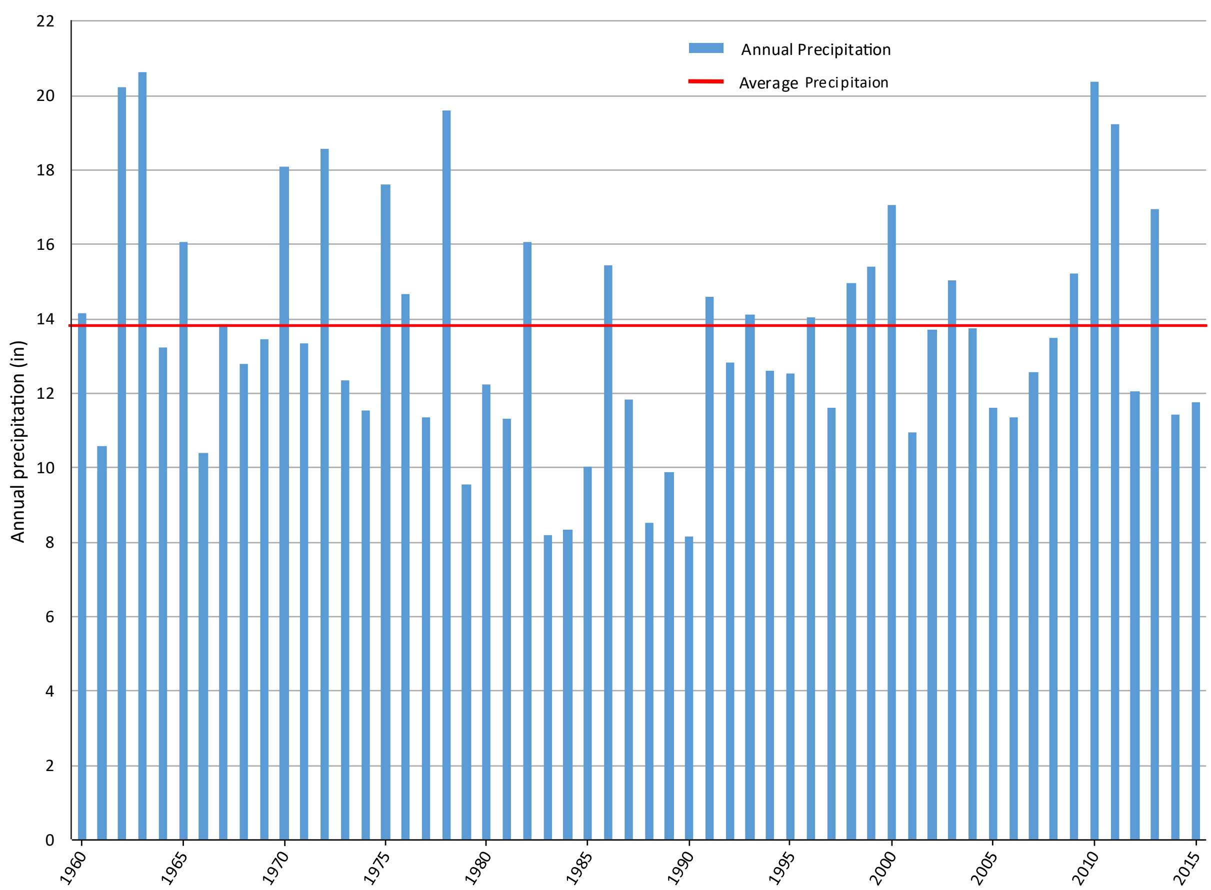


Figure 7. Annual precipitation for Medicine Lake from 1960 to 2015. http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?mt5572 [Accessed March 1, 2016].

# METHODS

## Data Compilation and Management

MBMG hydrogeologists compiled and verified Clear Lake aquifer data collected from 1980 to 2016. These data include lithologic and well completion logs, water chemistry analyses, and aquifer test reports stored in GWIC. These data are accessible through the GWIP project pages (http://mbmggwic.mtech.edu/sqlserver/v11/menus/menuProject.asp?mygroup=GWIP&myroot=BWIPCL&ord=1&).

## Geologic (Lithologic) Mapping

The parent materials of the different soil series (Richardson and Hanson, 1977) were used to construct a surficial geologic map based on the NRCS soil survey of Sheridan County. NRCS soil maps were used in ArcGIS to classify specific geologic units based on the parent material for that soil type. We conducted limited field investigation to verify the map units and confirm the geologic interpretations. The resulting lithostratigraphic map emphasizes the hydrogeologic characteristics of each mapped unit.

## Hydrogeologic Framework

Lithologic logs were simplified and entered into a digital format. This included verification and correction of well locations as needed. These logs show heterogeneous lithologic sequences common in glaciated terrains, where large lateral and vertical stratigraphic variation exists between closely spaced boreholes or within a single borehole. Lithologic descriptions were translated to major hydrogeologic units by combining materials with similar hydrologic properties. These modifications brought consistency to the wide range of terminology used by drillers and geologists. The simplified logs provided the information for developing stratigraphic cross sections, constructing aquifer maps, and groundwater modeling.

## Water Use

Water-use records were compiled for the project area. Data sources included electric utility records, flowmeters, and engine hour meters. Water-level responses to pumping in observation wells were used to determine when nearby irrigation wells were operated. Most methods for estimating water use require knowledge of the average pumping rate at each irrigation well. In the past, pumping rates were estimated by the pump installer or read directly from inline flowmeters. However, the accuracy of flowmeters decreases with time, and the SCCD used an ultrasonic flowmeter to improve accuracy in these measurements. The ultrasonic flowmeter used in this study was factory calibrated and the manufacturer claims pumping rate accuracy to ±1 percent of the actual flow.

## Monitoring Network

*Groundwater*

Data from a network of 189 wells were used for this project. These included observation wells, stock and domestic wells, and irrigation wells. These wells, shown on plate 1, are listed in appendix A.

The frequency of water-level measurements was variable. Observation wells adjacent to irrigation wells have data loggers programmed to record at 15-min intervals. Data loggers in other wells recorded water levels hourly. Water levels in irrigation wells are measured twice a year, typically with a steel tape. Late fall measurements record water levels during recovery from the recently completed irrigation season, and early spring measurements show recovered levels, prior to the onset of irrigation.

*Surface Water*

Prior to 2008, water levels in lakes and wetlands were monitored with staff gages. Most of these gages failed after a few years from ice jacking and damage from floating ice. These have been replaced with shallow wells constructed along shorelines of lakes and wetlands. The SCCD monitors 11 of these shallow wells to record surface-water fluctuations.

*Site Surveys*

The elevations and coordinates of all monitoring and irrigation wells were surveyed with a Leica 1200 GNSS GPS system. The well survey utilized a base station and rover to provide inch accuracy for altitude and the latitude–longitude at each location.

## Water Quality

The GWIC database contains 383 analyses collected in this area since 1960 (appendix B). Most samples were collected using MBMG Standard Operating Procedures (SOPs). Water was purged from the wells using pumps, bailers, or airlift methods. Purging continued until about three casing volumes of water was removed or until temperature, specific conductivity

(SC), and pH had stabilized. Surface water was collected by pumping or grab sampling from the wetland surface.

Several agencies collected water-quality samples contemporaneous with this GWIP project. The USFWS sampled surface water for inorganic constituents at 34 sites, and the SCCD sampled 27 wells as part of a coalbed-methane monitoring program. We also accessed results from 147 samples collected from wells and wetlands during previous MBMG, USFS, Department of Environmental Quality (DEQ), and DNRC-funded projects.

Samples submitted to the MBMG lab were field processed using the MBMG sampling protocol. This requires filtered and preserved samples for dissolved constituents and unfiltered samples for total recoverable constituents. All samples were cooled with ice or refrigeration to below 42ºF prior to analysis. Analytes tested at the MBMG Lab included major anions and cations and a standard list of trace elements.

Samples collected by well drillers or well owners since 1960 also provide some water-quality data. These samples, typically sent to private labs, were analyzed for specific conductance (SC), total dissolved solids (TDS), and the sodium absorption ratio (SAR). The parameters tested were limited to those needed to determine the usability of the groundwater for irrigation. We assume that these samples were untreated and collected at the wellhead or an available tap.

### Potentiometric Surface Map

A potentiometric surface map was constructed using water levels measured and water levels taken at other time periods but adjusted based on records from nearby wells completed at similar depths. Water levels measured in April–May 2015 were recovering from the 2014 irrigation season and did not appear to be affected by spring recharge prior to the 2015 irrigation season. The locations without April–May 2015 data were estimated by taking the non-pumping water-level data measured closest to the April–May timeframe and adjusting it in accordance with trends in nearby wells completed in the same zone. Water levels changed slightly during these months and the adjustments made to data from wells without April–May 2015 measurements were in the 2–5 ft range.

### Aquifer Test Data

Aquifer test data from previous investigations and water-permit applications (Donovan, 1988; Schuele, 1998; Reiten, 2002) were compiled for this investigation. These include single well tests (production well only) and multiple well tests where observation wells were available. Aquifer parameters determined from these tests are based on various analytical methods. Additional aquifer tests in the South Medicine Lake model area were analyzed by the MBMG using transducer data from observation wells located next to irrigation wells (appendix C). Normal irrigation operation resulted in 32 fortuitous aquifer tests during the 2015 growing season. Aquifer parameters estimated from these fortuitous tests used the Cooper–Jacob method only (Cooper and Jacob, 1946).

## RESULTS—REGIONAL CONDITIONS IN THE CLEAR LAKE AQUIFER

This section presents results and findings for the regionally extensive Clear Lake aquifer. Reiten (2002) summarized the history, status, and potential for additional irrigation development in the five management areas. Here, we present the hydrogeologic framework of the region, including aquifer delineation and properties, the nature of groundwater recharge and discharge, and surface water–groundwater interactions. The South Medicine Lake focus area is discussed in more detail in a later section of this report.

### Hydrogeologic Framework

The Clear Lake aquifer in Montana and equivalent Skjermo Lake aquifer in North Dakota lie within a buried valley that extends approximately 40 mi. Twelve miles of the aquifer are in North Dakota and the remaining 28 mi are in Montana (fig. 1). The Clear Lake aquifer includes the lower alluvial zone (Wiota gravel) that underlies the Medicine Lake swale (see plate 2). The upper outwash zone lies within the Clear Lake swale and parts of the Medicine Lake swale. Although the ancestral Missouri River deposits differ lithologically from overlying outwash deposits, these zones form the Clear Lake aquifer. The width of the Clear Lake aquifer ranges from 1.5 mi near Clear Lake where the channel narrows (referred to as the Clear Lake constriction) to more than 8 mi wide east of Medicine Lake (fig. 2).

Figure 8 shows the surficial geology in the project area. The Paleocene Fort Union Formation is the oldest unit mapped. The Fort Union Formation consists of fine-grained mudstones and siltstones interbedded with sandstone and coalbeds. The fine-grained units form aquitards and thin coalbeds and sandstones form low-yield aquifers. Most of the area is covered by Quaternary glacial till. The till is a poorly sorted mixture of clay, silt, sand, and gravel. This till generally restricts recharge at the surface and forms aquitards in the subsurface. Quaternary glacial outwash is the dominant surficial unit in the Clear Lake swale from Westby to several miles southwest of Dagmar. It is composed of blue to light brown fine sand grading to coarse gravel. This upper outwash zone forms moderate to high-yield regions of the aquifer. Quaternary glacial lake deposits composed of gray to dark blue silty clay and clayey silt form a minor surficial geologic unit. Lake deposits in the subsurface form extensive and commonly thick aquitards. Holocene alluvium forms minor surficial deposits along smaller streams including Lake Creek, Cottonwood Creek, and Sand Creek. Extensive alluvial deposits occur along Big Muddy Creek. These deposits range from light brown to dark grayish brown silt, silty clay, silty sand, and silty sand and gravel. Quaternary eolium deposits are largely brown to reddish brown, well-sorted fine to medium sand and range from 2 to 50 ft thick. The eolium, referred to in this report as sand hills, covers several square miles southeast of Medicine Lake where it forms a groundwater recharge area.

The aquifer materials are composed of three major lithologic components. These materials were transported from the west and north, and also include locally derived rocks. Although present in the subsurface, neither the Flaxville gravel nor the Wiota gravel are exposed in this area (fig. 8). Rocks eroded from the Rocky Mountains and transported from the west include distinctively colored (purple, red, green, and tan) quartzite, probably from the Belt Supergroup, and less abundant volcanic gravel (from the Bears Paw Mountains). These are the dominant lithology of the alluvial Flaxville and Wiota gravels. The Wiota gravel contains reworked Flaxville gravel and minor amounts of Canadian Shield rocks; the Wiota gravel is largely indistinguishable from the Flaxville gravel. Northern source rocks include igneous and metamorphic rocks from the Canadian Shield and Paleozoic carbonates transported to the study area by glaciers. Local source rocks include mudstone, sandstone, siltstone, and coal derived from the Fort Union Formation. The glacial outwash contains all three lithologic components, but is dominated by light-colored Paleozoic carbonates. In most areas, fine-grained lake clay or glacial till separates the upper outwash and lower alluvial zones of the aquifer.

The bedrock elevation contour map (fig. 9) depicts a 200- to 300-ft-deep buried valley extending from Homestead northeast towards the North Dakota border. The buried valley splits into two channels separated by a bedrock ridge near Medicine Lake. The northern channel contains both the upper outwash zone and lower alluvial zone of the aquifer. The southern channel comprises the lower alluvial zone, although hydraulically connected thin layers of outwash gravels overlie the lower alluvium. East of Medicine Lake, the two channels merge and continue in an easterly direction. Groundwater flow barriers form at the edge of buried valleys, where highly transmissive sand and gravel of the Clear Lake aquifer transitions to fine-grained bedrock of the Fort Union Formation. Several bedrock highs form ridges within buried valleys, and these can hydraulically isolate parts of the aquifer system similar to those observed in North Dakota by Shaver and Pusc (1992).

The buried valley-fill is highly heterogeneous across the study area. Complex stacking of these deposits indicates the buried valleys were reactivated during multiple glaciations. In all locations, the buried valley-fill is predominantly fine-grained sediments; these glacial till and glacial lake deposits form the aquitards. Remnants of a higher Wiota terrace form a separate aquifer capping the bedrock ridge in the South Medicine Lake area.

The Clear Lake aquifer thickness is highly variable, ranging from 10 to 250 ft. Figure 10 depicts areas of continuous sand and gravel greater than 100 ft thick located near the middle of the cross section. These highly transmissive zones, referred to as "central plugs" by Donovan (1988), are shown near well 44455, and may yield very large volumes of water to wells. Areas of the aquifer that are thinner but are hydraulically connected to these transmissive zones typically show greater aquifer transmissivity than would be expected based on gravel thickness reported in the well log.

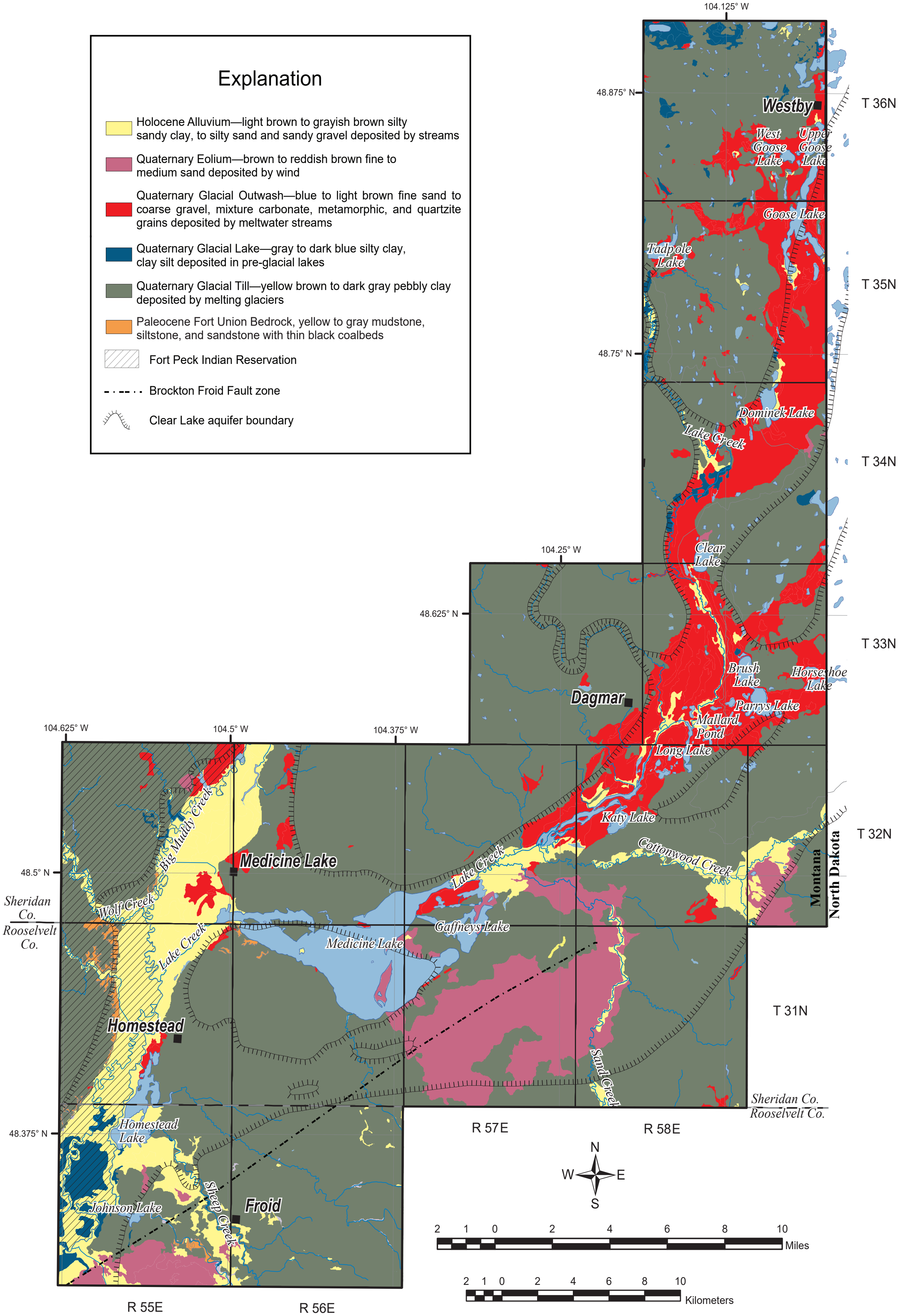


Figure 8. Surficial geology of the Clear Lake aquifer.

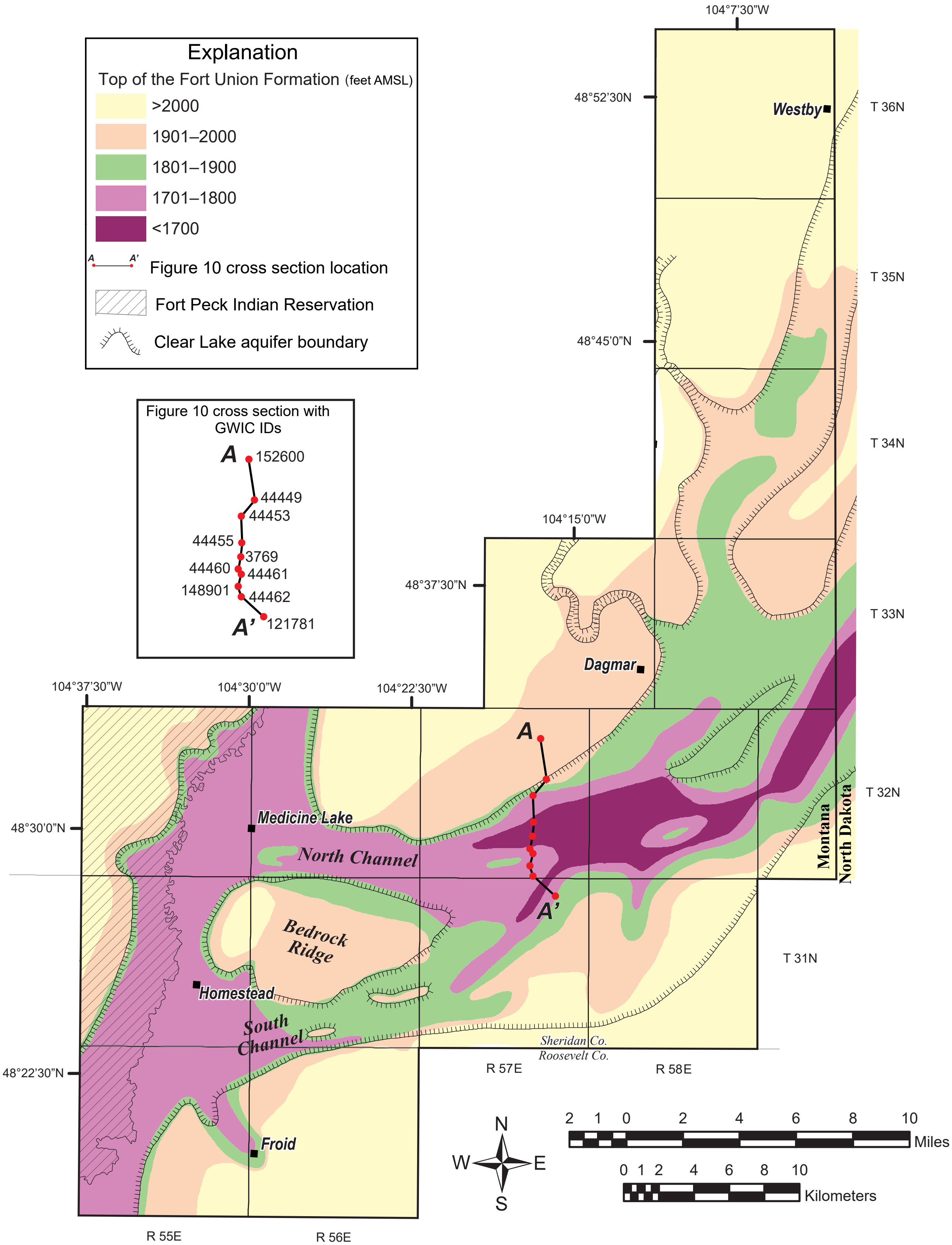


Figure 9. The top of the Fort Union Formation bedrock forms the base of the buried valley containing the Clear Lake aquifer. Contours are based on the elevation at 273 control points.

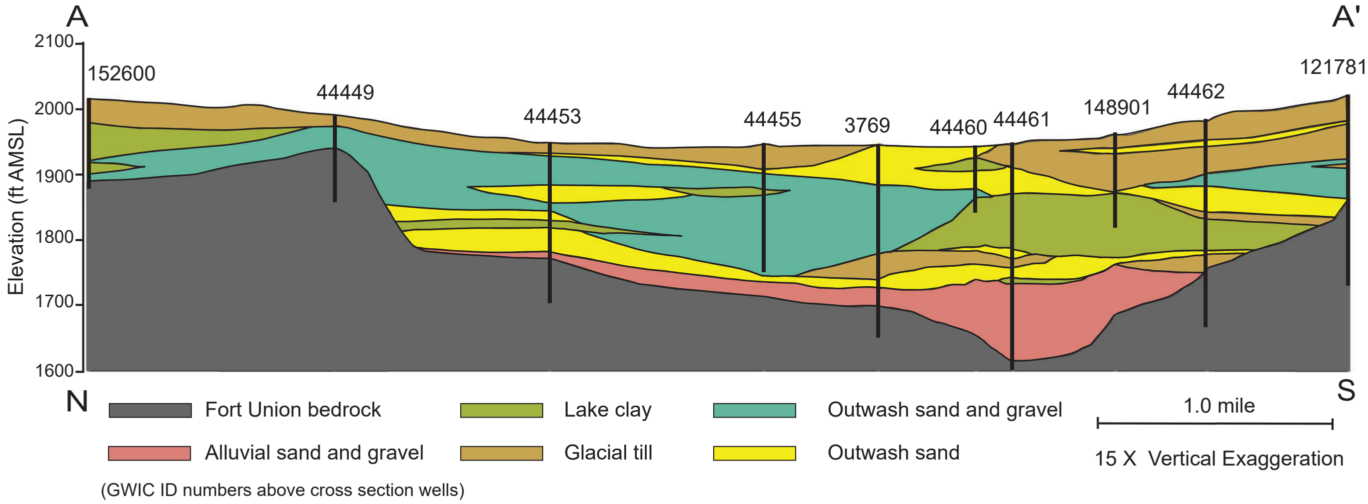


Figure 10. Geologic profile across the Clear Lake aquifer east of Medicine Lake. See figure 9 for location of the cross section.

Highly productive wells completed in relatively thin sand and gravel layers are explained using a schematic of glacial stratigraphy (fig. 11). A well at point A on figure 11 completed in *glacial outwash 1* has direct connection to the highly transmissive *glacial outwash 3*. A well at point B completed in *glacial outwash 2* has thicker outwash aquifer than the well at point A, but lower productivity because of limited storage in the aquifer. A well at point C encounters till and clay, but not the aquifer. The upper alluvial terraces are limited in aerial extent. Wells completed in the terraces, such as point D, may support domestic or stock uses, but typically lack the yield needed for irrigation. Direct recharge from precipitation and snowmelt and unconfined conditions occur in areas where the glacial outwash is exposed at the surface (fig. 11, *glacial outwash 3*).

## Groundwater/Surface-Water Connection

Results of this study support previous interpretations of the groundwater/surface-water connections of the Clear Lake aquifer (Donovan, 1988; Schuele, 1998; Reiten, 2002). The deposits form a heterogeneous system; the hydraulic connections among the aquifer, lakes, and wetlands vary from location to location. The land surface overlying the Clear Lake aquifer contains wetlands, sloughs, and lakes. Many of these water bodies are in kettles, which are depressions in the land surface formed when stagnant glacial ice melted and left behind an undulating topography of hills and depressions. These kettles formed the lakes and wetlands in the region today.

Complexly layered stratigraphy includes fine-grained glacial till (pebbly clay loam), lacustrine (silt

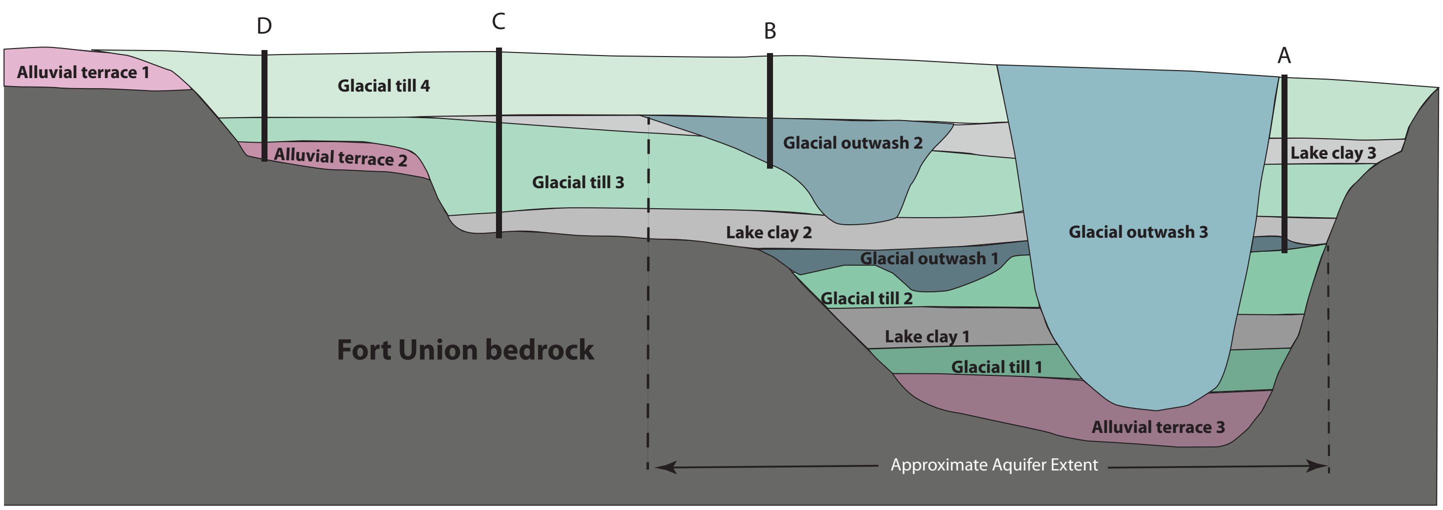


Figure 11. A schematic of glacial stratigraphy typical for the Medicine Lake area illustrates connectivity between deposits of different ages and heterogeneous sediments over short horizontal and vertical distances.

and clay) deposits, and slack water sediment (fine sand, silt, and clay). Where present, these materials form aquitards that restrict groundwater flow. Lakes and wetlands display a wide range of hydraulic connection to the underlying aquifer. Some are separated from the aquifer by fine-grained materials, others are separated by thick sodium sulfate salt deposits (up to 70 ft thick in Miller Lake near Westby; Murphy, 1996), and others are in good hydraulic connection with the underlying aquifer. The aquitards control the flow of water between the underlying aquifer and surface water in lakes and wetlands.

Groundwater is the primary source of recharge to the lakes, with minor contributions from direct precipitation and overland flow. Donovan (1988) categorized many of the lakes as open-, closed-, or restricted-outflow type lakes based on water quality. Closed or restricted-flow lakes allow very little outflow and have poor water quality because evaporation has increased the mineral concentration in the lake water. Flow in open-outflow lakes is not restricted, which results in better water quality. In either case, evapotranspiration concentrates dissolved minerals in surface water compared to nearby groundwater. In 1990, Reiten (1992) resampled lakes and wetlands that were initially sampled in 1984, before the extended drought of the 1980s. This showed 20 of 22 lakes had increases in SC ranging from 9 percent to 128 percent. In general, dissolved solids increased more in the closed-outflow lakes compared to open-outflow lakes.

Water quality is a good proxy for degree of hydraulic connection between the Clear Lake aquifer and lakes. Lakes with relatively fresh water indicate a good connection to the aquifer. Mallard Pond, an open-flow lake, had a TDS of 1,039 mg/L in 2005. A sample at the same time from a 10-ft-deep shoreline well (161782) completed in outwash had a TDS of 392 mg/L. The TDS of four closed or restricted-flow lakes sampled in 1990 varied from 6,090 mg/L (Brush Lake), 11,700 mg/L (Clear Lake), 28,800 mg/L (SE Goose Lake), and 264,000 mg/L (Horseshoe Lake). The aquifer adjacent to these lakes did not have the same poor water quality. Evapotranspiration causes lake levels to decline, inducing low-TDS groundwater flow to the lake, which improves surface-water quality.

The upper outwash zone on the north side of Medicine Lake has a direct hydraulic connection to the lake as indicated by similar water quality and level. The hydraulic connection between the lake and the lower alluvial zone appears to be limited by aquitards in both the north and south channels. Confining beds ranging in thickness from 37 to 184 ft are present near Medicine Lake; these aquitards overlie the lower alluvial zone and limit the movement of water. A discussion of the aquifer–lake hydraulic connection of the south channel is covered later in this report (see Hydrogeologic Framework in the section South Medicine Lake Focus Area).

Groundwater from the Clear Lake aquifer discharges to the aquifer underlying Big Muddy Creek. Low-permeability clay sediments ranging from 25 to 150 ft separate Big Muddy Creek from the underlying lower alluvial zone. Monitoring well water levels in this area show little fluctuation, indicating a constant upward gradient towards Big Muddy Creek. As a result, groundwater flow is restricted and relatively constant from the aquifer to the creek. Groundwater seepage helps maintain the baseflow in the creek, but the seepage rate does not appear to be affected by climatic fluctuations or groundwater withdrawals.

### Aquifer Properties

Hydraulic properties of the aquifer, including transmissivity, hydraulic conductivity, and storage coefficients, were compiled from earlier studies and analyses completed during this investigation. Data from several aquifer tests reported by Donovan (1988) and Schuele (1998) demonstrate the range and variability of the hydraulic properties of the Clear Lake aquifer. Tables 1 and 2 summarize these tests from outwash and alluvial deposits, respectively. Figure 12 shows the locations of the aquifer tests reported by Donovan (1988) and Schuele (1998). Estimates of hydraulic properties prepared by the MBMG within the South Medicine Lake focus area are presented below.

Transmissivity ranges from 960 $ft^2/d$ to 147,000 $ft^2/day$ in the upper outwash zone, with a geometric mean of 23,800 $ft^2/d$ (table 1). Hydraulic conductivity ranges from 60 ft/d to 6,280 ft/d, with a geometric mean of 960 ft/d. Donovan (1988) and Schuele (1998) estimated storage coefficients for the six aquifer tests where observation well data were available (table 1). Storage coefficient values indicate confined to unconfined conditions, and range from 0.0003 to 0.05 with an arithmetic mean of 0.015.

Table 1. Aquifer parameters for wells completed in the upper outwash zone of the Clear Lake aquifer.

| GWIC ID | Latitude | Longitude | Well Yield (gpm) | Test Duration (h) | Aquifer Thickness (ft) | Transmissivity (ft²/day) | Hydraulic Conductivity (ft/day) | Storage Coefficient |
|---|---|---|---|---|---|---|---|---|
| 3770 | 48.49775 | -104.28107 | 110 | 24.0 | 75 | 56,400 | 750 | NA |
| 3773 | 48.55502 | -104.18186 | 85 | 1.1 | 16 | 960 | 60 | NA |
| 3869 | 48.58408 | -104.14289 | 85 | 5.5 | 30 | 45,900 | 1,560 | NA |
| 3871 | 48.58553 | -104.14540 | 85 | 5.8 | 23 | 87,000 | 3,780 | NA |
| 3858 | 48.61384 | -104.14441 | 85 | 5.8 | 7 | 31,900 | 4,550 | NA |
| 3862 | 48.59823 | -104.09945 | 85 | 5.0 | 43 | 20,600 | 480 | NA |
| 3947 | 48.68554 | -104.14395 | 85 | 6.0 | 20 | 26,300 | 1,310 | NA |
| 3866 | 48.60633 | -104.04819 | 80 | 2.7 | 17 | 7,900 | 460 | NA |
| 3868 | 48.59207 | -104.04802 | 77 | 7.0 | 9 | 23,000 | 2,560 | NA |
| 3767 | 48.49082 | -104.45426 | 16 | 4.0 | 12 | 5,900 | 490 | NA |
| 3854 | 48.56920 | -104.19780 | 21 | 0.0 | 18 | 113,000 | 6,280 | NA |
| 3861 | 48.60401 | -104.10028 | 85 | 6.0 | 14 | 36,100 | 2,580 | 0.0003 |
| 3870 | 48.58656 | -104.14710 | 1,000 | 24.0 | 61 | 147,000 | 2,410 | 0.0030 |
| 46003 | 48.66799 | -104.15805 | 1,000 | 1.6 | 49 | 39,400 | 800 | 0.0500 |
| 150614 | 48.48351 | -104.29082 | 550 | 9.6 | 29 | 3,240 | 110 | 0.0010 |
| 45327 | 48.56610 | -104.16020 | 1,000 | 1.5 | 25 | 12,100 | 480 | 0.0030 |
| 3859 | 48.59520 | -104.13860 | 960 | 5.5 | 94 | 67,000 | 710 | 0.0090 |
| | | | | | Mean | 42,600[1] | 1,730[1] | 0.0200[2] |
| | | | | | Median | 31,900 | 800 | 0.0060 |
| | | | | | Minimum | 960 | 60 | 0.0003 |
| | | | | | Maximum | 147,000 | 6,280 | 0.0500 |
| | | | | | Geometric Mean | 23,800 | 960 | 0.0050 |

[1]Geometric mean.

[2]Arithmetic mean.

*Note.* Data compiled from Donovan (1988) and Schuele (1998).

Table 2. Aquifer properties for wells completed in the lower alluvial zone of the Clear Lake aquifer.

| GWIC ID | Latitude | Longitude | Well Yield (gpm) | Test Duration (h) | Aquifer Thickness (ft) | Transmissivity (ft²/day) | Hydraulic Conductivity (ft/day) | Storage Coefficient |
|---|---|---|---|---|---|---|---|---|
| 3867 | 48.59160 | -104.04800 | 52 | 6 | 9.8 | 2,800 | 280 | NA |
| 3779 | 48.49806 | -104.17297 | 47 | 6 | 36.1 | 16,400 | 460 | NA |
| 3766 | 48.49082 | -104.45425 | 28 | 5 | 13.1 | 1,300 | 100 | NA |
| 3677 | 48.38955 | -104.45278 | 50 | 4 | 75.5 | 5,380 | 70 | NA |
| 155931 | 48.48496 | -104.27037 | Variable | 2 | 29.5 | 2,160 | 70 | 0.0029 |
| 43116 | 48.40409 | -104.43808 | 550 | 6 | 13.1 | 4,250 | 320 | NA |
| 150615 | 48.48481 | -104.26836 | Variable | 5.3 | 29.5 | 5,580 | 190 | 0.0001 |
| 3769 | 48.49788 | -104.28109 | Variable | 1.6 | 29.5 | 6,930 | 240 | 0.0003 |
| 142105 | 48.56724 | -104.19445 | 1,250 | 74 | 52.5 | 6,000 | 110 | 0.0009 |
| 45315 | 48.59520 | -104.13860 | 1,000 | 1.6 | 19.7 | 8,840 | 450 | 0.0002 |
| | | | | | Mean | 5,970[1] | 230[1] | 0.0009[2] |
| | | | | | Median | 5,480 | 210 | 0.0003 |
| | | | | | Min | 1,310 | 70 | 0.0001 |
| | | | | | Max | 16,430 | 460 | 0.0029 |
| | | | | | Geometric Mean | 4,770 | 180 | 0.0004 |

[1]Geometric mean.

[2]Arithmetic mean.

*Note.* Data compiled from Donovan (1988) and Schuele (1998).

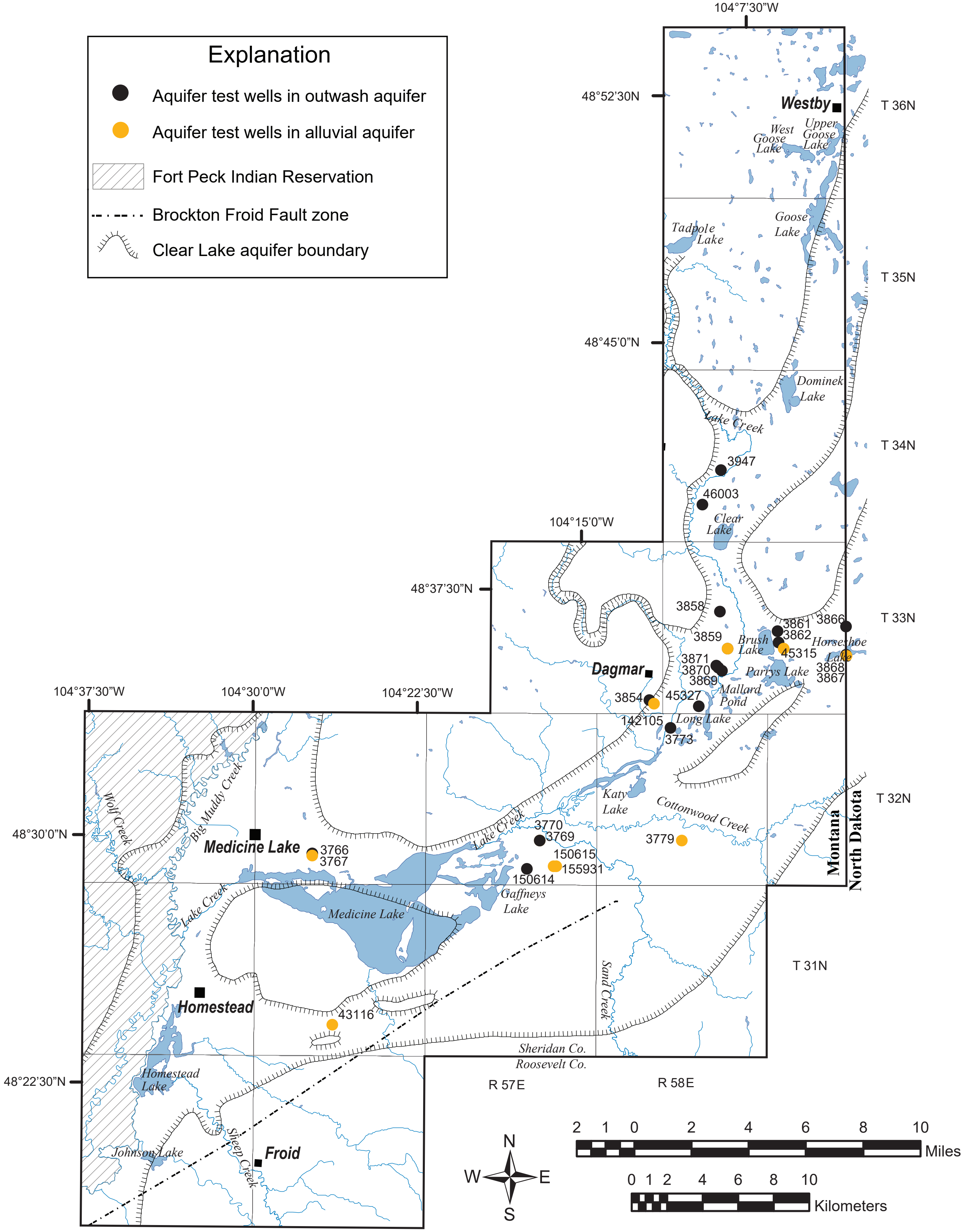


Figure 12. Locations of aquifer tests listed in tables 1 and 2.

Testing of the lower alluvial zone of the Clear Lake aquifer indicates transmissivity ranges from 1,300 $ft^2$/day to 16,400 $ft^2$/d, with a geometric mean of 4,770 $ft^2$/d (see table 2). Hydraulic conductivity ranges from 70 ft/d to 460 ft/d, with a geometric mean of 190 ft/d. Storage coefficients were calculated for 5 of the 10 aquifer tests and ranged from 0.0001 to 0.0003; the arithmetic mean was 0.00089. These data indicate that water in the alluvial portion of the Clear Lake aquifer is under confined to leaky confined conditions.

Although the ranges of these properties overlap for the upper outwash zone and the lower alluvial zone of the Clear Lake aquifer, the medians show significant differences (fig. 13). The lower alluvial zone of the Clear Lake aquifer is generally more confined, with hydraulic conductivity values about an order of magnitude less than the upper outwash zone. As a result, irrigation wells constructed in the upper outwash zone of the Clear Lake aquifer are typically more productive and produce less drawdown than wells completed in the lower alluvial zone.

## Groundwater Flow

Water levels measured during April and May 2015 were used to create a potentiometric surface of the Clear Lake aquifer (fig. 14). Groundwater flows from northeast to southwest from the North Dakota border near Westby towards Dagmar. Groundwater gradients increase from 0.0007 north of the Clear Lake constriction to 0.002 at the constriction and 0.001 below, near Dagmar.

Groundwater flow in the Clear Lake aquifer to the south of Medicine Lake is generally to the west. A groundwater mound underlies the sand hills (fig. 14) southeast of Medicine Lake. The high point of the mound forms a groundwater divide, with part of the flow to the north at a steep gradient (0.008) until it joins the westerly flow of the northern channel. Southwest of this groundwater divide, flow is westerly

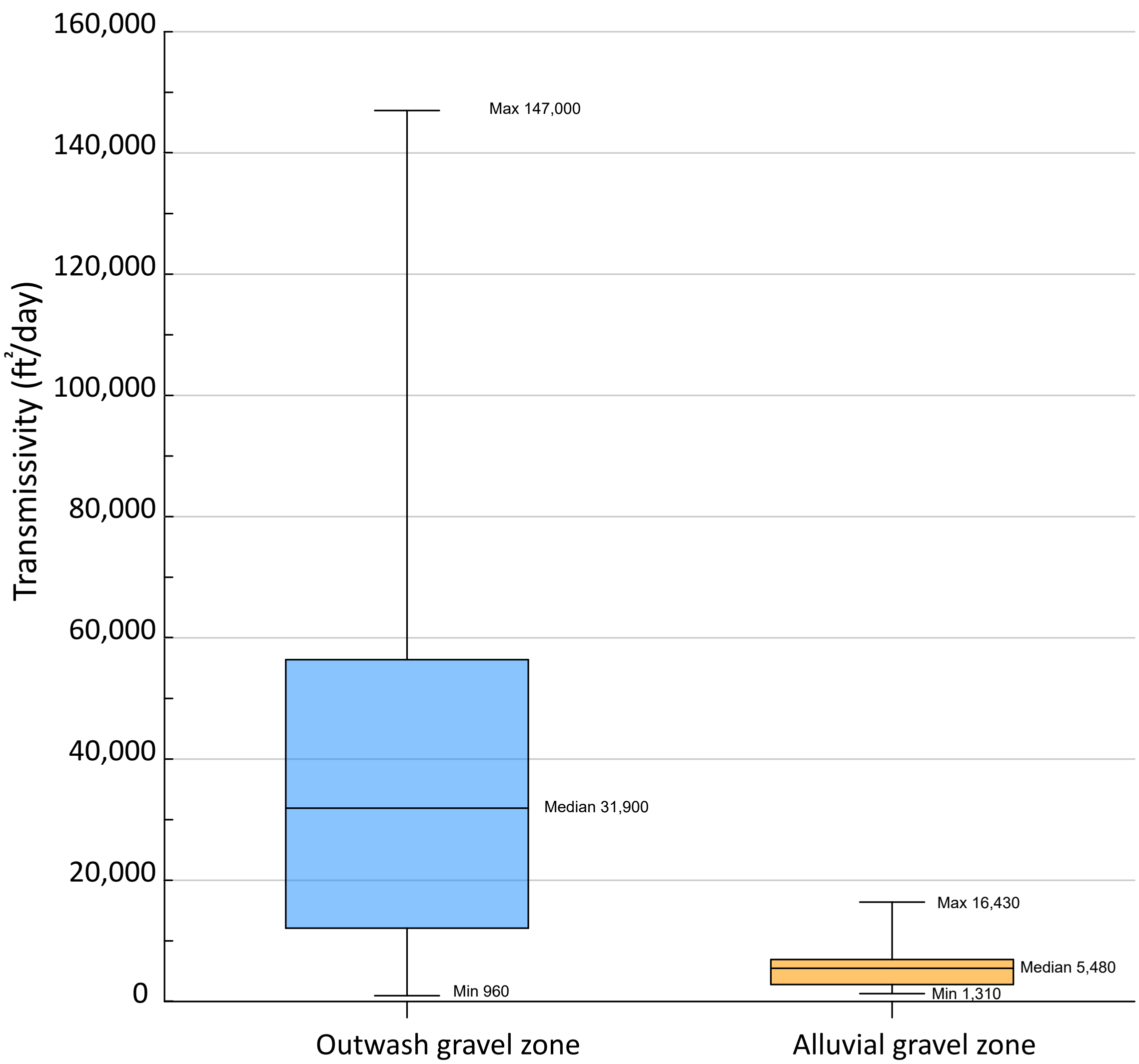


Figure 13. The transmissivity of the upper outwash zone is significantly higher than that of the lower alluvial zone in the Clear Lake aquifer ($p<0.01$, two-tail *t*-test assuming unequal variances).

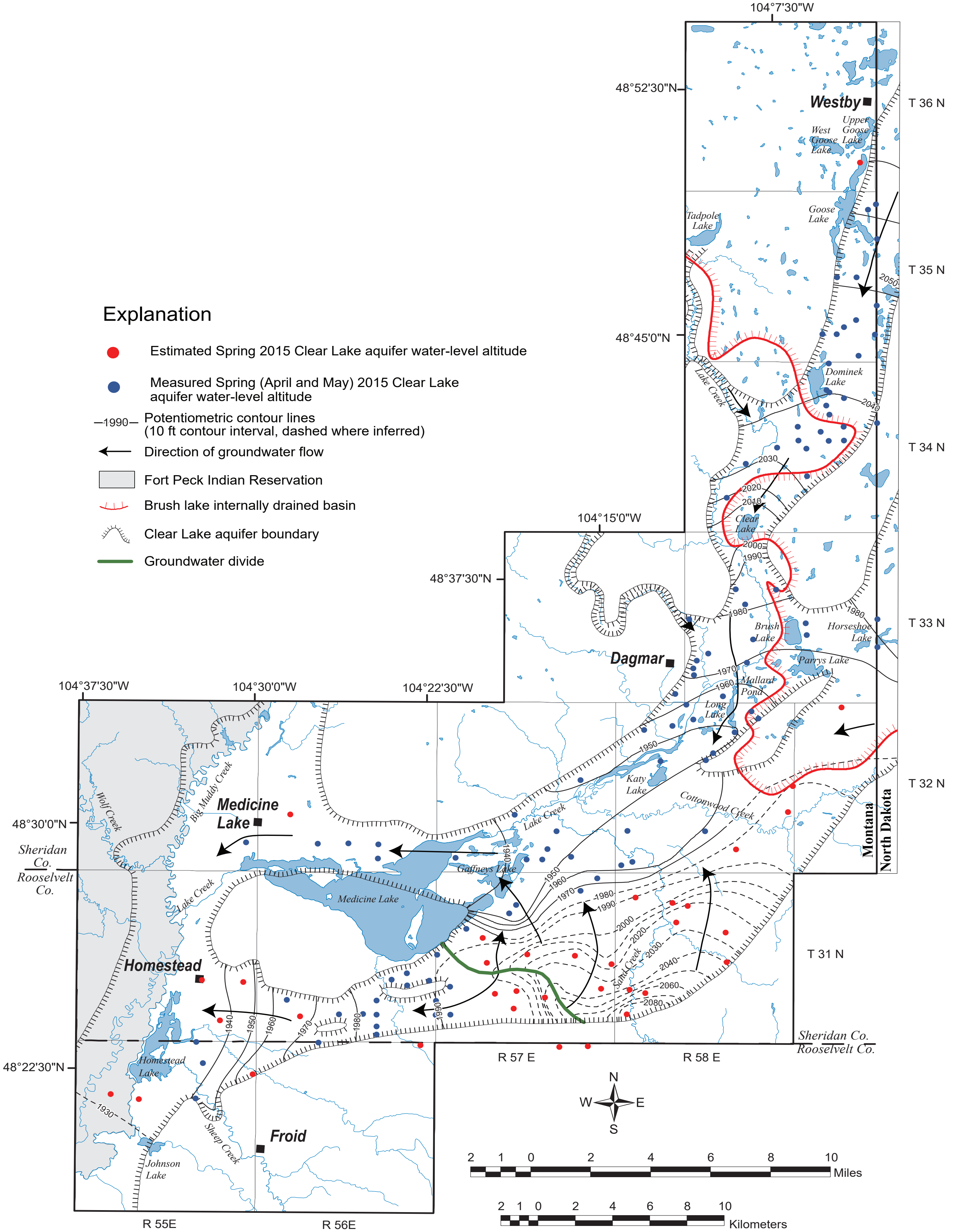


Figure 14. Potentiometric surface of the Clear Lake aquifer.

towards the Big Muddy Creek Valley. Relatively low hydraulic gradients (0.0007) extend throughout most of the South Medicine Lake area. Hydraulic gradients steepen to about 0.002 between this area and undeveloped portions of the aquifer underlying the Big Muddy Creek Valley.

In the center of the East Medicine Lake area (location shown in fig. 3), the upper outwash zone and lower alluvial zone are in direct hydraulic connection and form an area of high transmissivity (Donovan, 1988). Even within the highly transmissive area, vertical hydraulic gradients are upward, with heads in wells completed in the lower alluvial zone typically a few feet higher than wells completed in the upper outwash zone. Lateral gradients range from 0.0002 to 0.0001 from the East Medicine Lake area to Big Muddy Creek.

## Water Use

Figure 15 summarizes the estimated water use for irrigation from the Clear Lake aquifer. Because of the annual variation in crop moisture demands and precipitation, the annual water use fluctuates widely. Since 1994, water use has ranged from about 3,000 acre-ft to 6,000 acre-ft. High pumping costs promote water conservation, and producers limit irrigation to supplement normal growing season precipitation.

Water-use estimates depend on accurate pumping-rate measurements. Figure 16 compares pumping rates measured with an ultrasonic flowmeter to original reported rates. The original pumping rates are from a variety of measurement methods, including in-line flowmeters, well-driller reports, and designed rates for sprinkler-head nozzles. The original reported pumping rate was greater in 28 of the 37 well systems measured with the ultrasonic flowmeter in 2014 and 2015. The measured rate was lower in all of the wells with reported rates greater than 950 gpm. The 9 wells with higher reported rates tended to show greater differences between reported and measured values. Possible causes of the discrepancies are: sand degrading the impellers of the flowmeters, flowmeters breaking, decline in pump efficiency, or incorrect estimates of the original pumping rate. Current measurements of water use are more accurate than past estimates because of these improved measurement methods.

Water use in 2015 ranked 13th highest out of the 36 years recorded (fig. 15). The total volume pumped was 4,087 acre-ft, which is 352 acre-ft greater than the long-term average. Over this period, the mean (3,735 acre-ft) and median (3,758 acre-ft) were similar, indicating that annual water use is normally distributed over time.

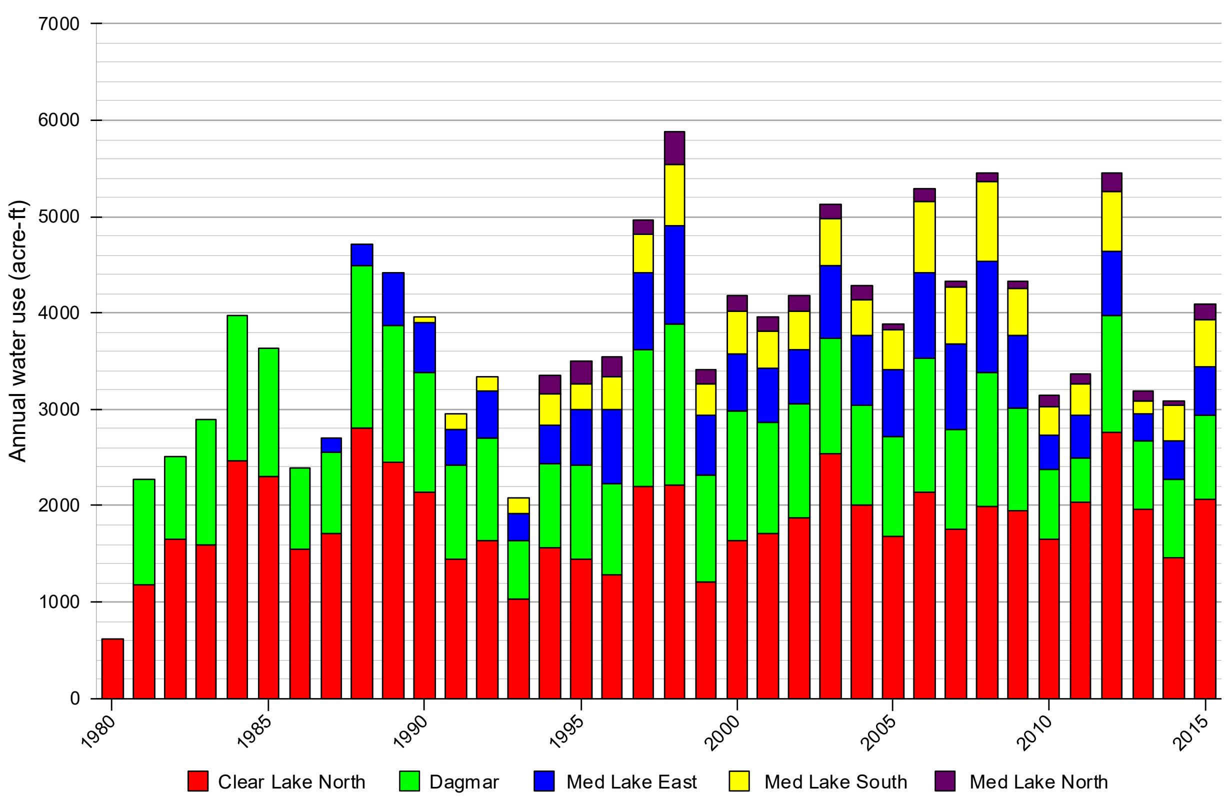


Figure 15. Estimated annual irrigation water use (acre-ft) from the Clear Lake aquifer by management area.

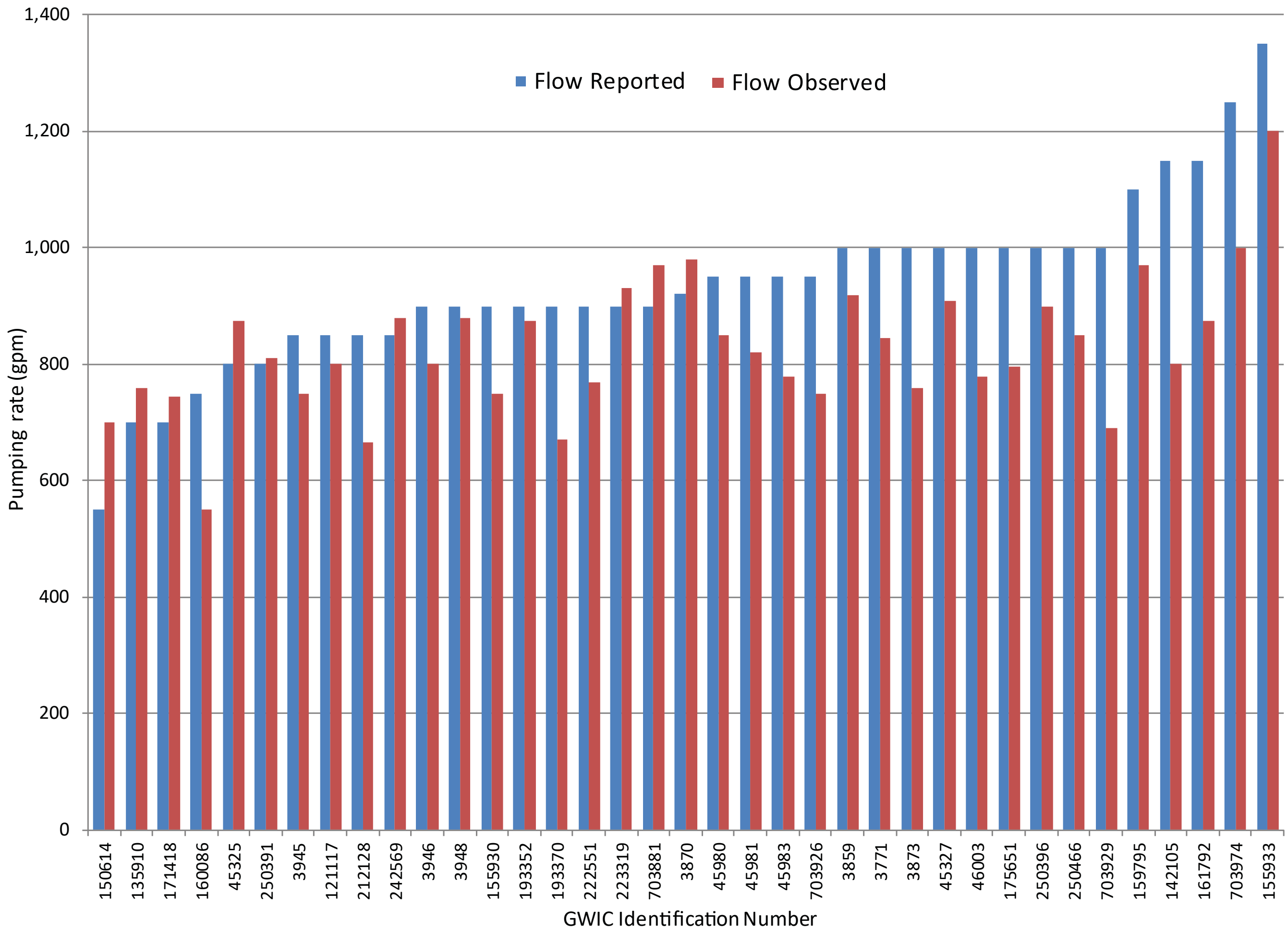


Figure 16. Comparison of reported pumping rates to those measured using an ultrasonic flowmeter shows that most of the wells pump at rates lower than reported.

## Groundwater Response to Climate and Pumping

Prior to this project, the primary tools for assessing irrigation impacts were observations of climate, water-use, and water-level changes. Water levels in monitoring wells near irrigation wells decline in response to irrigation withdrawals. These declines are greatest in tightly confined parts of the lower alluvial zone. In this setting, seasonal water-level declines can extend several miles from a pumping well. The water-level response is lower at monitoring wells in unconfined or leaky confined parts of the aquifer; often the response is limited to less than ½ mi from the pumped well. Following the irrigation season, water levels recover, approaching the original static water level before the next irrigation season. Long-term water-level trends follow precipitation trends, with declines apparent during the extended drought of the 1980s. As illustrated below, aquifer water levels have now recovered to those prior to irrigation development.

Representative hydrographs in each of the five management areas illustrate the influence of precipitation and irrigation on groundwater levels (plate 3). A more detailed discussion of the management areas is presented in Reiten (2002). Hydrographs shown on plate 3 demonstrate the variability of water-level fluctuations in the Clear Lake aquifer. Wells completed in the lower alluvial zone of the Clear Lake aquifer typically have greater fluctuations than those completed in the upper outwash zone of the aquifer.

Moving downgradient from the northeast, near Westby, the hydrographs at wells 149610, 3944, and 3947 show similar timing of water-level fluctuations, although their magnitudes vary (plate 3). Water levels at these wells declined about 5–7 ft from 1982 to 1993 during the 1980s drought. The rate of decline slowed, responding to higher precipitation and recharge in the 1990s and 2000s. Above-normal snowmelt and precipitation in 2009 and 2011 resulted in abrupt water-level rises.

The drought response in the 1980s was not as severe in the southern part of the study area. In the Dagmar and East Medicine Lake Management areas, the water-level decline was 2–4 ft, although the decrease was partially masked by the annual drawdown and recovery caused by irrigation. Water-level fluctuations at wells 3871, 45292, 3779, 3769, and 3770 show this pattern. The response at well 3871 (completed in the upper outwash zone) ranges from 2 to 5 ft and is attributed to seasonal irrigation drawdown. In contrast, the water-level response at well 45292 (completed in the lower alluvial zone) ranges from 10 to 20 ft.

Although proximity to a production well influences patterns of drawdown and recovery, so do differences in transmissivity and storage in the glacial outwash compared to the alluvium. Similar responses are shown at monitoring wells 3769 (lower alluvial zone) and 3770 (upper outwash zone). These wells are next to each other in the East Medicine Lake area and both respond to irrigation pumping from wells completed in the alluvial and outwash zones. Monitoring well 3779, 3 mi from the nearest irrigation well pumping from the deep alluvial gravel, shows a typical confined aquifer response.

The South Medicine Lake area has some of the largest water-level fluctuations observed in the Clear Lake aquifer. The annual water-level fluctuations at well 150940 range from 10 to 40 ft. High water-use years produce a larger fluctuation. The large response at this well is attributed to its proximity to several irrigation wells and to the hydraulic boundary located ¼ to ½ mi north.

The only well in the South Medicine Lake Management area with long-term monitoring is 3677. This well is in the lower alluvial gravel and it displays an unusual water-level response compared to other wells in this area. It is about 100 ft deeper than the other wells and appears to be in a deepened region of lower alluvial zone. Based on water-level responses and water chemistry, it also appears hydraulically separated from the irrigation wells by a longitudinal flow barrier. The subdued annual drawdown and recovery at this site are probably caused by cumulative impacts of irrigation withdrawals from distant wells. In contrast, other monitoring wells in this area exhibit an immediate or nearly immediate response to pumping.

### Regional Groundwater Recharge and Discharge

This section presents a discussion of the recharge and discharge processes that affect the Clear Lake aquifer, based largely on understanding of the geologic setting, the location of surface-water features in the landscape, and their role in the hydrologic system. The surficial geologic materials overlying the aquifer greatly influence groundwater recharge rates. Donovan (1988) mapped the highest recharge rates of about 9.3 in/yr in areas of glacial outwash or sand hills (fig. 8). Intermediate recharge rates of about 1.3 in/yr apply to Quaternary alluvium and glacial till (Donovan, 1988). Schuele (1998) estimated that ⅓ of the long-term average precipitation recharged the aquifer and the rest was lost to evapotranspiration. The Fort Union Formation aquifers have the potential to provide recharge to the Clear Lake aquifer through interaquifer flow. The hydraulic heads are higher in the Fort Union Formation surrounding the Clear Lake aquifer, suggesting inflow, but the recharge volume it provides is unknown.

The timing and rate of precipitation are not uniform across the landscape. Summer thunderstorms are intermittent, with no rain in one area and a deluge of several inches falling in another area. Snowfall collects in low areas, such as road ditches, while hilltops are blown free of snow. As a result, when the snowpack melts, recharge rates vary across the landscape. As snow accumulates on the prairie, the potential for infiltration depends on the thickness of frozen ground. Thick snow can insulate the ground, reducing the frost depth and extent. As the snow melts, downward infiltration of water has a greater potential to recharge the aquifer in areas with less frozen ground.

The discharge area for the Clear Lake aquifer is the Big Muddy Creek Valley between Homestead and Froid. A large volume of groundwater discharges to the lakes and wetlands as relatively high rates of evapotranspiration from these surface-water bodies drives the hydrologic flow system. Lakes alone cover about 15,075 acres overlying the aquifer (Donovan, 1988). There are several thousand additional acres of wetlands. Estimates of total annual evapotranspiration over the entire Clear Lake aquifer from previous models have ranged from 50,000 acre-ft (Donovan, 1988) to 150,000 acre-ft (Schuele, 1998). Recharge and discharge occur in close proximity where the surface glacial outwash (areas of high recharge rates) are adjacent to lakes and wetlands (areas of high evapotranspiration rates).

## Water Quality

Water-quality information was compiled from previous projects and samples collected as part of this project. The water quality of the Clear Lake aquifer is important for irrigation development, since the areas with high SAR water are not suitable for irrigation. Water quality was also examined to evaluate groundwater–surface water interactions and presence or absence of brine water co-produced with oil and gas development.

The water quality is highly variable in different zones of the Clear Lake aquifer and associated surface-water bodies. Table 3 summarizes analyses of water-quality samples in surface water, Clear Lake aquifer, Fort Union aquifer, the Fox Hills–Hell Creek aquifer, and Mesozoic (for example, Dakota Formation) and Paleozoic (Madison Group) reservoirs associated with hydrocarbon extraction. Appendix B lists all of the samples and water-quality data. Piper diagrams were constructed from 369 water samples.

Oil and gas exploration and development have targeted Paleozoic hydrocarbon reservoirs underlying most of northeast Montana. As a byproduct from hydrocarbon development, high-salinity wastewater is produced and then injected into Mesozoic reservoirs for disposal. Surface-water and groundwater influenced by this co-produced water (brines) have elevated chloride concentrations and fall in the yellow shaded area on the Piper plots (fig. 17). Samples from such sources potentially have contamination index (CI) values greater than 0.035. Reiten and Tischmak (1993) developed the CI as a screening tool for identifying oilfield contamination. The CI is the ratio of chloride concentration (mg/L) to specific conductance (SC, µS/cm). A value of 0.035 was empirically established as a lower limit of brine contamination.

Seventy-five surface-water samples were collected from lakes, streams, and wetlands overlying the Clear Lake aquifer. The lakes and wetlands are typically less than 10 ft deep. One exception is Brush Lake (east of Dagmar, shown in fig. 3), which reaches depths greater than 60 ft. The streams are slow moving and are perennial to intermittent. Lakes and streams along the Lake Creek drainage are controlled by headgates allowing managers to divert water when desired to enhance wildlife habitat. A diversion canal moves water from Big Muddy Creek to Medicine Lake for lake-level control. High rates of evapotranspiration in the summer concentrate the salts dissolved in surface-water bodies. Magnesium, sodium, bicarbonate plus carbonate, and sulfate dominate the dissolved constituents found in the surface water. Six samples are dominated by chloride anions, which we attribute to brine contamination. Chloride concentrations in 20 samples exceeded the lower CI limit of 0.035.

The upper outwash zone ranges from near-surface sand and gravel deposits to depths greater than 200 ft. A total of

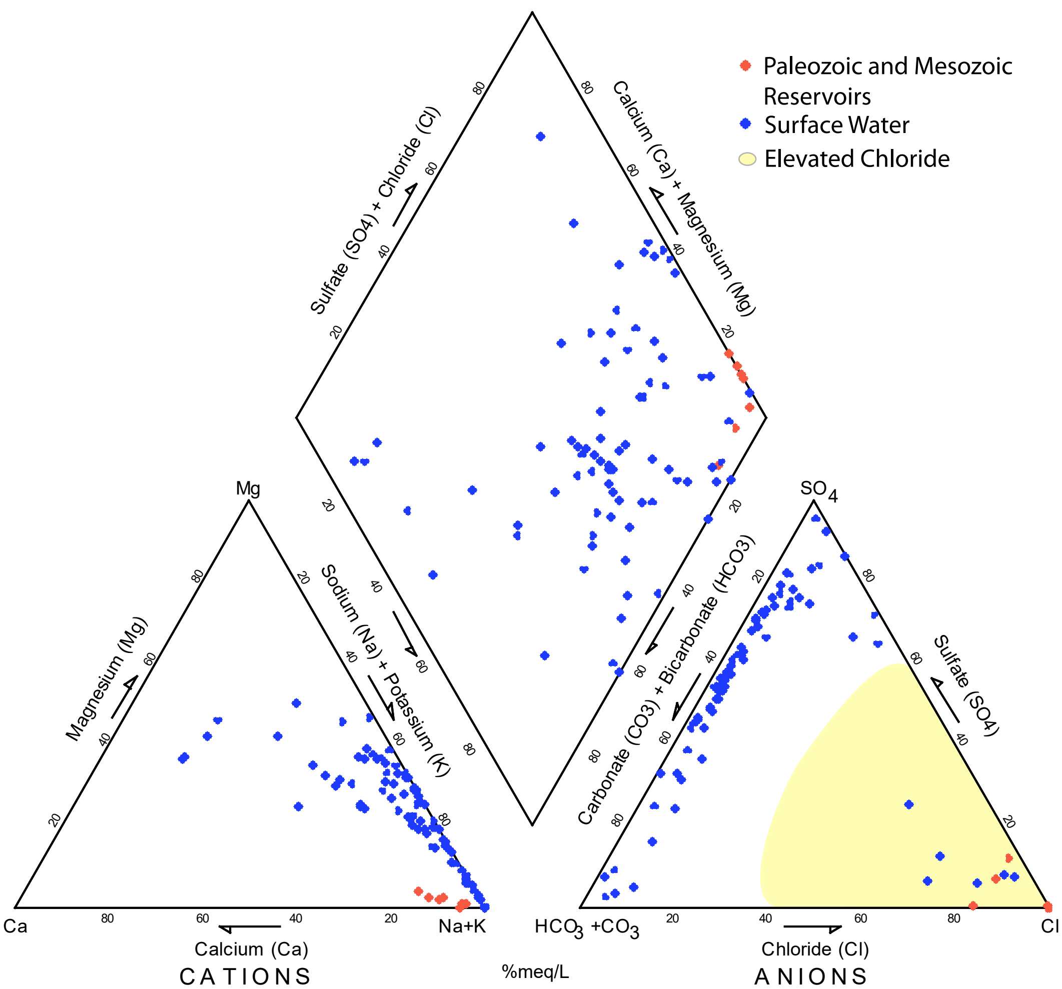


Figure 17. A Piper diagram of the surface-water samples and the samples from Mesozoic and Paleozoic reservoirs shows that elevated chloride (yellow shading) can be used to identify water impacted by brine contamination.

Table 3. Summary of inorganic water quality from groundwater and surface water associated with the Clear Lake aquifer.

| | Lab pH | Lab SC | Ca (mg/L) | Mg (mg/L) | Na (mg/L) | K (mg/L) | Fe (mg/L) | Mn (mg/L) | $SiO_2$ (mg/L) | $HCO_3$ (mg/L) | $CO_3$ (mg/L) | $SO_4$ (mg/L) | Cl (mg/L) | F (mg/L) | TDS (mg/L) | SAR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Surface Water*** | *n* = 75 samples | | | | | | | | | | | | | | | |
| Reported and Detections | 70 | 69 | 75 | 75.0 | 75.0 | 75.0 | 42.0 | 49.0 | 61.0 | 75.0 | 64.0 | 75.0 | 75.0 | 55.0 | 75 | 75.0 |
| Maximum | 10.09 | 174,957 | 699.0 | 1,940.0 | 108,000.0 | 1,050.0 | 1.0 | 2.7 | 33.7 | 71,000.0 | 54,800.0 | 93,300.0 | 10,500.0 | 10.5 | 282,003 | 4,229.4 |
| Minimum | 7.23 | 327 | 1.6 | 11.7 | 12.1 | 4.0 | 0.0 | 0.0 | 0.2 | 68.1 | 1.5 | 6.6 | 5.5 | 0.0 | 204 | 0.3 |
| Average | 8.92 | 14,786 | 70.8 | 299.5 | 5,848.9 | 136.9 | 0.2 | 0.1 | 8.6 | 2,574.0 | 1,493.0 | 8,379.8 | 888.0 | 0.5 | 18,174 | 130.4 |
| Median | 9.05 | 5,210 | 22.9 | 165.5 | 1,134.0 | 47.8 | 0.1 | 0.0 | 6.9 | 780.2 | 171.9 | 1,820.0 | 90.6 | 0.2 | 4,162 | 15.6 |
| Standard Deviation | 0.69 | 26,425 | 119.8 | 363.6 | 15,407.7 | 201.6 | 0.2 | 0.4 | 7.3 | 8,323.5 | 6,885.2 | 18,168.8 | 1,850.1 | 1.5 | 42,482 | 543.1 |
| ***Clear Lake Aquifer Outwash*** | *n* = 116 samples | | | | | | | | | | | | | | | |
| Reported and Detections | 116 | 116 | 116 | 116 | 116 | 116 | 109 | 101 | 101 | 115 | 3 | 116 | 116 | 96 | 116 | 116 |
| Maximum | 8.50 | 33,100 | 1,663.0 | 857.0 | 5,000.0 | 32.0 | 13.6 | 4.1 | 31.0 | 1,525.5 | 21.6 | 1,147.0 | 12,770.0 | 1.2 | 20,879.0 | 196.4 |
| Minimum | 6.74 | 509 | 0.7 | 0.3 | 2.1 | 0.9 | 0.0 | 0.0 | 9.2 | 98.2 | 2.0 | 9.0 | 1.0 | 0.1 | 284.6 | 0.1 |
| Average | 7.57 | 1,927 | 123.6 | 60.3 | 226.4 | 5.7 | 2.6 | 0.5 | 23.9 | 650.6 | 9.9 | 337.0 | 133.4 | 0.3 | 1,229.5 | 5.7 |
| Median | 7.51 | 1,434 | 104.8 | 48.8 | 135.6 | 5.3 | 2.5 | 0.3 | 25.0 | 612.5 | 6.0 | 288.5 | 11.0 | 0.2 | 1,031.5 | 2.6 |
| Standard Deviation | 0.34 | 3,105 | 151.1 | 79.1 | 467.3 | 3.0 | 2.3 | 0.7 | 4.1 | 268.6 | 8.4 | 243.9 | 1,179.1 | 0.2 | 1,889.7 | 18.2 |
| ***Clear Lake Aquifer Alluvium*** | *n* = 54 samples | | | | | | | | | | | | | | | |
| Reported and Detections | 54 | 54 | 54.0 | 54.0 | 54.0 | 54.0 | 48.0 | 48.0 | 49.0 | 53.0 | 5.0 | 52.0 | 53.0 | 47.0 | 54.0 | 54.0 |
| Maximum | 8.73 | 2,999 | 204.0 | 129.1 | 678.0 | 15.9 | 6.1 | 2.8 | 33.2 | 1,683.4 | 1,233.0 | 666.2 | 75.5 | 3.4 | 2,030.3 | 62.0 |
| Minimum | 7.08 | 845 | 3.4 | 2.0 | 24.4 | 2.3 | 0.1 | 0.0 | 10.4 | 513.0 | 2.0 | 0.4 | 1.2 | 0.1 | 430.7 | 0.5 |
| Average | 7.84 | 1,670 | 98.5 | 48.1 | 245.5 | 5.8 | 2.0 | 0.3 | 24.9 | 848.1 | 263.2 | 287.0 | 11.3 | 0.7 | 1,145.1 | 6.8 |
| Median | 7.85 | 1,692 | 102.1 | 44.5 | 175.9 | 5.5 | 1.5 | 0.2 | 25.7 | 775.9 | 19.2 | 251.4 | 7.0 | 0.5 | 1,121.6 | 3.7 |
| Standard Deviation | 0.32 | 516 | 47.1 | 21.5 | 164.6 | 2.0 | 1.7 | 0.4 | 4.5 | 281.1 | 485.3 | 186.9 | 14.4 | 0.6 | 395.3 | 9.0 |
| ***Fort Union Aquifer*** | *n* = 16 samples | | | | | | | | | | | | | | | |
| Reported and Detections | 16 | 16 | 16 | 16 | 16 | 16 | 14 | 13 | 15 | 15 | 3 | 16 | 16 | 16 | 16 | 16 |
| Maximum | 9.30 | 3,839 | 333.0 | 191.0 | 1,040.0 | 10.1 | 3.7 | 3.5 | 25.3 | 1,430.7 | 27.8 | 1,604.0 | 103.7 | 5.3 | 2,647.9 | 84.4 |
| Minimum | 7.12 | 1,030 | 2.0 | 0.9 | 54.0 | 2.0 | 0.1 | 0.0 | 6.4 | 497.0 | 20.2 | 1.2 | 0.8 | 0.1 | 670.8 | 0.9 |
| Average | 7.94 | 2,234 | 82.7 | 49.9 | 401.9 | 5.1 | 1.0 | 0.4 | 14.5 | 869.4 | 22.9 | 504.2 | 18.4 | 1.4 | 1,484.7 | 28.2 |
| Median | 7.82 | 2,044 | 49.2 | 36.3 | 334.8 | 5.2 | 0.3 | 0.0 | 13.5 | 749.0 | 20.6 | 454.0 | 6.3 | 0.4 | 1,342.6 | 8.6 |
| Standard Deviation | 0.54 | 789 | 91.2 | 52.7 | 283.4 | 2.4 | 1.2 | 0.9 | 6.9 | 298.2 | 3.5 | 391.0 | 26.0 | 1.6 | 542.0 | 30.4 |
| ***Fox Hills–Hell Creek Aquifer*** | *n* = 2 samples | | | | | | | | | | | | | | | |
| Reported and Detections | 2 | 2 | 2.0 | 2.0 | 2.0 | 2.0 | 1.0 | 1.0 | 2.0 | 2.0 | 2.0 | 1.0 | 2.0 | 2.0 | 2.0 | 2.0 |
| Maximum | 8.47 | 3,699 | 4.1 | 1.0 | 865.2 | 2.7 | 0.2 | 0.3 | 10.7 | 1,106.1 | 30.5 | 2.6 | 766.6 | 2.7 | 2,170.7 | 109.7 |
| Minimum | 8.21 | 3,340 | 3.1 | 0.9 | 804.5 | 1.9 | 0.2 | 0.3 | 9.3 | 994.4 | 12.1 | 2.6 | 594.3 | 2.3 | 1,975.8 | 94.4 |
| **Mesozoic and Paleozoic Reservoirs** | *n* = 4 samples | | | | | | | | | | | | | | | |
| Reported and Detections | 4 | 0 | 4 | 4 | 4 | 3 | 1 | 0 | 0 | 4 | 0 | 4 | 4 | 0 | 4 | 4 |
| Maximum | 7.80 | na | 13,800 | 2,760 | 110,800 | 4,200 | 26 | na | na | 2,560 | na | 780 | 202,950 | na | 330,965 | 252.9 |
| Minimum | 5.20 | na | 170 | 36 | 5,700 | 100 | 26 | na | na | 12 | na | 68 | 7,800 | na | 15,135 | 103.6 |
| Average | 6.44 | na | 8,065 | 1,405 | 77,550 | 2,190 | 26 | na | na | 727 | na | 447 | 138,163 | na | 227,731 | 208.0 |
| Median | 6.37 | na | 9,145 | 1,413 | 96,850 | 2,270 | 26 | na | na | 168 | na | 470 | 170,950 | na | 282,412 | 237.8 |
| Standard Deviation | 0.94 | na | 5,335 | 972 | 42,892 | 1,675 | 0 | na | na | 1,061 | na | 283 | 79,104 | na | 128,469 | 61.2 |

116 groundwater samples from the outwash were analyzed. Ions of calcium, magnesium, bicarbonate, and sulfate dominate the dissolved constituents. The cations range from nearly equal parts of calcium and magnesium to water high in sodium. The anions are dominated by bicarbonate plus carbonate, with a few samples high in sulfate. Four samples are dominated by chloride anions (fig. 18). We attribute the increased chloride concentrations and elevated CI to leaks and spills from facilities related to hydrocarbon development. Groundwater in the relatively shallow outwash zone is more vulnerable to near-surface brine releases than groundwater in the deeper alluvial zone. Chloride concentrations in 15 samples showed CI values greater than 0.035.

The upper outwash zone has good water quality over most of the Clear Lake aquifer, with the best-quality water from wells completed in relatively shallow outwash. Commonly, these wells are close to areas with surface deposits of sand and gravel, where precipitation recharge is likely. Multiple permeable layers in the upper outwash zone are isolated by confining layers of till or lake clay. Water in the deeper outwash commonly has higher SAR and SC than in the shallow. This water-quality stratification can pose a problem when developing irrigation supplies. Situations arise where potential pumping rates of the deeper, poor-quality water are high enough for irrigation development while the shallower, better-quality water does not produce enough water to support irrigation.

Most of the lower alluvial zone water samples are from wells completed in deep deposits, but samples from upper alluvial terrace aquifers are also included in this group (fig. 11). Fifty-four water samples from alluvial gravels were analyzed. Sodium, calcium, bicarbonate plus carbonate, and sulfate ions dominate the dissolved constituents associated with the alluvium. The cations show water dominated by calcium plus lesser amounts of magnesium to water dominated by sodium. Anions are dominated by bicarbonate and carbonate (fig. 18). One sample slightly exceeded the lower brine CI impact limit.

The inflow from bedrock often has poorer quality than water in the upper outwash or lower alluvial zones. Mixing of water from Fort Union sandstone and coal aquifers can significantly degrade water quality of the Clear Lake aquifer, primarily by increasing in the sodium concentration. This inflow can elevate the sodium adsorption ratios to levels above irrigation standards.

Wells completed in the Fort Union range in depth from less than 100 ft below the land surface to 350 ft. Sixteen samples from the Fort Union aquifer were analyzed; they showed a

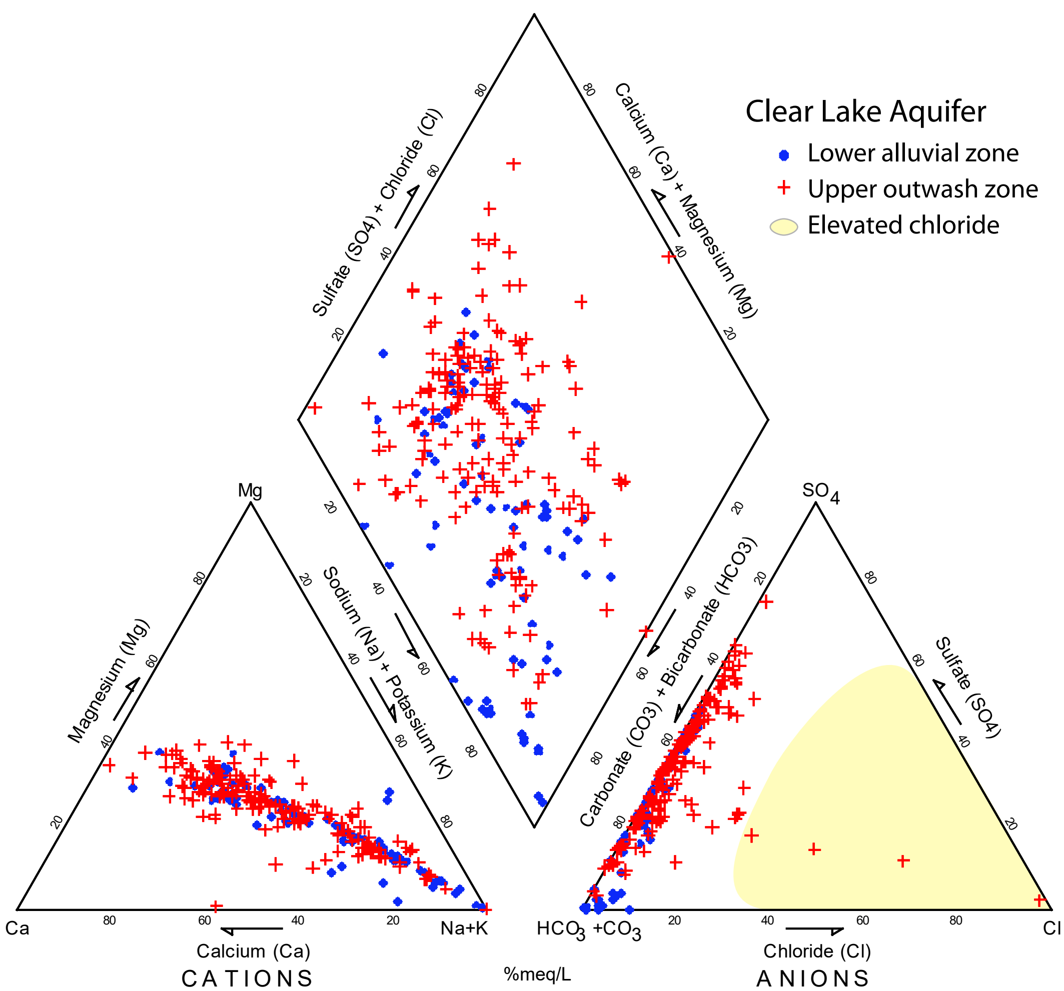


Figure 18. A Piper diagram of the Clear Lake aquifer water samples shows that there is more variability in the quality of the upper outwash zone than in the lower alluvial zone. Samples with elevated chloride (yellow shading) levels appear to be impacted by coproduced brine water from oil production.

wide range in water qualities (see fig. 19, table 3). Cations range from a calcium–magnesium mix to sodium, and anions range from sulfate-rich, to bicarbonate–carbonate. Chloride was uncommon in the Fort Union samples. The CI slightly exceeded the lower brine impact limit in only one sample. It is unlikely that brine contamination caused this exceedance.

Deeper bedrock aquifers have the potential to degrade the water quality of the Clear Lake aquifer where groundwater discharges from bedrock to the alluvial and outwash deposits. The Fox Hills–Hell Creek aquifer is about 800 to 1,200 ft deep in this area. Because of its depth, the Fox Hills–Hell Creek aquifer is not widely developed; only two wells near the study area are completed in this aquifer. Four water samples were analyzed from these two wells. Ions of sodium, bicarbonate, and chloride dominate the dissolved constituents (fig. 19). The elevated chloride in samples from the Fox Hills–Hell Creek aquifer causes a moderately high CI. This results from naturally occurring chloride concentrations and a relatively low SC, not because of brine contamination. Fox Hills–Hell Creek aquifer water discharging from flowing wells can give the appearance of brine contamination where it discharges to surface water or shallow fresh water aquifers.

Groundwater from formations deeper than the Fox Hills–Hell Creek is not used for irrigation or stock water in this area, but is produced as wastewater during oil and gas production. Groundwater from Mesozoic and Paleozoic reservoirs associated with hydrocarbon development is high in sodium and chloride ions. The average concentration based on four water samples was 77,550 mg/L for sodium and 138,000 mg/L for chloride (table 3). Figure 19 shows the contrast in major ion chemistry between the deep Mesozoic and Paleozoic reservoirs, the Fox Hills–Hell Creek aquifer, and Fort Union aquifers. Samples from the Mesozoic and Paleozoic reservoirs cluster near the maximum of the trilinear axes for sodium and chloride.

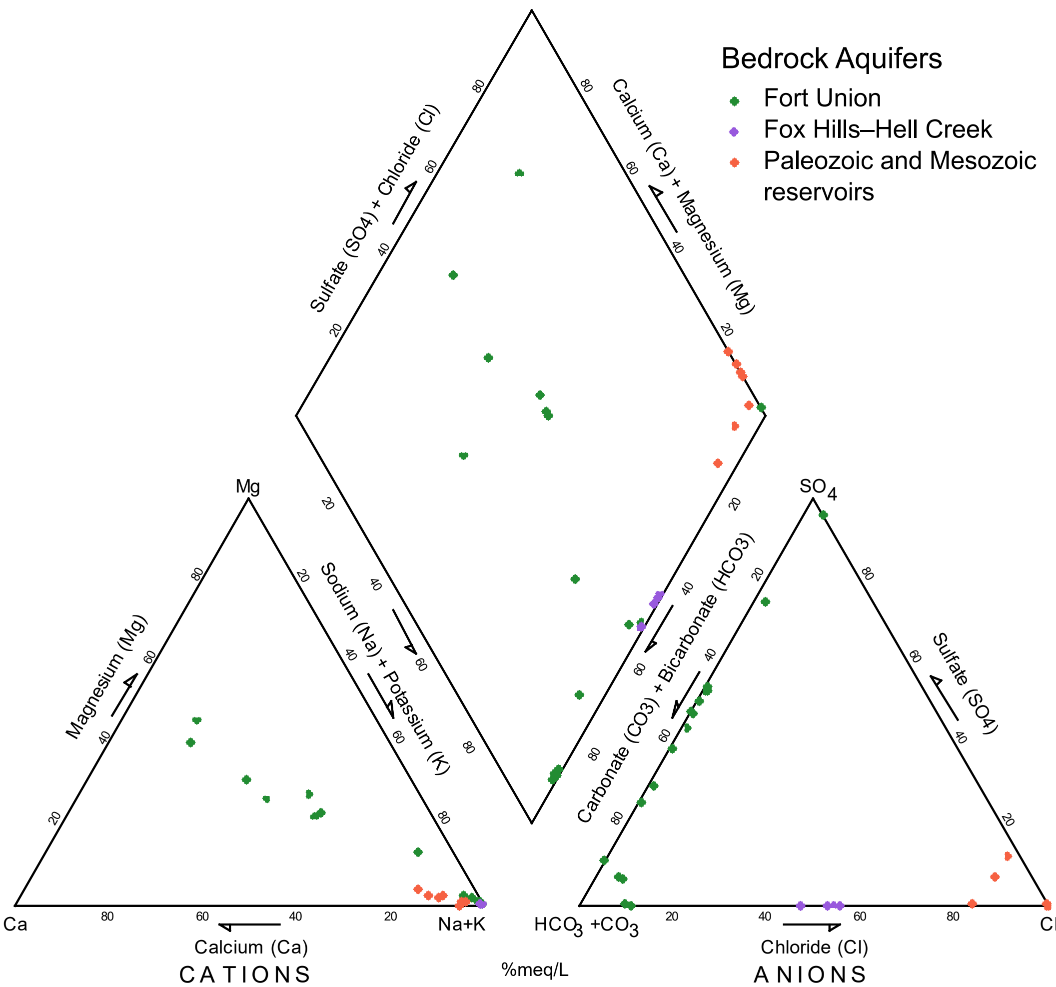


Figure 19. A Piper diagram of the bedrock aquifer samples shows the Fort Union Formation aquifers have the greatest variability in water quality. The Fox Hills–Hell Creek samples show elevated chloride (yellow shading), but are distinct from the Mesozoic and Paleozoic reservoir samples, which are strongly sodium chloride brine waters.

Poor water quality in parts of the Clear Lake aquifer can be a significant problem for irrigators; therefore the usability of groundwater for irrigation is often characterized by comparing the SC and SAR of the water. The SAR is the ratio of calcium plus magnesium to sodium with concentrations measured in milliequivalents per liter:

$$SAR = [Na] / \sqrt{\frac{[Ca] + [Mg]}{2}}$$

A plot of the SC versus the SAR (fig. 20) describes irrigation hazard potential (USDA, 1954). The SC increases with dissolved solids in the water and the SAR increases with

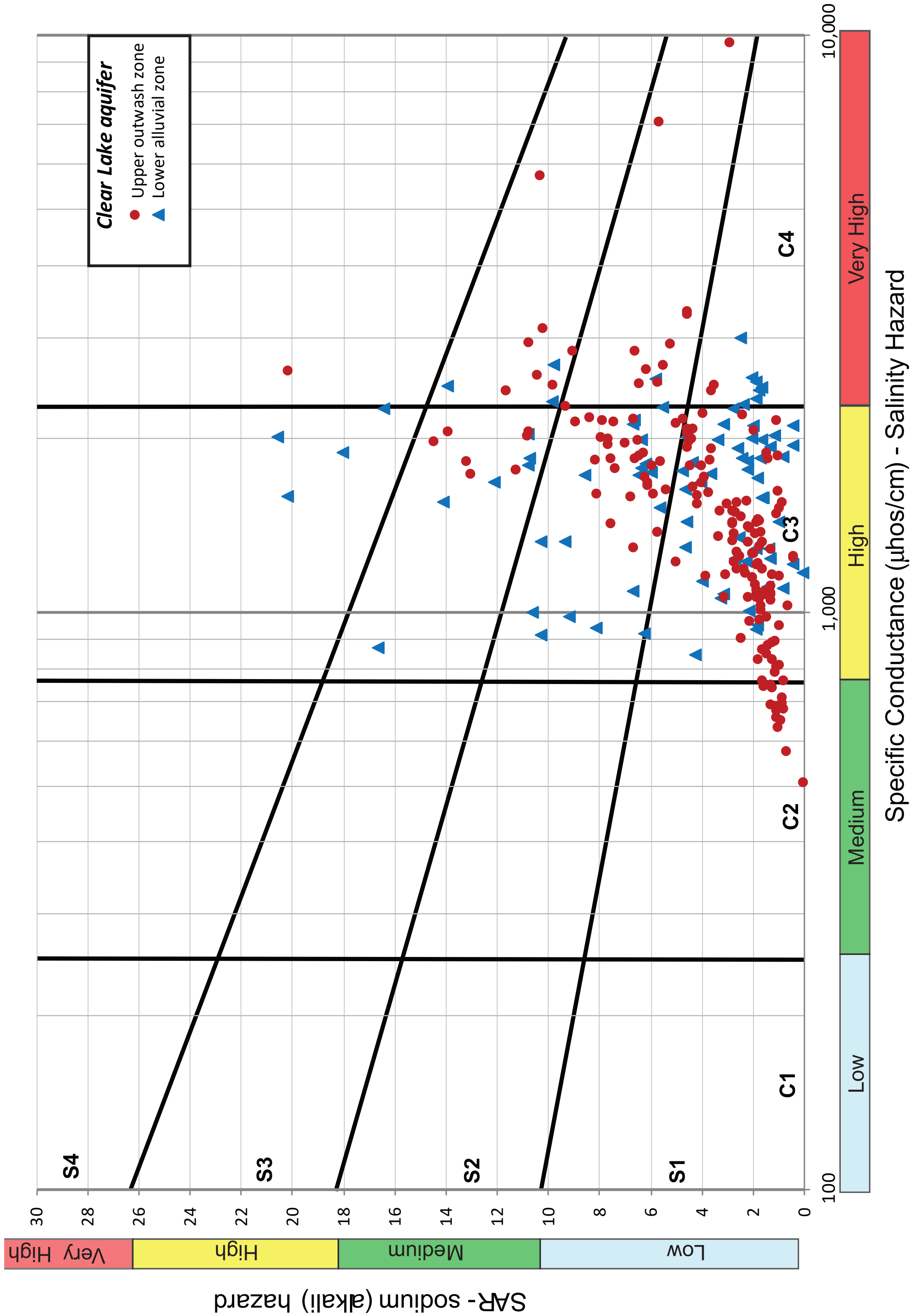


Figure 20. Plot of water samples from the Clear Lake aquifer using the USDA irrigation-water classification diagram (USDA, 1954).

an increase in sodium relative to the alkaline earth cations (calcium and magnesium). The groundwater SC commonly encountered in this area ranges from 750 to 2,250 micro-Siemens/cm (µS/cm). In this SC range, water poses a high-sodium (alkali) hazard at SAR greater than about 10–13; a medium hazard at SAR ranging from 4 to 10; and a low hazard below SAR of 4. In northeastern Montana, high-salinity hazards with SAR greater than 13 resulted in soil damage and abandonment of irrigation systems.

Figure 21 depicts areas of good and marginal water quality based on SAR in the upper outwash zone (fig. 21A) and lower alluvial zone (fig. 21B). The lower alluvial zone is more likely to have poor water quality based on SAR (fig. 21A). The buried alluvial valleys incise deeper into Fort Union bedrock than buried glacial outwash channels, and the buried alluvial valleys are more likely to intercept discharge from saturated coal and sandstone beds of the Fort Union aquifers (Seyoum and Eckstein, 2014).

As the high SC and SAR groundwater from the Fort Union Formation discharges into the buried valley aquifer, the bedrock groundwater mixes with the Clear Lake aquifer and decreases the SAR. This is illustrated by the SAR and SC from samples at wells 3612, 221637, 221634, and 169217 (figs. 21, 22). Water from the Fort Union bedrock well 3612, south of the buried valley, has an SAR value of 65.3. About 2 mi north, well 221637, completed 288 ft deep in the lower alluvial zone, has an SAR of 62. The SAR steadily decreases to the north as the high SAR bedrock groundwater is diluted. About ¼ mi north of 221637, the SAR at 221634 is 10.3. The SAR decreases to 2.1 at well 169217, 1 mi farther north. There apparently is enough high SAR water flowing from Fort Union aquifers to degrade the buried valley groundwater quality over large areas near the aquifer boundaries. Fresh, low SAR water enters the buried valley aquifer as precipitation recharges the sand hills area, to the east of the cross section in figure 22. This recharge results in water quality in the center of the aquifer suitable for irrigation development.

Groundwater can become unusable for irrigation if brines produced during hydrocarbon extraction infiltrate the aquifers. The TDS of water in deep aquifers associated with hydrocarbons can reach up to 10 times the TDS of seawater (Reiten and Tischmack, 1993). The average SAR of the brines produced with hydrocarbons is about 208 (table 3). Only small volumes from leaks and spills of produced water have been documented infiltrating irrigation supplies (Reiten, 2002). Because of high chloride concentrations in the produced water, spikes in chloride concentrations affect groundwater prior to major changes in SAR or SC. Samples collected from an irrigation well (3859) west of Brush Lake increased in chloride concentration from 32 mg/L in 1982 to 100 mg/L in 1995. In 2015, a sample from this well showed a small decrease in the chloride concentration, to 92 mg/L. Although the SC has increased about 20% since 1982, the SAR has remained stable at 1.9. While it appears that produced waters have affected the Clear Lake aquifer water quality at this site, the groundwater remains suitable for irrigation.

## SOUTH MEDICINE LAKE FOCUS AREA

The South Medicine Lake area was selected for a focused investigation because of concerns that irrigation withdrawals were affecting the water level in Medicine Lake and flows in Big Muddy Creek, and that additional groundwater development for irrigation could have detrimental effects on surface water. Irrigation wells in the South Medicine Lake area are 150–250 ft deep with static water levels 40 to 125 ft below the surface. The aquifer has variable water quality and is slow to recharge. Pumping for irrigation produces large drawdowns in some areas with the potential for well interference. Extensive test drilling and monitoring in this isolated branch of the Clear Lake aquifer provided hydrogeologic information for groundwater-flow models (Chandler and Reiten, 2019).

### Hydrogeologic Framework

The Clear Lake aquifer in the focus area occupies a west-to-east-trending buried valley located south of Medicine Lake. The aquifer is bounded to the north by a bedrock ridge that underlies the southern part of Medicine Lake. This effectively separates the south channel from the deeper north channel of the aquifer (fig. 23). The south channel boundary is a buried bedrock escarpment formed by erosion. A map of the elevation of the bedrock surface shows the incised valley, which is now filled by the aquifer materials and overlying sediments (fig. 23). The southern boundary crosses the surface expression of the Brockton–Froid Fault zone (Bergantino and Wilde, 1999; fig. 24).

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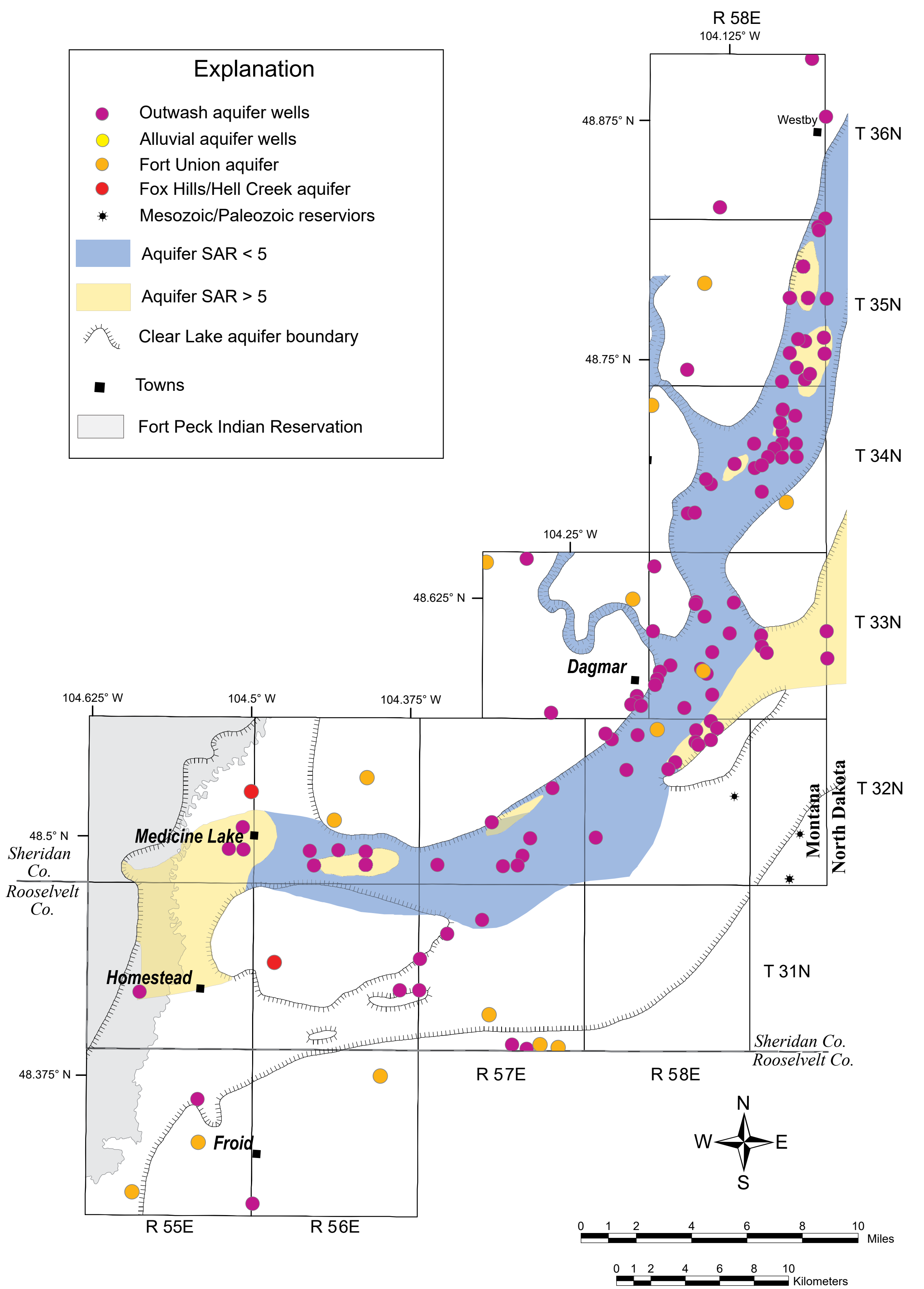
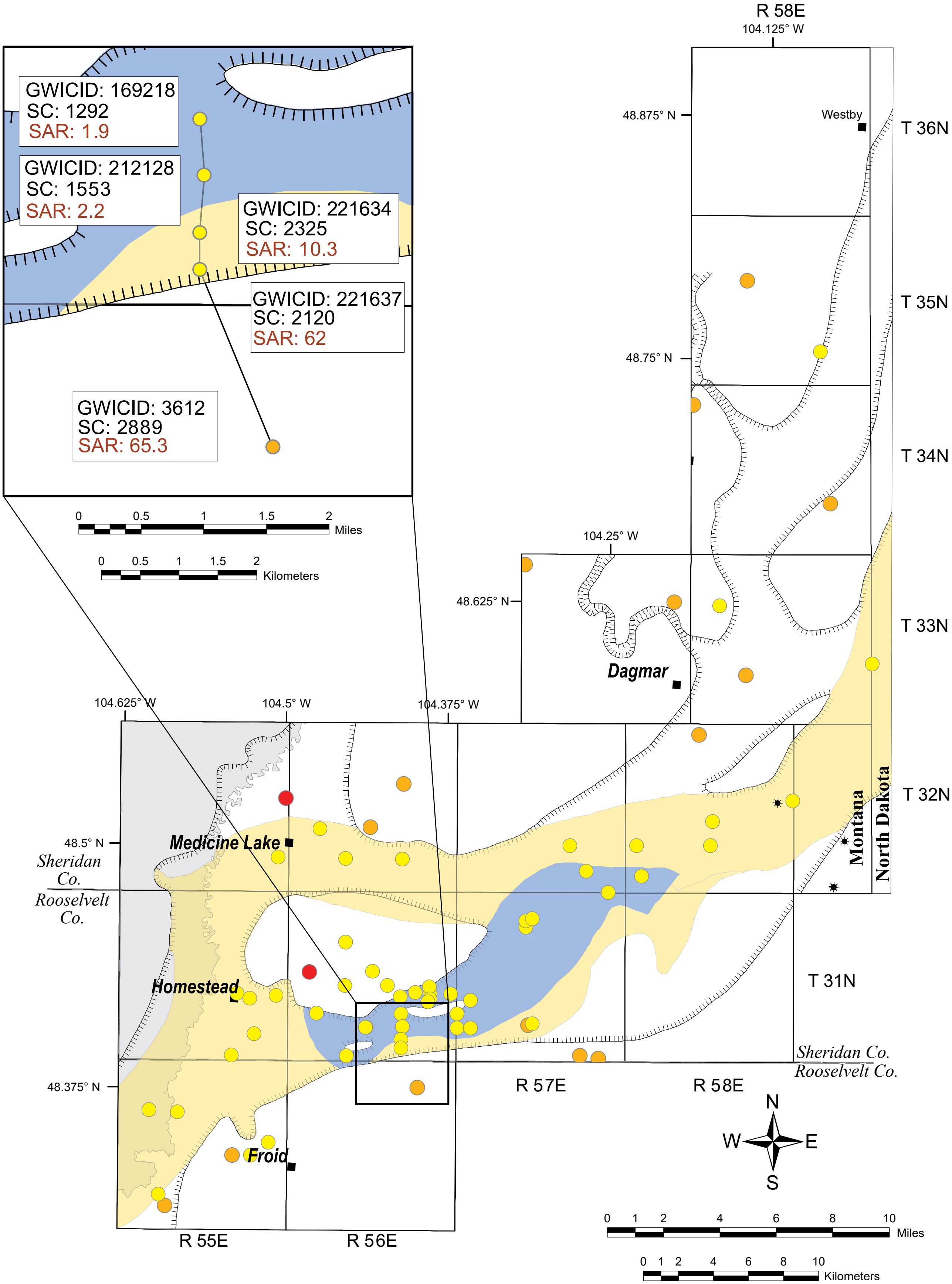



A. Outwash Gravel SAR

Figure 21. Clear Lake aquifer water quality based on sodium adsorption ratio. (A) Outwash gravel. B on following page.




## B. Alluvial Gravel SAR

Figure 21, continued. (B) alluvial gravel.

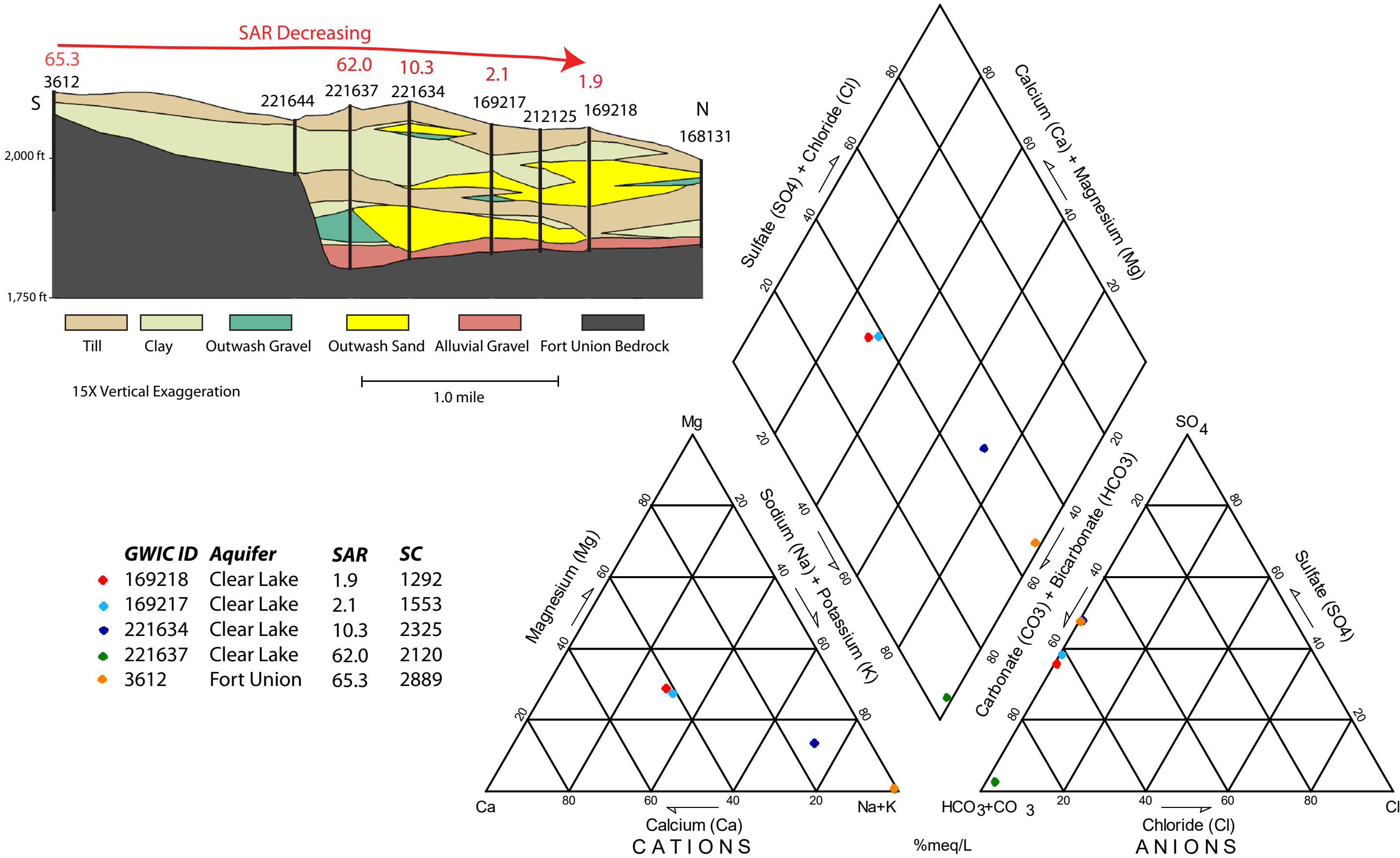



Figure 22. Piper plot showing water-quality differences near the southern boundary of the Clear Lake aquifer and cross section showing stratigraphy and changing SAR conditions in the aquifer. Well locations are on figure 21B, inset.

fault offsets deep basement rocks (Rogers and others, 1985) as well as Quaternary glacial sediments (Colton, 1963).

Lithologic logs and interpretations of hydrogeologic conditions were used to define the model boundaries of the Clear Lake aquifer. Four cross sections were constructed perpendicular to the buried valley (fig. 24). The farthest east cross section profiles three distinct alluvial channels separated by low-permeability bedrock boundaries (fig. 24, cross section A–A´). A bedrock high forms a hydraulic barrier separating the lower alluvial zone underlying the northern part of Medicine Lake from the lower alluvial zone in the focus area. Drilling density is insufficient to locate this boundary, but well logs indicated a thinning of the aquifer as shown in cross section A–A´ at well 169219.

Other hydrogeologic observations provided useful information for identifying aquifer boundaries. Well 169219 is completed in sand and gravel of the Clear Lake aquifer. Water-level fluctuations show a strong response at this well to pumping at irrigation well 121117 about 1 mi to the southwest, confirming that well 169219 has a good hydraulic connection to the Clear Lake aquifer (fig. 25). It typically has flowing artesian conditions with a potentiometric surface about 35–40 ft above the level of Medicine Lake (cross section A–A´). If the aquifer had a good hydraulic connection to the lake at this well, aquifer heads would equilibrate with the lake level and the well would not flow. These observations indicate confined conditions and a barrier boundary between well 169219 and the lake. Well 169220 is another flowing well located about 2.2 mi northeast of irrigation well 121117. Figure 25 compares the water-level fluctuations at well 43113 (25 ft NE of well 121117), well 169219 (5,035 ft NE), and well 169220 (11,670 ft NE); these wells respond to pumping at irrigation well 121117.

In the focus area, the aquifer splits into two southern channels. Bedrock highs form longitudinal hydraulic barriers, which restrict lateral flow within the aquifer (fig. 23). Shaver and Pusc (1992) identified similar longitudinal barriers in a buried valley aquifer near Minot, North Dakota. These longitudinal barriers compartmentalize buried valleys and isolate parts of the aquifer. Shaver and Pusc (1992) observed that these

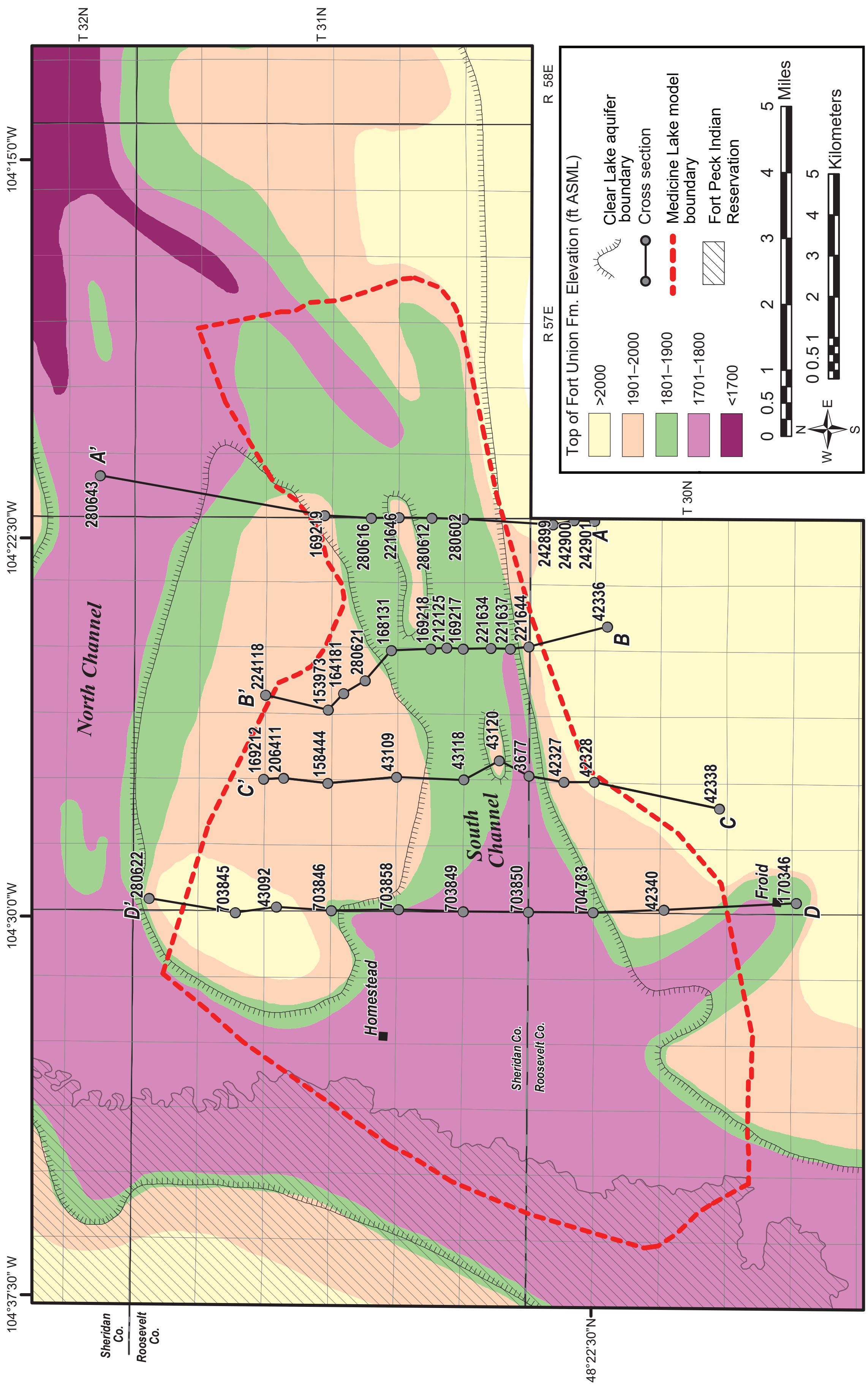



Figure 23. Altitude of the top of the Fort Union Formation showing the South Medicine Lake cross sections.

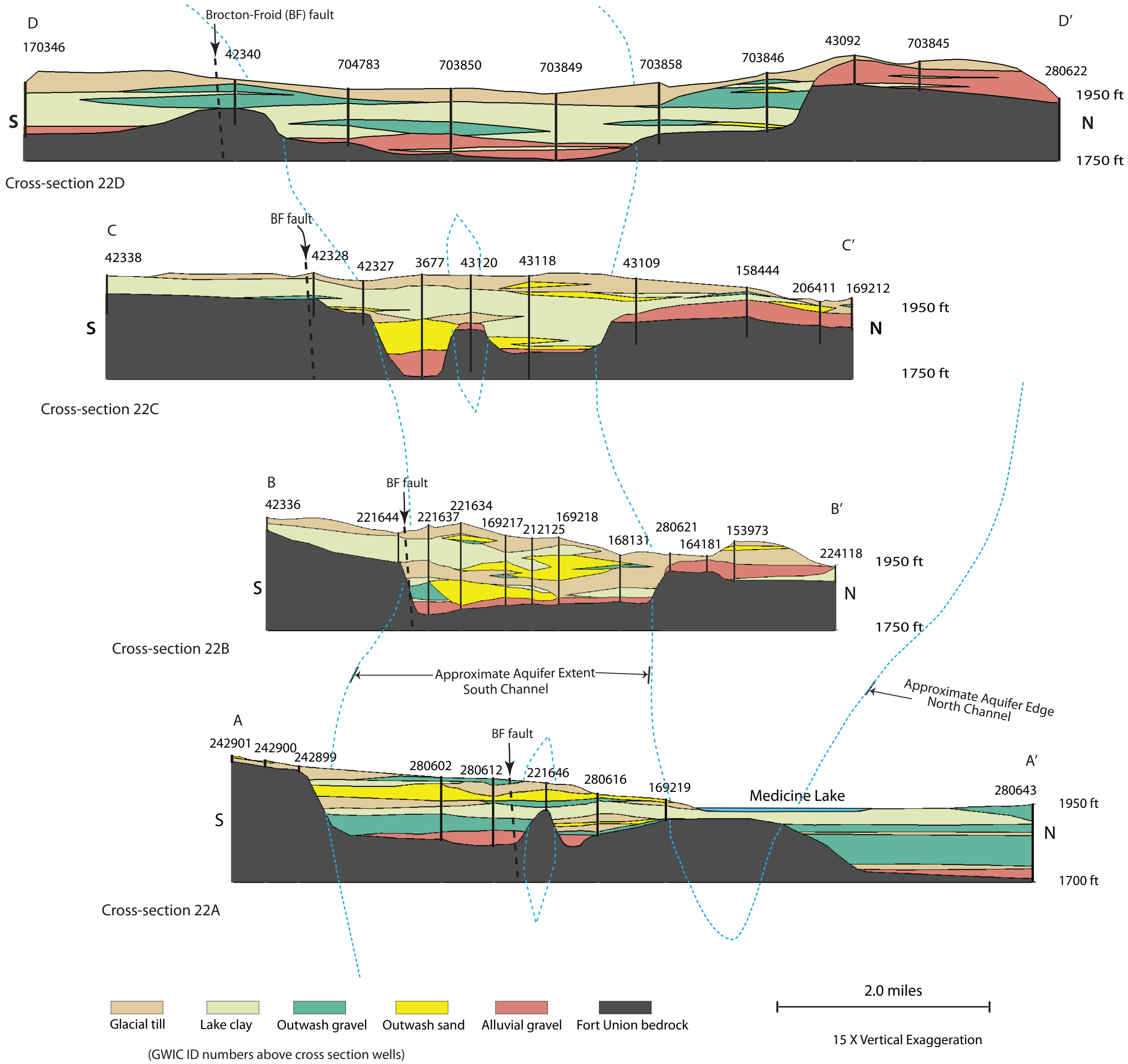



Figure 24. Cross sections constructed perpendicular to the axis of the South Medicine Lake buried valley display current interpretations of the hydrostratigraphy of the Clear Lake aquifer southern channel. (Cross section locations, fig. 23).

longitudinal barriers form at a variety of scales and can completely hydraulically isolate and compartmentalize subchannels or act as partial hydraulic barriers. Cross sections A–A′, B–B′, C–C′, and D–D′ (fig. 24) present an interpretation of the channel geometry and aquifer from east to west. Cross section B–B′ (fig. 24) profiles the buried valley as one channel bounded on the south by the Brockton–Froid Fault zone (labeled BF in fig. 24). This steep bedrock escarpment bounds the lower alluvial zone and groundwater inflow from the bedrock mixes with the alluvial groundwater. The northwest edge of the buried valley along cross section B–B′ is located between well 168131and well 280621. North of the buried channel, along this cross section, thick sand and gravel associated with a higher terrace of the ancestral Missouri River overlies Fort Union bedrock. This upper alluvial terrace forms an aquifer, which is hydrologically isolated from the Clear Lake aquifer by low conductivity glacial till and clay. Similar terraces occur along much of the northwest flank of the buried valley.

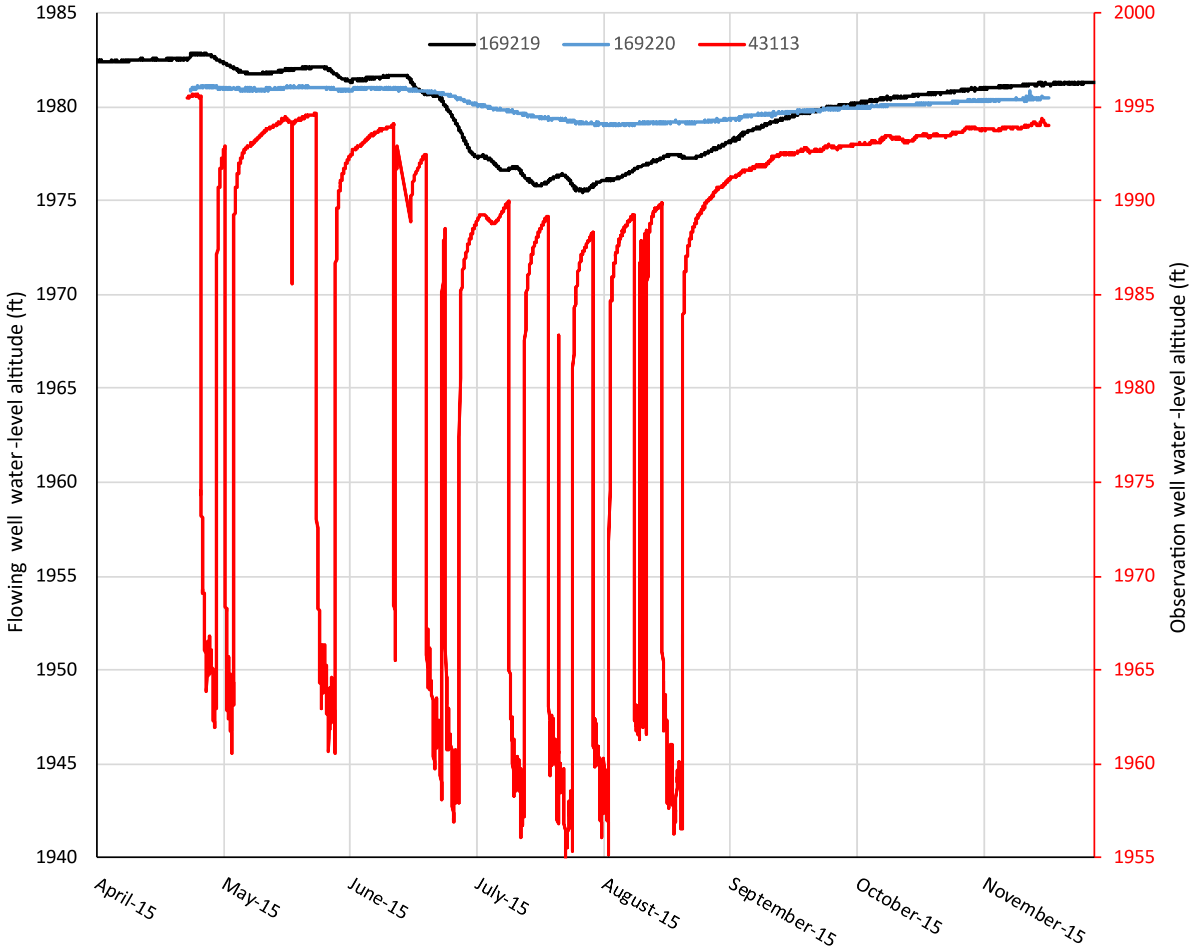



Figure 25. Hydrograph showing response at three wells to pumping of irrigation well 121117. Well 43113 is located 25 ft northeast of the irrigation well. Two wells under flowing artesian conditions were also monitored: well 169219 is 0.95 mi northeast and well 169220 is located 2.2 mi northeast. Right axis for well 43113.

To the west, cross section C–C′ (fig. 24) identifies two lower alluvial zone channels separated by a bedrock ridge. The southern channel incises into the Fort Union bedrock to a depth of 350 ft. This is about 100 ft deeper than any other segment of the buried valley aquifer in the south Medicine Lake area. As in other cross sections, relatively steep escarpments incised into the Fort Union bedrock form the lateral boundaries of the buried valley aquifer. A higher elevation alluvial gravel terrace overlies the bedrock ridge (well 43120). The groundwater in this terrace north of the buried valley is unconfined (wells 158444 and 206411). Heads in the terrace are about 20 ft lower than in the lower alluvial zone of the south channel. The upper terrace underlies most of the area between the south buried valley channel and Medicine Lake. Groundwater flow in the upper terrace aquifer is towards the lake and daylights at springs and seeps in the small drainages.

The westernmost cross section D–D′ (fig. 24) profiles a wide, buried valley portion of the Clear Lake aquifer bounded laterally by Fort Union bedrock. The southern boundary closely aligns with the Brockton–Froid Fault zone. South of the fault, a tributary channel to the buried valley projects into the cross section. This may be a lower alluvial channel or an upper outwash zone channel associated with Sheep Creek near Froid. On the north end of this cross section, the upper alluvial terrace aquifer is isolated from the lower alluvial zone of the Clear Lake aquifer.

## Aquifer Properties

Water-level monitoring in 2015 near four irrigation wells provided data to estimate aquifer parameters. Irrigation pumping resulted in drawdown in nearby monitoring wells, which was analyzed as fortuitous aquifer tests. Tables 4–7 summarize these tests, and interpretations are presented in appendix C.

Average parameters calculated from multiple tests at each well represent reasonable estimates of the aquifer conditions. The average transmissivity ranged from about 2,940 $ft^2/d$ to 9,900 $ft^2/d$. The average

Table 4. Summary of 2015 aquifer tests at Nelson 1 (121117), monitoring well 43113.

| Test | Test Date Range | Time Pumped (min) | Pumping Rate Q (gpm) | Transmissivity T (ft²/day) | Aquifer Thickness (ft) | Hydraulic Conductivity K (ft/day) | Storage Coefficient |
|---|---|---|---|---|---|---|---|
| 1 | 4/16–4/27 | 2,055 | 800 | 3,203 | 30 | 107 | 0.0026 |
| 2 | 5/2–5/4 | 2,755 | 800 | 3,240 | 30 | 108 | 0.0019 |
| 3 | 5/24–5/29 | 6,525 | 800 | 3,316 | 30 | 110 | 0.0025 |
| 4 | 6/11 | 495 | 800 | 3,203 | 30 | 107 | 0.0024 |
| 5 | 6/20–6/24 | 5,460 | 800 | 3,240 | 30 | 108 | 0.0019 |
| 6 | 6/25–6/28 | 4,920 | 800 | 3,240 | 30 | 108 | 0.0024 |
| 7 | 7/10–7/14 | 5,520 | 800 | 3,240 | 30 | 108 | 0.0019 |
| 8 | 7/20–7/26 | 8,520 | 800 | 3,203 | 30 | 107 | 0.0026 |
| 9 | 7/31–8/4 | 5,760 | 800 | 3,203 | 30 | 107 | 0.0023 |
| 10 | 8/10–8/11 | 1,755 | 800 | 3,240 | 30 | 108 | 0.0047 |
| 11 | 8/11 | 285 | 800 | 3,240 | 30 | 108 | 0.0024 |
| 12 | 8/12 | 270 | 800 | 3,240 | 30 | 108 | 0.0018 |
| 13 | 8/17–8/22 | 6,855 | 800 | 3,240 | 30 | 108 | 0.0015 |
| | | | Minimum | 3,203 | 30 | 107 | 0.0015 |
| | | | Maximum | 3,316 | 30 | 110 | 0.0047 |
| | | | Average | 3,234 | 30 | 108 | 0.0024 |

*Note.* Distance: *r* = 25, Cooper–Jacob method.

Table 5. Summary of 2015 aquifer tests at Nelson 2 (155930), monitoring well 155929.

| Test | Test Date Range | Timed Pumped (min) | Pumping Rate Q (gpm) | Transmissivity T ($ft^2$/day) | Aquifer Thickness (ft) | Hydraulic Conductivity (ft/day) | Storage Coefficient |
|---|---|---|---|---|---|---|---|
| 1 | 6/22–6/24 | 2,280 | 750 | 3,722 | 22 | 169 | 0.00021 |
| 2 | 7/22–7/25 | 3,570 | 750 | 4,556 | 22 | 207 | 0.00015 |
| 3 | 7/3–7/7 | 5,560 | 750 | 4,804 | 22 | 218 | 0.00015 |
| 4 | 7/10–7/13 | 3,660 | 750 | 4,719 | 22 | 214 | 0.00015 |
| 5 | 7/14–7/15 | 1,800 | 750 | 5,285 | 22 | 240 | 0.00017 |
| | | | Minimum | 3,722 | 22 | 169 | 0.00015 |
| | | | Maximum | 5,285 | 22 | 240 | 0.00021 |
| | | | Average | 4,617 | 22 | 210 | 0.00017 |

*Note.* Distance: *r* = 700 ft, Cooper–Jacob method.

hydraulic conductivity ranged from 108 ft/d to 450 ft/d. The average storage coefficient ranged from 0.00017 to 0.017. Storage coefficient estimates from monitoring wells less than 25 ft from the production wells were about one order of magnitude greater than estimates from more distant monitoring wells. These tests likely reflect non-linear flow and are not presented here. A reasonable estimate of storage coefficient in the South Medicine Lake focus area is about 0.0002. The range of estimates are similar to estimates for the lower alluvial zone shown in table 2. The presence of thick fine-grained sediments overlying the aquifer, the low magnitude of the storage coefficient, and observation of relatively high barometric efficiencies indicate confined aquifer conditions.

Water-level measurements from the 2015 irrigation season identified areas with large amounts of drawdown, which suggests proximity to barrier boundaries and potential well interference. When a cone of depression around a production well contacts a barrier boundary, the rate of change of drawdown doubles (Fetter, 2001). Boundary effects are shown on time-drawdown plots compiled in appendix C4. Figure 26 shows the maximum drawdown observed in moni-

Table 6. Summary of 2015 aquifer tests at Nelson 3 (212128), monitoring well 169217.

| Test | Test Date Range | Time Pumped (min) | Pumping Rate Q (gpm) | Transmissivity T (ft²/day) | Aquifer Thickness(ft) | Hydraulic Conductivity (ft/day) | Storage Coefficient |
|---|---|---|---|---|---|---|---|
| 1 | 5/2–5/4 | 2,805 | 665 | 10,413 | 22 | 473 | 0.00048 |
| 2 | 5/29–6/1 | 4,380 | 665 | 9,372 | 22 | 426 | 0.00020 |
| 3 | 6/12–6/13 | 1,185 | 665 | 9,117 | 22 | 414 | 0.00028 |
| 4 | 6/16–6/17 | 1,620 | 665 | 10,898 | 22 | 495 | 0.00013 |
| 5 | 6/22–6/23 | 1,560 | 665 | 10,276 | 22 | 467 | 0.00036 |
| 6 | 6/26–6/30 | 5,880 | 665 | 9,372 | 22 | 426 | 0.00027 |
| 7 | 7/3–7/7 | 5,565 | 665 | 9,602 | 22 | 436 | 0.00020 |
| 8 | 7/10–7/12 | 2,280 | 665 | 10,413 | 22 | 473 | 0.00013 |
| 9 | 7/22–7/26 | 5,640 | 665 | 9,448 | 22 | 429 | 0.00020 |
| | | | Minimum | 9,117 | 22 | 414 | 0.00013 |
| | | | Maximum | 10,898 | 22 | 495 | 0.00048 |
| | | | Average | 9,879 | 22 | 449 | 0.00025 |

*Note.* Distance: *r* = 210 ft, Cooper–Jacob method.

Table 7. Summary of 2015 aquifer tests at Bolstad (175651), monitoring well 43116.

| Test | Test Date Range | Time Pumped (min) | Pumping Rate Q (gpm) | Transmissivity T (ft²/day) | Aquifer Thickness (ft) | Hydraulic Conductivity K (ft/day) | Storage Coefficient |
|---|---|---|---|---|---|---|---|
| 1 | 4/28–4/29 | 1,275 | 795 | 2,745 | 30 | 152 | 0.0024 |
| 2 | 5/23–5/29 | 8,130 | 795 | 2,334 | 30 | 130 | 0.052 |
| 3 | 7/31–8/6 | 9,000 | 795 | 3,257 | 30 | 181 | 0.027 |
| 4 | 6/9–6/11 | 3,183 | 795 | 3,165 | 30 | 177 | 0.0024 |
| 5 | 8/10–8/17 | 10,000 | 795 | 3,220 | 30 | 179 | 0.0024 |
| | | | Minimum | 2,334 | 30 | 130 | 0.0024 |
| | | | Maximum | 3,257 | 30 | 181 | 0.0520 |
| | | | Average | 2,944 | 30 | 164 | 0.0172 |

*Note.* Distance: *r* = 20 ft, Cooper–Jacob method.

toring wells of the South Medicine Lake area during the summer 2015 irrigation season. The four irrigation wells in this area are identified along with the average pumping rate, volume of water pumped in 2015, and average hydraulic conductivity. Three of the wells—Nelson 1 (well 121117), Nelson 2 (well 155930), and Bolstad (well 175651)—are associated with the northern channel of the focus area. The fourth well (Nelson 3, 212128) is more aligned with the southern channel. The distribution of the aquifer parameters suggests higher transmissivity and hydraulic conductivity associated with the southernmost channel.

The greatest drawdown observed was in the immediate vicinity of the Bolstad well. Data loggers measured over 50 ft of drawdown at the monitoring well located about 25 ft from the Bolstad production well (well 43116). The largest area of cumulative drawdown was in the north channel of the aquifer near Nelson 1 and Nelson 2 irrigation wells, showing well interference. The large drawdowns are strong evidence for nearby hydraulic boundaries (van der Kamp and Maathuis, 2012).

## Groundwater Flow

The potentiometric map was constructed from water levels measured in April–May 2015 (fig. 14). Water levels were recovering from the 2014 irrigation season and did not appear to be affected by spring recharge prior to the 2015 irrigation season. Groundwater flows from northeast to southwest in much of the South Medicine Lake focus area (fig. 14). The flow is away from the groundwater mound underlying an area of focused recharge at the overlying sand hills.

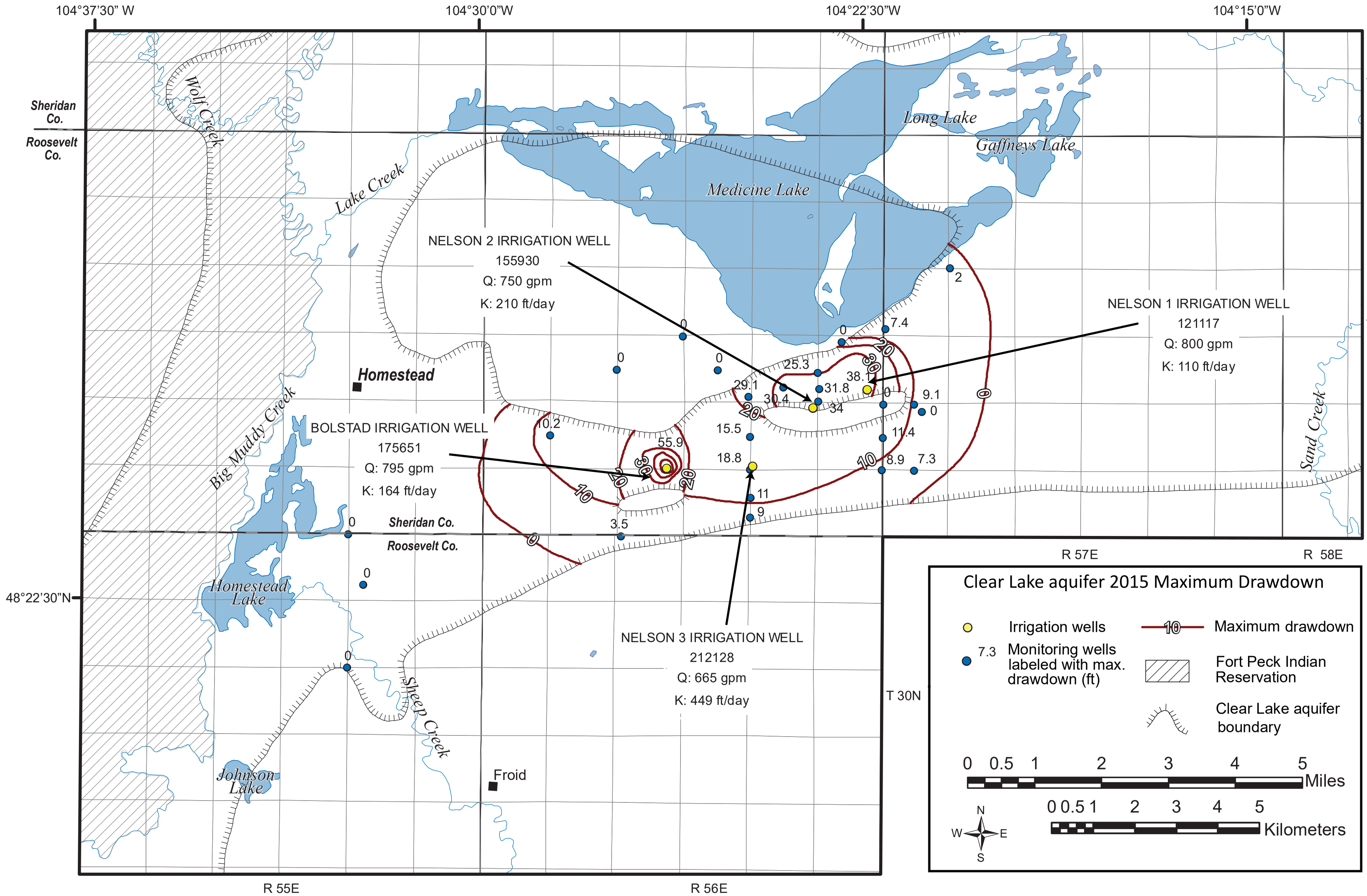



Figure 26. Map of maximum drawdown observed in the South Medicine Lake area during the 2015 irrigation season. For each irrigation well the GWIC ID, pumping rate (Q, gpm), and the average hydraulic conductivity (K, ft/day) are shown.

## Groundwater Recharge and Discharge

Infiltration of rainfall and snowmelt directly recharges the aquifer, and other areas extending several miles laterally likely provide additional recharge to the Clear Lake aquifer through groundwater flux. The permeability of surface materials is a dominant factor controlling recharge rates. This is evident in the sand hills, where the loose fine sand allows rapid infiltration without runoff. The Quaternary eolium mapped in figure 8 shows the extent of sand hills. Other sources of recharge likely include unmapped gravel deposits and the bedrock aquifers along the edges of the buried valley aquifer. The numeric model indicates these are both important, but poorly defined, sources of recharge (Chandler and Reiten, 2019).

Discharge from the South Medicine Lake portion of the Clear Lake aquifer is to deep and shallow deposits in the Big Muddy Creek Valley between Homestead and Froid (fig. 14). Several wells completed in deep gravel deposits indicate a continuation of the aquifer under the Big Muddy Creek Valley, but the extent and hydraulic gradient of this deep aquifer is unknown.

As groundwater flows towards Big Muddy Creek, there is likewise an unknown volume of upward seepage to the wetlands and the creek. This seepage is a fraction of wetland inflow as water also flows in from deep and shallow sources upgradient to the north and west. In this area south of Homestead, wetlands cover about four sections along the east side of Big Muddy Creek. ET from area wetlands is estimated to remove 3 to 5 ft per year (Donovan, 1988). Based on a four section area (2,560 acres), ET discharge from this part of the wetlands ranges from about 7,700 acre-ft/yr to 12,800 acre-ft/yr. The volume pumped for irrigation (typically less than 600 acre-ft/yr) is 5–7% of the estimated water loss to ET. For pumping to decrease aquifer seepage to the wetlands or creeks, there would have to be a decrease in the deep aquifer heads. We observed no head changes in response to irrigation pumping in deep upgradient wells. Deep aquifer water levels actually increased during the irrigation season of 2015 at well 3605, just east of Homestead Lake (fig. 27). It is unlikely that pumping from the four existing irrigation wells measurably affects water levels in the Homestead area wetlands or Big Muddy Creek.

## Groundwater Modeling and Water-Use Scenarios

The numerical models presented by Chandler and Reiten (2020) were based on detailed stratigraphic

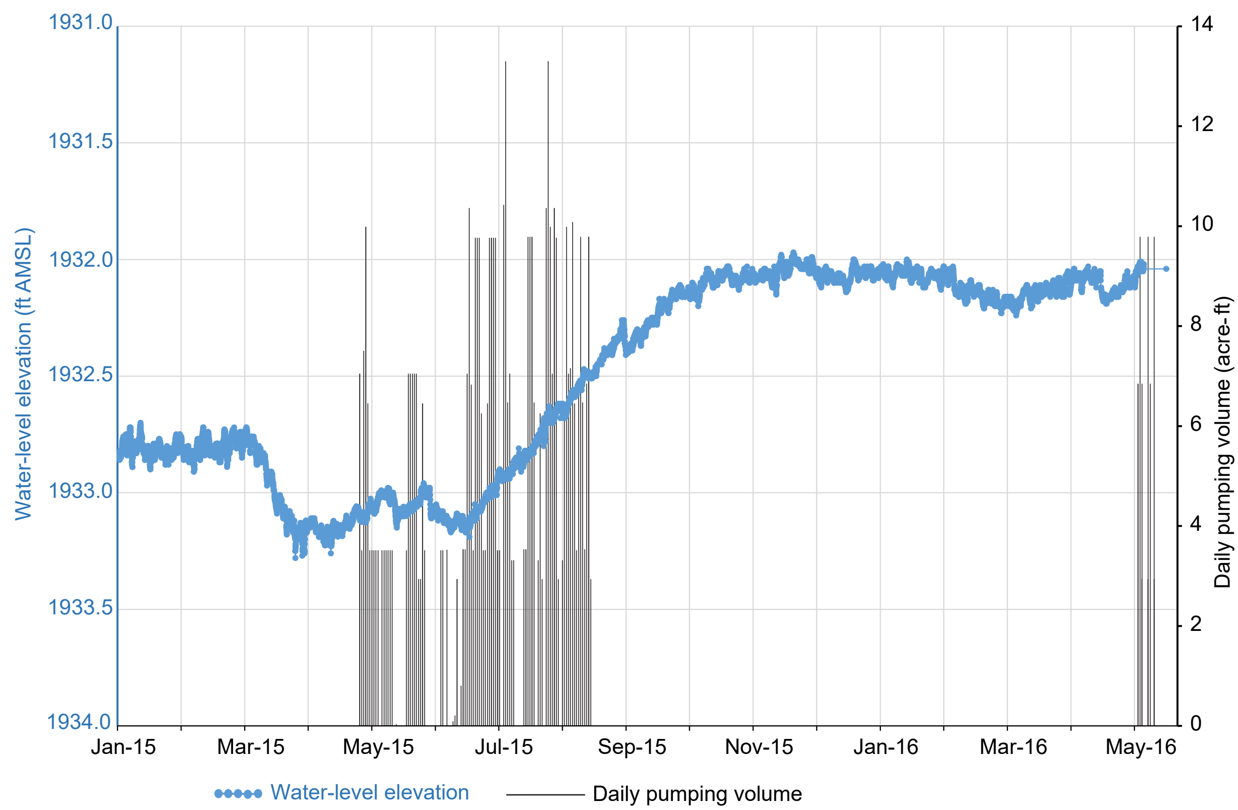



Figure 27. Water levels at well 3605 do not show response to irrigation well pumping from the Clear Lake aquifer south of Medicine Lake. Monitoring well 3605 (185 ft deep) is located south of Homestead in the Big Muddy Creek Valley (plate 3).

modeling, records of irrigation water-use and pumping duration, and aquifer parameters from this study. The model simulates the timing and magnitude of 2015 observed drawdown (Scenario 1). After calibration, a "no use" or "control" output was generated by simulating the system with no irrigation pumping (Scenario 2). Additional model runs simulated increased irrigation water use (Scenario 3) and twice the number of irrigation wells (Scenarios 4 and 5). The head changes resulting from increased use were isolated from those related to boundary condition effects (recharge and ET) by calculating the head difference between "increased use" and "no use" simulations. The head difference results for the time periods of maximum drawdown are contoured for comparison (figs. 28–31). Water-level changes were compared at four model cells in the Big Muddy Creek Valley. Cell 80239 showed the greatest drawdown of the four cells and is therefore mentioned in the scenarios for comparison. Hydrographs of water levels at four model cells near wetlands in the Big Muddy Creek alluvial valley illustrate results of Scenario 5, the greatest water use of these simulations (fig. 32).

## Scenario Results

*Scenario 1: Four Well 2015 Volume Pumping (483 acre-ft)*

The first scenario simulated the pumping schedule recorded in 2015 at the four existing irrigation wells. The results of scenario 1 show well interference between the irrigation wells (fig. 28). Drawdown greater than 30 ft was predicted for the eastmost well 121117. This well is the closest to the barrier boundary between the aquifer and Medicine Lake, and this explains the large drawdown here. Figure 28 shows the maximum drawdown simulated during 2015. The drawdown from the wells intersect, producing cumulative drawdown or well interference as several irrigation wells pump simultaneously. The cumulative drawdown cone extends for more than 4 mi, with a maximum drawdown of 0.35 ft at cell 80239 near Homestead.

*Scenario 2: "No use" (0 acre-ft)*

The "no use" scenario simulated heads before irrigation development and provided a baseline for comparison of the different pumping scenarios. This

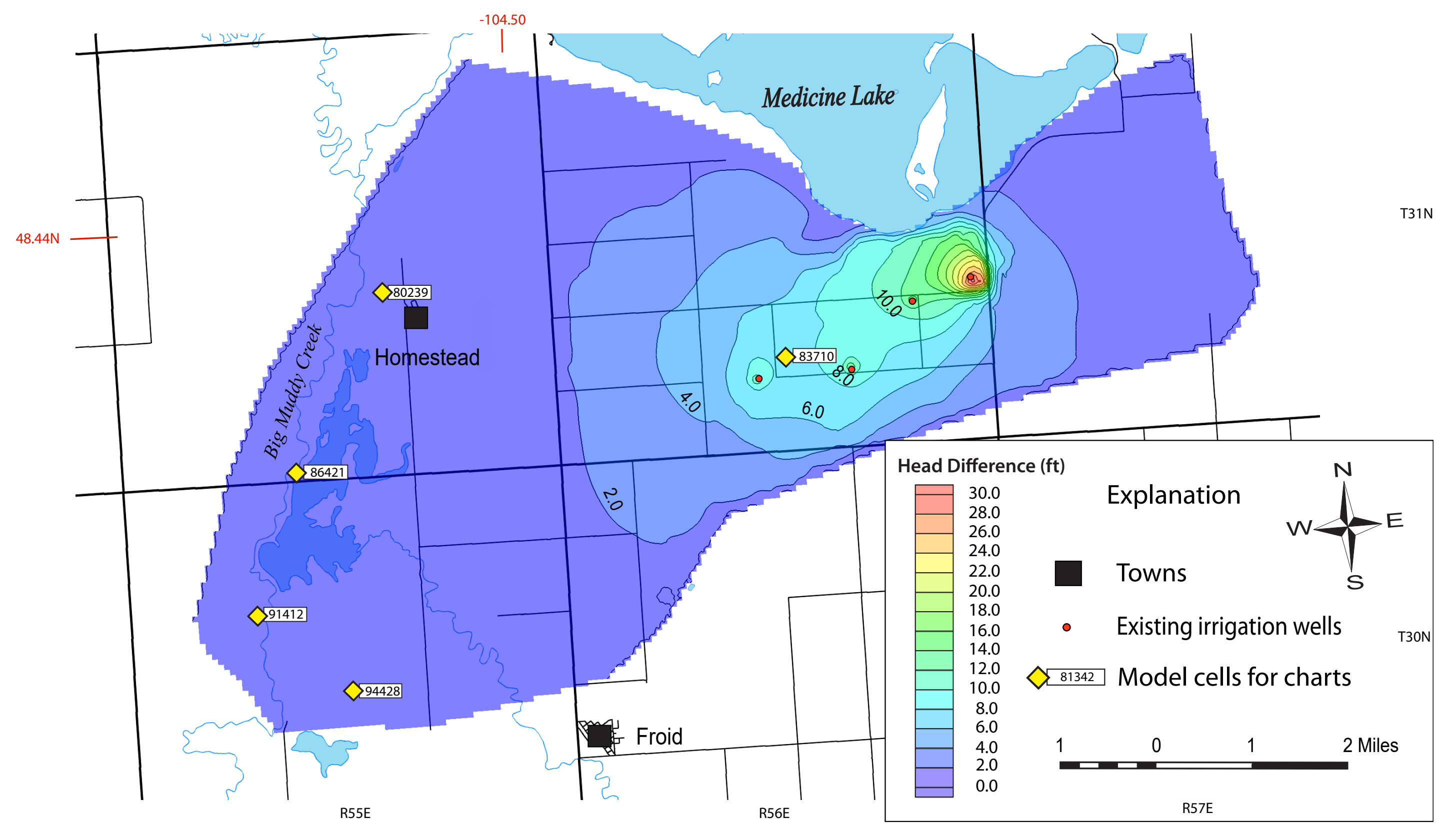



Figure 28. The difference between "no use" and 2015 volume scenarios shows well interference and the increased drawdown due to hydrogeologic boundaries at the eastmost irrigation well. This model output is for the point in time with greatest drawdown, mid-July.

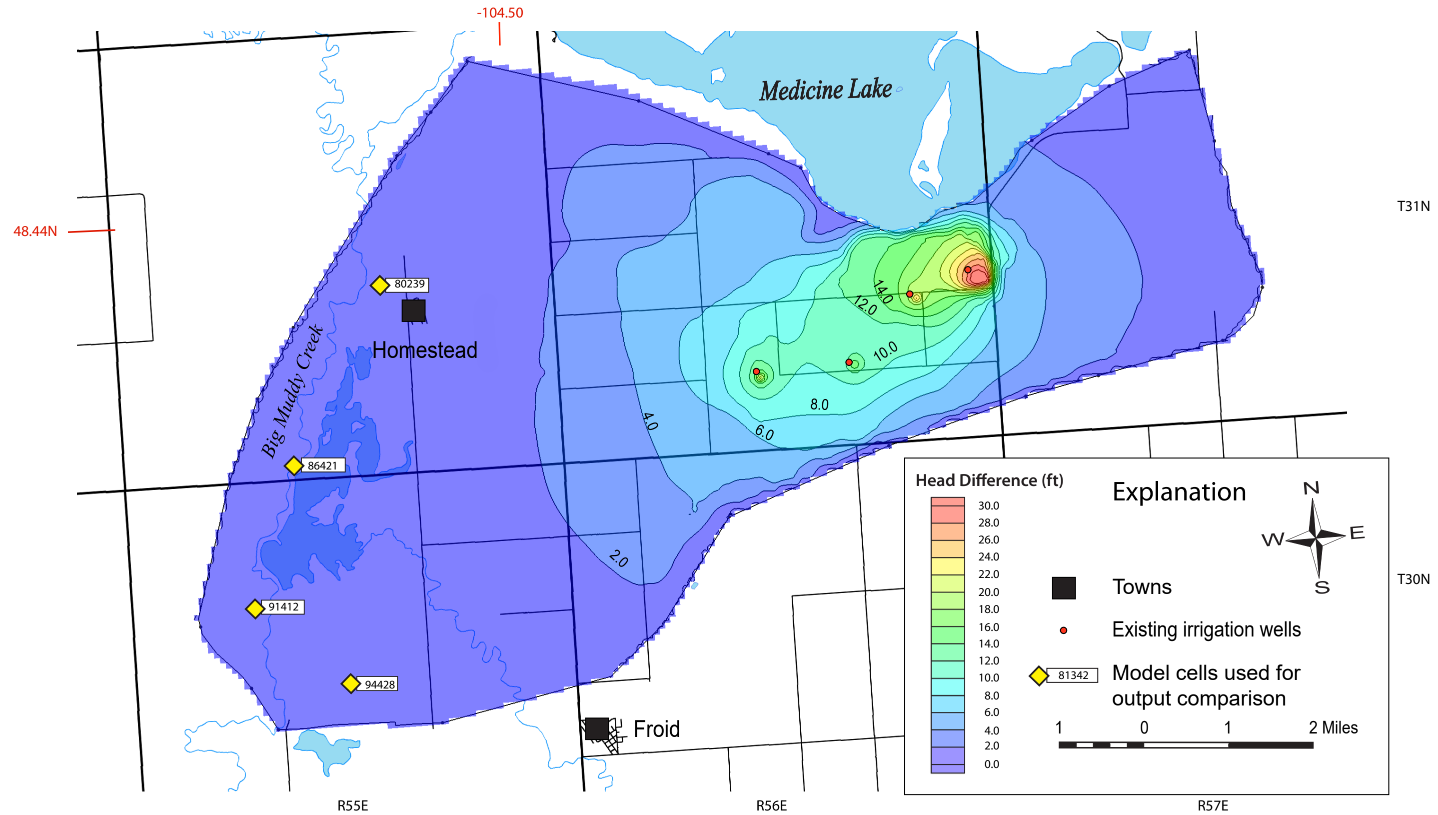



Figure 29. The head differences between the “no-use” scenario and a scenario where the four existing irrigation wells pump maximum allocation volumes show increased well interference. The model predicts an increased zone of influence with a maximum drawdown of 0.45 ft at cell 80239. This model output is for the point in time with greatest drawdown, mid-July.

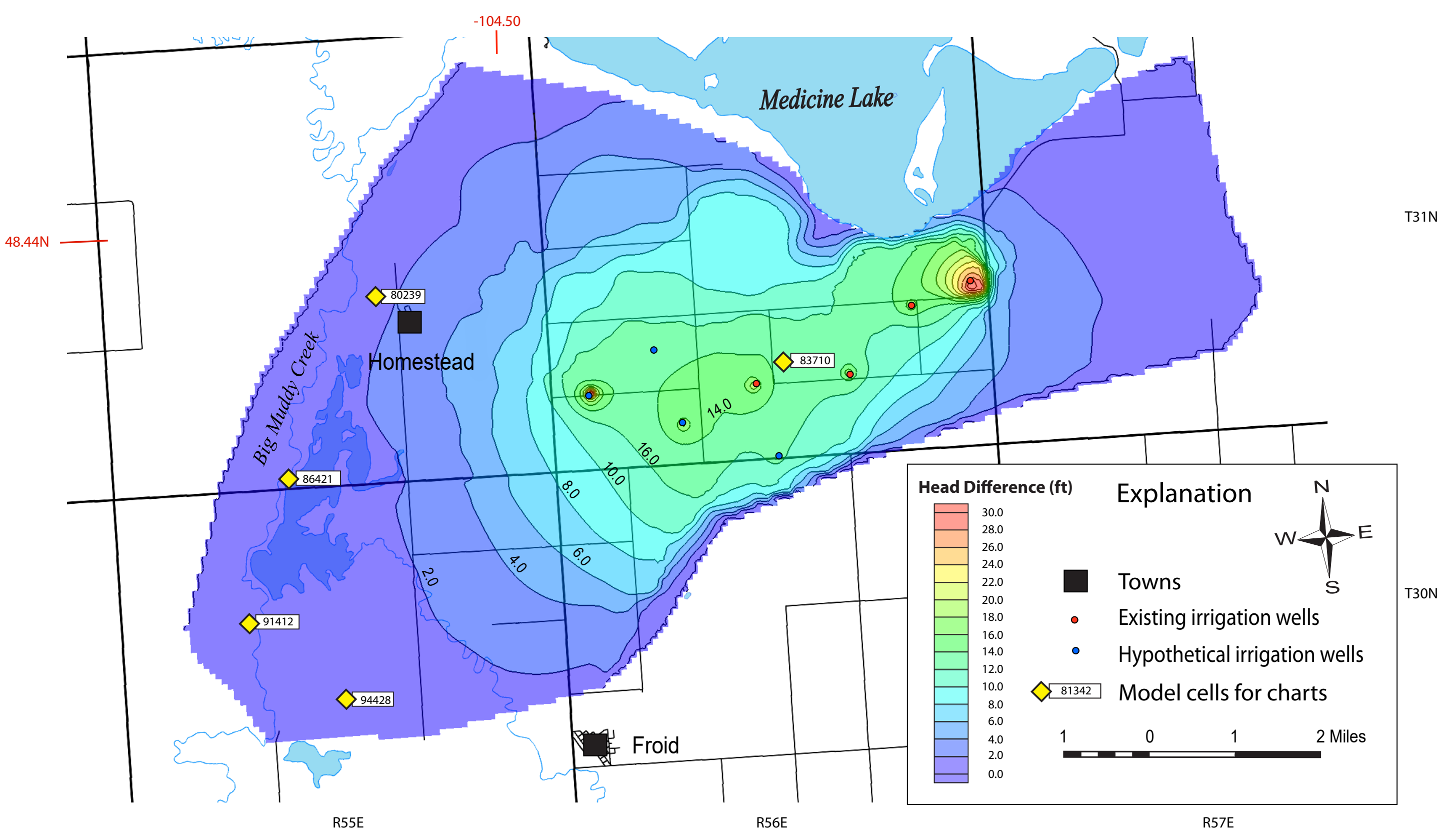



Figure 30. The head difference between a “no pumping” simulation and a simulation with eight irrigation wells pumping at 2015 volume predicts 2.1 ft of drawdown near the Big Muddy Creek wetlands at cell 80239. This model output is for the point in time with greatest drawdown, mid-July.

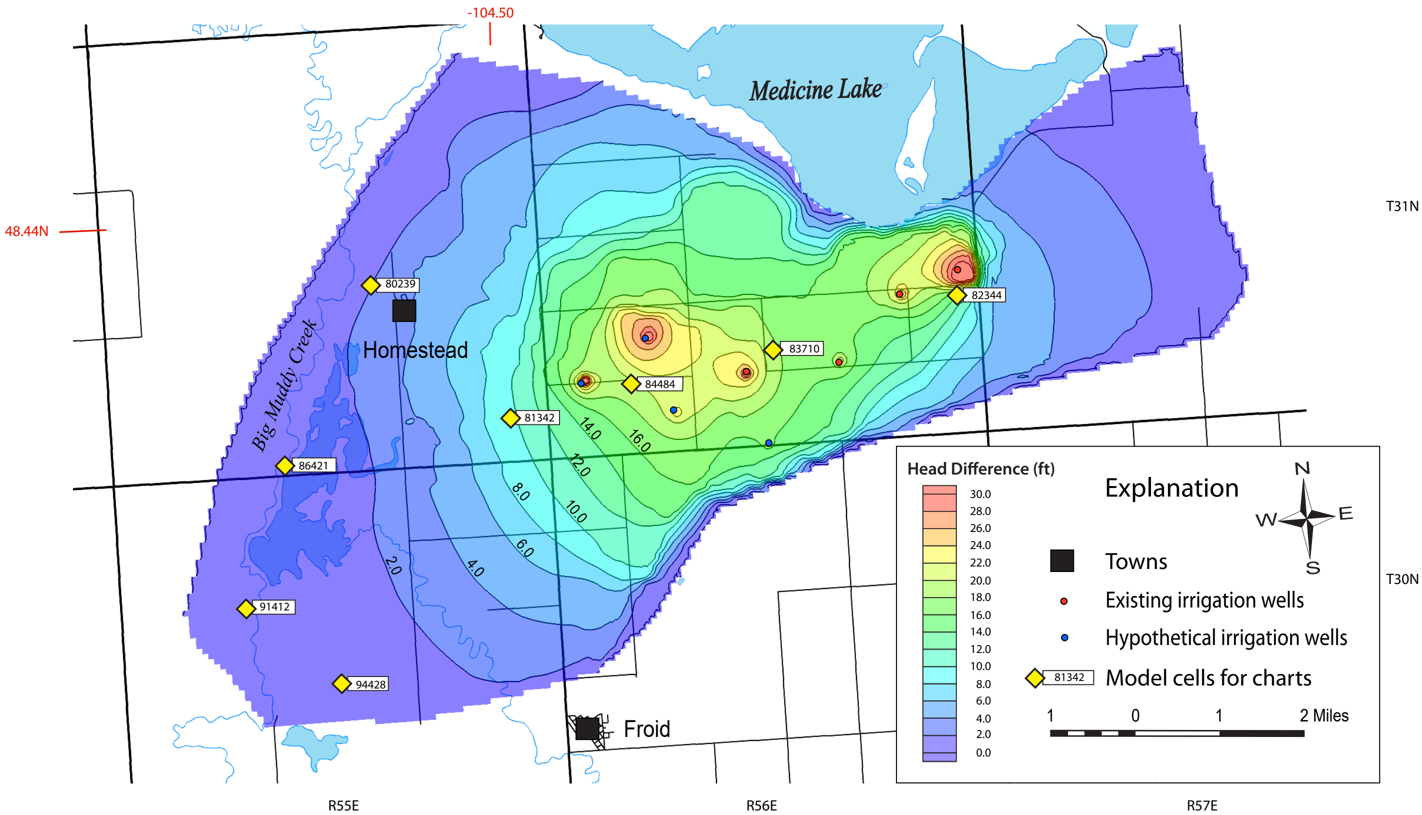



Figure 31. The head difference between a “no pumping” simulation and a simulation with all eight irrigation wells pumping with full allocation volumes predicts 2 ft of drawdown extending to the Big Muddy Creek wetlands near Homestead (cell 80239). This model output is for the point in time with greatest drawdown, mid-July.

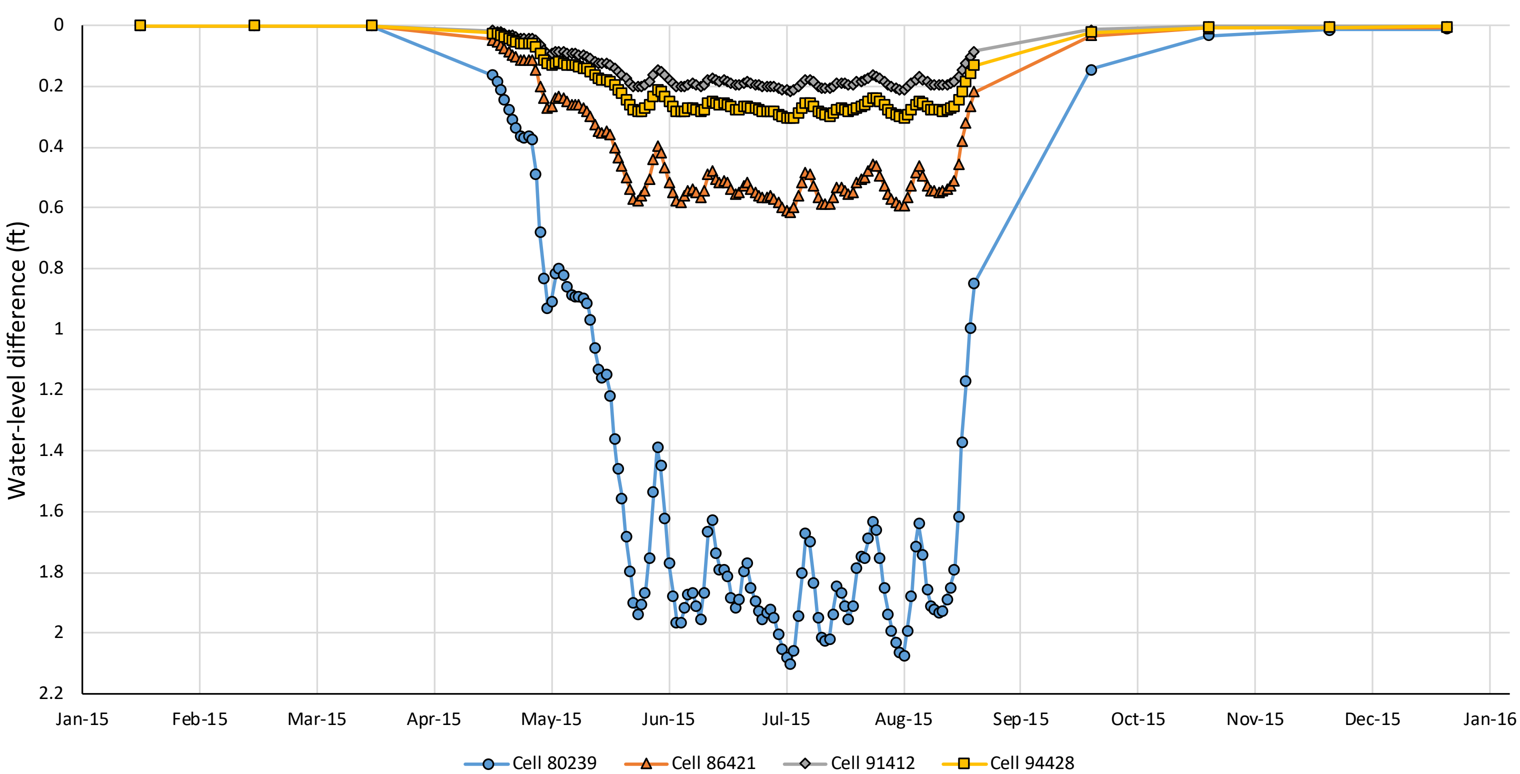



Figure 32. The water levels at four model cells along the Big Muddy show water-level declines of up to 2 ft with eight wells pumping the maximum allocation volume (2,585 acre-ft/yr total).

scenario showed minor seasonal water-level fluctuations resulting from ET and recharge. The time-series heads simulated for the other scenarios were subtracted from the "no use" heads. This removed fluctuations resulting from ET and recharge, thereby isolating the head changes resulting from pumping.

*Scenario 3: Four Well 2015 Full Allocation Volume Pumping (1,500 acre-ft)*

The third scenario simulated the four existing irrigation wells pumping at the full permitted allocation volume, increasing the cumulative aquifer drawdown. The water use during this scenario was 210 percent greater than the 2015 volume. To extract this volume during the model run, the four irrigation wells pumped nearly continuously. Water-use records show that area irrigators have not used the full allocation volume, even during dry years. The scenario predicts maximum drawdown of 0.45 ft at cell 80239 near Homestead (fig. 29).

*Scenario 4: Eight Wells Pumping at 2015 Volume (1,104 acre-ft)*

The fourth scenario simulated irrigation development by doubling the number of wells in the focus area. Four hypothetical wells were placed in an area with ample farmland and high-quality groundwater (locations shown in fig. 30), and thus suitable for irrigation expansion. The pumping schedule resembled that measured in the 2015 irrigation season. The hypothetical well pumping rates (set at 650, 700, 750, and 800 gpm) were similar to those of the existing irrigation wells (table 6). The total volume pumped from the four new wells was approximately 620 acre-ft. Pumping from the additional irrigation wells expanded the area of drawdown (fig. 30), primarily to the west, where the hypothetical wells were located. This scenario predicts approximately 1.4 ft of water-level change in the aquifer near cell 80239, west of Homestead.

*Scenario 5: Eight Wells Pumping the Full Allocation Volume (2,585 acre-ft)*

The fifth scenario simulated eight wells pumping the full allocation for a total volume of 2,585 acre-ft during the irrigation season. Pumping from the four existing wells equaled their permitted allocation of approximately 1,500 acre-ft. The four hypothetical wells pumped approximately 270 acre-ft each, for a total withdrawal of 1,080 acre-ft. Pumping was nearly continuous during the simulation to extract this volume.

This scenario produced the greatest drawdown of the four pumping scenarios tested (figs. 31, 32). The drawdown at four selected cells along the Big Muddy (cell locations in fig. 31) showed 2.1 ft at cell 80239 near Homestead, with less drawdown at the other cells to the southwest (fig. 32).

## SUMMARY AND CONCLUSIONS

Information compiled and collected during this project improved the understanding of the Clear Lake aquifer hydrogeologic system. Drilling activities added to the monitoring network, which provided data for aquifer mapping. Estimates of irrigation water use were improved by measuring pumping rates with an ultrasonic flowmeter and refining estimates of pumping duration at each irrigation well. The increased accuracy of these measurements likely improved the numeric model calibration and related conclusions about the effects of irrigation water use.

Data collected in the South Medicine Lake focus area resulted in a detailed conceptual model for this segment of the Clear Lake aquifer. The cross sections constructed from borehole analysis defined boundaries of the buried valley aquifer. These boundaries include longitudinal hydraulic barriers formed by bedrock ridges that restrict lateral flow in the aquifer. These barriers appear to eliminate direct hydraulic connection between the aquifer and Medicine Lake.

Findings of the hydrogeologic investigation and the numerical model development allowed for refinement of the conceptual model. Flow in the South Medicine Lake focus area starts at a groundwater divide beneath the sand hills southeast of Medicine Lake. Recharge to this area includes infiltration of precipitation and snowmelt in the sand hills, possible groundwater flow from unmapped gravel deposits, and flow from the Fort Union aquifers. From the divide, groundwater predominately flows southwest and discharges in the Big Muddy Creek Valley. Discharge from the buried valley aquifer is through seepage to wetlands along Big Muddy Creek and through the groundwater system to the lower alluvial zone downgradient from the focus area. Groundwater flow is driven by recharge in the sand hills area, discharge as seepage and ET at the wetlands, irrigation pumping, and interaquifer flow to the southwest.

The first objective of this project was to *Determine how much groundwater withdrawal from the Clear Lake aquifer is possible without adversely affecting groundwater and surface water*.

The model suggests that the maximum volume of groundwater withdrawals from the Clear Lake aquifer without detrimental effects is near. The model scenario simulating the 2015 irrigation season did not indicate appreciable drawdown near Homestead. The model run with existing wells pumping the full allocation volume simulates a decrease in heads up to 0.45 ft near Homestead, and other wetland locations showed declines less than 0.1 ft.

The 2014–2015 water-level trends in both groundwater and surface water show stable conditions and that current pumping has not degraded surface-water resources. The current management approach of using continuous monitoring and collaborative review of new water-use applications by the TAC while allowing relatively slow development has been successful at preventing conflict between stakeholders.

The second objective of this project was to *Determine if water development or other land uses have affected water quality in the Clear Lake aquifer*.

Two likely sources of poor-quality water that could affect the aquifer include: (1) flow from saline lakes into the aquifer induced by pumping associated with increased irrigation development, and (2) leaks and spills associated with hydrocarbon extraction. Water-quality monitoring in the Clear Lake aquifer has not identified increases in aquifer salinity induced by pumping near saline lakes. As of the completion of this investigation, leaks and spills of saline water and hydrocarbons associated with energy development have not degraded water in the Clear Lake aquifer to levels unusable for irrigation. Low-level concentrations of organic compounds likely associated with hydrocarbon extraction have been identified in the Clear Lake aquifer, but are unlikely to affect irrigation supplies owing to the low concentration levels detected (Meredith and Kuzara, 2018).

Areas of poor water quality described in this report result from naturally occurring aquifer conditions and may limit irrigation development in the Clear Lake aquifer. Where coal or sandstone aquifers in the Fort Union bedrock are hydraulically connected to the alluvial aquifer, discharge from the bedrock mixes with the lower alluvial zone and degrades water quality. Most of the lower alluvial zones of the Clear Lake aquifer have marginal to poor water quality for irrigation use. The best water quality in the lower alluvial zone is located within 6 mi of the sand hills southeast of Medicine Lake (fig. 21B). Outside of this area, development of groundwater for irrigation may encounter elevated SAR.

The upper outwash zone of the Clear Lake aquifer has lower SAR values and better irrigation potential (fig. 21A). Most of these areas have glacial outwash at the surface and are likely recharged by direct infiltration of rainwater and snowmelt. Water quality in several isolated areas are mapped as marginal to poor water quality. Where permeable outwash zones are layered in the subsurface, water quality varies with depth. This is an important consideration for future development, and the limited available data indicate improved water quality in the shallower zones.

## RECOMMENDATIONS

Maintaining the existing network of monitoring wells is critical to track water-level fluctuations throughout the aquifer. Long-term records provide a broader view of aquifer conditions and the data necessary to manage water resources during periods of drought and climate change, as recharge, ET, and water use changes. The continuous water-level records provide comprehensive data needed to evaluate new irrigation development.

Information gained from new irrigation development will include results from new aquifer tests. As new test data become available, the spatial distribution and range of aquifer parameters will be refined. These refinements could be used to update the existing groundwater models.

The model calibration could be improved by including the water-level data collected in 2016 and 2017. There was little water use in 2016 owing to the higher than normal precipitation, which was followed by a year of high water use in the extreme drought of 2017. A 3-yr transient calibration would extend the predictive power of the current model, and would help define the role of local recharge given the extreme changes between 2016 and 2017.

The connections between the Clear Lake aquifer and the Big Muddy Creek Valley wetlands are poorly understood, and there is little monitoring of water levels or quality. Modeling the connections between the aquifer and surface-water features will require additional investigation.

Investigating the vertical variability of aquifer yield and water quality may identify additional productive zones of high-quality water within the aquifer. In the past, wells were drilled into the deepest, most productive aquifer zone, but better water quality is often encountered in shallower layers. These shallow zones may show development potential when isolated from deeper poor-water-quality zones.

New technology advances have shown that aerial electromagnetic surveys (AEM) are better and less expensive at defining buried valley aquifers than exploration drilling. Recent work in the Canadian prairies, North Dakota, and Nebraska have demonstrated the value of this geophysical tool. An AEM survey could potentially identify additional productive areas of the Clear Lake aquifer.

## ACKNOWLEDGMENTS

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# APPENDIX A

# CLEAR LAKE AQUIFER GROUNDWATER MONITORING NETWORK

| GWIC ID | Latitude | Longitude | Geomethod | Datum | Ground Surface Altitude (ft amsl) | Twn | Rng | Sec | Quarter Section | Total Depth (ft) | Date Completed m/d/yr | Aquifer Code* | First Date Measured (m/d/yr) | Last Date Measured (m/d/yr) | No. of Readings |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3605 | 48.38959 | -104.54132 | MAP | NAD83 | 1945.94 | 30N | 55E | 3 | AAAA | 185 | 10/12/1984 | 112ALVM | 11/30/1984 | 8/4/2016 | 51066 |
| 3606 | 48.36071 | -104.54148 | NAV-GPS | NAD83 | 1973.65 | 30N | 55E | 10 | DDDD | 147 | 10/11/1984 | 112OTSH | 11/30/1984 | 8/4/2016 | 243 |
| 3607 | 48.36020 | -104.58270 | UNKNOWN | NAD27 | 1942 | 30N | 55E | 16 | BBBA | 172 | 11/20/1983 | 112ALVM | 8/19/1985 | 4/21/1998 | 48 |
| 3613 | 48.38880 | -104.25861 | NAV-GPS | WGS84 | 2230 | 30N | 57E | 1 | BBB | 162 | NA | 125FRUN | 7/26/2016 | 7/26/2016 | 1 |
| 3677 | 48.38955 | -104.45278 | NAV-GPS | WGS84 | 2107.9 | 31N | 56E | 33 | CCCD | 350 | 9/22/1984 | 112ALVM | 10/11/1984 | 10/1/2016 | 54597 |
| 3678 | 48.47396 | -104.25133 | NAV-GPS | WGS84 | 1991.63 | 31N | 57E | 1 | BACA | 125 | NA | 112ALVM | 7/19/1983 | 10/17/2016 | 203 |
| 3679 | 48.46017 | -104.31014 | NAV-GPS | NAD83 | 1969.69 | 31N | 57E | 9 | ABAD | 220 | 6/22/1983 | 112ALVM | 7/18/1983 | 10/15/2016 | 125 |
| 3680 | 48.40629 | -104.30985 | NAV-GPS | WGS84 | 2105 | 31N | 57E | 28 | ABDA | 230 | NA | 112ALVM | 7/26/2016 | 7/26/2016 | 1 |
| 3682 | 48.39012 | -104.29468 | NAV-GPS | WGS84 | 2209 | 31N | 57E | 34 | CDDC | 90 | 1/1/1909 | 112OTSH | 1/9/1999 | 3/19/1999 | 155 |
| 3762 | 48.49138 | -104.50619 | NAV-GPS | NAD83 | 1951.06 | 32N | 55E | 25 | DCCD | 200 | 6/27/1987 | 112ALVM | 1/1/1900 | 8/4/2016 | 6195 |
| 3763 | 48.49138 | -104.50619 | NAV-GPS | NAD83 | 1951.15 | 32N | 55E | 25 | DCCD | 200 | 6/27/1987 | 112OTSH | 5/9/1995 | 8/4/2016 | 21984 |
| 3764 | 48.49138 | -104.50619 | NAV-GPS | NAD83 | 1951.15 | 32N | 55E | 25 | DCCD | 200 | 6/27/1987 | 112ALVM | 5/9/1995 | 8/4/2016 | 6640 |
| 3765 | 48.50580 | -104.47440 | MAP | NAD27 | 1985 | 32N | 56E | 20 | CCCC | 240 | 4/2/1975 | 112ALVM | 6/4/2014 | 6/12/2014 | 150 |
| 3766 | 48.49082 | -104.45425 | NAV-GPS | NAD83 | 1986.76 | 32N | 56E | 29 | DDDD | 233 | 9/19/1984 | 112ALVM | 10/9/1984 | 10/15/2016 | 81093 |
| 3767 | 48.49082 | -104.45426 | NAV-GPS | NAD83 | 1986.54 | 32N | 56E | 29 | DDDD | 118 | 9/19/1984 | 112OTSH | 10/11/1984 | 10/15/2016 | 61478 |
| 3769 | 48.49788 | -104.28109 | NAV-GPS | NAD83 | 1950.49 | 32N | 57E | 26 | CBBB | 270 | 7/17/1984 | 112ALVM | 7/18/1984 | 10/17/2016 | 40517 |
| 3770 | 48.49775 | -104.28107 | NAV-GPS | NAD83 | 1950.19 | 32N | 57E | 26 | CBBB | 140 | 7/17/1984 | 112OTSH | 8/10/1984 | 10/17/2016 | 21282 |
| 3771 | 48.48874 | -104.28746 | NAV-GPS | NAD83 | 1947.99 | 32N | 57E | 34 | ABDC | 100 | 6/24/1988 | 112OTSH | 8/15/1995 | 10/17/2016 | 41 |
| 3772 | 48.55496 | -104.18183 | NAV-GPS | NAD83 | 1976.85 | 32N | 58E | 4 | DBBD | 318 | 7/19/1984 | 125FRUN | 7/26/1984 | 10/9/2016 | 218 |
| 3773 | 48.55502 | -104.18186 | NAV-GPS | NAD83 | 1977 | 32N | 58E | 4 | DBBD | 143 | 7/25/1984 | 112OTSH | 7/26/1984 | 10/9/2016 | 42115 |
| 3774 | 48.53424 | -104.17277 | NAV-GPS | NAD83 | 2006.16 | 32N | 58E | 10 | CCCC | 210 | 8/28/1984 | 112ALVM | 11/30/1984 | 10/19/2016 | 10349 |
| 3776 | 48.52110 | -104.10940 | MAP | NAD27 | 2040 | 32N | 58E | 13 | DDDB | 295 | 4/22/1961 | 112ALVM | 1/14/2000 | 2/14/2000 | 66 |
| 3777 | 48.53376 | -104.20560 | NAV-GPS | NAD83 | 1959.23 | 32N | 58E | 17 | ABBB | 80 | 8/23/1986 | 112OTSH | 6/5/1995 | 10/19/2016 | 14471 |
| 3779 | 48.49806 | -104.17297 | NAV-GPS | NAD83 | 2012.8 | 32N | 58E | 27 | BCCC | 270 | 9/18/1984 | 112ALVM | 11/30/1984 | 10/19/2016 | 6268 |
| 3854 | 48.56920 | -104.19780 | NAV-GPS | NAD27 | 2001 | 33N | 57E | 36 | CAAA | 140 | 7/30/1985 | 112OTSH | 7/30/1985 | 5/19/2001 | 74 |
| 3858 | 48.61384 | -104.14441 | NAV-GPS | NAD83 | 1994.04 | 33N | 58E | 17 | ADDD | 130 | 7/30/1984 | 112OTSH | 8/9/1984 | 9/19/2016 | 56588 |
| 3861 | 48.60401 | -104.10028 | NAV-GPS | NAD83 | 2011.09 | 33N | 58E | 23 | BBCB | 137 | 8/29/1985 | 112OTSH | 9/11/1985 | 9/19/2016 | 764 |
| 3862 | 48.59823 | -104.09945 | NAV-GPS | NAD83 | 2010.47 | 33N | 58E | 23 | CBBC | 150 | 8/1/1984 | 112OTSH | 11/6/1982 | 9/19/2016 | 3585 |
| 3866 | 48.60633 | -104.04819 | NAV-GPS | NAD83 | 2012.2 | 33N | 58E | 24 | AAAA | 238 | 8/21/1984 | 112OTSH | 11/30/1984 | 9/19/2016 | 241 |
| 3867 | 48.59160 | -104.04800 | MAP | NAD27 | 1990.9 | 33N | 58E | 25 | AAAA | 336 | 8/24/1984 | 112ALVM | 6/9/1985 | 10/8/1987 | 20 |
| 3868 | 48.59207 | -104.04802 | NAV-GPS | NAD83 | 1989.4 | 33N | 58E | 25 | AAAA | 150 | 8/24/1984 | 112OTSH | 11/30/1984 | 8/11/2016 | 41843 |
| 3869 | 48.58408 | -104.14289 | NAV-GPS | NAD83 | 1990.69 | 33N | 58E | 28 | CBBA | 130 | 7/30/1984 | 112OTSH | 5/21/1985 | 9/17/2016 | 227 |
| 3870 | 48.58656 | -104.14710 | NAV-GPS | NAD83 | 1992.08 | 33N | 58E | 29 | ACDA | 100 | 9/17/1980 | 112OTSH | 11/6/1982 | 10/20/2016 | 56 |
| 3871 | 48.58553 | -104.14540 | NAV-GPS | NAD83 | 1993.13 | 33N | 58E | 29 | ADDB | 98 | 7/25/1984 | 112OTSH | 7/26/1984 | 10/20/2016 | 461 |
| 3872 | 48.58555 | -104.14546 | NAV-GPS | NAD83 | 1992.84 | 33N | 58E | 29 | ADDB | 330 | 7/30/1984 | 125FRUN | 8/8/1984 | 10/20/2016 | 261 |
| 3873 | 48.58856 | -104.17115 | NAV-GPS | NAD83 | 1994.44 | 33N | 58E | 30 | ACAA | 150 | 9/18/1980 | 112OTSH | 5/9/1995 | 10/20/2016 | 44 |
| 3944 | 48.71518 | -104.08545 | NAV-GPS | NAD83 | 2057.39 | 34N | 58E | 11 | DBAB | 130 | 8/7/1984 | 112OTSH | 8/8/1984 | 4/13/2016 | 16499 |
| 3945 | 48.70438 | -104.07265 | MAP | NAD83 | 2065.62 | 34N | 58E | 13 | BBDD | 153 | 11/12/1980 | 112OTSH | 4/1/1981 | 4/20/2016 | 58 |
| 3946 | 48.69723 | -104.07247 | MAP | NAD83 | 2092.48 | 34N | 58E | 13 | CDBB | 154 | NA | 112OTSH | 4/1/1981 | 4/20/2016 | 58 |
| 3947 | 48.68554 | -104.14395 | NAV-GPS | NAD83 | 2041.33 | 34N | 58E | 20 | DAAA | 110 | 8/10/1984 | 112OTSH | 8/11/1984 | 9/19/2016 | 5054 |
| 3948 | 48.69160 | -104.10529 | MAP | NAD83 | 2044.11 | 34N | 58E | 22 | AACC | 104 | 11/5/1980 | 112OTSH | 4/1/1981 | 4/20/2016 | 59 |
| 3949 | 48.69338 | -104.09972 | MAP | NAD83 | 2049.61 | 34N | 58E | 23 | BBBB | 90 | 11/9/1980 | 112OTSH | 4/1/1981 | 4/14/2016 | 58 |
| 4048 | 48.82194 | -104.04952 | NAV-GPS | NAD83 | 2076.2 | 35N | 58E | 1 | AADA | 45 | NA | 112OTSH | 5/9/1995 | 4/14/2016 | 42 |
| 42303 | 48.36305 | -104.61023 | TRS-SEC | NAD83 | 1926 | 30N | 55E | 7 | DDB | 95 | 8/5/1980 | 112ALVM | 5/8/2012 | 5/9/2012 | 89 |
| 43113 | 48.42142 | -104.37297 | NAV-GPS | NAD83 | 2013.4 | 31N | 56E | 24 | DDBB | 160 | 3/5/1990 | 112ALVM | 5/9/1995 | 10/13/2016 | 69622 |

| GWIC ID | Latitude | Longitude | Geomethod | Datum | Ground Surface Altitude (ft amsl) | Twn | Rng | Sec | Quarter Section | Total Depth (ft) | Date Completed m/d/yr | Aquifer Code* | First Date Measured (m/d/yr) | Last Date Measured (m/d/yr) | No. of Readings |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 43116 | 48.40409 | -104.43808 | NAV-GPS | NAD83 | 2088.99 | 31N | 56E | 28 | DDCC | 253 | 3/28/1990 | 112ALVM | 5/9/1995 | 10/12/2016 | 65451 |
| 43124 | 48.46831 | -104.25584 | TRS-SEC | NAD83 | 2015 | 31N | 57E | 1 | CBA | 88 | 11/11/1961 | 112ALVM | 8/18/2004 | 8/18/2004 | 1 |
| 43144 | 48.41494 | -104.32505 | NAV-GPS | WGS84 | 2099 | 31N | 57E | 29 | ADAA | 170 | 4/24/1958 | 112SNGR | 7/27/2016 | 7/27/2016 | 1 |
| 43145 | 48.15773 | -104.35419 | NAV-GPS | WGS84 | 2032 | 31N | 57E | 30 | ABDB | 210 | 3/4/1988 | 112ALVM | 10/21/2015 | 10/13/2016 | 7 |
| 44469 | 48.53786 | -104.16732 | NAV-GPS | NAD83 | 2012.16 | 32N | 58E | 10 | CCAA | 131 | 9/17/1984 | 112OTSH | 6/4/1996 | 10/19/2016 | 29231 |
| 44482 | 48.53385 | -104.20577 | NAV-GPS | NAD83 | 1961.69 | 32N | 58E | 17 | ABBB | 146 | 8/21/1986 | 112OTSH | 6/13/1995 | 10/19/2016 | 200 |
| 44484 | 48.53386 | -104.20577 | NAV-GPS | NAD83 | 1961.58 | 32N | 58E | 17 | ABBB | 146 | 8/21/1986 | 112OTSH | 6/13/1995 | 10/19/2016 | 198 |
| 44497 | 48.48055 | -104.23389 | NAV-GPS | NAD83 | 1978.3 | 32N | 58E | 31 | CBDC | 270 | 6/20/1988 | 112ALVM | 5/7/1996 | 10/17/2016 | 191 |
| 44498 | 48.48240 | -104.22572 | NAV-GPS | NAD83 | 1976.34 | 32N | 58E | 31 | DBBD | 271 | 8/27/1988 | 112ALVM | 10/19/1995 | 10/17/2016 | 42 |
| 45291 | 48.56800 | -104.20220 | NAV-GPS | NAD27 | 2000 | 33N | 57E | 36 | CACA | 80 | 3/7/1990 | 112OTSH | 5/11/1995 | 9/26/2001 | 55 |
| 45292 | 48.56797 | -104.19496 | NAV-GPS | NAD83 | 1986.4 | 33N | 57E | 36 | DBDB | 100 | 3/8/1990 | 112ALVM | 5/11/1995 | 10/19/2016 | 17892 |
| 45325 | 48.58122 | -104.18204 | MAP | NAD83 | 1989.23 | 33N | 58E | 30 | CBDD | 120 | 8/1/1988 | 112OTSH | 5/9/1995 | 10/20/2016 | 44 |
| 45336 | 48.60170 | -104.09913 | TRS-SEC | NAD83 | 1982 | 33N | 58E | 23 | BCBD | 147 | 8/30/1985 | 112ALVM | 9/11/1985 | 9/11/1985 | 1 |
| 45977 | 48.70631 | -104.04834 | NAV-GPS | NAD83 | 2093.25 | 34N | 58E | 13 | AAAD | 180 | 8/8/1984 | 112ALVM | 8/11/1984 | 9/19/2016 | 28932 |
| 45978 | 48.70610 | -104.04837 | NAV-GPS | NAD83 | 2094.76 | 34N | 58E | 13 | AAAD | 105 | 8/9/1984 | 112OTSH | 10/29/1984 | 9/19/2016 | 230 |
| 45980 | 48.70431 | -104.08356 | MAP | NAD83 | 2060.24 | 34N | 58E | 14 | ACAA | 126 | 10/2/1980 | 112OTSH | 5/9/1995 | 4/14/2016 | 44 |
| 45981 | 48.69721 | -104.09453 | MAP | NAD83 | 2056.53 | 34N | 58E | 14 | CBDD | 150 | 5/6/1977 | 112OTSH | 11/5/1982 | 5/1/2016 | 65 |
| 45982 | 48.69735 | -104.09486 | NAV-GPS | NAD83 | 2054.9 | 34N | 58E | 14 | CBDD | 160 | 12/1/1976 | 112OTSH | 5/9/1995 | 10/22/2015 | 60499 |
| 45983 | 48.69711 | -104.08363 | MAP | NAD83 | 2060.51 | 34N | 58E | 14 | DBDD | 95 | 6/26/1980 | 112OTSH | 5/9/1995 | 4/14/2016 | 43 |
| 46003 | 48.66799 | -104.15805 | MAP | NAD83 | 2034.9 | 34N | 58E | 29 | CDBA | 81 | 10/23/1980 | 112OTSH | 11/6/1982 | 4/20/2016 | 60 |
| 46960 | 48.81598 | -104.05489 | TRS-SEC | NAD83 | 2071 | 35N | 58E | 1 | DAB | 45 | 10/18/1982 | 112OTSH | 10/20/2005 | 4/14/2016 | 13 |
| 46965 | 48.81575 | -104.05469 | MAP | NAD83 | 2068.8 | 35N | 58E | 1 | DBDD | 40 | 10/18/1982 | 112OTSH | 4/8/1983 | 4/14/2016 | 59 |
| 121117 | 48.42134 | -104.37299 | NAV-GPS | NAD83 | 2007 | 31N | 56E | 24 | DDBB | 155 | 8/15/1990 | 112ALVM | 10/19/1995 | 10/13/2016 | 42 |
| 121781 | 48.46745 | -104.26332 | NAV-GPS | NAD83 | 2026.41 | 31N | 57E | 2 | DAC | 130 | 9/7/1990 | 112ALVM | 7/11/1996 | 10/17/2016 | 176 |
| 135910 | 48.49137 | -104.50671 | TRS-SEC | NAD83 | 1952.55 | 32N | 55E | 25 | DCCD | 220 | 12/10/1992 | 112ALVM | 5/9/1995 | 10/19/1995 | 2 |
| 148578 | 48.60575 | -104.10702 | NAV-GPS | NAD83 | 1960.1 | 33N | 58E | 22 | ABAA | 6 | 6/1/1989 | 112OTSH | 8/8/1990 | 9/19/2016 | 68591 |
| 149003 | 48.57771 | -104.19310 | MAP | NAD83 | 2022.1 | 33N | 57E | 25 | DCCC | 120 | 2/14/1995 | 112OTSH | 5/9/1995 | 10/20/2016 | 36 |
| 149610 | 48.78025 | -104.04866 | NAV-GPS | NAD83 | 2093.1 | 35N | 58E | 24 | AAAA | 92.5 | 5/12/1982 | 112OTSH | 6/8/1982 | 9/19/2016 | 232 |
| 150614 | 48.48351 | -104.29082 | NAV-GPS | NAD83 | 1951.73 | 32N | 57E | 34 | DBBB | 68 | NA | 112OTSH | 5/9/1995 | 10/17/2016 | 42 |
| 150615 | 48.48481 | -104.26836 | NAV-GPS | NAD83 | 1961.4 | 32N | 57E | 35 | ACCBA | 260 | NA | 112ALVM | 8/15/1995 | 10/17/2016 | 162 |
| 150769 | 48.55256 | -104.22214 | LORAN-C | NAD83 | 2002 | 32N | 58E | 6 | DBDD | 100 | NA | 112OTSH | 5/9/1995 | 10/16/2007 | 25 |
| 150940 | 48.42164 | -104.38857 | NAV-GPS | NAD83 | 2013.84 | 31N | 56E | 24 | CBB | 150 | 2/4/1995 | 112ALVM | 5/11/1995 | 10/12/2016 | 92800 |
| 152253 | 48.57369 | -104.17279 | NAV-GPS | NAD83 | 1967 | 33N | 58E | 31 | ACAB | 5 | 6/1/1995 | 112OTSH | 6/20/1995 | 10/19/2016 | 34270 |
| 152254 | 48.40416 | -104.43792 | NAV-GPS | NAD83 | 2089.49 | 31N | 56E | 28 | DDCC | 244 | 7/27/1990 | 112ALVM | 5/9/1995 | 10/12/2016 | 43 |
| 153314 | 48.59577 | -104.13847 | MAP | NAD83 | 1997.97 | 33N | 58E | 21 | CCAA | 110 | NA | 112OTSH | 6/9/1982 | 10/20/2016 | 48 |
| 154292 | 48.80007 | -104.04857 | NAV-GPS | NAD83 | 2093.8 | 35N | 58E | 12 | DAD | 180 | 10/13/1981 | 112OTSH | 2/2/1996 | 9/19/2016 | 186 |
| 154904 | 48.52152 | -104.50057 | TRS-SEC | NAD83 | 1965 | 32N | 55E | 13 | DD | 840 | 6/1/1995 | 211FHHC | 6/18/2013 | 6/18/2013 | 1 |
| 155430 | 48.56689 | -104.16035 | NAV-GPS | NAD83 | 1987.62 | 33N | 58E | 32 | CACC | 91 | NA | 112OTSH | 8/16/1982 | 10/19/2016 | 66 |
| 155431 | 48.66799 | -104.15801 | MAP | NAD83 | 2034.9 | 34N | 58E | 29 | CDBA | 81 | NA | 112OTSH | 5/9/1995 | 9/19/2016 | 40 |
| 155916 | 48.69728 | -104.10583 | NAV-GPS | NAD83 | 2054.6 | 34N | 58E | 15 | DACC | 160 | 6/19/1996 | 112OTSH | 6/19/1996 | 4/23/2016 | 55209 |
| 155919 | 48.70433 | -104.10619 | NAV-GPS | NAD83 | 2052.69 | 34N | 58E | 15 | ABDD | 160 | 6/19/1996 | 112OTSH | 6/19/1996 | 4/23/2016 | 36008 |
| 155920 | 48.48337 | -104.29126 | NAV-GPS | NAD83 | 1947 | 32N | 57E | 34 | DBBB | 69 | 6/17/1996 | 112OTSH | 7/17/1996 | 10/17/2016 | 52314 |
| 155921 | 48.58843 | -104.18214 | NAV-GPS | NAD83 | 2018.5 | 33N | 58E | 30 | BACC | 115 | 6/17/1996 | 112OTSH | 6/4/1997 | 10/20/2016 | 163 |
| 155929 | 48.41896 | -104.38884 | NAV-GPS | NAD83 | 2029.74 | 31N | 56E | 24 | CCCC | 180 | 6/7/1996 | 112ALVM | 6/4/1996 | 7/5/2016 | 33709 |
| 155930 | 48.41736 | -104.39052 | NAV-GPS | NAD83 | 2025.9 | 31N | 56E | 26 | ABDD | 180 | 4/5/1996 | 112ALVM | 10/25/1996 | 10/13/2016 | 37 |

| GWIC ID | Latitude | Longitude | Geomethod | Datum | Ground Surface Altitude (ft amsl) | Twn | Rng | Sec | Quarter Section | Total Depth (ft) | Date Completed m/d/yr | Aquifer Code* | First Date Measured (m/d/yr) | Last Date Measured (m/d/yr) | No. of Readings |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 155931 | 48.48496 | -104.27037 | NAV-GPS | NAD83 | 1961 | 32N | 57E | 35 | BCDD | 260 | 5/11/1996 | 112ALVM | 6/4/1996 | 10/17/2016 | 32662 |
| 155933 | 48.48512 | -104.27018 | NAV-GPS | NAD83 | 1961 | 32N | 57E | 35 | BCDD | 260 | 5/31/1996 | 112ALVM | 5/31/1996 | 10/17/2016 | 40 |
| 157817 | 48.50183 | -104.29233 | NAV-GPS | NAD83 | 1943.67 | 32N | 57E | 27 | ABAA | 7 | NA | 112OTSH | 5/15/1996 | 10/15/2016 | 47542 |
| 159786 | 48.48339 | -104.30252 | NAV-GPS | NAD83 | 1959.03 | 32N | 57E | 34 | CBBB | 160 | 9/24/1996 | 112OTSH | 6/3/1997 | 10/15/2016 | 2959 |
| 159791 | 48.45504 | -104.31903 | TRS-SEC | NAD83 | | 31N | 57E | 9 | BDCC | 160 | 9/26/1996 | 112OTSH | 7/22/1997 | 4/7/1998 | 10 |
| 159795 | 48.53778 | -104.16746 | NAV-GPS | NAD83 | 2012.42 | 32N | 58E | 10 | CCAA | 150 | 5/17/1986 | 112OTSH | 6/4/1996 | 11/1/2012 | 29 |
| 160086 | 48.58499 | -104.17939 | MAP | NAD83 | 1990.31 | 33N | 58E | 30 | BDDD | 132 | 11/29/1996 | 112OTSH | 11/7/1996 | 10/20/2016 | 41 |
| 161780 | 48.48532 | -104.30012 | NAV-GPS | NAD83 | 1940.09 | 32N | 57E | 34 | BCBD | 8.6 | NA | 112OTSH | 5/30/1997 | 9/17/2016 | 63811 |
| 161781 | 48.50532 | -104.26018 | NAV-GPS | NAD83 | 1949.83 | 32N | 57E | 23 | DDDA | 8.6 | 5/28/1997 | 112OTSH | 5/28/1997 | 10/17/2016 | 48541 |
| 161782 | 48.57331 | -104.13838 | NAV-GPS | NAD83 | 1957 | 33N | 58E | 33 | BDBC | 10 | 5/28/1997 | 112OTSH | 6/3/1997 | 10/20/2016 | 52011 |
| 161783 | 48.56249 | -104.18696 | NAV-GPS | NAD83 | 1960.48 | 32N | 58E | 4 | BAAB | 5 | 5/28/1997 | 112OTSH | 5/28/1997 | 10/19/2016 | 43747 |
| 161784 | 48.72023 | -104.08409 | NAV-GPS | NAD83 | 2040.7 | 34N | 58E | 11 | ABDA | 8.3 | 5/29/1997 | 112OTSH | 5/29/1997 | 10/22/2015 | 46584 |
| 161785 | 48.73691 | -104.08469 | NAV-GPS | NAD83 | 2045 | 34N | 58E | 2 | ABAA | 8.8 | 5/29/1997 | 112OTSH | 5/29/1997 | 10/22/2015 | 45916 |
| 161786 | 48.79906 | -104.05065 | NAV-GPS | NAD83 | 2052.4 | 35N | 58E | 12 | DADC | 9.2 | 5/29/1997 | 112OTSH | 6/17/1997 | 8/20/2016 | 49450 |
| 161787 | 48.43178 | -104.38128 | NAV-GPS | NAD83 | 1951.38 | 31N | 56E | 24 | BBDA | 10 | 5/30/1997 | 112OTSH | 5/30/1997 | 10/21/2015 | 38561 |
| 161788 | 48.43128 | -104.38802 | NAV-GPS | NAD83 | 1946.78 | 31N | 56E | 24 | BBCB | 10 | 5/30/1997 | 112OTSH | 6/20/1997 | 10/13/2016 | 164 |
| 161792 | 48.57803 | -104.18350 | TRS-SEC | NAD83 | 1982 | 33N | 58E | 30 | CCDD | 118 | 4/7/1997 | 112OTSH | 4/29/1997 | 10/20/2016 | 38 |
| 161801 | 48.57757 | -104.18137 | NAV-GPS | NAD83 | 1986.51 | 33N | 58E | 30 | CDD | 120 | 4/5/1997 | 112OTSH | 5/8/1997 | 10/19/2016 | 15213 |
| 161802 | 48.74050 | -104.06180 | NAV-GPS | NAD83 | 2065.72 | 35N | 58E | 36 | DBB | 90 | 11/12/1996 | 112OTSH | 10/10/2003 | 9/19/2016 | 2513 |
| 168129 | 48.71896 | -104.07255 | NAV-GPS | NAD83 | 2066.63 | 34N | 58E | 12 | BDDD | 140 | 4/27/1998 | 112OTSH | 7/24/1998 | 9/19/2016 | 3055 |
| 168130 | 48.42194 | -104.40010 | NAV-GPS | NAD83 | 1995.6 | 31N | 56E | 23 | CDAA | 160 | 2/5/1998 | 112ALVM | 4/7/1998 | 10/12/2016 | 91365 |
| 168131 | 48.41981 | -104.41144 | NAV-GPS | NAD83 | 1994.52 | 31N | 56E | 22 | DDDA | 160 | 2/6/1998 | 112ALVM | 4/7/1998 | 10/12/2016 | 65505 |
| 168132 | 48.42030 | -104.50760 | NAV-GPS | NAD27 | 1978 | 31N | 55E | 24 | DCBC | 240 | NA | 112ALVM | 4/2/1998 | 4/23/2004 | 23 |
| 168866 | 48.45911 | -104.31505 | NAV-GPS | NAD83 | 1970.62 | 31N | 57E | 9 | BC | 240 | 4/10/1998 | 112ALVM | 8/4/1998 | 10/15/2016 | 37 |
| 168867 | 48.45591 | -104.31508 | NAV-GPS | NAD83 | 1974.63 | 31N | 57E | 9 | BB | 240 | 4/11/1998 | 112ALVM | 5/6/1998 | 10/13/2016 | 50982 |
| 169212 | 48.44777 | -104.45417 | NAV-GPS | NAD83 | 2027.4 | 31N | 56E | 9 | CCCC | 108 | 4/19/1999 | 112ALVM | 5/17/1999 | 10/12/2016 | 158 |
| 169213 | 48.43284 | -104.43302 | NAV-GPS | NAD83 | 2057.55 | 31N | 56E | 21 | AAAA | 130 | 4/20/1999 | 112ALVM | 5/17/1999 | 10/12/2016 | 53071 |
| 169214 | 48.42557 | -104.45436 | NAV-GPS | NAD83 | 2091.14 | 31N | 56E | 20 | DAAA | 160 | 4/20/1999 | 112ALVM | 5/17/1999 | 10/12/2016 | 27543 |
| 169215 | 48.41124 | -104.47590 | NAV-GPS | NAD83 | 2058.69 | 31N | 56E | 29 | BCCC | 190 | 4/21/1999 | 112ALVM | 5/17/1999 | 10/1/2016 | 54734 |
| 169217 | 48.40406 | -104.41092 | NAV-GPS | NAD83 | 2058.11 | 31N | 56E | 27 | DDDD | 227 | 4/22/1999 | 112ALVM | 5/17/1999 | 10/12/2016 | 120401 |
| 169218 | 48.41118 | -104.41090 | NAV-GPS | NAD83 | 2054.23 | 31N | 56E | 27 | DAAA | 224 | 4/22/1999 | 112ALVM | 4/27/1999 | 10/12/2016 | 92363 |
| 169219 | 48.43462 | -104.36716 | NAV-GPS | NAD83 | 1973.54 | 31N | 57E | 18 | CCCB | 80 | 4/23/1999 | 112OTSH | 5/17/1999 | 8/13/2014 | 83 |
| 169220 | 48.44792 | -104.34620 | NAV-GPS | NAD83 | 1972.22 | 31N | 57E | 8 | CCCC | 135 | 4/23/1999 | 112OTSH | 6/17/1999 | 10/22/2013 | 76 |
| 169372 | 48.72187 | -104.08309 | NAV-GPS | NAD83 | 2050.6 | 34N | 58E | 11 | AABB | 220 | 3/17/1999 | 112OTSH | 5/18/1999 | 7/23/2016 | 8808 |
| 169373 | 48.72200 | -104.08313 | NAV-GPS | NAD83 | 2048.3 | 34N | 58E | 11 | AABB | 30 | 3/19/1999 | 112OTSH | 4/20/1999 | 7/23/2016 | 1230 |
| 169374 | 48.73665 | -104.08366 | NAV-GPS | NAD83 | 2050 | 34N | 58E | 2 | ABAA | 200 | 3/19/1999 | 112OTSH | 4/20/1999 | 7/23/2016 | 1155 |
| 171418 | 48.69772 | -104.10579 | NAV-GPS | NAD83 | 2055.14 | 34N | 58E | 15 | DBDD | 130 | 4/27/1999 | 112OTSH | 10/24/2005 | 4/20/2016 | 21 |
| 175651 | 48.40411 | -104.43792 | NAV-GPS | NAD83 | 2089.88 | 31N | 56E | 28 | DDC | 246 | 8/26/1999 | 112ALVM | 4/17/2001 | 4/21/2016 | 30 |
| 184125 | 48.37863 | -104.53640 | NAV-GPS | NAD83 | 1956.31 | 30N | 55E | 2 | CAA | 184 | 2/11/1998 | 112OTSH | 8/11/2000 | 7/5/2016 | 8898 |
| 193352 | 48.71881 | -104.07310 | NAV-GPS | NAD83 | 2069 | 34N | 58E | 12 | B | 108 | 10/11/2001 | 112OTSH | 10/20/2005 | 4/13/2016 | 24 |
| 193370 | 48.70441 | -104.10550 | MAP | NAD83 | 2053.74 | 34N | 58E | 15 | A | 142 | 10/5/2001 | 112OTSH | 4/27/2006 | 4/20/2016 | 22 |
| 206410 | 48.40052 | -104.52432 | NAV-GPS | NAD83 | 1954 | 31N | 55E | 35 | AACA | 180 | 4/26/1998 | 112ALVM | 10/26/2004 | 10/31/2012 | 15 |
| 206533 | 48.78048 | -104.06338 | NAV-GPS | NAD83 | 2070.3 | 35N | 58E | 13 | CCDC | 80 | 9/15/2003 | 112OTSH | 9/17/2003 | 9/20/2016 | 96 |
| 206537 | 48.78051 | -104.07771 | NAV-GPS | NAD83 | 2066.5 | 35N | 58E | 13 | CCCC | 100 | 9/16/2003 | 112OTSH | 9/16/2003 | 8/20/2016 | 43041 |
| 206538 | 48.78050 | -104.08172 | NAV-GPS | NAD83 | 2071.8 | 35N | 58E | 14 | DDCC | 125 | 9/16/2003 | 112OTSH | 9/17/2003 | 9/19/2016 | 92 |

| GWIC ID | Latitude | Longitude | Geomethod | Datum | Ground Surface Altitude (ft amsl) | Twn | Rng | Sec | Quarter Section | Total Depth (ft) | Date Completed m/d/yr | Aquifer Code* | First Date Measured (m/d/yr) | Last Date Measured (m/d/yr) | No. of Readings |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 206539 | 48.75147 | -104.04999 | NAV-GPS | NAD83 | 2052 | 35N | 58E | 25 | DDDD | 180 | 9/16/2003 | 112OTSH | 9/17/2003 | 9/19/2016 | 99 |
| 206541 | 48.83900 | -104.06100 | NAV-GPS | NAD27 | 2060 | 36N | 58E | 25 | DCCC | 133 | 9/15/2003 | 112OTSH | 9/15/2003 | 9/15/2003 | 1 |
| 206546 | 48.75152 | -104.07788 | NAV-GPS | NAD83 | 2064.3 | 35N | 58E | 25 | CCCC | 120 | 9/18/2003 | 112OTSH | 9/18/2003 | 9/20/2016 | 13905 |
| 206547 | 48.54852 | -104.15179 | NAV-GPS | NAD83 | 1984.14 | 32N | 58E | 10 | AAAA | 200 | 9/18/2003 | 112OTSH | 9/18/2003 | 10/19/2016 | 9843 |
| 206548 | 48.55929 | -104.13953 | NAV-GPS | NAD83 | 1993.68 | 32N | 58E | 2 | ABCC | 180 | 9/19/2003 | 112OTSH | 9/19/2003 | 10/19/2016 | 8594 |
| 212128 | 48.40471 | -104.41003 | NAV-GPS | NAD83 | 2056.85 | 31N | 56E | 27 | DDDD | 240 | 3/27/2004 | 112ALVM | 4/8/2004 | 10/12/2016 | 381 |
| 215189 | 48.75153 | -104.08830 | NAV-GPS | NAD83 | 2052.8 | 35N | 58E | 26 | DCCC | 175 | 11/7/2004 | 112ALVM | 12/3/2004 | 9/19/2016 | 82 |
| 215220 | 48.69356 | -104.12128 | NAV-GPS | NAD27 | 2047.05 | 34N | 58E | 15 | CCCC | 140 | 11/7/2004 | 112OTSH | 12/3/2004 | 9/20/2016 | 85 |
| 215223 | 48.67910 | -104.09940 | NAV-GPS | WGS84 | 2061.7 | 34N | 58E | 23 | CCCC | 140 | 11/8/2004 | 112OTSH | 12/3/2004 | 9/20/2016 | 81 |
| 221597 | 48.62120 | -104.12170 | NAV-GPS | NAD83 | 2009.8 | 33N | 58E | 10 | CCCC | 128 | 9/12/2005 | 112OTSH | 9/18/2005 | 9/20/2016 | 73 |
| 221602 | 48.62140 | -104.15120 | NAV-GPS | NAD83 | 2008.49 | 33N | 58E | 8 | DDCC | 108 | 9/13/2005 | 112OTSH | 9/18/2005 | 9/20/2016 | 49395 |
| 221606 | 48.62121 | -104.16607 | NAV-GPS | NAD83 | 2055.08 | 33N | 58E | 8 | DDDD | 88 | 9/13/2005 | 112ALVM | 9/18/2005 | 9/19/2016 | 73 |
| 221614 | 48.49810 | -104.22950 | NAV-GPS | NAD83 | 1979.1 | 32N | 58E | 30 | BDDC | 288 | 9/14/2005 | 112ALVM | 9/18/2005 | 10/17/2016 | 37262 |
| 221630 | 48.49818 | -104.22954 | NAV-GPS | NAD83 | 1979.1 | 32N | 58E | 30 | BDDC | 168 | 9/14/2005 | 112OTSH | 9/18/2005 | 10/17/2016 | 44799 |
| 221634 | 48.39805 | -104.41073 | NAV-GPS | NAD83 | 2100.03 | 31N | 56E | 35 | BCCB | 278 | 9/15/2005 | 112ALVM | 9/20/2005 | 10/12/2016 | 72 |
| 221637 | 48.39378 | -104.41078 | NAV-GPS | NAD83 | 2093.13 | 31N | 56E | 35 | CBBC | 288 | 9/16/2005 | 112ALVM | 9/19/2005 | 10/12/2016 | 61602 |
| 221646 | 48.41830 | -104.36772 | NAV-GPS | NAD83 | 2029.1 | 31N | 57E | 30 | BBBB | 68 | 9/20/2005 | 112OTSH | 9/20/2005 | 10/13/2016 | 22045 |
| 221647 | 48.40400 | -104.35750 | NAV-GPS | NAD83 | 2044.13 | 31N | 57E | 30 | CDDD | 195 | 9/19/2005 | 112ALVM | 9/20/2005 | 10/13/2016 | 55020 |
| 221649 | 48.49065 | -104.41029 | NAV-GPS | NAD83 | 1983.41 | 32N | 56E | 35 | BBBB | 168 | 9/22/2005 | 112OTSH | 11/10/2005 | 10/15/2016 | 50878 |
| 221651 | 48.49065 | -104.41037 | NAV-GPS | NAD83 | 1983.6 | 32N | 56E | 35 | BBBB | 248 | 9/21/2005 | 112ALVM | 9/22/2005 | 10/15/2016 | 48345 |
| 221652 | 48.41830 | -104.35762 | NAV-GPS | NAD83 | 2022.41 | 31N | 57E | 30 | BAAA | 180 | 9/21/2005 | 112ALVM | 11/8/2005 | 7/26/2016 | 64046 |
| 222551 | 48.69308 | -104.09996 | TRS-SEC | NAD83 | 2049.81 | 34N | 58E | 23 | BBBB | 95 | 5/11/2005 | 112OTSH | 4/25/2006 | 4/14/2016 | 22 |
| 223319 | 48.74060 | -104.06160 | NAV-GPS | NAD83 | 2067.69 | 35N | 58E | 36 | DDBB | 180 | 12/5/2005 | 112OTSH | 4/25/2006 | 4/13/2016 | 19 |
| 223321 | 48.81505 | -104.05506 | NAV-GPS | WGS84 | 2068.6 | 35N | 58E | 1 | ACCC | 40 | 12/12/2005 | 112OTSH | 4/25/2006 | 4/14/2016 | 18 |
| 235004 | 48.75516 | -104.07262 | NAV-GPS | NAD83 | 2085.18 | 35N | 58E | 25 | C | 170 | 3/13/2007 | 112OTSH | 5/22/2009 | 8/20/2016 | 31194 |
| 242569 | 48.54974 | -104.21745 | NAV-GPS | NAD83 | 1982.48 | 32N | 58E | 5 | DDDD | 100 | 4/10/2008 | 112OTSH | 10/29/2008 | 10/19/2016 | 18 |
| 247227 | 48.69718 | -104.07322 | MAP | NAD83 | 2096.5 | 34N | 58E | 13 | CDBB | 150 | NA | 112OTSH | 7/23/2008 | 4/20/2016 | 393 |
| 250391 | 48.75877 | -104.07110 | NAV-GPS | NAD83 | 2084.43 | 35N | 58E | 25 | CAB | 150 | 4/1/2009 | 112OTSH | 5/22/2009 | 10/30/2012 | 8 |
| 250399 | 48.71494 | -104.08201 | NAV-GPS | NAD83 | 2056.16 | 34N | 58E | 11 | DAB | 140 | 4/9/2009 | 112OTSH | 4/27/2009 | 10/22/2015 | 10 |
| 250466 | 48.75513 | -104.07211 | NAV-GPS | NAD83 | 2083.06 | 35N | 58E | 25 | CCA | 160 | 3/26/2009 | 112OTSH | 5/22/2009 | 10/22/2015 | 13 |
| 252391 | 48.75873 | -104.06383 | TRS-SEC | NAD83 | 2083.73 | 35N | 58E | 25 | DBB | 130 | 4/9/2009 | 112OTSH | 5/22/2009 | 8/20/2016 | 57740 |
| 252392 | 48.71063 | -104.08316 | NAV-GPS | NAD83 | 2058.12 | 34N | 58E | 11 | D | 100 | 9/30/2009 | 112OTSH | 11/4/2009 | 8/20/2016 | 80149 |
| 263859 | 48.49147 | -104.50597 | NAV-GPS | NAD83 | 1952.3 | 32N | 55E | 25 | DCCD | 72 | NA | 112OTSH | 5/9/1995 | 8/4/2016 | 53 |
| 267045 | 48.36127 | -104.60488 | NAV-GPS | NAD83 | 1930 | 30N | 55E | 8 | CCBD | 100 | NA | 112ALVM | 5/8/2012 | 5/9/2012 | 93 |
| 268466 | 48.36119 | -104.60484 | TRS-SEC | NAD83 | 1930 | 30N | 55E | 8 | CCC | 105 | 5/1/2012 | 112ALVM | 5/8/2012 | 5/9/2012 | 103 |
| 273937 | 48.60614 | -104.18503 | NAV-GPS | NAD83 | 2019.99 | 33N | 58E | 19 | BBBA | 136 | 6/4/2013 | 112OTSH | 6/4/2013 | 10/20/2016 | 15900 |
| 280602 | 48.40408 | -104.36800 | NAV-GPS | WGS84 | 2047.04 | 31N | 56E | 25 | DDDD | 203 | 10/15/2014 | 112ALVM | 10/15/2014 | 10/13/2016 | 10100 |
| 280612 | 48.41113 | -104.36776 | NAV-GPS | WGS84 | 2043 | 31N | 56E | 25 | DAAA | 220 | 10/16/2014 | 112ALVM | 10/16/2014 | 10/13/2016 | 14854 |
| 280618 | 48.42514 | -104.38897 | NAV-GPS | WGS84 | 1984.82 | 31N | 56E | 24 | CBBB | 140 | 10/17/2014 | 112ALVM | 11/24/2014 | 10/12/2016 | 10592 |
| 280621 | 48.42556 | -104.42151 | MAP | WGS84 | 2001 | 31N | 56E | 22 | CBBB | 59 | 10/18/2014 | 112ALVM | 10/18/2014 | 10/12/2016 | 15650 |
| 280641 | 48.48351 | -104.41044 | NAV-GPS | WGS84 | 1959.55 | 32N | 56E | 35 | BCCC | 140 | 10/20/2014 | 112OTSH | 10/20/2014 | 10/15/2016 | 6462 |
| 280643 | 48.48396 | -104.35423 | NAV-GPS | WGS84 | 1957.7 | 32N | 57E | 31 | ACCD | 248 | 10/21/2013 | 112OTSH | 10/20/2014 | 9/19/2016 | 10260 |
| 280645 | 48.50608 | -104.31126 | NAV-GPS | WGS84 | 1961.32 | 32N | 57E | 21 | DCCD | 120 | 10/22/2014 | 112OTSH | 10/22/2014 | 10/15/2016 | 479 |
| 280650 | 48.52396 | -104.26361 | NAV-GPS | WGS84 | 1973.71 | 32N | 57E | 14 | DACD | 90 | 10/22/2014 | 112OTSH | 10/22/2014 | 9/20/2016 | 7899 |
| 280651 | 48.55559 | -104.13442 | NAV-GPS | WGS84 | 1991.65 | 32N | 58E | 2 | DABB | 105 | 10/23/2014 | 112OTSH | 10/23/2014 | 3/29/2016 | 7592 |

| GWIC ID | Latitude | Longitude | Geomethod | Datum | Ground Surface Altitude (ft amsl) | Twn | Rng | Sec | Quarter Section | Total Depth (ft) | Date Completed m/d/yr | Aquifer Code* | First Date Measured (m/d/yr) | Last Date Measured (m/d/yr) | No. of Readings |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 280652 | 48.49110 | -104.43201 | NAV-GPS | WGS84 | 1977.88 | 32N | 56E | 28 | DDDD | 140 | 10/23/2014 | 112OTSH | 11/23/2014 | 10/15/2016 | 10082 |
| 283920 | 48.49167 | -104.51806 | NAV-GPS | WGS84 | | 32N | 55E | 25 | CCC | 64 | 7/16/2014 | 112OTSH | 8/18/2015 | 9/14/2015 | 2 |
| 703881 | 48.55179 | -104.19691 | NAV-GPS | NAD83 | 1973.22 | 32N | 58E | 5 | DDAB | 112 | 9/13/1980 | 112OTSH | 5/9/1995 | 10/19/2016 | 42 |
| 703926 | 48.70161 | -104.08961 | MAP | NAD83 | 2054.52 | 34N | 58E | 14 | BDDD | 90 | 1/1/1974 | 112OTSH | 5/9/1995 | 4/20/2016 | 43 |
| 703929 | 48.66817 | -104.15251 | MAP | NAD83 | 2040 | 34N | 58E | 29 | DCBA | 122 | 9/10/1981 | 112OTSH | 5/9/1995 | 4/20/2016 | 42 |
| 703974 | 48.81774 | -104.05506 | NAV-GPS | NAD83 | 2071.1 | 35N | 58E | 1 | ACDA | 32 | NA | 112OTSH | 5/10/1995 | 9/19/2016 | 184 |
| 703976 | 48.81778 | -104.04941 | MAP | NAD83 | 2080.8 | 35N | 58E | 1 | ADDA | 48 | NA | 112OTSH | 5/9/1995 | 4/14/2016 | 40 |
| 703979 | 48.76604 | -104.04861 | NAV-GPS | NAD83 | 2064.9 | 35N | 58E | 24 | DDDD | 73 | 5/25/1982 | 112OTSH | 6/8/1982 | 9/19/2016 | 231 |

| *AQUIFER CODE | DESCRIPTION |
|---|---|
| 112OTSH | PLEISTOCENE OUTWASH |
| 112ALVM | PLEISTOCENE ALLUVIUM |
| 125FRUN | FORT UNION FM |
| 211FHHC | FOX HILLS–HELL CREEK FM |

*Note.* The aquifer codes were assigned based on well depth, lithologies encountered, and geologic setting at each well.

# APPENDIX B

# WATER-QUALITY DATA

| GWIC ID | Sample Number | Site Type | Depth (ft) | Sample Date | Water Temp ºC | Lab pH | Lab SC (µS/cm) | Ca | Mg | Na | K | Fe | Mn | $SiO_2$ | $HCO_3$ | $SO_4$ | Cl | $NO_3$-N | F | TDS | SAR unit-less | Contam. Index unit less |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Water quality of the alluvial aquifer** | | | | | | | | | | | | | | | | | | | | | | |
| 3605 | 1984Q1146 | WELL | 185 | 10/15/1984 | 8.7 | 7.95 | 1,991 | 102 | 60 | 306 | 5.7 | 0.2 | 0.07 | 23.1 | 941 | 396 | 5 | 0.02 | 0.2 | 1,361 | 6.0 | 0.002 |
| 3605 | 206981 | WELL | 185 | 6/13/2014 | 9.2 | 8.07 | 1,994 | 101 | 60 | 320 | 5.5 | 0.9 | 0.06 | 21.3 | 931 | 437 | 6 | <0.010 | 0.62 | 1,410 | 6.2 | 0.003 |
| 3607 | 1985Q0824 | WELL | 172 | 7/8/1985 | | 7.75 | 2,431 | 106 | 63 | 437 | 6.1 | 1.0 | 0.09 | 27.3 | 1069 | 569 | 9 | 0.11 | 0.7 | 1,746 | 8.3 | 0.004 |
| 3607 | 1996Q0267 | WELL | 172 | 8/14/1995 | 12.6 | 7.94 | 2,260 | 111 | 64 | 436 | 5.8 | 3.2 | 0.04 | 26.4 | 1074 | 550 | 10 | 0.05 | 0.2 | 1,736 | 8.1 | 0.004 |
| 3608 | 1985Q0437 | WELL | | 5/27/1985 | 9.2 | 7.45 | 2,040 | 160 | 65 | 272 | 6.9 | 5.4 | 0.54 | 30.9 | 776 | 606 | 8 | 0.6 | 0.3 | 1,538 | 4.6 | 0.004 |
| 3609 | 1984Q0036 | WELL | 85 | 4/2/1984 | | 7.38 | 2,020 | 153 | 64 | 250 | 6.9 | 4.6 | 0.51 | 27.4 | 748 | 571 | 7 | 0.67 | 0.2 | 1,454 | 4.3 | 0.004 |
| 3671 | 1985Q0565 | WELL | 222 | 6/12/1985 | | 7.68 | 1,850 | 49 | 31 | 386 | 5.7 | 2.3 | 0.14 | 20.5 | 1096 | 170 | 10 | 0.2 | 0.8 | 1,216 | 10.6 | 0.005 |
| 3672 | 1983Q0696 | WELL | 213 | 7/20/1983 | | 8.03 | 1,858 | 41 | 25 | 401 | 5.0 | 2.7 | 0.12 | 17.9 | 1004 | 248 | 20 | 0.22 | 1.2 | 1,257 | 12.1 | 0.011 |
| 3677 | 1985Q0374 | WELL | 350 | 5/3/1985 | | 7.76 | 2,003 | 137 | 69 | 281 | 7.5 | 0.8 | 0.10 | 30.8 | 847 | 522 | 5 | 0.06 | 0.6 | 1,472 | 4.9 | 0.003 |
| 3677 | 206980 | WELL | 350 | 6/13/2014 | 9.3 | 7.63 | 2,560 | 204 | 96 | 321 | 8.2 | 0.7 | 0.20 | 26.8 | 920 | 666 | 7 | <0.050 | 0.67 | 1,784 | 4.6 | 0.003 |
| 3678 | 1984Q0790 | WELL | 125 | 8/12/1984 | 9.0 | 7.7 | 939 | 116 | 42 | 40 | 5.5 | 3.4 | 0.21 | 30.6 | 556 | 87 | 1 | 1.95 | 0.3 | 602 | 0.8 | 0.001 |
| 3679 | 1983Q0668 | WELL | 220 | 7/18/1983 | | 8 | 845 | 87 | 40 | 62 | 4.3 | 2.6 | 0.29 | 21.4 | 615 | 2 | 2 | 0.03 | 0.6 | 525 | 1.4 | 0.002 |
| 3680 | 1981Q0366 | WELL | 230 | 5/13/1981 | | 7.66 | 1,581 | 65 | 32 | 230 | 6.1 | 3.5 | 0.06 | 29.1 | 701 | 257 | 4 | 0.1 | 0.65 | 974 | 5.8 | 0.002 |
| 3762 | 1987Q0487 | WELL | 200 | 6/30/1987 | | 8.01 | 1,809 | 90 | 44 | 284 | 4.5 | 2.0 | 0.06 | 27.3 | 982 | 160 | 33 | 0.08 | 0.5 | 1,129 | 6.1 | 0.018 |
| 3762 | 206983 | WELL | 200 | 6/12/2014 | 8.4 | 8.04 | 1,774 | 92 | 43 | 293 | 4.7 | 0.1 | 0.05 | 23.3 | 989 | 173 | 46 | <0.010 | 0.56 | 1,163 | 6.3 | 0.026 |
| 3764 | 1987Q0488 | WELL | 200 | 7/1/1987 | | 7.89 | 2,153 | 103 | 59 | 321 | 5.4 | 2.3 | 0.11 | 25.9 | 1014 | 348 | 27 | 0.06 | 0.4 | 1,390 | 6.3 | 0.012 |
| 3764 | 206963 | WELL | 200 | 6/12/2014 | 8.8 | 7.83 | 2,012 | 111 | 67 | 304 | 5.9 | 1.4 | 0.16 | 23.9 | 1026 | 360 | 34 | <0.010 | 0.59 | 1,413 | 5.6 | 0.017 |
| 3765 | 1979Q0389 | WELL | 240 | 8/21/1978 | | 8.13 | 1,796 | 13 | 13 | 436 | 3.6 | 0.4 | 0.82 | 10.4 | 1124 | 0 | 76 | <.1 | 2.7 | 1,109 | 20.6 | 0.042 |
| 3766 | 1984Q1143 | WELL | 233 | 10/14/1984 | | 8.06 | 1,729 | 49 | 30 | 355 | 4.1 | 0.1 | 0.04 | 19.0 | 1192 | 9 | 23 | 0.02 | 1.2 | 1,077 | 9.9 | 0.013 |
| 3766 | 2001Q0014 | WELL | 233 | 6/28/2000 | 9.0 | 7.87 | 1,780 | 47 | 31 | 324 | 4.3 | 3.2 | 0.12 | 18.4 | 1187 | <25 | 26 | <.5 | 0.92 | 1,038 | 9.0 | 0.015 |
| 3766 | 206953 | WELL | 233 | 6/12/2014 | 9.1 | 8.37 | 1,687 | 46 | 30 | 362 | 4.4 | 0.1 | 0.09 | 17.2 | 1200 | 10 | 30 | <0.010 | 0.86 | 1,114 | 10.2 | 0.018 |
| 3766 | 210030 | WELL | 233 | 8/31/2015 | 9.8 | 7.64 | 1,754 | 48 | 30 | 356 | 4.5 | 3.7 | 0.11 | 19.1 | 1230 | 10 | 32 | <0.010 | 0.99 | 1,112 | 9.9 | 0.018 |
| 3769 | 1984Q0792 | WELL | 270 | 8/10/1984 | | 7.81 | 1,762 | 32 | 17 | 397 | 3.7 | 0.8 | 0.04 | 15.9 | 1088 | 89 | 30 | 0.05 | 0.3 | 1,122 | 14.2 | 0.017 |
| 3769 | 2001Q0015 | WELL | 270 | 6/27/2000 | | 8.51 | 2,250 | 19 | 11 | 454 | 3.5 | 0.8 | 0.02 | 10.9 | 1247 | 43 | 55 | <.5 | 1.45 | 1,213 | 20.5 | 0.024 |
| 3769 | 206945 | WELL | 270 | 6/12/2014 | 9.7 | 8.14 | 1,856 | 59 | 32 | 378 | 4.8 | <0.04 | 0.06 | 18.3 | 1027 | 237 | 24 | <0.010 | 0.85 | 1,268 | 9.8 | 0.013 |
| 3776 | 1979Q0392 | WELL | 295 | 8/26/1978 | 10.0 | 7.83 | 2,114 | 63 | 40 | 442 | 4.2 | 2.8 | 0.05 | 28.3 | 1293 | 172 | 18 | 1.4 | 0.8 | 1,409 | 10.7 | 0.008 |
| 3778 | 1985Q0731 | WELL | 222 | 6/21/1985 | 9.5 | 8.15 | 1,735 | 64 | 39 | 355 | 3.1 | 0.1 | 0.08 | 29.4 | 1315 | 8 | 7 | 0.15 | 0.7 | 1,155 | 8.6 | 0.004 |
| 3779 | 1985Q1038 | WELL | 270 | 9/12/1985 | | 7.51 | 1,330 | 82 | 53 | 445 | 4.4 | 7.1 | 0.10 | 28.3 | 1269 | 299 | 42 | 0.65 | 0.3 | 1,587 | 9.4 | 0.031 |
| 3779 | 2001Q0016 | WELL | 270 | 6/28/2000 | | 7.99 | 2,510 | 80 | 5 | 403 | 5.1 | 7.3 | 0.11 | 26.7 | 855 | 478 | 8 | <.5 | 0.76 | 1,435 | 11.8 | 0.003 |
| 3779 | 206906 | WELL | 270 | 6/11/2014 | 8.8 | 8.27 | 2,346 | 82 | 57 | 442 | 5.2 | 0.2 | 0.09 | 24.6 | 1116 | 524 | 8 | 0.06 | 0.58 | 1,712 | 9.2 | 0.003 |
| 3867 | 1984Q1142 | WELL | 336 | 10/13/1984 | | 8.05 | 2,999 | 62 | 40 | 678 | 6.6 | 0.1 | 0.51 | 23.0 | 1682 | 359 | 31 | 0.03 | 0.2 | 2,030 | 16.4 | 0.010 |
| 43116 | 1996Q0266 | WELL | 253 | 8/14/1995 | | 7.79 | 1,330 | 132 | 55 | 110 | 6.2 | 4.2 | 0.16 | 28.6 | 664 | 250 | 4 | <.05 | 0.5 | 918 | 2.0 | 0.003 |
| 44498 | 209590 | WELL | 271 | 6/29/2015 | 11.3 | 7.84 | 1,427 | 109 | 44 | 153 | 5.7 | 3.7 | 0.22 | 27.4 | 725 | 208 | 4 | 0.04 | 0.55 | 913 | 3.1 | 0.003 |
| 121117 | 1996Q0259 | WELL | 155 | 8/14/1995 | 9.1 | 8.21 | 1,102 | 121 | 44 | 84 | 5.2 | 4.6 | 0.25 | 29.7 | 587 | 150 | 4 | <.05 | 0.3 | 732 | 1.7 | 0.003 |
| 135910 | 1996Q0263 | WELL | 220 | 8/14/1995 | 11.3 | 7.71 | 1,744 | 85 | 49 | 312 | 5.2 | 3.6 | 0.06 | 26.0 | 1031 | 213 | 33 | <.05 | <.1 | 1,234 | 6.7 | 0.019 |
| 135910 | 207271 | WELL | 220 | 6/23/2014 | 10.8 | 7.4 | 1,823 | 92 | 51 | 307 | 5.1 | 0.5 | 0.05 | 25.9 | 1076 | 206 | 42 | 0.05 | 0.61 | 1,260 | 6.4 | 0.023 |

| GWIC ID | Sample Number | Site Type | Depth (ft) | Sample Date | Water Temp ºC | Lab pH | Lab SC (µS/cm) | Ca | Mg | Na | K | Fe | Mn | $SiO_2$ | $HCO_3$ | $SO_4$ | Cl | $NO_3$-N | F | TDS | SAR unit-less | Contam. Index unit less |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 150615 | 1996Q0270 | WELL | 260 | 8/15/1995 | 10.9 | 8.16 | 950 | 90 | 39 | 79 | 4.9 | 4.0 | 0.09 | 25.7 | 572 | 100 | 3 | <.05 | 0.5 | 629 | 1.8 | 0.003 |
| 150940 | 206965 | WELL | 150 | 6/12/2014 | 9.1 | 7.92 | 1,131 | 111 | 44 | 93 | 5.0 | 2.4 | 0.15 | 28.2 | 610 | 204 | 3 | <0.010 | 0.45 | 790 | 1.9 | 0.002 |
| 155929 | 206966 | WELL | 180 | 6/12/2014 | 11.5 | 7.86 | 1,111 | 112 | 47 | 72 | 6.0 | <0.038 | 0.17 | 27.8 | 589 | 175 | 3 | <0.010 | 0.37 | 733 | 1.4 | 0.003 |
| 155930 | 209589 | WELL | 180 | 6/29/2015 | 9.4 | 7.63 | 1,292 | 121 | 52 | 96 | 5.7 | 5.8 | 0.16 | 29.6 | 648 | 216 | 4 | <0.010 | 0.47 | 850 | 1.8 | 0.003 |
| 168130 | 206967 | WELL | 160 | 6/12/2014 | 9.5 | 7.91 | 1,076 | 105 | 41 | 77 | 5.0 | 0.4 | 0.18 | 27.4 | 571 | 178 | 3 | <0.010 | 0.47 | 718 | 1.6 | 0.002 |
| 168131 | 206964 | WELL | 160 | 6/12/2014 | 8.9 | 8.04 | 1,297 | 82 | 39 | 174 | 5.3 | 0.2 | 0.05 | 25.7 | 682 | 225 | 3 | <0.010 | 0.59 | 890 | 4.0 | 0.002 |
| 168132 | 1996Q5000 | WELL | 240 | 2/11/1996 | | 8.57 | 1,434 | 79 | 20 | 223 | 8.0 | 0.0 | | | 598 | 323 | 15 | 0.5 | | 970 | 5.8 | 0.010 |
| 168132 | 2004Q0323 | WELL | 240 | 12/12/2003 | 8.3 | 8.03 | 1,853 | 28 | 17 | 383 | 3.7 | 1.3 | 0.10 | 14.9 | 987 | 234 | 7 | <0.5 | <0.5 | 1,175 | 14.1 | 0.004 |
| 168866 | 1998Q5000 | WELL | 240 | 4/13/1998 | | 8.46 | 867 | 60 | 33 | 74 | 5.0 | 0.1 | | | 513 | 0 | 4 | 0 | | 431 | 1.9 | 0.005 |
| 168867 | 2000Q0467 | WELL | 240 | 11/5/1999 | | 7.55 | 920 | 62 | 33 | 93 | 4.7 | 1.6 | 0.19 | 23.4 | 532 | 80 | 1 | <.5 | 0.46 | 560 | 2.4 | 0.001 |
| 168867 | 206969 | WELL | 240 | 6/13/2014 | 10.0 | 8.05 | 914 | 62 | 33 | 101 | 4.0 | 0.1 | 0.16 | 21.0 | 581 | 64 | 1 | <0.010 | 0.61 | 573 | 2.6 | 0.001 |
| 169212 | 2000Q0468 | WELL | 108 | 11/4/1999 | 9.4 | 7.17 | 1,171 | 82 | 40 | 150 | 5.7 | 0.2 | 0.55 | 19.8 | 668 | 195 | 5 | <.5 | 0.75 | 829 | 3.4 | 0.005 |
| 169212 | 206901 | WELL | 108 | 6/10/2014 | 8.9 | 7.6 | 1,591 | 125 | 61 | 177 | 6.6 | 0.3 | 0.77 | 19.9 | 784 | 342 | 11 | 0.05 | 0.54 | 1,131 | 3.2 | 0.007 |
| 169213 | 2000Q0473 | WELL | 130 | 11/4/1999 | 9.2 | 7.12 | 1,240 | 108 | 53 | 92 | 8.9 | 0.1 | 0.67 | 18.6 | 605 | 213 | 11 | <.5 | 0.68 | 805 | 1.8 | 0.009 |
| 169213 | 206902 | WELL | 130 | 6/10/2014 | 10.0 | 7.45 | 1,211 | 112 | 57 | 87 | 6.5 | <0.038 | 0.28 | 21.7 | 537 | 285 | 11 | 0.16 | 0.51 | 846 | 1.7 | 0.009 |
| 169214 | 2000Q0461 | WELL | 160 | 11/4/1999 | 9.5 | 7.37 | 1,923 | 108 | 21 | 267 | 11.3 | <.05 | 0.61 | 18.0 | 732 | 406 | 6 | <.5 | 0.64 | 1,200 | 6.1 | 0.003 |
| 169214 | 206903 | WELL | 160 | 6/10/2014 | 9.7 | 7.34 | 1,678 | 153 | 50 | 176 | 15.9 | 6.1 | 2.83 | 17.3 | 828 | 341 | 4 | 0.22 | 0.4 | 1,174 | 3.2 | 0.002 |
| 169215 | 2000Q0469 | WELL | 190 | 11/4/1999 | 10.0 | 7.54 | 1,346 | 92 | 47 | 159 | 7.8 | 1.4 | 0.09 | 26.7 | 689 | 253 | 4 | <.5 | 0.69 | 932 | 3.4 | 0.003 |
| 169217 | 2000Q0462 | WELL | 227 | 11/2/1999 | 9.4 | 7.14 | 1,835 | 199 | 79 | 105 | 6.7 | 2.8 | 0.50 | 27.6 | 720 | 539 | 5 | <.5 | 0.54 | 1,321 | 1.6 | 0.003 |
| 169217 | 206977 | WELL | 227 | 6/13/2014 | 9.6 | 7.79 | 1,581 | 164 | 62 | 122 | 5.4 | 2.1 | 0.34 | 26.5 | 677 | 379 | 4 | <0.010 | 0.41 | 1,099 | 2.1 | 0.003 |
| 169218 | 2000Q0460 | WELL | 224 | 11/4/1999 | 10.1 | 7.45 | 1,228 | 113 | 47 | 95 | 6.0 | 4.1 | 0.15 | 30.0 | 611 | 227 | 3 | <.5 | 0.64 | 827 | 1.9 | 0.003 |
| 169218 | 206968 | WELL | 224 | 6/12/2014 | 9.4 | 7.85 | 1,292 | 126 | 53 | 98 | 5.4 | 1.6 | 0.14 | 28.5 | 621 | 274 | 3 | <0.010 | 0.48 | 895 | 1.9 | 0.002 |
| 175651 | 206986 | WELL | 246 | 5/31/2014 | 12.1 | 7.72 | 1,707 | 168 | 71 | 156 | 6.7 | 1.5 | 0.18 | 27.3 | 786 | 443 | 5 | 0.05 | 0.5 | 1,267 | 2.5 | 0.003 |
| 186196 | 1998Q5005 | WELL | 190 | 4/27/1998 | | 7.98 | 984 | 12 | 33 | 138 | 4.0 | 0.2 | | | 580 | 0 | 4 | 0 | | 477 | 4.7 | 0.004 |
| 206410 | 1998Q5011 | WELL | 180 | 4/27/1998 | | 8.08 | 1,899 | 28 | 60 | 273 | 7.0 | 0.1 | | | 903 | 279 | 7 | 0 | | 1,099 | 6.7 | 0.004 |
| 212128 | 209385 | WELL | 240 | 6/1/2015 | 9.9 | 7.45 | 1,553 | 147 | 60 | 126 | 6.2 | 3.1 | 0.25 | 33.2 | 646 | 318 | 4 | <0.010 | 0.47 | 1,015 | 2.2 | 0.002 |
| 215189 | 2005Q5004 | WELL | 175 | 3/22/2005 | | 8.31 | 2,688 | 48 | 18 | 532 | 6.0 | 0.9 | | | 915 | 634 | 10 | 0 | | 1,700 | 16.6 | 0.004 |
| 221606 | 2006Q0687 | WELL | 88 | 12/28/2005 | 7.6 | 7.37 | 1,440 | 155 | 78 | 103 | 7.0 | 0.2 | 0.89 | 22.8 | 635 | 385 | 3 | 1.21 | <0.5 | 1,065 | 1.7 | 0.002 |
| 221614 | 2006Q0653 | WELL | 288 | 12/29/2005 | 9.3 | 7.78 | 2,450 | 86 | 53 | 480 | 5.9 | 5.6 | 0.09 | 23.8 | 985 | 583 | 11 | 0.698 | 0.8 | 1,735 | 10.1 | 0.004 |
| 221614 | 206985 | WELL | 288 | 6/11/2014 | 9.9 | 8.09 | 2,537 | 82 | 50 | 503 | 5.2 | <0.075 | 0.07 | 21.6 | 1152 | 575 | 9 | <0.010 | 0.69 | 1,814 | 10.8 | 0.003 |
| 221634 | 2006Q0688 | WELL | 278 | 1/17/2006 | 7.4 | 8.11 | 2,120 | 74 | 38 | 443 | 6.8 | 0.0 | 0.10 | 26.1 | 846 | 526 | 9 | <0.5 | 1.14 | 1,540 | 10.5 | 0.004 |
| 221634 | 206978 | WELL | 278 | 6/13/2014 | 11.0 | 8.08 | 2,325 | 75 | 45 | 456 | 6.1 | <0.075 | 0.05 | 25.6 | 868 | 637 | 8 | <0.010 | 1.1 | 1,682 | 10.3 | 0.004 |
| 221637 | 2006Q0691 | WELL | 288 | 1/13/2006 | 7.7 | 8.77 | 1,939 | 8 | 3 | 531 | 3.0 | 0.1 | 0.02 | 26.2 | 1193 | 29 | 19 | <0.5 | <0.05 | 1,292 | 40.0 | 0.010 |
| 221637 | 206979 | WELL | 288 | 6/13/2014 | 10.2 | 8.73 | 2,120 | 3 | 2 | 582 | 2.3 | 0.1 | <0.010 | 24.6 | 1376 | 33 | 19 | 0.05 | 3.36 | 1,401 | 62.0 | 0.009 |
| 221647 | 2006Q0689 | WELL | 195 | 1/9/2006 | 9.0 | 7.38 | 1,523 | 149 | 83 | 122 | 7.1 | 6.6 | 0.71 | 28.2 | 718 | 326 | 5 | <0.5 | 0.59 | 1,083 | 2.0 | 0.004 |
| 221647 | 206975 | WELL | 195 | 6/13/2014 | 9.3 | 7.96 | 1,633 | 148 | 82 | 115 | 6.5 | 1.1 | 0.32 | 24.6 | 775 | 372 | 5 | <0.010 | 0.44 | 1,137 | 1.9 | 0.003 |
| 221651 | 2006Q0690 | WELL | 248 | 12/30/2005 | 8.5 | 8.02 | 2,270 | 38 | 25 | 558 | 5.3 | 1.5 | 0.06 | 20.4 | 1546 | 51 | 50 | <0.5 | <0.05 | 1,510 | 17.2 | 0.022 |

| GWIC ID | Sample Number | Site Type | Depth (ft) | Sample Date | Water Temp °C | Lab pH | Lab SC (µS/cm) | Ca | Mg | Na | K | Fe | Mn | $SiO_2$ | $HCO_3$ | $SO_4$ | Cl | $NO_3$-N | F | TDS | SAR unit-less | Contam. Index unit less |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 221651 | 206946 | WELL | 248 | 6/12/2014 | 8.8 | 8.38 | 2,300 | 33 | 23 | 560 | 5.2 | 0.3 | 0.05 | 18.9 | 1594 | 38 | 58 | 0.04 | 1.73 | 1,557 | 18.2 | 0.025 |
| 221651 | 222085 | WELL | 248 | 9/19/2016 | 10.5 | 7.67 | 2,475 | 34 | 24 | 559 | 5.0 | 2.0 | 0.04 | 21.4 | 1683 | 46 | 60 | <0.010 | 1.71 | 1,582 | 18.0 | 0.024 |
| 221652 | 206971 | WELL | 180 | 6/13/2014 | 9.5 | 7.77 | 1,005 | 141 | 42 | 24 | 3.9 | 0.8 | 1.03 | 24.8 | 514 | 140 | 3 | <0.010 | 0.12 | 634 | 0.5 | 0.003 |
| 252906 | 1.028E+10 | WELL | 130 | 9/30/2014 | | | 1,000 | 122 | 57 | 27 | 4.9 | 0.5 | 0.50 | | | 117 | 2 | | 0.18 | 332 | 0.5 | 0.002 |
| 267045 | 2012Q5003 | WELL | 100 | 10/10/2011 | | 8.1 | 1,988 | 92 | 19 | 414 | 5.0 | 0.4 | | | | 107 | 7 | | | 1,877 | 10.3 | 0.004 |
| 280602 | 208671 | WELL | 203 | 11/24/2014 | 8.0 | 7.8 | 2,106 | 193 | 129 | 165 | 11.0 | 0.8 | 0.07 | 24.3 | 924 | 664 | 7 | <0.010 | 0.4 | 1,649 | 2.3 | 0.003 |
| 280618 | 208674 | WELL | 140 | 11/24/2014 | 8.5 | 7.75 | 1,056 | 104 | 41 | 97 | 5.0 | 3.6 | 0.18 | 27.1 | 610 | 147 | 2 | <0.010 | 0.49 | 727 | 2.0 | 0.002 |
| 280618 | 222090 | WELL | 140 | 9/19/2016 | 10.4 | 7.08 | 1,087 | 103 | 41 | 89 | 5.5 | 4.7 | 0.16 | 30.8 | 618 | 148 | 3 | <0.010 | 0.48 | 730 | 1.9 | 0.002 |
| 280621 | 210405 | WELL | 59 | 11/20/2015 | 8.5 | 7.27 | 2,029 | 165 | 84 | 173 | 9.0 | 0.1 | 1.09 | 27.5 | 779 | 510 | 20 | 4.82 | 0.75 | 1,378 | 2.7 | 0.010 |
| 280621 | 222091 | WELL | 59 | 9/19/2016 | 11.0 | 7.25 | 1,949 | 171 | 90 | 176 | 10.0 | <0.038 | 0.98 | 28.7 | 776 | 530 | 21 | 2.6 | 0.49 | 1,414 | 2.7 | 0.011 |
| **Water quality of the glacial outwash aquifer** | | | | | | | | | | | | | | | | | | | | | | |
| 3606 | 1984Q1145 | WELL | 147 | 10/15/1984 | 7.7 | 7.79 | 2,488 | 95 | 45 | 464 | 6.2 | 0.2 | 0.75 | 18.7 | 871 | 680 | 7 | 0.05 | 0.2 | 1,746 | 9.8 | 0.003 |
| 3606 | 206982 | WELL | 147 | 6/13/2014 | 9.1 | 8.4 | 2,632 | 35 | 19 | 597 | 4.3 | <0.075 | 0.09 | 13.8 | 972 | 572 | 7 | <0.050 | 0.73 | 1,750 | 20.2 | 0.003 |
| 3611 | 1982Q0428 | WELL | 47 | 6/10/1982 | | 7.32 | 2,069 | 185 | 133 | 144 | 7.5 | 1.2 | 0.10 | 13.9 | 573 | 853 | 4 | 2.5 | 0.52 | 1,628 | 2.0 | 0.002 |
| 3614 | 1981Q0365 | WELL | 48 | 5/13/1981 | | 8.13 | 1,292 | 105 | 58 | 69 | 4.5 | 0.0 | 0.02 | 12.6 | 422 | 184 | 18 | 33.9 | 0.2 | 694 | 1.3 | 0.014 |
| 3673 | 1983Q0844 | WELL | 50 | 8/8/1983 | | 7.85 | 1,301 | 48 | 28 | 236 | 3.4 | 0.3 | 0.06 | 12.4 | 700 | 158 | 5 | 0.02 | 0.5 | 836 | 6.7 | 0.004 |
| 3676 | 1982Q0950 | WELL | 40 | 8/27/1982 | | 7.83 | 1,249 | 184 | 61 | 26 | 7.4 | 0.0 | 1.04 | 26.9 | 534 | 254 | 20 | 1.57 | 0.3 | 845 | 0.4 | 0.016 |
| 3682 | 1982Q0951 | WELL | 90 | 8/30/1982 | | 7.72 | 1,256 | 166 | 73 | 26 | 5.2 | 0.0 | 0.04 | 21.2 | 503 | 241 | 20 | 9.44 | 0.2 | 809 | 0.4 | 0.016 |
| 3683 | 1981Q0369 | WELL | 140 | 5/13/1981 | | 7.67 | 1,829 | 65 | 53 | 253 | 7.9 | 1.3 | 0.04 | 9.5 | 711 | 343 | 4 | 0.03 | 0.24 | 1,088 | 5.6 | 0.002 |
| 3761 | 1982Q0430 | WELL | 40 | 6/11/1982 | 6.5 | 7.43 | 2,842 | 150 | 92 | 417 | 9.9 | 0.3 | 1.82 | 19.2 | 788 | 865 | 135 | 0.65 | 0.58 | 2,080 | 6.6 | 0.048 |
| 3763 | 1987Q0486 | WELL | 200 | 7/1/1987 | | 7.78 | 1,973 | 84 | 47 | 324 | 5.1 | 2.3 | 0.06 | 27.5 | 991 | 239 | 29 | 0.06 | 0.6 | 1,247 | 7.0 | 0.015 |
| 3763 | 206962 | WELL | 200 | 6/12/2014 | 8.6 | 7.91 | 1,871 | 89 | 53 | 313 | 5.5 | 0.1 | 0.06 | 24.7 | 1,018 | 253 | 43 | <0.010 | 0.57 | 1,285 | 6.5 | 0.023 |
| 3767 | 1984Q1144 | WELL | 118 | 10/14/1984 | 8.1 | 7.92 | 2,003 | 142 | 77 | 263 | 6.3 | 0.2 | 0.09 | 26.5 | 1,080 | 291 | 40 | 0.03 | 0.2 | 1,378 | 4.4 | 0.020 |
| 3767 | 2001Q0017 | WELL | 118 | 6/28/2000 | 9.0 | 8.26 | 2,220 | 154 | 77 | 241 | 6.2 | 6.6 | 0.12 | 27.4 | 1,120 | 310 | 37 | <.5 | <.5 | 1,411 | 4.0 | 0.017 |
| 3767 | 206957 | WELL | 118 | 6/12/2014 | 8.5 | 7.76 | 2,087 | 150 | 80 | 268 | 6.5 | 0.3 | 0.11 | 25.8 | 1,067 | 353 | 41 | <0.010 | 0.26 | 1,451 | 4.4 | 0.020 |
| 3767 | 209930 | WELL | 118 | 8/3/2015 | 21.1 | 7.16 | 2,166 | 148 | 82 | 289 | 6.4 | 3.7 | 3.36 | 30.1 | 1,141 | 351 | 42 | <0.010 | 0.33 | 1,516 | 4.7 | 0.019 |
| 3770 | 1984Q0793 | WELL | 140 | 8/11/1984 | 8.5 | 7.8 | 1,600 | 108 | 51 | 213 | 5.0 | 5.5 | 0.20 | 26.0 | 779 | 304 | 3 | 0.03 | 0.1 | 1,099 | 4.2 | 0.002 |
| 3770 | 2001Q0020 | WELL | 140 | 8/26/2000 | | 7.64 | 1,679 | 107 | 50 | 203 | 5.1 | 5.3 | 0.21 | 25.6 | 775 | 304 | 6 | <.5 | 0.69 | 1,089 | 4.1 | 0.003 |
| 3770 | 206900 | WELL | 140 | 6/9/2014 | 9.1 | 7.64 | 1,659 | 110 | 55 | 224 | 5.9 | 4.8 | 0.31 | 25.6 | 794 | 367 | 8 | <0.010 | 0.46 | 1,192 | 4.3 | 0.005 |
| 3771 | 1988Q1401 | WELL | 100 | 8/21/1988 | | 8.3 | 1,058 | 94 | 51 | 85 | 4.1 | 3.2 | 0.24 | 29.1 | 682 | 73 | 2 | 0.21 | 0.4 | 676 | 1.8 | 0.002 |
| 3771 | 1996Q0268 | WELL | 100 | 8/15/1995 | 9.2 | 7.93 | 1,224 | 101 | 49 | 136 | 4.9 | 2.5 | 0.28 | 25.4 | 662 | 200 | 4 | <.05 | 0.1 | 849 | 2.8 | 0.003 |
| 3773 | 1984Q0795 | WELL | 143 | 8/10/1984 | | 7.34 | 1,307 | 128 | 62 | 99 | 4.8 | 3.1 | 0.25 | 25.4 | 646 | 265 | 2 | 0.04 | 0.1 | 907 | 1.8 | 0.002 |
| 3773 | 2001Q0019 | WELL | 143 | 6/27/2000 | 12.0 | 7.52 | 1,380 | 126 | 60 | 93 | 5.9 | 0.1 | 0.23 | 23.7 | 614 | 265 | 3 | 0.641 | <.5 | 878 | 1.7 | 0.002 |
| 3773 | 222103 | WELL | 143 | 9/21/2016 | 8.4 | 7.17 | 1,325 | 126 | 62 | 92 | 4.9 | 3.0 | 0.23 | 25.2 | 612 | 274 | 3 | <0.010 | 0.19 | 892 | 1.7 | 0.002 |
| 3774 | 1986Q0957 | WELL | 210 | 6/10/1986 | | 7.59 | 1,522 | 171 | 73 | 61 | 5.1 | 2.8 | 0.41 | 30.6 | 422 | 497 | 7 | 0.09 | 0.3 | 1,056 | 1.0 | 0.005 |
| 3774 | 206905 | WELL | 210 | 6/11/2014 | 9.2 | 7.67 | 2,162 | 293 | 123 | 91 | 6.9 | 4.7 | 0.85 | 25.9 | 438 | 1,147 | 19 | 0.05 | 0.19 | 1,928 | 1.1 | 0.009 |
| 3777 | 1986Q0958 | WELL | 80 | 8/23/1986 | | 7.92 | 1,501 | 118 | 57 | 176 | 5.1 | 0.4 | 0.11 | 30.0 | 768 | 267 | 11 | 0.08 | 0.4 | 1,043 | 3.3 | 0.007 |

| GWIC ID | Sample Number | Site Type | Depth (ft) | Sample Date | Water Temp ºC | Lab pH | Lab SC (µS/cm) | Ca | Mg | Na | K | Fe | Mn | $SiO_2$ | $HCO_3$ | $SO_4$ | Cl | $NO_3$-N | F | TDS | SAR unit-less | Contam. Index unit less |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3777 | 222100 | WELL | 80 | 9/20/2016 | 8.9 | 7.4 | 1,927 | 145 | 69 | 215 | 6.1 | 5.4 | 0.13 | 27.8 | 805 | 483 | 16 | 0.05 | 0.25 | 1,364 | 3.7 | 0.008 |
| 3848 | 1982Q0949 | WELL | 30 | 8/25/1982 | | 8.23 | 509 | 75 | 26 | 2 | 1.1 | <.002 | 0.00 | 12.5 | 302 | 9 | 3 | 7.34 | 0.1 | 285 | 0.1 | 0.005 |
| 3852 | 1982Q0948 | WELL | 90 | 8/24/1982 | | 7.33 | 2,205 | 177 | 139 | 179 | 8.3 | 11.8 | 0.23 | 18.0 | 833 | 726 | 7 | 0.062 | 0.4 | 1,679 | 2.4 | 0.003 |
| 3853 | 1985Q0564 | WELL | 101 | 6/9/1985 | 10.6 | 7.82 | 1,558 | 183 | 89 | 59 | 5.8 | 3.3 | 0.85 | 26.2 | 662 | 405 | 3 | 0.17 | 0.1 | 1,101 | 0.9 | 0.002 |
| 3854 | 1985Q1035 | WELL | 140 | 7/30/1985 | | 7.55 | 1,622 | 173 | 83 | 67 | 5.8 | 0.1 | 0.93 | 28.5 | 681 | 346 | 3 | 0.27 | 0.2 | 1,044 | 1.0 | 0.002 |
| 3855 | 1982Q0946 | WELL | 128 | 8/17/1982 | | 7.73 | 1,031 | 125 | 59 | 35 | 5.1 | 0.5 | 0.41 | 20.0 | 550 | 84 | 3 | 0.11 | 0.2 | 603 | 0.6 | 0.003 |
| 3856 | 1982Q0953 | WELL | 30 | 8/13/1982 | | 7.92 | 1,191 | 64 | 62 | 124 | 11.8 | 0.4 | 0.53 | 28.2 | 534 | 201 | 23 | 0.2 | 0.5 | 779 | 2.6 | 0.020 |
| 3857 | 1982Q0952 | WELL | 40 | 8/19/1982 | | 8.19 | 679 | 72 | 28 | 44 | 4.2 | 2.7 | 0.30 | 25.5 | 349 | 88 | 2 | 0.11 | 0.1 | 439 | 1.1 | 0.003 |
| 3858 | 1984Q0799 | WELL | 130 | 8/9/1984 | | 7.77 | 660 | 68 | 26 | 42 | 3.8 | 2.5 | 0.31 | 26.7 | 347 | 89 | 2 | 0.09 | 0.1 | 431 | 1.1 | 0.003 |
| 3858 | 2001Q0022 | WELL | 130 | 6/27/2000 | 10.1 | 7.84 | 808 | 80 | 30 | 45 | 4.2 | 2.8 | 0.34 | 25.5 | 337 | 95 | 38 | <.5 | <.5 | 487 | 1.1 | 0.047 |
| 3858 | 210025 | WELL | 130 | 8/30/2015 | 8.4 | 7.36 | 892 | 89 | 35 | 51 | 4.8 | 3.4 | 0.35 | 26.5 | 352 | 121 | 82 | <0.010 | 0.21 | 586 | 1.2 | 0.092 |
| 3859 | 1982Q0432 | WELL | 120 | 6/9/1982 | | 7.35 | 864 | 74 | 36 | 69 | 5.1 | 2.1 | 0.29 | 25.6 | 401 | 131 | 32 | 0.08 | 0.26 | 573 | 1.6 | 0.037 |
| 3859 | 1996Q0264 | WELL | 120 | 8/17/1995 | 9.7 | 7.69 | 1,092 | 93 | 40 | 72 | 5.3 | 3.2 | 0.37 | 25.6 | 380 | 100 | 110 | <.05 | <.1 | 636 | 1.6 | 0.101 |
| 3859 | 209588 | WELL | 120 | 6/15/2015 | 8.2 | 7.71 | 1,079 | 83 | 43 | 84 | 5.9 | 3.1 | 0.35 | 24.9 | 402 | 135 | 92 | <0.010 | 0.18 | 669 | 1.9 | 0.086 |
| 3861 | 1985Q1039 | WELL | 137 | 9/4/1985 | | 7.71 | 1,227 | 67 | 33 | 200 | 4.4 | 2.9 | 0.13 | 27.1 | 682 | 168 | 9 | 0.06 | 0.5 | 847 | 5.0 | 0.007 |
| 3862 | 1984Q0800 | WELL | 150 | 8/9/1984 | | 7.89 | 1,426 | 53 | 27 | 271 | 4.1 | 1.5 | 0.07 | 25.2 | 842 | 143 | 10 | 0.1 | 0.2 | 950 | 7.6 | 0.007 |
| 3866 | 1985Q1036 | WELL | 238 | 9/10/1985 | | 7.44 | 2,023 | 65 | 31 | 426 | 6.3 | 2.3 | 0.05 | 29.2 | 1,281 | 174 | 1 | 0.08 | 0.1 | 1,366 | 10.9 | 0.001 |
| 3868 | 1985Q1037 | WELL | 150 | 9/9/1985 | | 7.51 | 1,780 | 84 | 35 | 322 | 5.0 | 3.8 | 0.10 | 29.5 | 971 | 120 | 110 | 0.07 | 0.3 | 1,189 | 7.4 | 0.062 |
| 3869 | 1984Q0796 | WELL | 130 | 8/8/1984 | | 7.52 | 1,161 | 110 | 50 | 51 | 4.9 | 5.2 | 0.43 | 26.8 | 317 | 86 | 181 | 0.07 | 0.2 | 672 | 1.0 | 0.156 |
| 3869 | 2001Q0018 | WELL | 130 | 6/1/2000 | 9.8 | 7.57 | 880 | 71 | 32 | 58 | 4.2 | 3.3 | 0.27 | 26.0 | 336 | 86 | 56 | <.5 | <.5 | 501 | 1.4 | 0.064 |
| 3869 | 210028 | WELL | 130 | 8/31/2015 | 9.6 | 7.25 | 831 | 76 | 36 | 53 | 4.4 | 3.5 | 0.27 | 27.5 | 339 | 107 | 76 | <0.010 | 0.25 | 550 | 1.3 | 0.091 |
| 3870 | 1982Q0434 | WELL | 100 | 6/13/1982 | 8.5 | 7.35 | 1,077 | 104 | 53 | 68 | 4.5 | 3.4 | 0.34 | 25.8 | 540 | 191 | 4 | 0.49 | 0.24 | 720 | 1.4 | 0.004 |
| 3870 | 1996Q0271 | WELL | 100 | 8/17/1995 | 9.1 | 7.84 | 650 | 67 | 28 | 36 | 3.5 | 2.6 | 0.33 | 26.4 | 330 | 100 | 7 | <.05 | 0.1 | 433 | 0.9 | 0.010 |
| 3871 | 1984Q0797 | WELL | 98 | 8/8/1984 | | 7.72 | 634 | 62 | 27 | 39 | 3.4 | 2.6 | 0.31 | 26.9 | 336 | 80 | 2 | 0.13 | 0.1 | 408 | 1.0 | 0.003 |
| 3871 | 2001Q0021 | WELL | 98 | 6/28/2000 | 9.0 | 7.77 | 699 | 65 | 28 | 35 | 3.4 | 2.7 | 0.31 | 25.5 | 323 | 76 | 10 | <.5 | <.5 | 405 | 0.9 | 0.015 |
| 3871 | 210026 | WELL | 98 | 8/30/2015 | 8.4 | 7.44 | 711 | 73 | 34 | 36 | 3.8 | 3.2 | 0.34 | 26.8 | 331 | 107 | 33 | <0.010 | 0.23 | 480 | 0.9 | 0.046 |
| 3873 | 1984Q0540 | WELL | 150 | 6/12/1984 | 8.0 | 7.73 | 1,055 | 104 | 54 | 67 | 4.5 | 0.1 | 0.34 | 26.6 | 538 | 186 | 5 | 0.29 | 0.2 | 713 | 1.3 | 0.005 |
| 3873 | 1996Q0262 | WELL | 150 | 8/17/1995 | 11.1 | 7.49 | 1,081 | 107 | 56 | 68 | 4.8 | 3.2 | 0.35 | 25.0 | 562 | 200 | 4 | <.05 | <.1 | 745 | 1.3 | 0.004 |
| 3873 | 204784 | WELL | 150 | 8/22/2013 | 10.6 | 7.26 | 1,168 | 111 | 60 | 67 | 5.4 | 1.7 | 0.35 | 24.2 | 560 | 224 | 4 | <0.010 | 0.26 | 772 | 1.3 | 0.004 |
| 3944 | 1984Q0801 | WELL | 130 | 8/8/1984 | | 7.61 | 1,542 | 107 | 48 | 209 | 5.6 | 5.1 | 0.17 | 26.8 | 677 | 367 | 5 | 0.12 | 0.2 | 1,107 | 4.2 | 0.003 |
| 3944 | 2008Q5024 | WELL | 130 | 5/7/2008 | | 6.98 | 7,102 | 56 | 55 | 251 | 5.8 | 0.0 | | | 598 | 521 | 77 | 1.2 | | 1,261 | 5.7 | 0.011 |
| 3945 | 1982Q0436 | WELL | 153 | 6/13/1982 | | 7.2 | 971 | 90 | 39 | 79 | 3.4 | 3.8 | 0.29 | 27.7 | 442 | 199 | 5 | 0.02 | 0.24 | 664 | 1.8 | 0.005 |
| 3945 | 207615 | WELL | 153 | 7/15/2014 | 9.5 | 7.49 | 1,094 | 102 | 45 | 90 | 3.5 | 3.2 | 0.36 | 26.2 | 455 | 290 | 9 | <0.010 | 0.22 | 793 | 1.9 | 0.008 |
| 3946 | 1982Q0435 | WELL | 154 | 6/13/1982 | | 7.2 | 1,211 | 121 | 48 | 96 | 4.5 | 0.9 | 0.54 | 23.7 | 503 | 294 | 5 | 0.26 | 0.21 | 843 | 1.9 | 0.004 |
| 3946 | 207760 | WELL | 154 | 7/30/2014 | 8.4 | 7.41 | 1,220 | 99 | 44 | 87 | 4.0 | 0.6 | 0.50 | 23.4 | 328 | 286 | 7 | <0.010 | 0.17 | 712 | 1.8 | 0.005 |
| 3947 | 1984Q0802 | WELL | 110 | 8/11/1984 | | 7.61 | 1,279 | 104 | 48 | 130 | 5.4 | 4.8 | 0.47 | 28.2 | 576 | 273 | 3 | 0.13 | 0.2 | 879 | 2.7 | 0.002 |
| 3947 | 2001Q0013 | WELL | 110 | 6/27/2000 | 10.0 | 7.43 | 1,466 | 124 | 55 | 132 | 5.6 | 5.8 | 0.62 | 26.0 | 565 | 348 | 5 | <.5 | 0.37 | 981 | 2.5 | 0.004 |

| GWIC ID | Sample Number | Site Type | Depth (ft) | Sample Date | Water Temp ºC | Lab pH | Lab SC (µS/cm) | Ca | Mg | Na | K | Fe | Mn | $SiO_2$ | $HCO_3$ | $SO_4$ | Cl | $NO_3$-N | F | TDS | SAR unit-less | Contam. Index unit less |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3947 | 210023 | WELL | 110 | 8/30/2015 | 8.4 | 7.12 | 1,430 | 117 | 57 | 147 | 6.1 | 5.3 | 0.56 | 26.9 | 595 | 359 | 7 | <0.010 | 0.32 | 1,018 | 2.8 | 0.005 |
| 3948 | 1982Q0437 | WELL | 104 | 6/13/1982 | | 7.71 | 968 | 80 | 35 | 92 | 3.6 | 2.8 | 0.28 | 27.0 | 439 | 192 | 4 | 0.16 | 0.26 | 653 | 2.2 | 0.004 |
| 3948 | 204782 | WELL | 104 | 8/21/2013 | 9.3 | 7.38 | 1,063 | 94 | 43 | 87 | 4.4 | 2.1 | 0.39 | 24.1 | 397 | 283 | 14 | <0.010 | 0.18 | 747 | 1.9 | 0.013 |
| 3949 | 1982Q0438 | WELL | 90 | 6/13/1982 | | 7.62 | 830 | 69 | 31 | 72 | 3.2 | 2.4 | 0.25 | 26.8 | 398 | 145 | 3 | 0.21 | 0.26 | 547 | 1.8 | 0.004 |
| 3949 | 1996Q0269 | WELL | 90 | 8/17/1995 | 10.5 | 7.86 | 888 | 88 | 39 | 57 | 3.0 | 2.2 | 0.34 | 25.9 | 355 | 200 | 7 | <.05 | 0.1 | 597 | 1.3 | 0.007 |
| 4048 | 1983Q0666 | WELL | 45 | 7/14/1983 | 8.0 | 7.97 | 764 | 66 | 24 | 62 | 3.7 | 0.3 | 0.46 | 20.3 | 249 | 117 | 57 | 0.01 | 0.08 | 473 | 1.7 | 0.074 |
| 4051 | 1973Q0403 | WELL | | 7/10/1973 | | 7.39 | 2,930 | 181 | 142 | 390 | 4.4 | 0.0 | 2.30 | 19.9 | 956 | 1,022 | 26 | 0.54 | 0.1 | 2,259 | 5.3 | 0.009 |
| 4052 | 1984Q0541 | WELL | 140 | 6/12/1984 | 8.5 | 7.53 | 1,501 | 135 | 55 | 154 | 5.7 | 2.7 | 0.20 | 28.4 | 601 | 387 | 8 | 0.04 | 0.2 | 1,072 | 2.8 | 0.005 |
| 4149 | 1973Q0402 | WELL | | 7/1/1973 | | 7.44 | 33,100 | 1,663 | 857 | 5,000 | 32.0 | 0.1 | 1.42 | 9.2 | 272 | 413 | 12,770 | <.023 | <.1 | 20,879 | 24.8 | 0.386 |
| 44438 | 1982Q0431 | WELL | 82 | 6/11/1982 | 8.2 | 7.24 | 1,798 | 128 | 63 | 224 | 5.8 | 5.6 | 0.07 | 27.2 | 997 | 202 | 41 | 0.04 | 0.47 | 1,188 | 4.1 | 0.023 |
| 44466 | 222021 | WELL | 91 | 8/24/2016 | 8.4 | 7.3 | 1,939 | 145 | 66 | 265 | 6.0 | 4.8 | 0.06 | 25.7 | 899 | 444 | 53 | 0.08 | 0.25 | 1,452 | 4.6 | 0.027 |
| 44469 | 1984Q5003 | WELL | 131 | 9/18/1984 | | 7.92 | 1,636 | 122 | 24 | 250 | 7.0 | 1.0 | | | 1,037 | 93 | 1 | 8 | | 1,017 | 5.4 | 0.001 |
| 44473 | 222020 | WELL | 100 | 8/24/2016 | 9.6 | 7.31 | 2,308 | 1 | 0 | 605 | 0.9 | 0.1 | <0.010 | 22.1 | 854 | 528 | 66 | <0.010 | 0.25 | 1,642 | 196.4 | 0.028 |
| 45291 | 1990Q5000 | WELL | 80 | 3/8/1990 | NA | 7.89 | 1,079 | 168 | 56 | 91 | 8.0 | 0.0 | NA | NA | 622 | 346 | 8 | 0 | NA | 983 | 1.6 | 0.007 |
| 45292 | 1990Q5001 | WELL | 100 | 3/8/1990 | NA | 7.92 | 1,150 | 196 | 56 | 125 | 8.0 | 0.1 | NA | NA | 732 | 355 | 14 | 0 | NA | 1,115 | 2.0 | 0.012 |
| 45315 | 1982Q0433 | WELL | 152 | 6/9/1982 | 8.8 | 7.58 | 1,833 | 40 | 20 | 409 | 4.4 | 1.0 | 0.04 | 19.7 | 1,060 | 151 | 49 | 0.11 | 1.06 | 1,217 | 13.2 | 0.027 |
| 45315 | 1984Q0791 | WELL | 152 | 8/9/1984 | 8.5 | 7.78 | 1,742 | 38 | 19 | 394 | 4.0 | 1.1 | 0.04 | 19.8 | 1,005 | 146 | 29 | 1.63 | 0.2 | 1,148 | 13.1 | 0.017 |
| 45325 | 1989Q1374 | WELL | 120 | 10/13/1989 | 8.5 | 7.95 | 1,565 | 96 | 73 | 122 | 5.8 | <.004 | <.002 | 24.0 | 617 | 318 | 5 | <.007 | 0.65 | 948 | 2.3 | 0.003 |
| 45325 | 1996Q0260 | WELL | 120 | 8/15/1995 | 10.0 | 7.59 | 1,374 | 125 | 64 | 107 | 5.2 | 2.1 | 0.35 | 23.2 | 619 | 300 | 6 | <.05 | 0.2 | 937 | 1.9 | 0.004 |
| 45325 | 207618 | WELL | 120 | 7/16/2014 | 9.6 | 7.46 | 1,442 | 143 | 74 | 104 | 4.9 | 2.5 | 0.39 | 22.5 | 645 | 386 | 7 | <0.010 | 0.2 | 1,063 | 1.8 | 0.005 |
| 45327 | 1996Q0272 | WELL | 91 | 8/14/1995 | 9.9 | 7.83 | 848 | 83 | 35 | 64 | 4.8 | 1.8 | 0.33 | 26.2 | 436 | 100 | 7 | 0.1 | 0.2 | 537 | 1.5 | 0.008 |
| 45980 | 207612 | WELL | 126 | 7/9/2014 | 10.2 | 7.35 | 1,434 | 121 | 57 | 149 | 4.9 | 3.9 | 0.30 | 24.7 | 577 | 398 | 12 | 0.9 | 0.21 | 1,056 | 2.8 | 0.008 |
| 45981 | 204781 | WELL | 150 | 8/21/2013 | 9.6 | 7.08 | 1,498 | 122 | 54 | 144 | 5.3 | 4.7 | 0.19 | 25.7 | 469 | 418 | 40 | 0.07 | 0.18 | 1,045 | 2.7 | 0.027 |
| 45983 | 207611 | WELL | 95 | 7/9/2014 | 12.0 | 6.74 | 1,113 | 117 | 51 | 69 | 3.7 | 3.1 | 0.53 | 24.5 | 385 | 341 | 14 | 0.36 | 0.17 | 813 | 1.3 | 0.012 |
| 46003 | 204783 | WELL | 81 | 8/21/2013 | 19.5 | 7.13 | 1,408 | 126 | 57 | 115 | 6.8 | 2.8 | 0.68 | 22.8 | 467 | 393 | 23 | 0.07 | 0.14 | 977 | 2.1 | 0.016 |
| 46965 | 1983Q0665 | WELL | 40 | 7/14/1983 | | 7.8 | 1,842 | 127 | 46 | 191 | 5.8 | 1.6 | 0.66 | 23.5 | 282 | 105 | 403 | 2.58 | 0.08 | 1,047 | 3.7 | 0.219 |
| 47739 | 1985Q0832 | WELL | 95 | 7/23/1985 | 8.9 | 7.52 | 1,375 | 115 | 48 | 139 | 6.1 | 1.6 | 0.41 | 26.1 | 418 | 356 | 40 | 5.87 | 0.3 | 944 | 2.7 | 0.029 |
| 126758 | 1990Q5002 | WELL | 80 | 6/24/1990 | NA | 7.78 | 1,384 | 108 | 29 | 260 | 7.0 | 0.0 | NA | NA | 842 | 286 | 20 | 0.6 | NA | 1,126 | 5.7 | 0.014 |
| 142105 | 207274 | WELL | 100 | 6/24/2014 | 9.0 | 7.02 | 1,490 | 175 | 82 | 69 | 5.8 | 3.2 | 0.70 | 24.0 | 703 | 382 | 4 | 0.31 | 0.21 | 1,092 | 1.1 | 0.002 |
| 149610 | 1982Q5050 | WELL | 92.5 | 6/8/1982 | | 7.9 | 574 | 62 | 23 | 26 | 4.2 | 0.9 | 0.54 | 23.0 | 296 | 65 | 4 | 0.22 | 0.3 | 355 | 0.7 | 0.006 |
| 150614 | 1996Q0265 | WELL | 68 | 8/17/1995 | 9.5 | 7.39 | 1,893 | 251 | 107 | 113 | 7.4 | 10.6 | 0.25 | 26.6 | 586 | 800 | 12 | <.05 | 0.3 | 1,616 | 1.5 | 0.006 |
| 150614 | 207272 | WELL | 68 | 6/23/2014 | 9.1 | 7.24 | 1,411 | 139 | 59 | 123 | 6.0 | 5.7 | 0.15 | 26.1 | 679 | 320 | 6 | <0.010 | 0.46 | 1,019 | 2.2 | 0.004 |
| 150769 | 1996Q0273 | WELL | 100 | 8/15/1995 | 11.0 | 7.85 | 1,854 | 214 | 129 | 108 | 7.2 | 4.6 | 0.62 | 23.2 | 595 | 750 | 8 | 0.1 | 0.3 | 1,538 | 1.4 | 0.004 |
| 159786 | 1997Q5000 | WELL | 160 | 9/24/1996 | | 8.11 | 1,899 | 75 | 60 | 302 | 1.0 | 0.4 | | | 732 | 474 | 12 | 0.1 | | 1,285 | 6.3 | 0.006 |
| 159786 | 2000Q0466 | WELL | 160 | 11/5/1999 | 9.5 | 7.72 | 1,190 | 91 | 46 | 112 | 4.8 | 3.9 | 0.21 | 26.4 | 662 | 157 | 4 | <.5 | 0.57 | 772 | 2.4 | 0.003 |
| 159789 | 2000Q0470 | WELL | 180 | 11/5/1999 | 8.9 | 7.82 | 750 | 71 | 28 | 53 | 4.2 | 2.4 | 0.14 | 20.3 | 455 | 44 | 1 | <.5 | 0.47 | 447 | 1.4 | 0.002 |
| 159791 | 1997Q5001 | WELL | 160 | 10/7/1996 | | 8.5 | 902 | 123 | 1 | 101 | 5.0 | 0.2 | | | 488 | 119 | 6 | 0.1 | | 601 | 2.5 | 0.007 |

| GWIC ID | Sample Number | Site Type | Depth (ft) | Sample Date | Water Temp ºC | Lab pH | Lab SC (µS/cm) | Ca | Mg | Na | K | Fe | Mn | $SiO_2$ | $HCO_3$ | $SO_4$ | Cl | $NO_3$-N | F | TDS | SAR unit-less | Contam. Index unit less |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 159795 | 1986Q5015 | WELL | 150 | 5/20/1986 | | 7.47 | 2,002 | 87 | 37 | 340 | 5.0 | 0.2 | | | 1,233 | 120 | 10 | 0 | | 1,209 | 7.7 | 0.005 |
| 159795 | 1986Q5014 | WELL | 150 | 5/28/1986 | | 7.9 | 1,848 | 87 | 43 | 345 | 5.0 | 0.1 | | | 1,245 | 120 | 10 | 0 | | 1,223 | 7.6 | 0.005 |
| 159795 | 2010Q5098 | WELL | 150 | 12/2/2009 | | 7.86 | 1,683 | 60 | 44 | 257 | 6.0 | 0.1 | | | 988 | 145 | 5 | 0 | | 1,004 | 6.1 | 0.003 |
| 159795 | 2010Q5099 | WELL | 150 | 12/22/2009 | | 7.88 | 1,854 | 64 | 49 | 289 | 7.0 | 0.3 | | | 1,159 | 103 | 0 | 0 | | 1,083 | 6.6 | 0.000 |
| 159795 | 207273 | WELL | 150 | 6/24/2014 | 9.5 | 7.51 | 1,846 | 78 | 41 | 359 | 4.6 | 1.8 | 0.12 | 24.6 | 1,271 | 129 | 10 | 0.06 | 0.79 | 1,276 | 8.2 | 0.006 |
| 160086 | 207763 | WELL | 132 | 7/29/2014 | 10.3 | 7.47 | 1,082 | 94 | 49 | 67 | 3.6 | 1.7 | 0.22 | 15.7 | 196 | 107 | 2 | 0.57 | 0.1 | 438 | 1.4 | 0.002 |
| 161782 | 2006Q0295 | WELL | 10 | 9/16/2005 | 14.5 | 7.69 | 682 | 72 | 30 | 34 | 4.8 | | | | 408 | 44 | 5 | | | 391 | 0.8 | 0.007 |
| 161785 | 2006Q0309 | WELL | 8.8 | 9/15/2005 | 10.1 | 7.22 | 1,615 | 129 | 59 | 206 | 7.1 | | | | 698 | 414 | 15 | | | 1,174 | 3.8 | 0.009 |
| 161792 | 1997Q5003 | WELL | 118 | NA | | 7.69 | 1,434 | 121 | 74 | 107 | 6.0 | 0.1 | | | 622 | 304 | 55 | 0.1 | | 973 | 1.9 | 0.038 |
| 161802 | 2003Q5036 | WELL | 90 | 4/28/2003 | | 7.08 | 2,140 | 71 | 48 | 333 | 5.4 | 0.2 | | | 568 | 659 | 16 | 0.1 | | 1,426 | 7.5 | 0.007 |
| 161802 | 2004Q0324 | WELL | 90 | 12/12/2003 | 7.7 | 7.61 | 1,667 | 73 | 37 | 257 | 5.3 | 3.4 | 0.58 | 25.4 | 634 | 404 | 13 | <0.5 | <0.5 | 1,130 | 6.1 | 0.008 |
| 161802 | 1997Q5004 | WELL | 90 | NA | | 8.01 | 1,766 | 36 | 29 | 376 | 8.0 | 0.0 | | | 598 | 446 | 26 | 0.3 | | 1,216 | 11.3 | 0.015 |
| 161803 | 1997Q5005 | WELL | 180 | NA | | 8.13 | 2,434 | 46 | 50 | 481 | 110 | 0.6 | | | 610 | 741 | 28 | 0.2 | | 1,658 | 11.7 | 0.012 |
| 161804 | 1997Q5006 | WELL | 130 | NA | | 8.16 | 2,060 | 44 | 42 | 416 | 9.0 | 0.3 | | | 525 | 592 | 38 | 0.2 | | 1,400 | 10.8 | 0.018 |
| 168129 | 1998Q5006 | WELL | 140 | 5/4/1998 | | 8.15 | 1,065 | 69 | 29 | 123 | 6.0 | 0.2 | | | 476 | 223 | 7 | 0 | | 691 | 3.1 | 0.007 |
| 168129 | 2008Q5025 | WELL | 140 | 5/2/2008 | | 7.2 | 9,752 | 102 | 32 | 132 | 4.4 | 0.2 | | | 445 | 383 | 26 | 0.2 | | 899 | 2.9 | 0.003 |
| 169219 | 2000Q0465 | WELL | 80 | 11/4/1999 | 8.3 | 7.55 | 950 | 104 | 38 | 48 | 4.2 | 6.5 | 0.80 | 27.6 | 642 | 24 | 2 | <.5 | 0.26 | 572 | 1.0 | 0.002 |
| 169220 | 2000Q0464 | WELL | 135 | 11/4/1999 | 8.7 | 7.76 | 790 | 73 | 33 | 48 | 4.8 | 2.2 | 0.68 | 23.4 | 492 | 47 | 1 | <.5 | 0.43 | 475 | 1.2 | 0.001 |
| 169372 | 2000Q0472 | WELL | 220 | 11/2/1999 | 7.2 | 7.23 | 1,338 | 114 | 49 | 143 | 5.7 | 4.5 | 0.17 | 25.5 | 572 | 368 | 13 | <.5 | <.5 | 1,005 | 2.8 | 0.010 |
| 169373 | 2000Q0471 | WELL | 30 | 11/2/1999 | 7.4 | 7.78 | 745 | 51 | 31 | 58 | 2.7 | <.01 | 0.18 | 19.1 | 315 | 94 | 3 | 15.89 | <.5 | 413 | 1.6 | 0.003 |
| 169374 | 2000Q0463 | WELL | 200 | 11/7/1999 | 6.9 | 7.44 | 1,804 | 125 | 59 | 244 | 7.4 | 6.4 | 0.14 | 23.6 | 747 | 467 | 11 | <.5 | <.5 | 1,311 | 4.5 | 0.006 |
| 186197 | 1998Q5007 | WELL | 90 | 5/4/1998 | | 8.33 | 1,605 | 36 | 36 | 288 | 7.0 | 0.4 | | | 586 | 446 | 16 | 0.8 | | 1,121 | 8.1 | 0.010 |
| 193352 | 204320 | WELL | 108 | 7/18/2013 | 10.5 | 7.41 | 1,170 | 98 | 42 | 108 | 4.2 | 2.4 | 0.21 | 27.2 | 478 | 273 | 8 | 0.2 | 0.19 | 797 | 2.3 | 0.007 |
| 193370 | 207761 | WELL | 142 | 7/30/2014 | 9.1 | 7.36 | 1,325 | 102 | 49 | 109 | 4.8 | 4.7 | 0.22 | 25.0 | 413 | 287 | 6 | <0.010 | 0.17 | 791 | 2.2 | 0.005 |
| 206533 | 2004Q0326 | WELL | 80 | 12/9/2003 | 7.6 | 7.67 | 1,964 | 73 | 39 | 329 | 8.4 | 3.2 | 0.34 | 25.3 | 675 | 500 | 10 | 0.568 | <0.5 | 1,320 | 7.7 | 0.005 |
| 206533 | 222092 | WELL | 80 | 9/20/2016 | 8.6 | 7.34 | 2,178 | 81 | 45 | 380 | 9.2 | 4.7 | 0.25 | 28.7 | 790 | 530 | 13 | <0.010 | 0.16 | 1,481 | 8.4 | 0.006 |
| 206537 | 2004Q0321 | WELL | 100 | 12/9/2003 | 7.4 | 7.3 | 1,987 | 132 | 60 | 250 | 7.4 | 7.0 | 0.11 | 27.0 | 666 | 578 | 10 | <0.5 | <0.5 | 1,399 | 4.5 | 0.005 |
| 206539 | 2004Q0320 | WELL | 180 | 12/12/2003 | 6.9 | 7.71 | 2,850 | 118 | 60 | 487 | 6.7 | 5.1 | 0.55 | 24.1 | 892 | 882 | 34 | <0.5 | <1.0 | 2,058 | 9.1 | 0.012 |
| 206546 | 2004Q0322 | WELL | 120 | 12/9/2003 | 7.9 | 7.54 | 2,050 | 136 | 61 | 257 | 6.8 | 7.1 | 0.16 | 27.7 | 686 | 556 | 9 | <0.5 | <0.5 | 1,399 | 4.6 | 0.004 |
| 206546 | 2005Q5003 | WELL | 120 | 3/22/2005 | | 7.88 | 2,082 | 179 | 31 | 254 | 9.0 | 0.1 | | | 732 | 553 | 8 | 0 | | 1,395 | 4.6 | 0.004 |
| 206546 | 222093 | WELL | 120 | 9/20/2016 | 9.7 | 7.09 | 2,134 | 136 | 67 | 287 | 7.3 | 6.7 | 0.08 | 31.0 | 806 | 593 | 10 | <0.010 | 0.19 | 1,535 | 5.0 | 0.005 |
| 206547 | 2004Q0325 | WELL | 200 | 12/9/2003 | 6.8 | 7.72 | 1,994 | 109 | 39 | 312 | 4.9 | 4.9 | 0.10 | 24.3 | 1,108 | 211 | 43 | <0.5 | <0.5 | 1,294 | 6.5 | 0.021 |
| 206547 | 206904 | WELL | 200 | 6/11/2014 | 8.8 | 7.97 | 2,013 | 104 | 40 | 376 | 5.4 | 0.0 | 0.09 | 24.6 | 1,026 | 243 | 50 | <0.010 | 0.36 | 1,349 | 7.9 | 0.025 |
| 206548 | 2004Q0327 | WELL | 180 | 12/12/2003 | 7.8 | 7.81 | 2,160 | 84 | 49 | 369 | 7.3 | 5.0 | 0.15 | 24.5 | 1,209 | 291 | 52 | <0.5 | <0.5 | 1,478 | 7.9 | 0.024 |
| 206548 | 2006Q0297 | WELL | 180 | 9/11/2005 | 9.3 | 7.58 | 2,150 | 79 | 46 | 404 | 7.2 | | | | 1,138 | 262 | 47 | | | 1,406 | 8.9 | 0.022 |
| 206548 | 206899 | WELL | 180 | 6/9/2014 | 8.2 | 7.37 | 2,279 | 86 | 49 | 438 | 7.7 | 4.7 | 0.11 | 25.0 | 1,192 | 305 | 60 | 0.06 | 0.44 | 1,563 | 9.3 | 0.026 |
| 215220 | 222094 | WELL | 140 | 9/20/2016 | 9.2 | 7.38 | 1,610 | 73 | 40 | 252 | 6.1 | 1.8 | 0.12 | 25.8 | 840 | 258 | 4 | <0.010 | 0.16 | 1,075 | 5.9 | 0.003 |

| GWIC ID | Sample Number | Site Type | Depth (ft) | Sample Date | Water Temp °C | Lab pH | Lab SC (µS/cm) | Ca | Mg | Na | K | Fe | Mn | $SiO_2$ | $HCO_3$ | $SO_4$ | Cl | $NO_3$-N | F | TDS | SAR unit-less | Contam. Index unit less |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 215223 | 222095 | WELL | 140 | 9/20/2016 | 8.8 | 7.38 | 1,361 | 99 | 41 | 158 | 5.1 | 0.6 | 0.20 | 25.8 | 587 | 315 | 9 | <0.010 | 0.2 | 943 | 3.4 | 0.006 |
| 221597 | 2006Q0652 | WELL | 128 | 12/27/2005 | 8.4 | 7.67 | 1,157 | 77 | 42 | 169 | 5.9 | 2.5 | 0.31 | 23.2 | 613 | 222 | 15 | <0.5 | <0.50 | 859 | 3.9 | 0.013 |
| 221597 | 222096 | WELL | 128 | 9/20/2016 | 9.7 | 7.41 | 1,163 | 82 | 39 | 135 | 4.9 | 3.5 | 0.16 | 26.0 | 676 | 136 | 5 | <0.010 | 0.35 | 765 | 3.1 | 0.005 |
| 221602 | 2006Q0685 | WELL | 108 | 12/28/2005 | 7.7 | 7.53 | 694 | 68 | 27 | 51 | 4.2 | 1.6 | 0.27 | 24.1 | 349 | 99 | 6 | 1.27 | 0.15 | 454 | 1.3 | 0.009 |
| 221602 | 222097 | WELL | 108 | 9/20/2016 | 8.8 | 7.51 | 741 | 76 | 29 | 51 | 4.1 | 1.6 | 0.25 | 24.3 | 377 | 112 | 11 | <0.010 | 0.14 | 495 | 1.3 | 0.015 |
| 221630 | 2006Q0654 | WELL | 168 | 12/29/2005 | 8.5 | 7.62 | 1,063 | 88 | 45 | 101 | 5.1 | 5.5 | 0.19 | 25.0 | 659 | 94 | 4 | <0.5 | <0.05 | 691 | 2.2 | 0.004 |
| 221630 | 206984 | WELL | 168 | 6/11/2014 | 9.6 | 7.82 | 1,123 | 99 | 49 | 94 | 4.4 | 1.6 | 0.18 | 23.3 | 692 | 98 | 3 | <0.010 | 0.55 | 714 | 1.9 | 0.002 |
| 221646 | 2006Q0650 | WELL | 68 | 1/5/2006 | 8.6 | 7.52 | 811 | 91 | 30 | 44 | 3.9 | 0.9 | 0.95 | 26.2 | 515 | 73 | 4 | <0.5 | 0.22 | 528 | 1.0 | 0.005 |
| 221646 | 206970 | WELL | 68 | 6/13/2014 | 8.6 | 8.1 | 765 | 92 | 29 | 35 | 3.4 | <0.015 | 0.75 | 26.0 | 476 | 66 | 4 | <0.010 | 0.17 | 491 | 0.8 | 0.005 |
| 221649 | 2006Q0686 | WELL | 168 | 12/30/2005 | 8.1 | 7.59 | 2,170 | 115 | 73 | 374 | 6.8 | 4.6 | 0.27 | 26.5 | 1,053 | 461 | 15 | <0.5 | 0.5 | 1,597 | 6.7 | 0.007 |
| 221649 | 206947 | WELL | 168 | 6/12/2014 | 8.3 | 7.92 | 2,493 | 132 | 88 | 390 | 6.4 | 2.3 | 0.11 | 24.5 | 1,127 | 636 | 16 | 0.04 | 0.33 | 1,850 | 6.4 | 0.006 |
| 221649 | 222086 | WELL | 168 | 9/19/2016 | 11.1 | 7.22 | 2,649 | 142 | 92 | 385 | 6.7 | 5.6 | 0.12 | 27.6 | 1,261 | 603 | 16 | <0.050 | 0.53 | 1,902 | 6.2 | 0.006 |
| 222551 | 207759 | WELL | 95 | 7/30/2014 | 8.4 | 7.13 | 1,192 | 105 | 48 | 81 | 3.2 | 3.2 | 0.44 | 25.3 | 307 | 356 | 20 | <0.010 | 0.14 | 791 | 1.6 | 0.016 |
| 223319 | 2008Q5023 | WELL | 180 | 5/2/2008 | | 7.65 | 5,724 | 44 | 44 | 406 | 5.8 | 0.2 | | | 610 | 732 | 51 | 1.2 | | 1,608 | 10.3 | 0.009 |
| 223319 | 207614 | WELL | 180 | 7/15/2014 | 10.5 | 7.63 | 1,594 | 62 | 34 | 269 | 4.8 | 2.5 | 0.10 | 25.9 | 646 | 399 | 17 | <0.010 | 0.32 | 1,133 | 6.8 | 0.011 |
| 242569 | 207616 | WELL | 100 | 7/16/2014 | 10.5 | 7.3 | 1,878 | 222 | 114 | 76 | 5.9 | 5.0 | 0.47 | 18.7 | 516 | 768 | 30 | 0.6 | 0.25 | 1,495 | 1.0 | 0.016 |
| 248885 | 2009Q5001 | WELL | | 12/16/2008 | | 8.22 | 2,935 | 64 | 36 | 435 | 6.0 | 0.7 | | | 1,135 | 255 | 6 | 0 | | 1,362 | 10.8 | 0.002 |
| 250391 | 207613 | WELL | 150 | 7/15/2014 | 9.7 | 7.43 | 1,255 | 108 | 49 | 126 | 5.1 | 3.5 | 0.18 | 25.7 | 521 | 343 | 6 | <0.010 | 0.12 | 922 | 2.5 | 0.005 |
| 250396 | 204318 | WELL | 200 | 7/16/2013 | 10.9 | 7.6 | 1,546 | 112 | 51 | 155 | 5.3 | 1.6 | 0.19 | 27.0 | 593 | 350 | 13 | 0.16 | 0.42 | 1,008 | 3.0 | 0.009 |
| 262871 | 209975 | WELL | 115 | 8/19/2015 | 7.3 | 7.31 | 2,579 | 89 | 45 | 485 | 6.8 | 2.1 | 3.53 | 26.3 | 950 | 664 | 14 | <0.010 | 0.25 | 1,804 | 10.5 | 0.005 |
| 262872 | 209976 | WELL | 50 | 8/19/2015 | 8.9 | 7.29 | 3,110 | 126 | 62 | 560 | 9.2 | 3.0 | 2.95 | 27.6 | 946 | 961 | 30 | <0.050 | 0.35 | 2,248 | 10.2 | 0.010 |
| 273937 | 207042 | WELL | 136 | 6/11/2014 | 7.8 | 8 | 1,268 | 106 | 58 | 102 | 5.0 | 2.1 | 0.35 | 24.6 | 627 | 252 | 3 | <0.010 | 0.23 | 862 | 2.0 | 0.003 |
| 273937 | 210092 | WELL | 136 | 9/13/2015 | 8.0 | 7.06 | 1,268 | 107 | 58 | 107 | 4.8 | 5.0 | 0.36 | 25.1 | 616 | 255 | 4 | <0.010 | 0.27 | 869 | 2.1 | 0.003 |
| 280641 | 208669 | WELL | 140 | 11/23/2014 | 7.8 | 7.77 | 1,725 | 86 | 50 | 296 | 5.6 | 0.3 | 0.08 | 22.6 | 958 | 285 | 12 | <0.010 | 0.47 | 1,230 | 6.3 | 0.007 |
| 280641 | 222087 | WELL | 140 | 9/19/2016 | 10.3 | 7.26 | 1,804 | 86 | 49 | 279 | 5.9 | 3.0 | 0.06 | 26.8 | 978 | 269 | 12 | <0.010 | 0.45 | 1,213 | 6.0 | 0.007 |
| 280643 | 208668 | WELL | 248 | 11/23/2014 | 8.5 | 8.15 | 1,986 | 38 | 24 | 464 | 4.6 | 0.2 | 0.05 | 20.0 | 1,269 | 115 | 41 | <0.010 | 1.22 | 1,343 | 14.5 | 0.021 |
| 280643 | 222088 | WELL | 248 | 9/19/2016 | 11.0 | 7.71 | 2,062 | 38 | 25 | 449 | 4.8 | 1.7 | 0.04 | 22.1 | 1,306 | 104 | 44 | <0.010 | 1.2 | 1,333 | 13.9 | 0.021 |
| 280645 | 208667 | WELL | 120 | 11/23/2014 | 7.1 | 7.83 | 2,511 | 149 | 97 | 366 | 5.3 | 1.3 | 0.42 | 14.3 | 697 | 975 | 11 | <0.010 | 0.34 | 1,962 | 5.7 | 0.005 |
| 280645 | 222098 | WELL | 120 | 9/20/2016 | 8.8 | 7.36 | 2,681 | 152 | 98 | 357 | 6.1 | 3.9 | 0.34 | 15.7 | 715 | 1,002 | 12 | <0.050 | 0.39 | 1,999 | 5.6 | 0.004 |
| 280650 | 210404 | WELL | 90 | 11/20/2015 | 8.1 | 7.27 | 2,489 | 171 | 108 | 240 | 5.8 | <0.038 | 1.32 | 21.9 | 756 | 747 | 22 | 6.69 | 0.66 | 1,698 | 3.5 | 0.009 |
| 280650 | 222099 | WELL | 90 | 9/20/2016 | 8.5 | 7.35 | 2,429 | 176 | 110 | 251 | 5.9 | <0.075 | 1.37 | 21.9 | 754 | 804 | 25 | 7.56 | 0.35 | 1,773 | 3.7 | 0.010 |
| 280651 | 208666 | WELL | 105 | 11/23/2014 | 7.5 | 7.54 | 1,718 | 133 | 64 | 219 | 6.3 | 0.6 | 0.13 | 22.0 | 871 | 337 | 29 | <0.010 | 0.34 | 1,240 | 3.9 | 0.017 |
| 280652 | 208672 | WELL | 140 | 11/23/2014 | 7.6 | 7.71 | 3,325 | 298 | 153 | 393 | 8.6 | 2.8 | 0.40 | 23.7 | 1,466 | 850 | 21 | <0.050 | 0.38 | 2,473 | 4.6 | 0.006 |
| 280652 | 222084 | WELL | 140 | 9/19/2016 | 10.7 | 7 | 3,287 | 286 | 139 | 378 | 8.3 | 13.6 | 0.32 | 28.3 | 1,526 | 904 | 22 | <0.050 | 0.4 | 2,530 | 4.6 | 0.007 |
| 283920 | 209968 | WELL | 64 | 8/18/2015 | 9.6 | 7.3 | 1,027 | 108 | 33 | 80 | 3.1 | 4.0 | 4.13 | 21.8 | 578 | 126 | 7 | <0.010 | 0.44 | 671 | 1.7 | 0.007 |
| 283920 | 210098 | WELL | 64 | 9/14/2015 | 9.3 | 7.37 | 1,014 | 108 | 32 | 80 | 2.7 | 4.6 | 1.63 | 22.8 | 580 | 116 | 7 | <0.010 | 0.43 | 661 | 1.7 | 0.006 |
| 703881 | 207617 | WELL | 112 | 7/16/2014 | 9.8 | 7.5 | 1,450 | 141 | 71 | 108 | 4.6 | 3.7 | 0.23 | 22.9 | 677 | 368 | 4 | <0.010 | 0.19 | 1,057 | 1.9 | 0.003 |

| GWIC ID | Sample Number | Site Type | Depth (ft) | Sample Date | Water Temp ºC | Lab pH | Lab SC (µS/cm) | Ca | Mg | Na | K | Fe | Mn | $SiO_2$ | $HCO_3$ | $SO_4$ | Cl | $NO_3$-N | F | TDS | SAR unit-less | Contam. Index unit less |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 703926 | 204319 | WELL | 90 | 7/16/2013 | 9.7 | 7.52 | 1,550 | 128 | 57 | 143 | 5.3 | 2.5 | 0.62 | 24.1 | 485 | 420 | 49 | 1.45 | 0.18 | 1,069 | 2.6 | 0.031 |
| 703929 | 207762 | WELL | 122 | 7/29/2014 | 8.2 | 7.59 | 986 | 78 | 32 | 63 | 4.1 | 3.6 | 0.25 | 18.5 | 98 | 128 | 6 | 38.09 | 0.1 | 420 | 1.5 | 0.006 |
| 703974 | 204317 | WELL | 32 | 7/16/2013 | 9.2 | 7.46 | 691 | 71 | 26 | 43 | 3.2 | 0.4 | 0.59 | 22.4 | 302 | 131 | 7 | 0.38 | 0.14 | 453 | 1.1 | 0.010 |
| **Water quality of the Fort Union Formation aquifer.** | | | | | | | | | | | | | | | | | | | | | | |
| 3610 | 1979Q0512 | WELL | 186 | 9/20/1978 | | 8.53 | 2,090 | 3 | 2 | 550 | 2.1 | 0.1 | 0.01 | 7.1 | 1,245 | 127 | 1 | 0.4 | 5.3 | 1,330 | 64.2 | 0.000 |
| 3612 | 1981Q1189 | WELL | 195 | 7/31/1981 | | 8.18 | 2,889 | 4 | 3 | 736 | 2.5 | 0.2 | 0.01 | 6.8 | 959 | 690 | 4 | 0.09 | 2 | 1,922 | 65.3 | 0.001 |
| 3613 | 1981Q0367 | WELL | 162 | 5/13/1981 | | 7.53 | 2,530 | 139 | 97 | 326 | 10.1 | 2.1 | 0.25 | 13.5 | 864 | 798 | 7 | <.02 | 0.31 | 1,819 | 5.2 | 0.003 |
| 3615 | 1981Q0368 | WELL | 87 | 5/13/1981 | | 7.64 | 3,335 | 333 | 191 | 152 | 8.4 | 0.2 | 0.25 | 10.7 | 619 | 1,604 | 40 | 3.8 | 0.26 | 2,648 | 1.6 | 0.012 |
| 3681 | 1979Q0379 | WELL | 83 | 8/24/1978 | | 9.3 | 1,993 | 33 | 35 | 396 | 5.9 | 1.1 | 0.04 | 15.0 | 749 | 397 | 6 | 1.6 | 2.7 | 1,284 | 11.5 | 0.003 |
| 3772 | 1984Q0794 | WELL | 318 | 8/10/1984 | | 8.11 | 2,186 | 3 | 1 | 579 | 1.7 | 0.1 | 0.02 | 10.0 | 1,410 | 3 | 87 | 0.04 | 0.1 | 1,379 | 73.2 | 0.040 |
| 3772 | 222102 | WELL | 318 | 9/21/2016 | 9.3 | 8.29 | 2,314 | 2 | 1 | 582 | 2.0 | <0.075 | <0.010 | 6.5 | 1,431 | 1 | 104 | <0.010 | 2.99 | 1,406 | 84.4 | 0.045 |
| 3850 | 1982Q0954 | WELL | 110 | 8/15/1982 | | 7.86 | 1,565 | 157 | 113 | 73 | 6.4 | 0.3 | 0.03 | 19.0 | 634 | 511 | 5 | 0.42 | 0.2 | 1,201 | 1.1 | 0.003 |
| 3872 | 1984Q0798 | WELL | 330 | 8/9/1984 | | 8.21 | 1,940 | 3 | 1 | 502 | 2.2 | 0.4 | 0.01 | 11.7 | 1,174 | 75 | 40 | 0.38 | 0.1 | 1,213 | 67.9 | 0.021 |
| 3872 | 210027 | WELL | 330 | 8/30/2015 | 10.4 | 8.51 | 1,998 | 2 | 1 | 499 | 2.2 | <0.038 | <0.005 | 6.4 | 1,214 | 76 | 50 | <0.010 | 4.18 | 1,266 | 72.9 | 0.025 |
| 3943 | 1983Q0845 | WELL | 183 | 8/8/1983 | | 7.82 | 1,110 | 7 | 4 | 265 | 3.0 | 0.3 | 0.01 | 22.3 | 548 | 148 | 3 | 0.04 | 0.3 | 722 | 19.6 | 0.003 |
| 3950 | 1979Q0388 | WELL | 150 | 8/21/1978 | 8.5 | 7.65 | 1,030 | 80 | 38 | 109 | 4.1 | 0.4 | 0.65 | 22.1 | 497 | 167 | 5 | 0.2 | 0.3 | 671 | 2.5 | 0.005 |
| 4050 | 1976Q1648 | WELL | 70 | 3/7/1977 | | 7.35 | 1,903 | 164 | 88 | 177 | 6.8 | 0.1 | 0.55 | 22.6 | 732 | 527 | 7 | 1.446 | 0.1 | 1,356 | 2.8 | 0.003 |
| 157676 | 209610 | WELL | 260 | 7/8/2015 | 10.2 | 8.04 | 3,839 | 14 | 10 | 875 | 5.1 | 0.3 | <0.020 | 8.2 | 1,382 | 864 | 22 | <0.050 | 1.15 | 2,480 | 43.5 | 0.006 |
| 206406 | 200284 | WELL | 105 | 6/28/2011 | 9.5 | 7.38 | 2,127 | 137 | 81 | 358 | 6.6 | 6.8 | 0.38 | 26.1 | 825 | 744 | 8 | 0.05 | 0.38 | 1,775 | 6.0 | 0.004 |
| 206406 | 209979 | WELL | 105 | 8/20/2015 | 9.8 | 7.54 | 2,557 | 145 | 77 | 344 | 6.1 | 3.6 | 3.53 | 25.3 | 853 | 770 | 9 | 0.05 | 0.53 | 1,805 | 5.8 | 0.004 |
| 255044 | 1.028E+10 | WELL | 444 | 9/30/2014 | | | 3,360 | 9 | 6 | 1,040 | 4.2 | 0.2 | 0.01 | | | 692 | 22 | | 1.9 | 1,775 | 65.1 | 0.007 |
| **Water quality of the Fox Hills–Hell Creek aquifer** | | | | | | | | | | | | | | | | | | | | | | |
| 43095 | 1979Q0378 | PETWELL | 1,160 | 8/24/1978 | | 8.66 | 3,532 | 4 | 1 | 800 | 2.6 | 0.1 | <.01 | 12.8 | 942 | 3 | 709 | <.1 | 0.6 | 2,036 | 88.4 | 0.201 |
| 43095 | 1982Q0429 | PETWELL | 1,160 | 6/11/1982 | 11.0 | 8.15 | 3,502 | 5 | 1 | 813 | 1.9 | 0.0 | <.001 | 12.2 | 1,040 | <.1 | 686 | 0.43 | 2.9 | 2,034 | 92.8 | 0.196 |
| 43095 | 209967 | PETWELL | 1,160 | 8/18/2015 | 10.9 | 8.47 | 3,699 | 3 | 1 | 865 | 2.7 | 0.2 | 0.28 | 9.3 | 994 | 3 | 767 | <0.050 | 2.72 | 2,171 | 109.7 | 0.207 |
| 154904 | 204148 | WELL | 840 | 6/18/2013 | 11.9 | 8.28 | 3,250 | 4 | 1 | 692 | 2.4 | 0.1 | <0.010 | 10.2 | 1,075 | <2.500 | 578 | <0.050 | 2.16 | 1,836 | 83.1 | 0.178 |
| 154904 | 210102 | WELL | 840 | 9/14/2015 | 16.5 | 8.21 | 3,340 | 4 | 1 | 805 | 1.9 | <0.075 | <0.010 | 10.7 | 1,106 | <2.500 | 594 | <0.050 | 2.29 | 1,976 | 94.4 | 0.178 |
| **Water quality of Mesozoic and Paleozoic reservoirs associated with hydrocarbon development** | | | | | | | | | | | | | | | | | | | | | | |
| 895341 | 1985Q1242 | PETWELL | 4,949 | 2/11/1985 | | 8.01 | 17,000 | 295 | <0.1 | 5,910 | 109.0 | 0.5 | | | 1,281 | 945 | 8,210 | 18 | | 16,128 | 94.8 | 0.483 |
| 895523 | 1968Q0004 | PETWELL | 4,590 | 3/20/1968 | | 7.8 | 16,000 | 170 | 36 | 5,700 | 100.0 | | | | 2,560 | 68 | 7,800 | | | 15,135 | 103.6 | 0.488 |
| 895504 | 1977Q0024 | PETWELL | 4,990 | NA | | 7.5 | 36,000 | 504 | 72 | 13,010 | 127.0 | | | | 903 | 3,500 | 18,300 | | | 35,958 | 143.6 | 0.508 |
| 895581 | 1986Q5012 | PETWELL | 10,808 | 7/7/1986 | | 6.14 | 237,000 | 6,290 | 1,225 | 83,700 | 2,270.0 | 26.0 | | | 226 | 780 | 141,900 | 378 | | 236,680 | 252.9 | 0.599 |
| 895604 | 1960Q0011 | PETWELL | 7,976 | 10/26/1960 | | 6.6 | 328,000 | 12,000 | 1,600 | 110,000 | 4,200.0 | | | | 110 | 290 | 200,000 | | | 328,144 | 250.4 | 0.610 |
| 3851 | 1960Q0061 | PETWELL | 7,558 | NA | | 6.2 | 319,000 | 9,600 | 1,392 | 112,800 | | | | | 168 | 419 | 194,600 | | | 318,894 | 284.8 | 0.610 |
| 3775 | 1960Q0060 | PETWELL | 7,864 | NA | | 5.2 | 331,000 | 13,800 | 2,760 | 110,800 | | | | | 12 | 649 | 202,950 | | | 330,965 | 225.2 | 0.613 |
| **Water quality of surface water** | | | | | | | | | | | | | | | | | | | | | | |
| 3860 | 1987Q0485 | LAKE | | 6/29/1987 | 21.8 | 9.2 | 5,722 | 5 | 232 | 1,134 | 61.0 | 0.0 | <.002 | 2.5 | 1,050 | 2,101 | 59 | 0.08 | 0.2 | 4,344 | 15.9 | 0.010 |

| GWIC ID | Sample Number | Site Type | Depth (ft) | Sample Date | Water Temp ºC | Lab pH | Lab SC (µS/cm) | Ca | Mg | Na | K | Fe | Mn | $SiO_2$ | $HCO_3$ | $SO_4$ | Cl | $NO_3$-N | F | TDS | SAR unit-less | Contam. Index unit less |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3860 | 1995Q5014 | LAKE | | 9/25/1994 | | 9.21 | 5,950 | 5 | 284 | 1,360 | 75.6 | 0.0 | 0.01 | 2.5 | <1 | 2,396 | 73 | <0.01 | 0.34 | 5,217 | 17.2 | 0.012 |
| 3860 | 1995Q5015 | LAKE | | 11/27/1994 | | 9.17 | 6,010 | 6 | 296 | 1,290 | 76.9 | 0.0 | 0.01 | 2.2 | <1 | 2,343 | 74 | <0.01 | 0.38 | 4,588 | 16.0 | 0.012 |
| 3860 | 1995Q5016 | LAKE | | 12/26/1994 | | 9.2 | 5,010 | 6 | 287 | 1,300 | 74.9 | 0.0 | 0.01 | 3.0 | <1 | 2,335 | 73 | 0.02 | 0.32 | 4,549 | 16.4 | 0.015 |
| 3860 | 1995Q5017 | LAKE | | 1/29/1995 | | 9.14 | 5,930 | 4 | 300 | 1,320 | 81.6 | 0.0 | 0.01 | 2.7 | <1 | 2,379 | 73 | 0.06 | 0.36 | 4,561 | 16.3 | 0.012 |
| 3860 | 1995Q5018 | LAKE | | 2/27/1995 | | 9.14 | 5,610 | 7 | 258 | 1,130 | 89.5 | 0.1 | 0.04 | 3.1 | <1 | 2,177 | 69 | 0.19 | 0.34 | 3,974 | 15.0 | 0.012 |
| 3860 | 1995Q5019 | LAKE | | 4/1/1995 | | 9.23 | 1,724 | 3 | 65 | 247 | 20.1 | 0.0 | 0.01 | 5.7 | <1 | 441 | 16 | 0.13 | 0.13 | 974 | 6.5 | 0.009 |
| 3860 | 1995Q5020 | LAKE | | 5/1/1995 | | 9.17 | 5,620 | 4 | 273 | 1,040 | 86.8 | 0.0 | 0.01 | 1.6 | <1 | 2,175 | 69 | 0.06 | 0.33 | 4,646 | 13.4 | 0.012 |
| 120843 | 1990Q0326 | LAKE | | 8/29/1990 | 21.4 | 9.49 | 4,727 | 17 | 141 | 1,050 | 49.7 | 0.1 | 0.01 | 3.9 | 1,240 | 1,460 | 71 | 0.32 | 0.34 | 3,596 | 18.3 | 0.015 |
| 120844 | 1990Q0324 | LAKE | | 8/25/1990 | 22.0 | 9.41 | 5,396 | 10 | 161 | 1,190 | 88.7 | 0.1 | 0.01 | 12.2 | 1,870 | 1,270 | 91 | 0.25 | 0.21 | 3,998 | 19.8 | 0.017 |
| 120845 | 1990Q0323 | LAKE | | 8/23/1990 | 23.3 | 9.74 | 11,374 | 4 | 322 | 2,990 | 272.0 | 0.0 | 0.01 | 5.5 | 2,420 | 4,760 | 128 | <.07 | 0.03 | 10,297 | 35.6 | 0.011 |
| 120847 | 1990Q0331 | LAKE | | 8/24/1990 | 19.0 | 9.29 | 24,490 | 3 | 411 | 7,360 | 360.0 | 0.0 | 0.00 | <.1 | 3,760 | 12,800 | 365 | 0.1 | 0.11 | 24,031 | 77.7 | 0.015 |
| 120848 | 1990Q0325 | LAKE | | 8/25/1990 | 21.9 | 9.52 | 2,684 | 12 | 131 | 471 | 33.5 | 0.0 | 0.01 | 13.0 | 632 | 864 | 26 | <.07 | 0.36 | 1,985 | 8.6 | 0.010 |
| 120848 | 2006Q0322 | LAKE | | 9/16/2005 | | 9.4 | 1,650 | 13 | 83 | 262 | 17.5 | | | | 553 | 222 | 55 | | | 1,039 | 5.9 | 0.033 |
| 120850 | 1990Q0327 | LAKE | | 8/27/1990 | 19.9 | 9.79 | 27,374 | 9 | 274 | 8,840 | 224.0 | 0.1 | 0.06 | 3.3 | 2,740 | 14,800 | 1,070 | <.07 | 0.4 | 27,386 | 113.4 | 0.039 |
| 120852 | 1990Q0328 | LAKE | | 8/26/1990 | 19.6 | 9.43 | 7,291 | 14 | 118 | 1,800 | 35.3 | 0.1 | 0.01 | 3.2 | 1,120 | 3,040 | 80 | <.07 | 0.13 | 5,814 | 34.4 | 0.011 |
| 120854 | 1990Q0330 | LAKE | | 8/26/1990 | 20.8 | 9.38 | 57,987 | 7 | 512 | 32,700 | 1,050.0 | 0.0 | 0.00 | <.1 | 9,300 | 53,000 | 4,110 | <.10 | 0.04 | 99,630 | 308.6 | 0.071 |
| 120861 | 1990Q0346 | LAKE | | 8/24/1990 | 25.3 | 8.87 | 6,525 | 19 | 517 | 1,030 | 96.6 | 0.0 | <.002 | 16.2 | 1,200 | 3,080 | 61 | 1.08 | 0.15 | 5,546 | 9.6 | 0.009 |
| 120862 | 1990Q0337 | LAKE | | 8/29/1990 | 21.5 | 9.35 | 5,521 | 17 | 89 | 1,280 | 59.6 | 0.2 | 0.02 | 5.6 | 1,464 | 1,500 | 97 | 0.17 | 0.24 | 3,967 | 27.5 | 0.018 |
| 120862 | 208372 | LAKE | | 9/9/2014 | 14.3 | 9 | 3,488 | 25 | 93 | 689 | 34.1 | <0.075 | <0.010 | 1.4 | 947 | 828 | 61 | <0.050 | 0.3 | 2,334 | 14.2 | 0.018 |
| 120863 | 1990Q0336 | LAKE | | 8/24/1990 | 26.5 | 9.78 | 32,748 | 2 | 111 | 11,240 | 554.0 | 0.0 | 0.01 | 1.3 | 7,420 | 12,800 | 725 | <.10 | 0.24 | 32,398 | 227.6 | 0.022 |
| 120864 | 1990Q0338 | LAKE | | 8/24/1990 | 25.5 | 9.74 | 27,769 | 3 | 139 | 9,740 | 350.0 | <.004 | <.002 | 7.0 | 9,690 | 7,060 | 977 | <.10 | 1.1 | 27,080 | 176.0 | 0.035 |
| 120865 | 1990Q0335 | LAKE | | 8/26/1990 | 16.7 | 9.05 | 15,949 | 8 | 706 | 3,780 | 246.0 | 0.1 | 0.01 | 2.4 | 1,810 | 8,640 | 265 | <.07 | 0.05 | 14,843 | 30.4 | 0.017 |
| 120866 | 1990Q0334 | LAKE | | 8/24/1990 | 21.0 | 9.34 | 9,409 | 4 | 335 | 2,220 | 194.0 | 0.0 | 0.01 | 2.5 | 2,920 | 2,860 | 75 | <.07 | 0.08 | 7,777 | 25.9 | 0.008 |
| 120867 | 1990Q0340 | LAKE | | 8/24/1990 | 24.7 | 9.79 | 174,957 | 3 | 194 | 4,110 | 320.0 | <.004 | 0.01 | 4.4 | 3,580 | 4,650 | 135 | <.07 | 0.15 | 12,599 | 63.0 | 0.001 |
| 120868 | 1990Q0342 | LAKE | | 8/25/1990 | 25.2 | 9.07 | 3,573 | 12 | 191 | 610 | 89.5 | 0.1 | 0.01 | 6.8 | 1,200 | 947 | 28 | 1.19 | 0.15 | 2,615 | 9.3 | 0.008 |
| 120869 | 1990Q0344 | LAKE | | 8/26/1990 | 18.4 | 9.11 | 12,579 | 10 | 272 | 3,100 | 181.0 | 0.1 | 0.02 | 3.4 | 2,650 | 4,790 | 256 | 1.47 | 0.2 | 10,307 | 39.9 | 0.020 |
| 120870 | 1990Q0333 | LAKE | | 8/26/1990 | 20.0 | 9.6 | 17,952 | 25 | 302 | 7,170 | 130.0 | 0.2 | 0.01 | 6.9 | 979 | 11,000 | 3,070 | 0.1 | 0.08 | 22,558 | 86.4 | 0.171 |
| 120871 | 1990Q0343 | LAKE | | 8/27/1990 | 23.0 | 9.95 | 60,143 | 4 | 31 | 56,000 | 520.0 | 0.1 | 0.01 | 15.0 | 15,900 | 84,600 | 2,870 | <.20 | 1.45 | 162,274 | 2079.6 | 0.048 |
| 120872 | 1990Q0345 | LAKE | | 8/29/1990 | 22.5 | 9 | 61,732 | 376 | 1,600 | 47,000 | 704.0 | 0.0 | 0.02 | 0.3 | 309 | 93,300 | 10,500 | <.20 | 0.04 | 153,740 | 235.7 | 0.170 |
| 120873 | 1990Q0332 | LAKE | | 8/29/1990 | 22.4 | 8.72 | 28,872 | 299 | 1,940 | 5,780 | 322.0 | 0.3 | 0.02 | 2.0 | 212 | 15,100 | 4,180 | <.10 | 0.03 | 27,775 | 26.9 | 0.145 |
| 120876 | 1990Q0347 | LAKE | | 8/24/1990 | 25.0 | 10 | 2,282 | 6 | 151 | 430 | 23.1 | 0.0 | <.002 | 15.2 | 700 | 515 | 12 | 0.07 | 0.14 | 1,802 | 7.4 | 0.005 |
| 120885 | 1990Q0365 | LAKE | | 8/30/1990 | 25.8 | 10 | 98,083 | 2 | 29 | 108,000 | 750.0 | 0.8 | 0.01 | 22.0 | 71,000 | 75,700 | 7,690 | <.20 | 10.5 | 282,003 | 4229.4 | 0.078 |
| 120886 | 1990Q0366 | LAKE | | 9/3/1990 | 20.4 | 9.23 | 17,952 | 6 | 621 | 4,660 | 358.0 | 0.2 | 0.01 | 12.5 | 3,790 | 8,720 | 262 | 0.38 | 0.26 | 17,003 | 40.0 | 0.015 |
| 120887 | 1990Q0367 | LAKE | | 8/31/1990 | 18.6 | 8.94 | 14,846 | 25 | 944 | 3,410 | 369.0 | 0.0 | <.002 | 33.7 | 1,601 | 9,310 | 258 | 0.82 | 0.09 | 15,379 | 23.6 | 0.017 |
| 214744 | 2005Q0045 | WETLAND | | 7/21/2004 | 26.0 | 9.63 | 9,220 | 5 | 209 | 2,304 | 86.0 | | | | 1,424 | 4,100 | 298 | | | 8,053 | 33.9 | 0.032 |
| 214747 | 2005Q0047 | WETLAND | | 7/23/2004 | 21.0 | 8.01 | 3,960 | 136 | 280 | 343 | 43.2 | | | | 398 | 457 | 770 | | | 2,225 | 3.9 | 0.194 |
| 214788 | 2005Q0185 | WETLAND | | 9/14/2004 | 16.0 | 7.23 | 7,270 | 267 | 337 | 1,063 | 29.8 | 0.5 | 0.11 | 12.5 | 304 | 339 | 2,687 | <0.50 | <0.50 | 4,886 | 10.2 | 0.370 |

| GWIC ID | Sample Number | Site Type | Depth (ft) | Sample Date | Water Temp ºC | Lab pH | Lab SC (µS/cm) | Ca | Mg | Na | K | Fe | Mn | $SiO_2$ | $HCO_3$ | $SO_4$ | Cl | $NO_3$-N | F | TDS | SAR unit-less | Contam. Index unit less |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 214789 | 2005Q0186 | WETLAND | | 9/10/2004 | 16.0 | 9.27 | 6,900 | 9 | 73 | 2,094 | 58.3 | 0.1 | <0.010 | 1.6 | 2,317 | 1,738 | 279 | <2.50 | <2.50 | 5,898 | 50.9 | 0.040 |
| 214790 | 2005Q0187 | WETLAND | | 9/14/2004 | 13.0 | 8.05 | 7,510 | 321 | 358 | 1,025 | 25.7 | 0.5 | 0.22 | 26.1 | 697 | 257 | 2,639 | <0.50 | <0.50 | 4,995 | 9.4 | 0.351 |
| 214791 | 2005Q0188 | WETLAND | | 9/14/2004 | 13.0 | 7.37 | 15,370 | 699 | 752 | 2,492 | 67.8 | 0.9 | 0.78 | 15.0 | 479 | 763 | 6,770 | 0.833 | <0.50 | 11,798 | 15.6 | 0.440 |
| 214792 | 2005Q0189 | WETLAND | | 9/14/2004 | 13.0 | 7.84 | 5,210 | 148 | 163 | 723 | 34.1 | 0.2 | 0.38 | 10.7 | 531 | 310 | 1,287 | <0.50 | <0.50 | 2,938 | 9.8 | 0.247 |
| 214907 | 2005Q0217 | STREAM | | 9/29/2004 | 16.2 | 8.91 | 2,580 | 34 | 93 | 553 | 22.4 | 0.3 | 0.03 | 10.1 | 704 | 950 | 34 | <0.50 | <0.50 | 2,109 | 11.1 | 0.013 |
| 214929 | 2005Q0226 | STREAM | | 9/29/2004 | 15.5 | 8.64 | 2,430 | 36 | 80 | 554 | 9.2 | 0.0 | 0.00 | 0.4 | 634 | 787 | 21 | <0.50 | 0.36 | 1,849 | 11.8 | 0.009 |
| 214929 | 2009Q5011 | STREAM | | 8/19/2008 | | | 3,685 | 23 | 87 | 693 | 14.0 | | | | 805 | 1,100 | 33 | | | 2,457 | 14.8 | 0.009 |
| 221718 | 2006Q0298 | POND | | 9/16/2005 | 20.0 | 9.17 | 22,800 | 28 | 898 | 8,307 | 176.0 | | | | 1,150 | 16,887 | 1,338 | | | 28,500 | 58.9 | 0.059 |
| 262048 | 200282 | LAKE | | 6/30/2011 | 22.0 | 8.7 | 1,973 | 25 | 68 | 412 | 22.7 | <0.040 | <0.020 | 7.5 | 514 | 687 | 31 | <0.050 | 0.13 | 1,548 | 9.7 | 0.015 |
| 262048 | 206368 | LAKE | | 5/14/2014 | 11.0 | 8.77 | 2,409 | 22 | 76 | 455 | 22.2 | <0.038 | <0.005 | 6.8 | 604 | 787 | 35 | 0.14 | 0.21 | 1,738 | 10.3 | 0.014 |
| 262243 | 207632 | LAKE | | 7/18/2014 | 24.8 | 9.12 | 5,275 | 8 | 121 | 1,219 | 65.2 | <0.150 | <0.020 | 8.8 | 1,300 | 1,690 | 95 | <0.050 | 0.25 | 4,059 | 23.3 | 0.018 |
| 262246 | 207635 | LAKE | | 7/18/2014 | 23.5 | 9.12 | 1,598 | 23 | 94 | 245 | 12.2 | 0.1 | 0.02 | 8.5 | 472 | 457 | 17 | <0.010 | 0.2 | 1,177 | 5.1 | 0.011 |
| 262247 | 207634 | LAKE | | 7/18/2014 | 23.1 | 8.79 | 2,800 | 40 | 131 | 498 | 17.4 | <0.075 | <0.010 | 17.7 | 770 | 883 | 38 | <0.010 | 0.24 | 2,078 | 8.6 | 0.014 |
| 262248 | 207644 | LAKE | | 7/18/2014 | 25.0 | 9.13 | 2,759 | 28 | 122 | 485 | 16.1 | <0.075 | 0.01 | 6.9 | 647 | 894 | 37 | <0.010 | 0.24 | 2,019 | 8.8 | 0.014 |
| 262249 | 207633 | LAKE | | 7/18/2014 | 23.9 | 8.7 | 2,400 | 37 | 96 | 433 | 22.3 | <0.038 | <0.005 | 8.8 | 693 | 689 | 34 | <0.010 | 0.23 | 1,735 | 8.5 | 0.014 |
| 262250 | 208368 | LAKE | | 9/8/2014 | 15.0 | 8.94 | 5,137 | 21 | 194 | 1,038 | 39.4 | <0.150 | 0.04 | 2.1 | 1,046 | 2,008 | 80 | <0.050 | 0.33 | 4,049 | 15.5 | 0.016 |
| 262251 | 208365 | LAKE | | 9/8/2014 | 17.5 | 9.24 | 2,657 | 50 | 116 | 477 | 22.0 | <0.038 | 0.01 | 2.1 | 461 | 1,002 | 41 | <0.010 | 0.3 | 2,059 | 8.5 | 0.015 |
| 262252 | 208361 | LAKE | | 9/8/2014 | 19.7 | 8.58 | 4,571 | 99 | 265 | 720 | 31.3 | <0.150 | 0.42 | 6.2 | 568 | 2,239 | 89 | <0.050 | 0.28 | 3,788 | 8.6 | 0.019 |
| 262254 | 208369 | LAKE | | 9/8/2014 | 17.3 | 9.44 | 3,049 | 32 | 81 | 594 | 20.9 | <0.075 | <0.010 | 0.3 | 445 | 864 | 46 | <0.050 | 0.27 | 2,053 | 12.7 | 0.015 |
| 262255 | 208367 | LAKE | | 9/10/2014 | 10.1 | 8.69 | 2,260 | 34 | 77 | 414 | 20.3 | <0.038 | <0.005 | 8.8 | 604 | 753 | 31 | 0.1 | 0.26 | 1,679 | 9.0 | 0.014 |
| 262256 | 208362 | STREAM | | 9/8/2014 | 19.2 | 8.59 | 1,632 | 56 | 58 | 269 | 9.4 | <0.038 | <0.005 | 8.6 | 495 | 528 | 13 | <0.010 | 0.24 | 1,212 | 6.0 | 0.008 |
| 277423 | 206960 | WETLAND | | 6/6/2014 | 14.2 | 8.03 | 18,185 | 337 | 1,600 | 4,488 | 181.3 | <0.750 | <0.100 | 1.7 | 292 | 16,108 | 808 | <0.100 | <0.100 | 23,666 | 22.7 | 0.044 |
| 277462 | 207020 | WETLAND | | 6/6/2014 | 17.7 | 9.64 | 65,461 | 15 | 36 | 28,741 | 126.4 | <0.750 | <0.100 | 16.2 | 2,955 | 34,617 | 2,157 | <1.000 | 4.08 | 69,939 | 918.2 | 0.033 |
| 277471 | 207422 | WETLAND | | 7/8/2014 | 18.9 | 8.31 | 4,602 | 154 | 171 | 790 | 47.8 | 0.2 | 0.14 | 12.1 | 780 | 2,239 | 104 | <0.050 | 0.29 | 3,920 | 10.4 | 0.023 |
| 277475 | 207330 | WETLAND | | 6/17/2014 | | 7.64 | 899 | 67 | 55 | 13 | 54.8 | 0.1 | 0.30 | 13.9 | 510 | 24 | 31 | <0.010 | 0.27 | 511 | 0.3 | 0.034 |
| 277481 | 206956 | WETLAND | | 6/5/2014 | 17.9 | 7.49 | 3,193 | 443 | 213 | 171 | 33.4 | 0.6 | 2.73 | 18.5 | 407 | 1,766 | 205 | <0.010 | 0.35 | 3,054 | 1.7 | 0.064 |
| 277533 | 206370 | WETLAND | | 5/22/2014 | 17.5 | 8.16 | 1,543 | 13 | 34 | 346 | 22.7 | 0.1 | 0.07 | 18.2 | 842 | 140 | 48 | <0.010 | 0.08 | 1,037 | 11.5 | 0.031 |
| 277540 | 207421 | WETLAND | | 7/10/2014 | 24.7 | 7.7 | 854 | 75 | 51 | 43 | 4.0 | 0.0 | 0.14 | 27.5 | 555 | 37 | 6 | <0.010 | 0.26 | 516 | 0.9 | 0.006 |
| 277572 | 206954 | WETLAND | | 6/11/2014 | 17.7 | 8.57 | 10,573 | 216 | 658 | 1,855 | 87.5 | <0.750 | <0.100 | <1.000 | 307 | 4,820 | 1,705 | <0.100 | <0.100 | 9,536 | 14.2 | 0.161 |
| 277581 | 207022 | WETLAND | | 6/10/2014 | 20.9 | 8.2 | 3,933 | 50 | 234 | 668 | 70.0 | <0.150 | 0.08 | 6.3 | 869 | 1,821 | 67 | <0.050 | 0.28 | 3,368 | 8.8 | 0.017 |
| 277595 | 206951 | WETLAND | | 6/11/2014 | 16.5 | 7.57 | 4,362 | 117 | 165 | 565 | 19.6 | <0.150 | 0.12 | 4.8 | 649 | 149 | 1,177 | <0.050 | 0.32 | 2,518 | 7.9 | 0.270 |
| 277600 | 207420 | WETLAND | | 7/10/2014 | 24.6 | 9.63 | 13,983 | 197 | 926 | 3,246 | 89.3 | 1.0 | <0.100 | <1.000 | 68 | 10,188 | 194 | <0.100 | <0.100 | 14,962 | 21.5 | 0.014 |
| 277607 | 206950 | WETLAND | | 6/1/2014 | 17.5 | 8.15 | 674 | 73 | 36 | 12 | 35.1 | 0.0 | 0.01 | 6.3 | 448 | 10 | 12 | 0.05 | 0.24 | 407 | 0.3 | 0.018 |
| 277612 | 206369 | WETLAND | | 5/28/2014 | 23.6 | 8.25 | 1,205 | 56 | 63 | 150 | 11.3 | 0.1 | 0.01 | 14.0 | 632 | 179 | 18 | <0.010 | 0.2 | 809 | 3.3 | 0.015 |
| 277631 | 207349 | WETLAND | | 6/19/2014 | 23.5 | 8.55 | 14,399 | 157 | 375 | 3,838 | 40.6 | <0.750 | 0.25 | 12.3 | 963 | 8,272 | 582 | <0.100 | <0.100 | 13,812 | 37.9 | 0.040 |
| 278957 | 208359 | POND | | 9/9/2014 | 14.2 | 8.57 | 327 | 21 | 12 | 28 | 24.9 | 0.0 | 0.02 | 2.7 | 176 | 7 | 8 | <0.010 | 0.17 | 204 | 1.2 | 0.024 |
| 278958 | 208371 | POND | | 9/9/2014 | 14.9 | 9.1 | 1,774 | 32 | 121 | 219 | 28.7 | <0.038 | 0.01 | 0.2 | 316 | 682 | 29 | <0.010 | 0.34 | 1,348 | 4.0 | 0.016 |

| GWIC ID | Sample Number | Site Type | Depth (ft) | Sample Date | Water Temp ºC | Lab pH | Lab SC (µS/cm) | Ca | Mg | Na | K | Fe | Mn | $SiO_2$ | $HCO_3$ | $SO_4$ | Cl | $NO_3$-N | F | TDS | SAR unit-less | Contam. Index unit less |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 278960 | 208363 | POND | | 9/9/2014 | 13.0 | 8.96 | 550 | 33 | 36 | 44 | 22.2 | 0.0 | 0.01 | 0.5 | 305 | 32 | 7 | <0.010 | 0.2 | 360 | 1.3 | 0.013 |
| 278961 | 208364 | LAKE | | 9/9/2014 | 15.2 | 9.38 | 2,425 | 19 | 101 | 460 | 24.0 | <0.038 | <0.005 | 4.3 | 471 | 775 | 39 | <0.010 | 0.28 | 1,824 | 9.3 | 0.016 |
| 278962 | 208366 | POND | | 9/9/2014 | 13.2 | 9.26 | 2,601 | 19 | 81 | 516 | 38.5 | <0.075 | 0.01 | 8.0 | 626 | 757 | 43 | <0.010 | 0.25 | 1,927 | 11.5 | 0.017 |
| 279776 | 208370 | LAKE | | 9/18/2014 | 23.7 | 8.95 | 9,367 | 17 | 381 | 2,005 | 50.0 | <0.150 | <0.020 | 11.9 | 1,382 | 2,853 | 89 | <0.050 | 0.28 | 6,339 | 21.7 | 0.009 |
| 890926 | 1989Q1375 | LAKE | | 10/13/1989 | 12.4 | 10.1 | 4,626 | 12 | 656 | 27,600 | 724.0 | 0.1 | 0.01 | 0.3 | 5,490 | 47,600 | 4,070 | 2.94 | 0.2 | 86,539 | 229.8 | 0.880 |

*Note.* Units are mg/L unless noted.

# APPENDIX C

# SOUTH MEDICINE LAKE AQUIFER TESTS

Data loggers measured water levels at 15-min intervals during normal seasonal crop irrigation at the four irrigation well sites in the South Medicine Lake management area. Drawdown was recorded at nearby monitoring wells that are completed in the same aquifer as the irrigation well. The test data were interpreted using the Cooper–Jacob analytical method. Tables summarizing results are shown in the main body of this report (tables 4–7, p. 39–40).

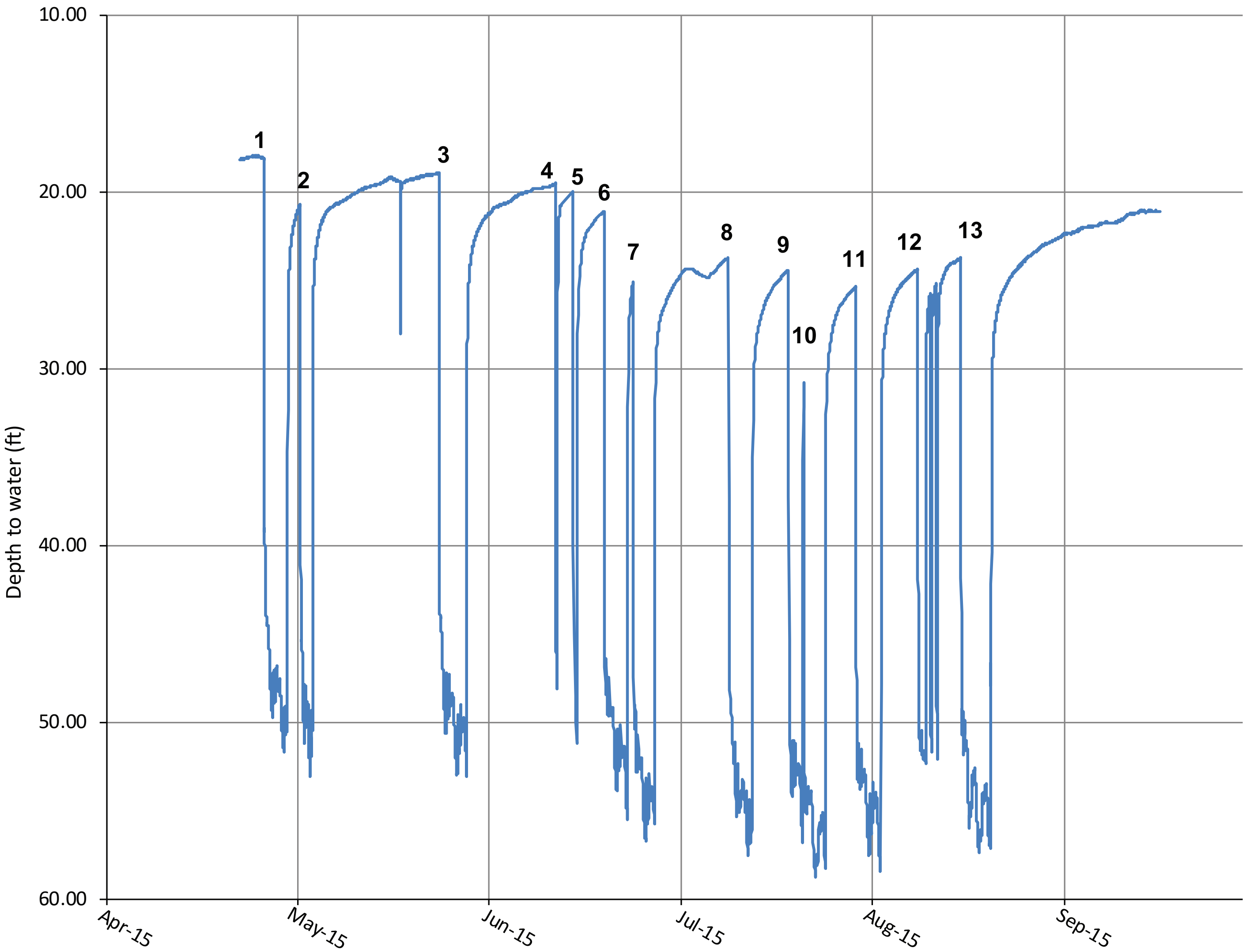


Figure C1-1. Timing of 13 aquifer tests at Nelson 1, pumping irrigation well 121117 and monitoring drawdown at well 43113 located 25 ft away from the irrigation well.

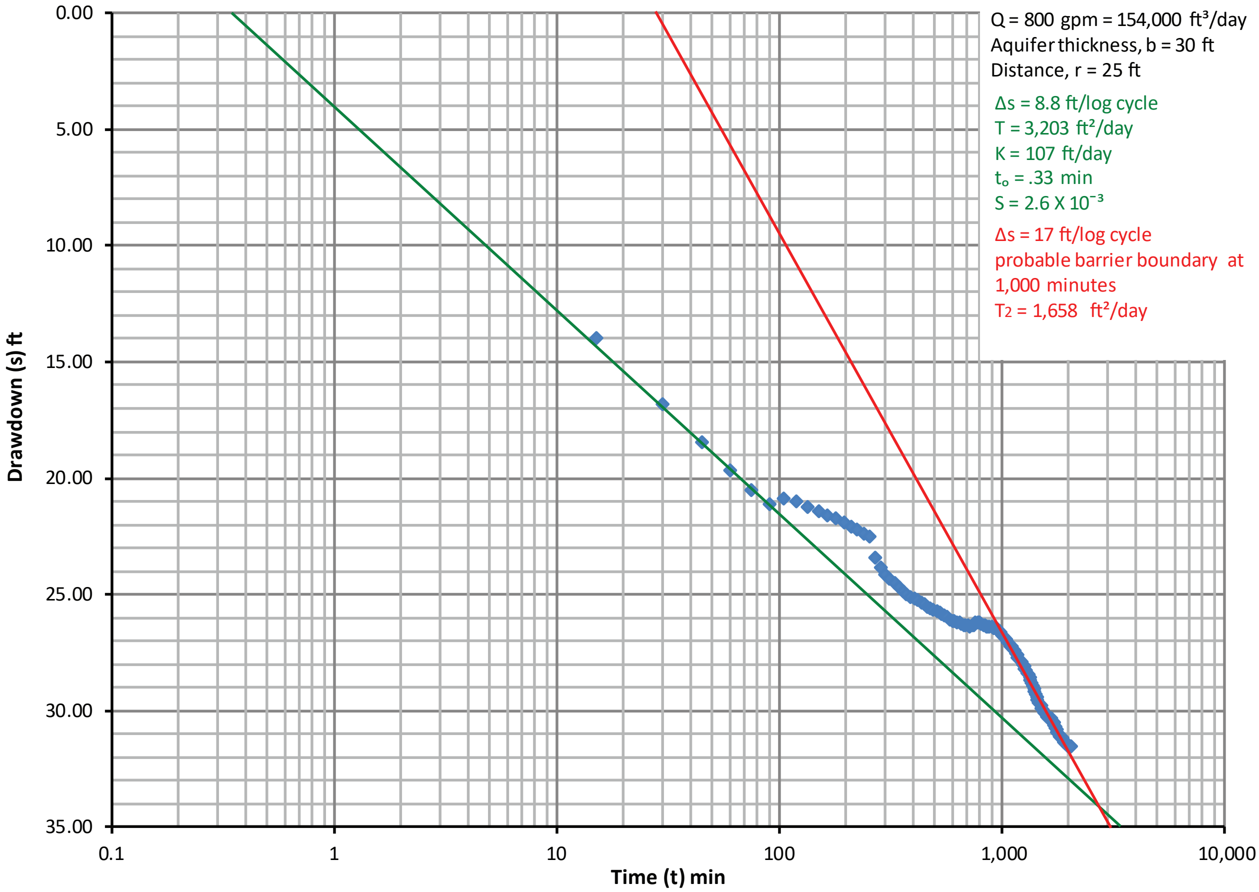


Figure C1-2. Results of Nelson 1 aquifer test #1.

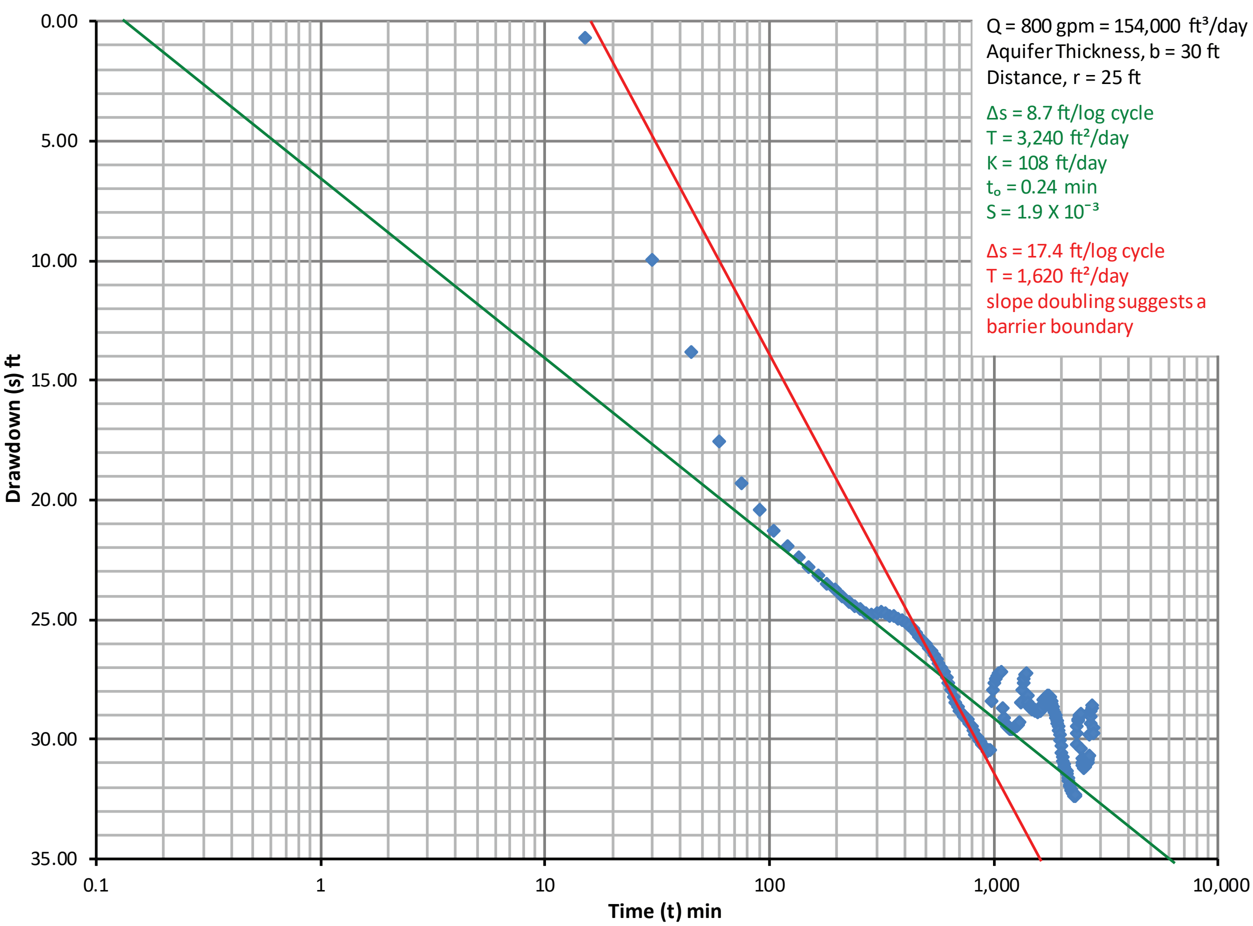


Figure C1-3. Results of Nelson 1 aquifer test #2.

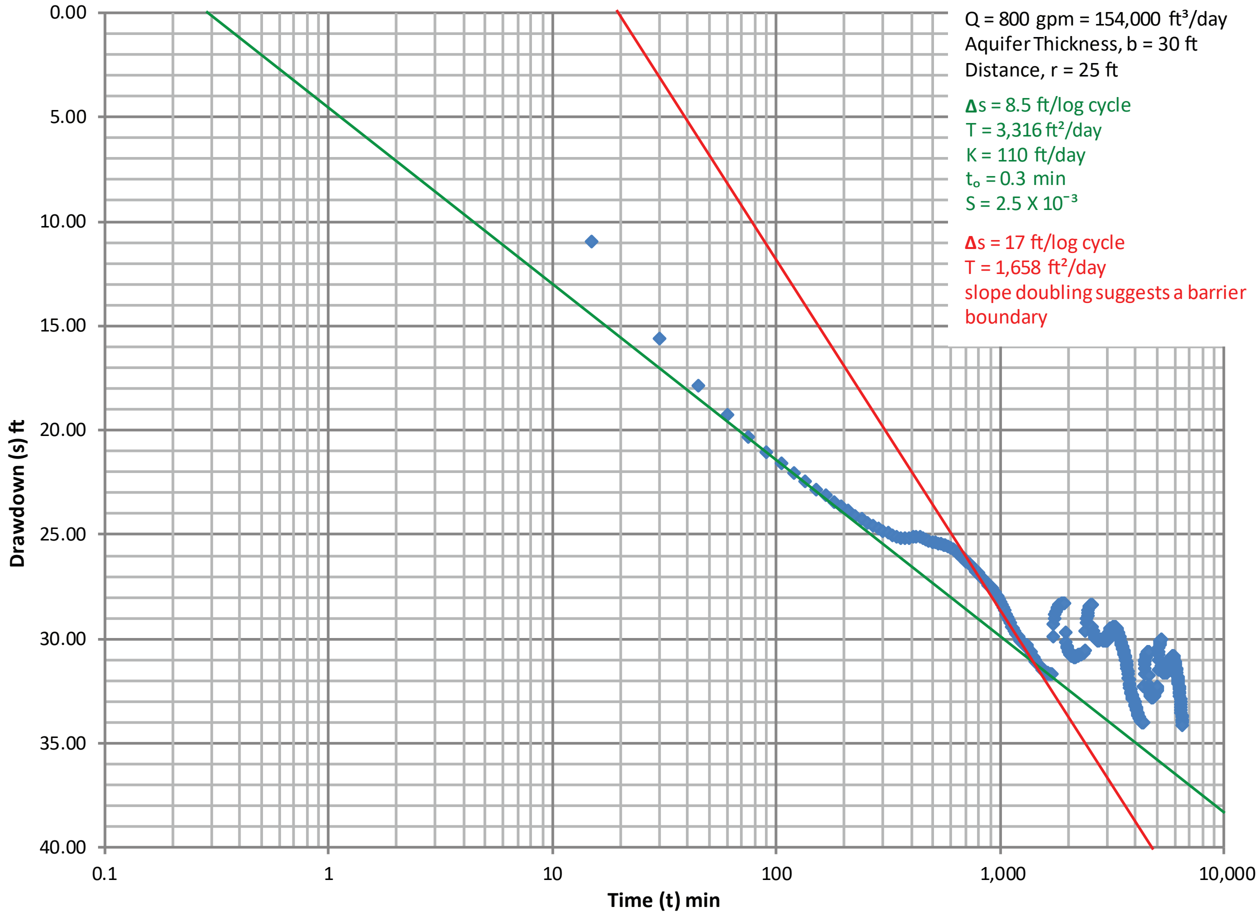


Figure C1-4. Results of Nelson 1 aquifer test #3.

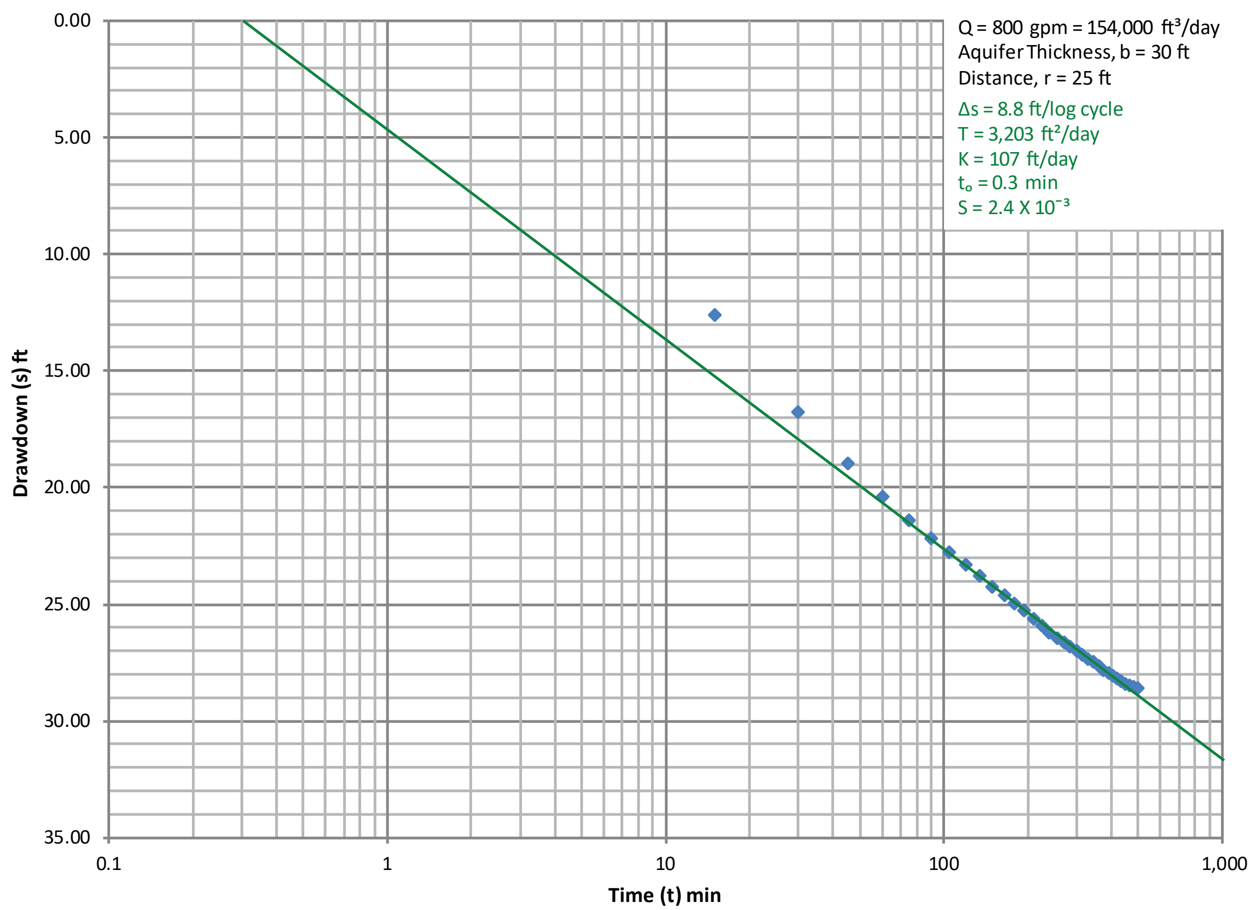


Figure C1-5. Results of Nelson 1 aquifer test #4.

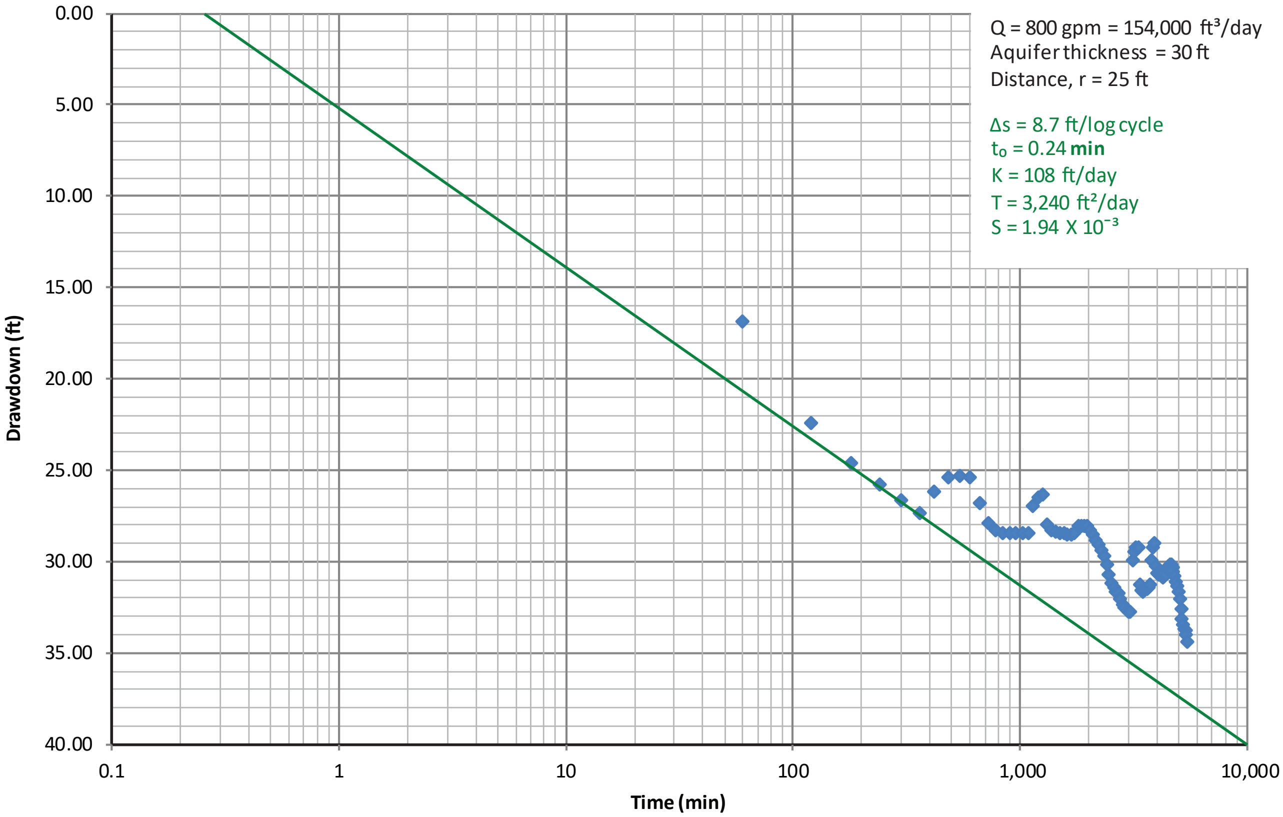


Figure C1-6. Results of Nelson 1 aquifer test #5.

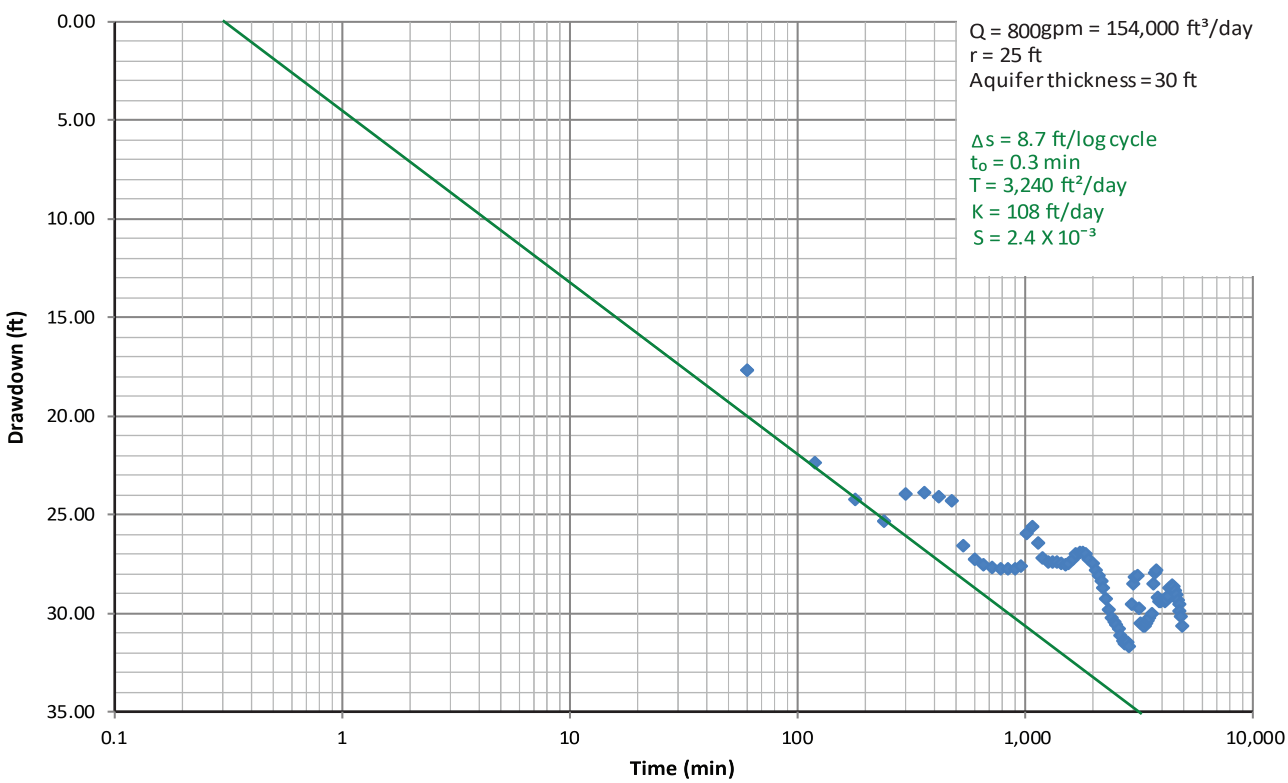


Figure C1-7. Results of Nelson aquifer test #6.

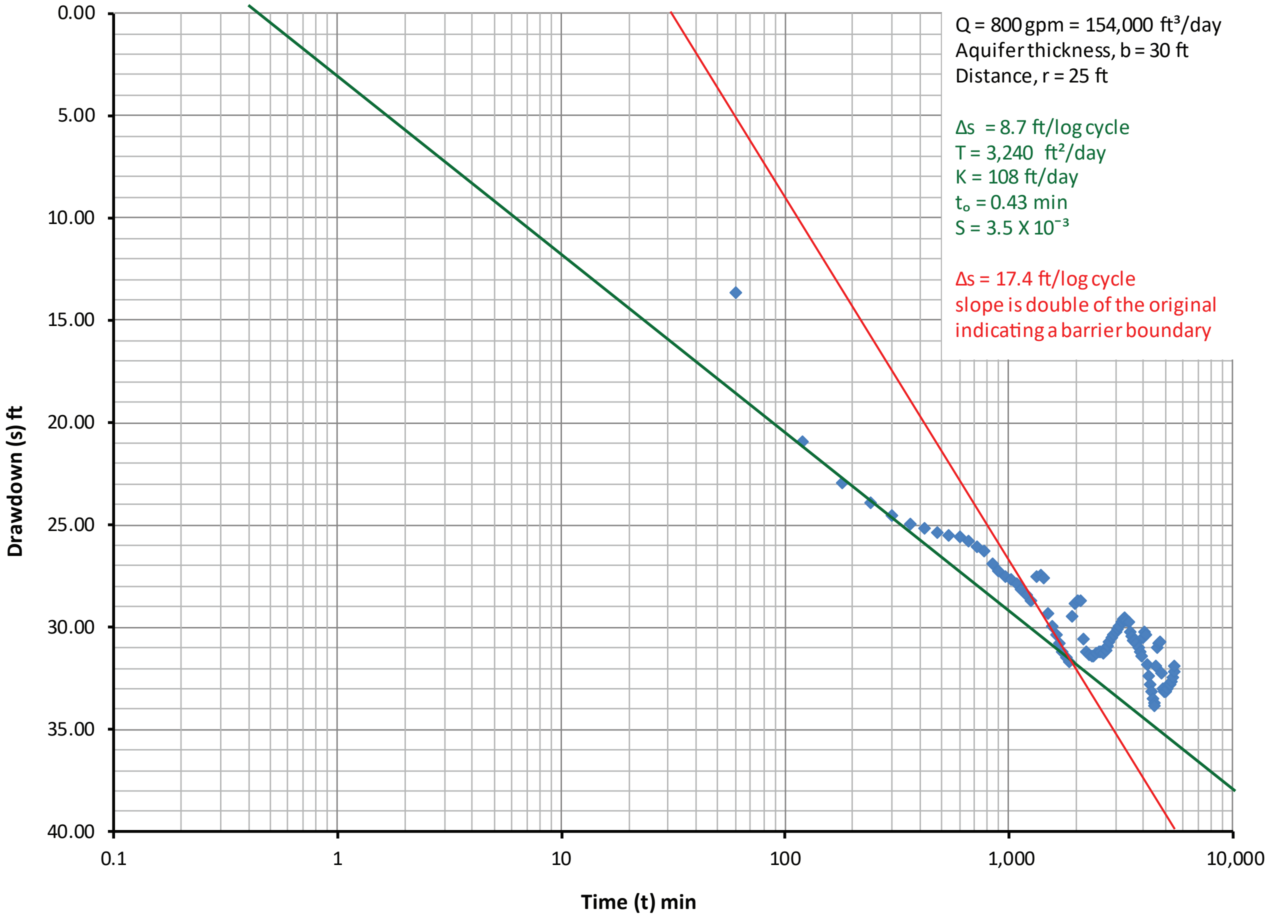


Figure C1-8. Results of Nelson 1 aquifer test #7.

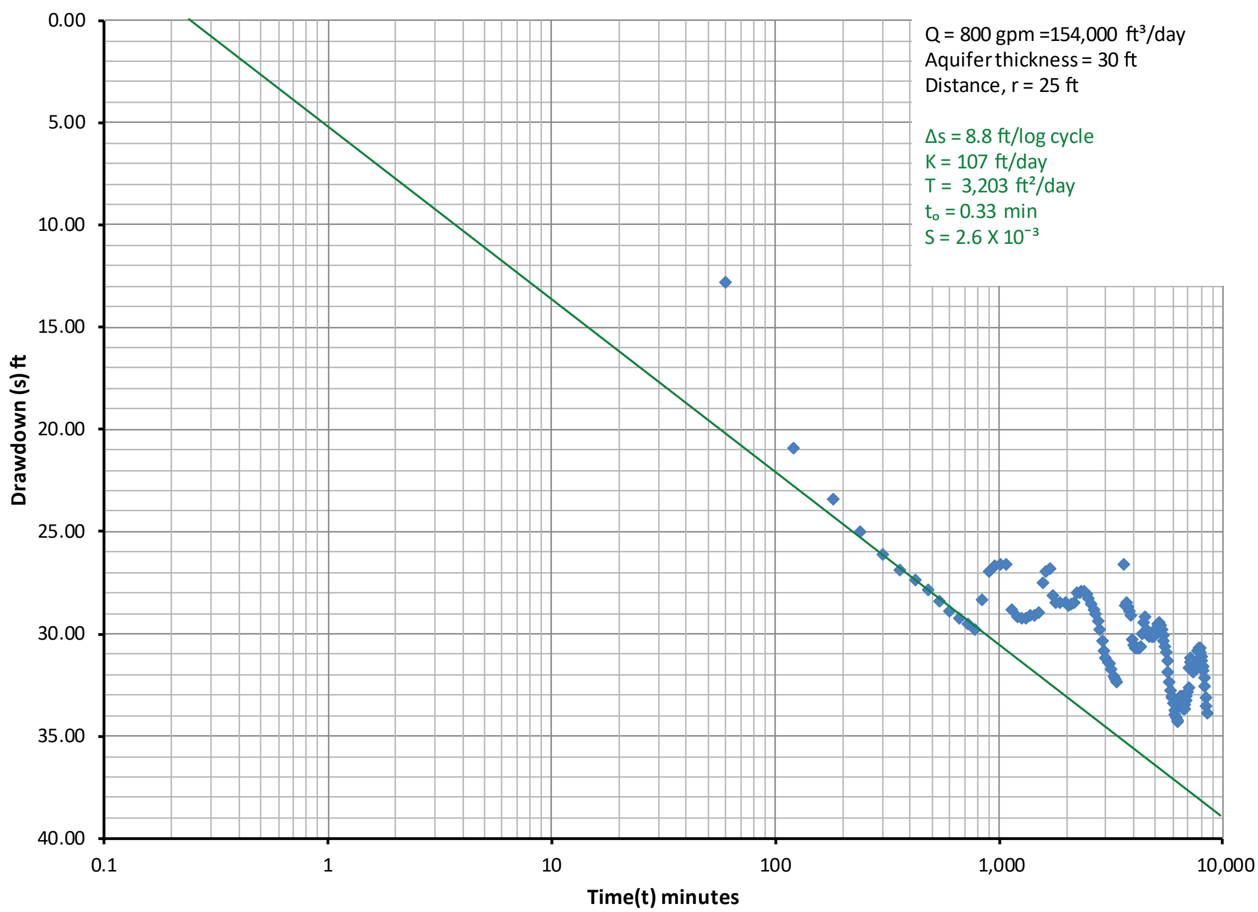


Figure C1-9. Results of Nelson 1 aquifer test #8.

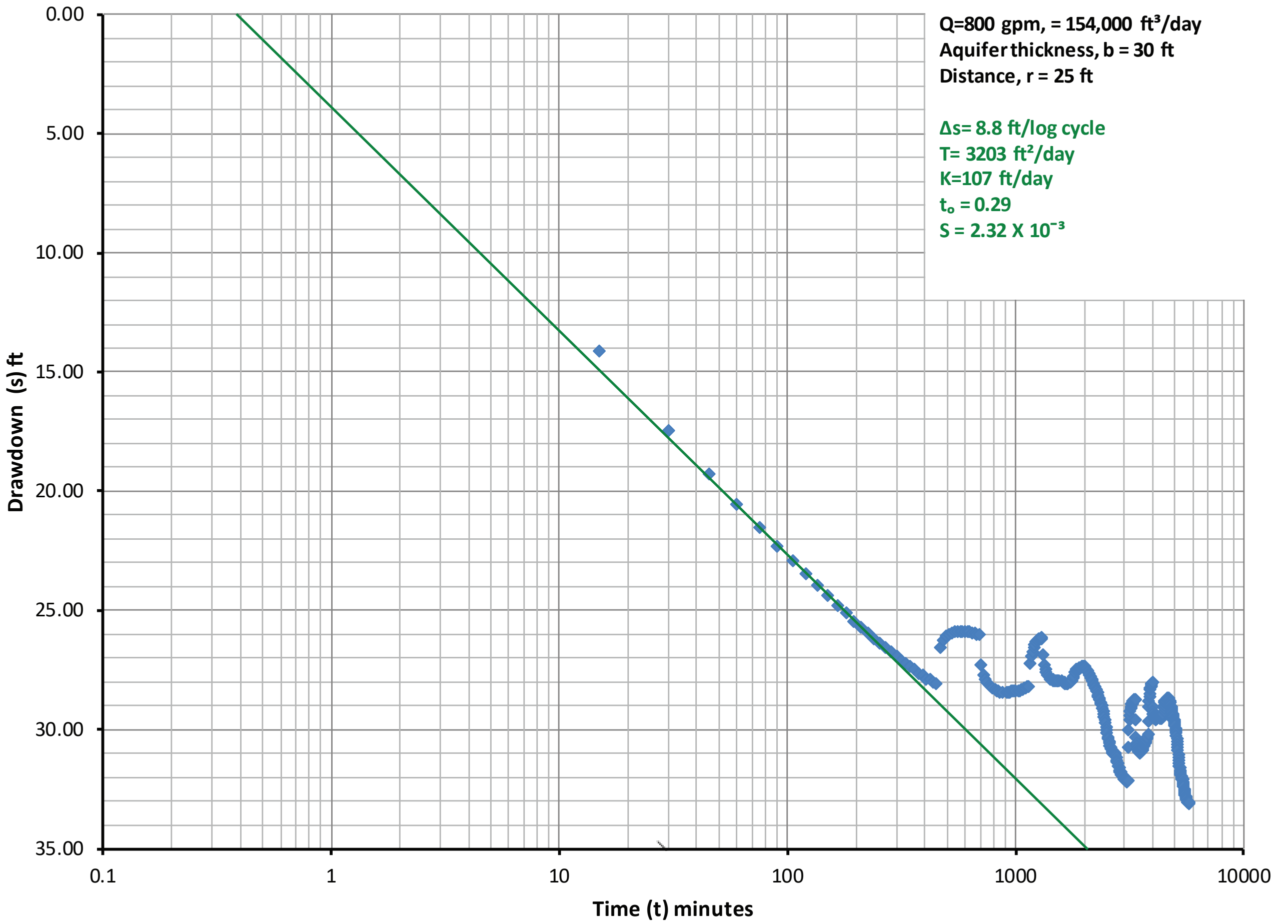


Figure C1-10. Results of Nelson 1 aquifer test #9.

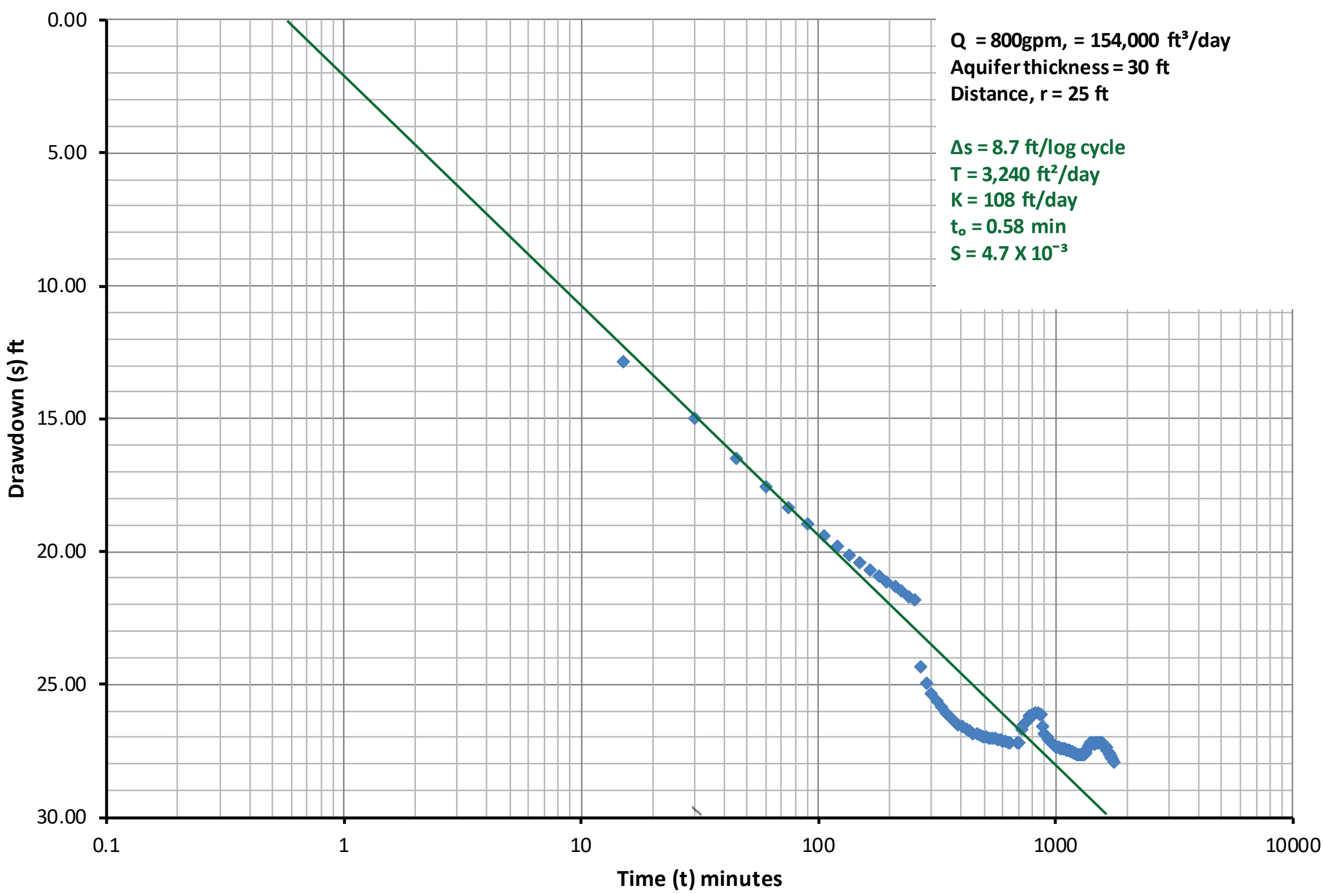


Figure C1-11. Results of Nelson 1 aquifer test #10.

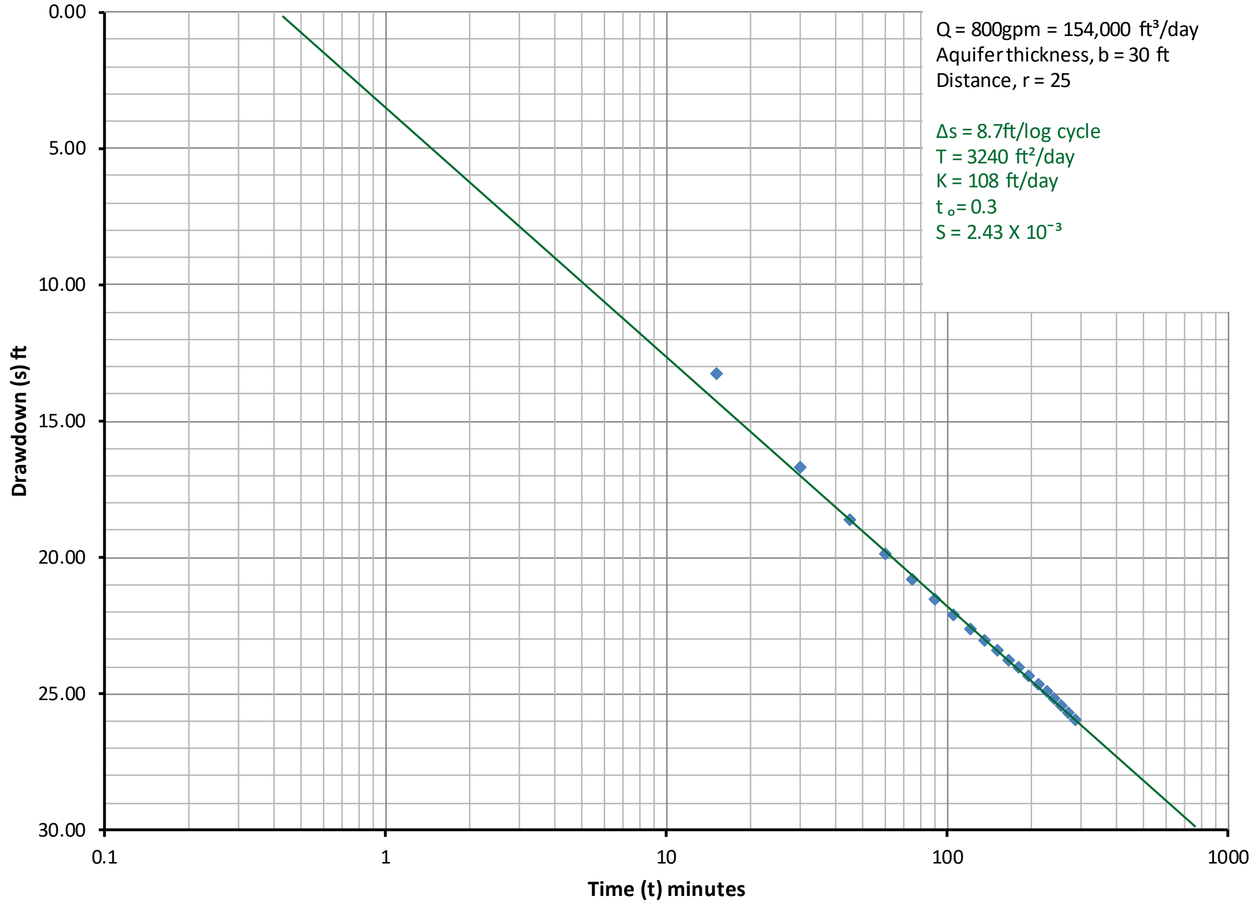


Figure C1-12. Results of Nelson 1 aquifer test #11.

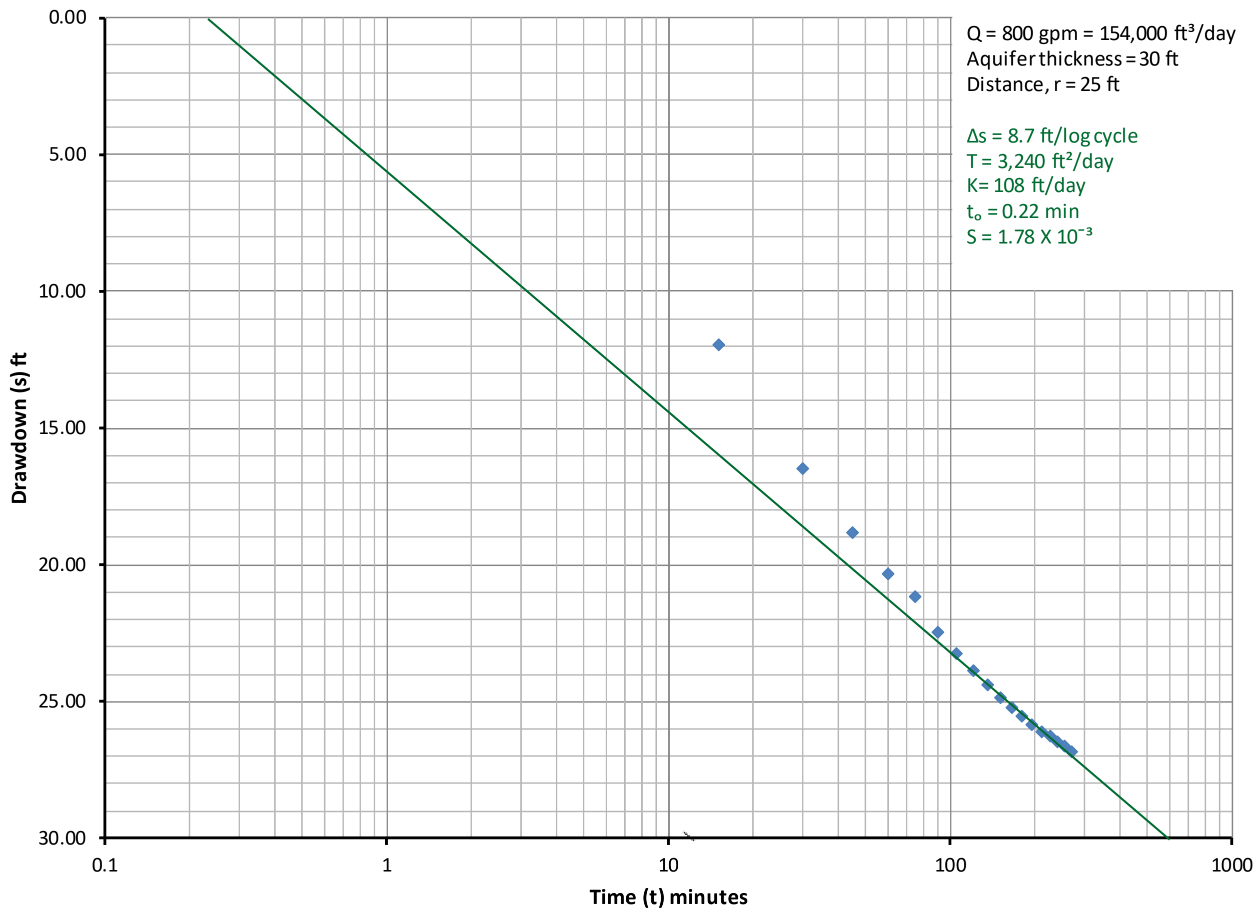


Figure C1-13. Results of Nelson 1 aquifer test #12.

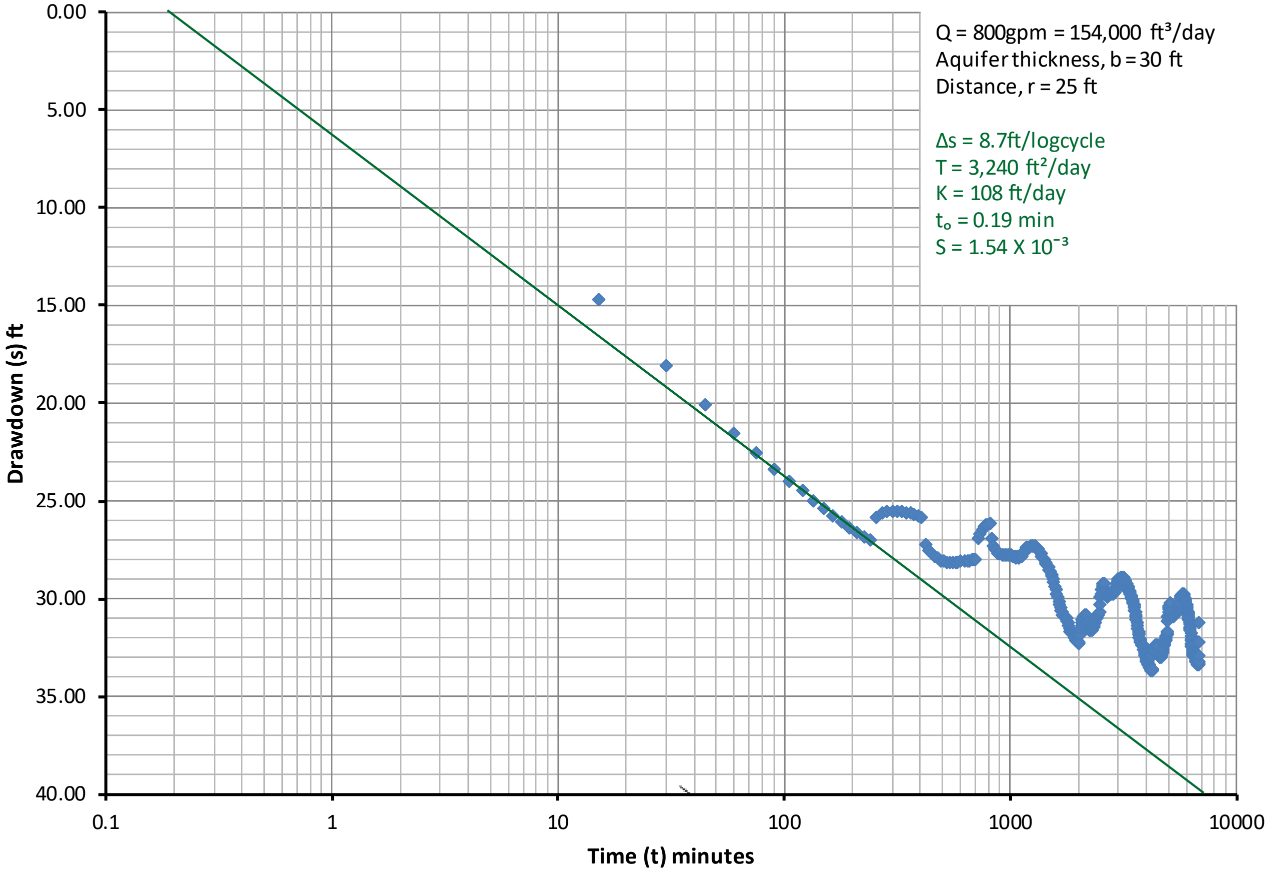


Figure C1-14. Results of Nelson 1 aquifer test #13.

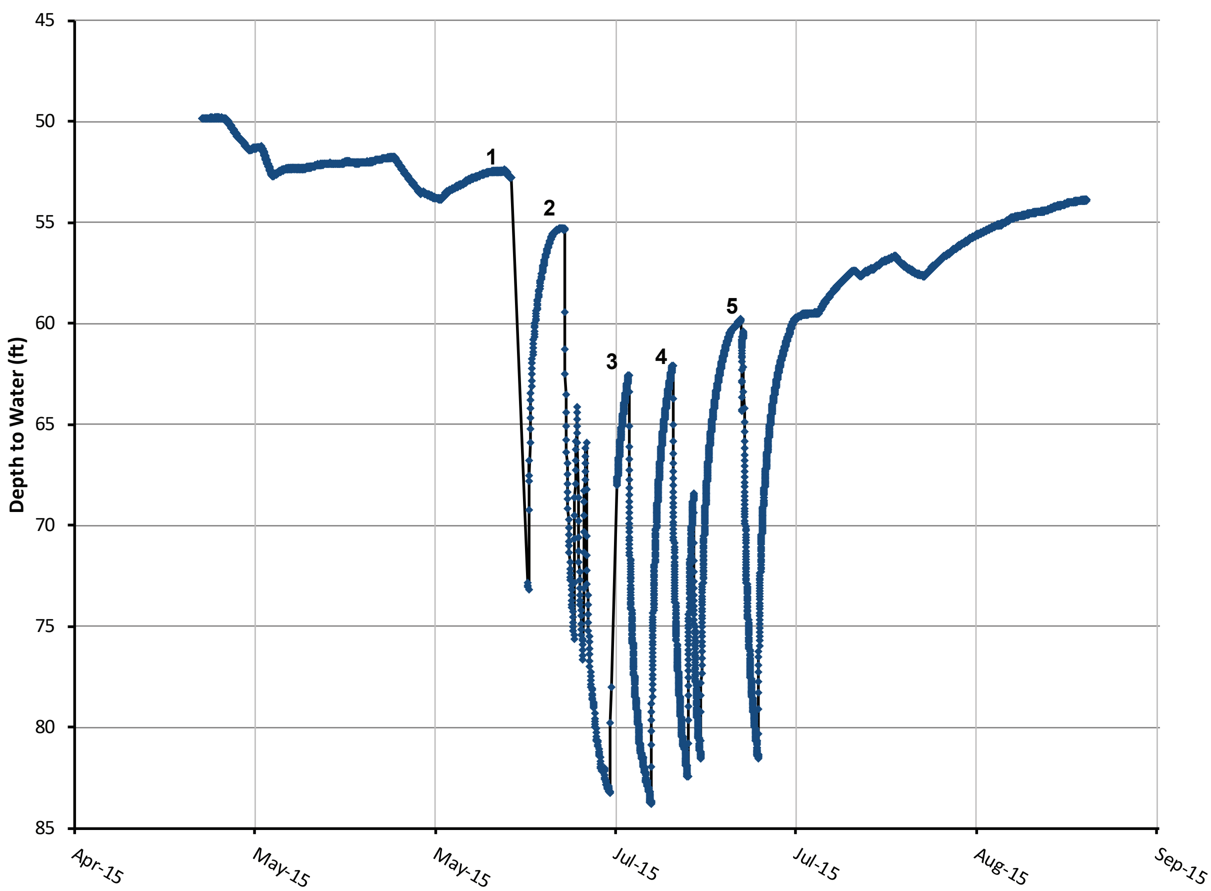


Figure C2-1. Timing of five aquifer tests at Nelson 2, pumping irrigation well 155930 and monitoring drawdown at well 155929 located 680 ft away from the irrigation well.

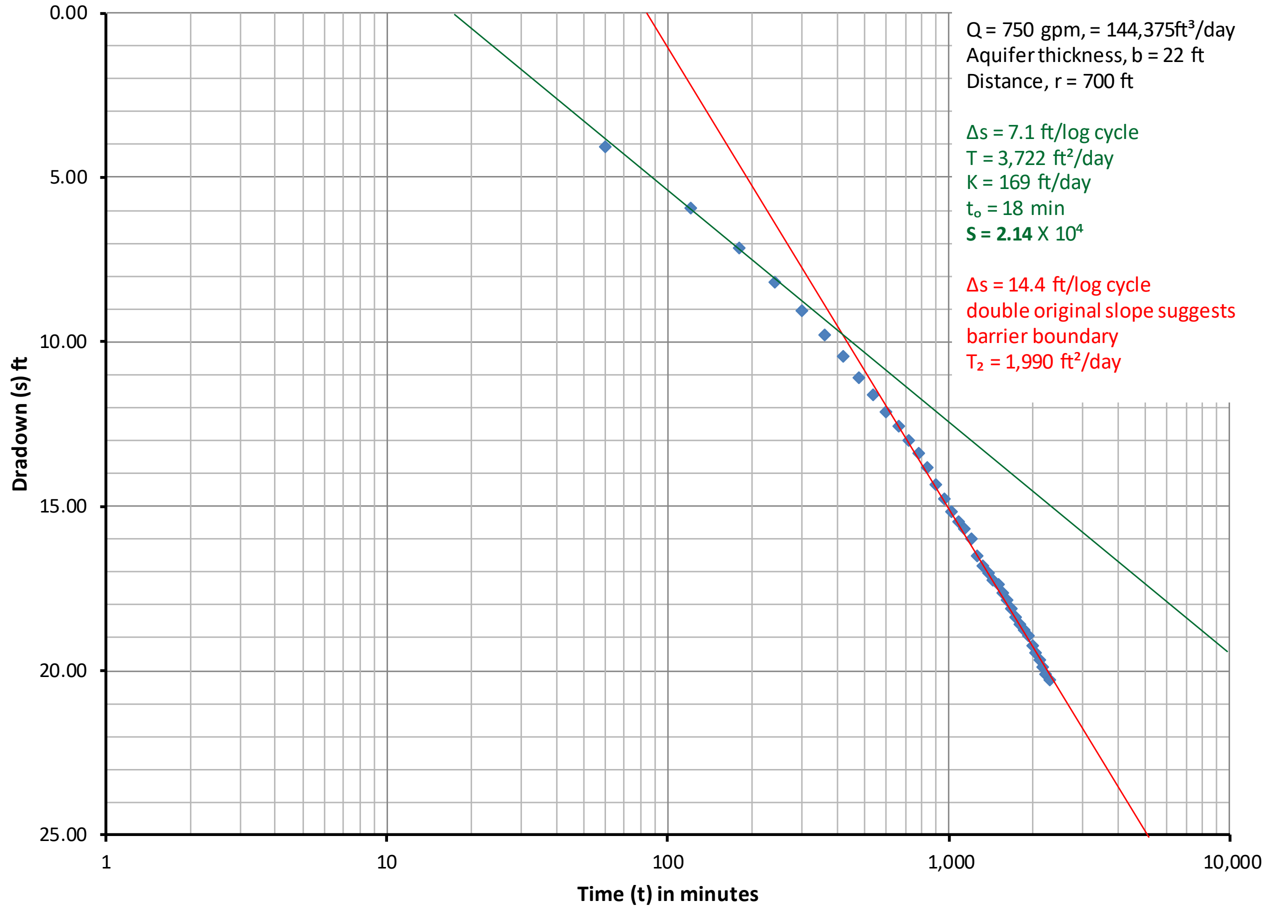


Figure C2-2. Results of Nelson 2 aquifer test #1.

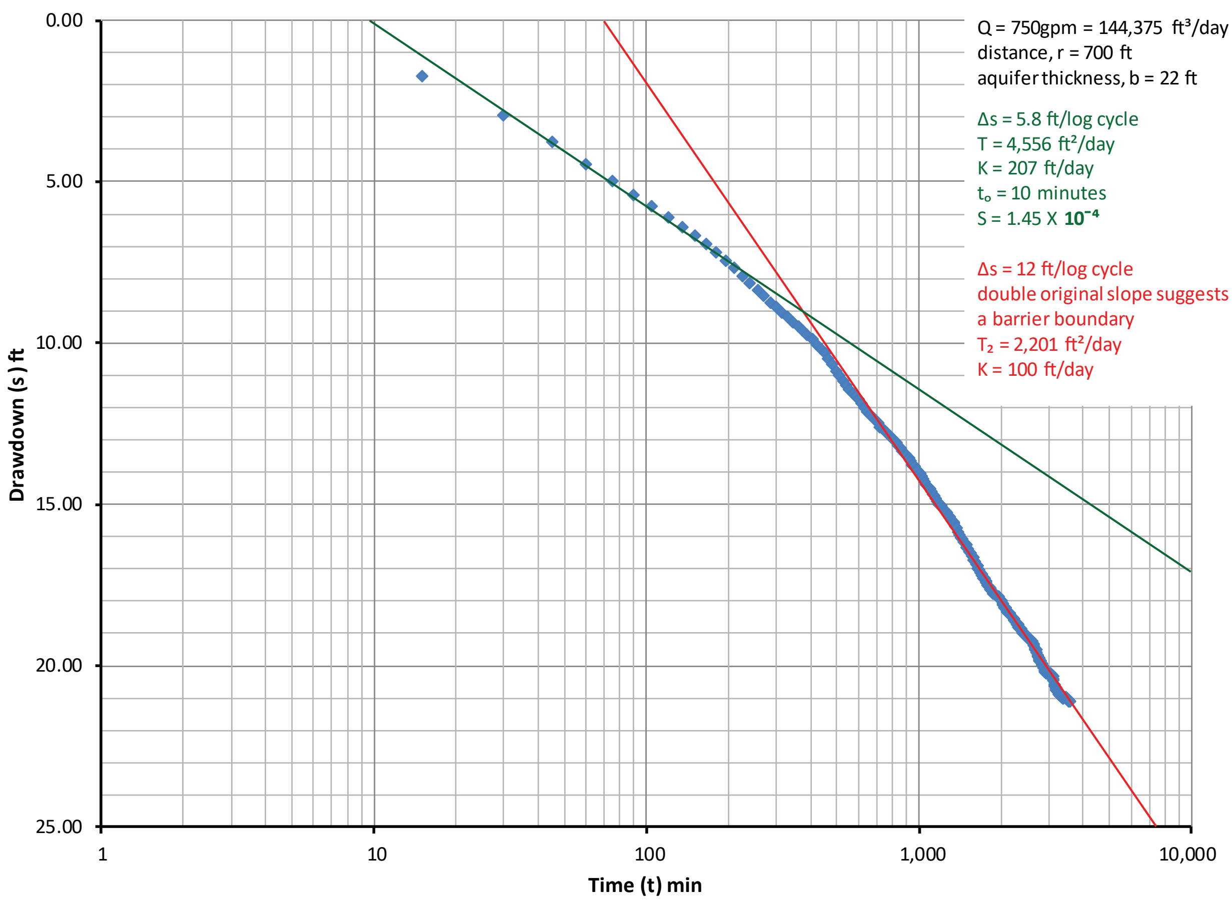


Figure C2-3. Results of Nelson 2 aquifer test #2.

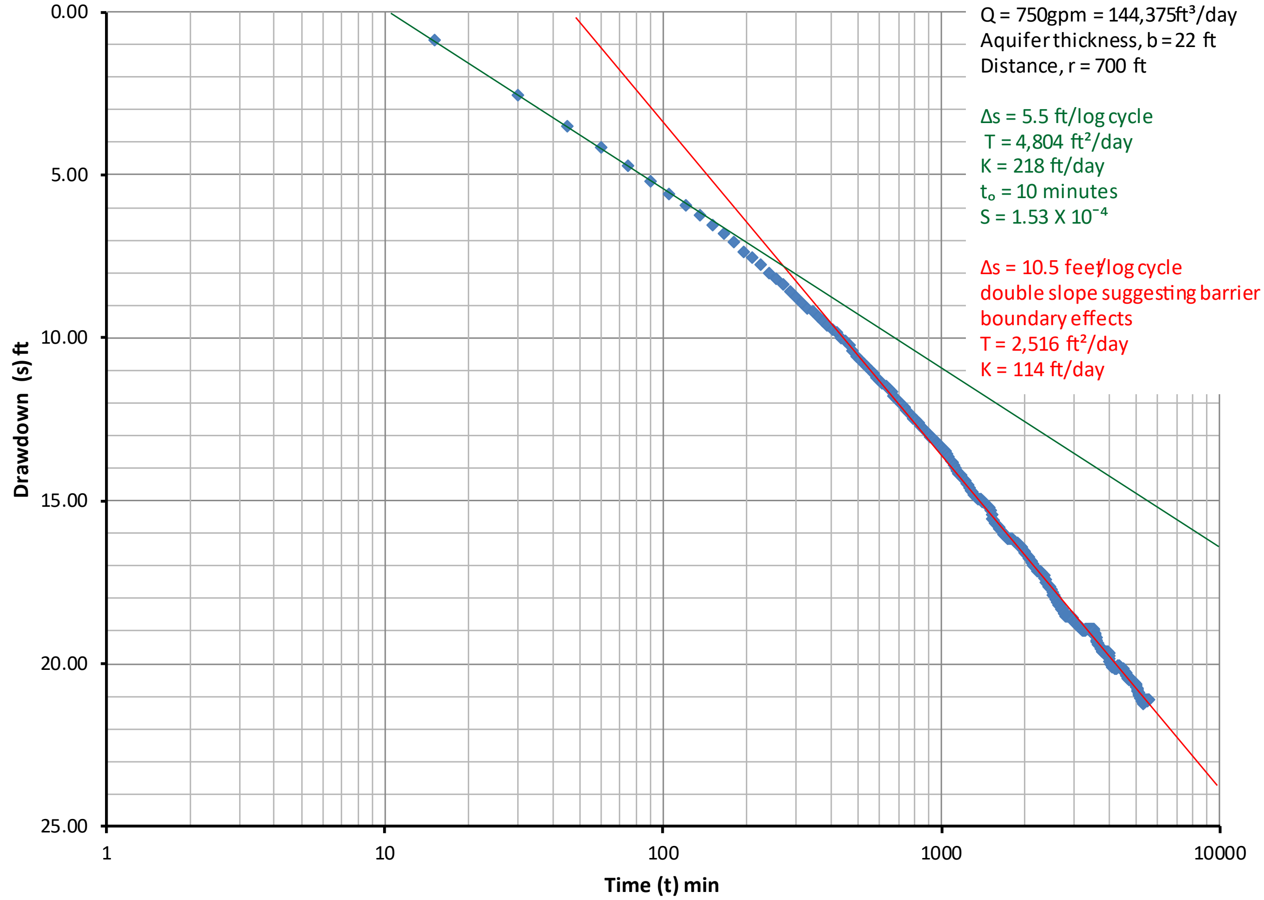


Figure C2-4. Results of Nelson 2 aquifer test #3.

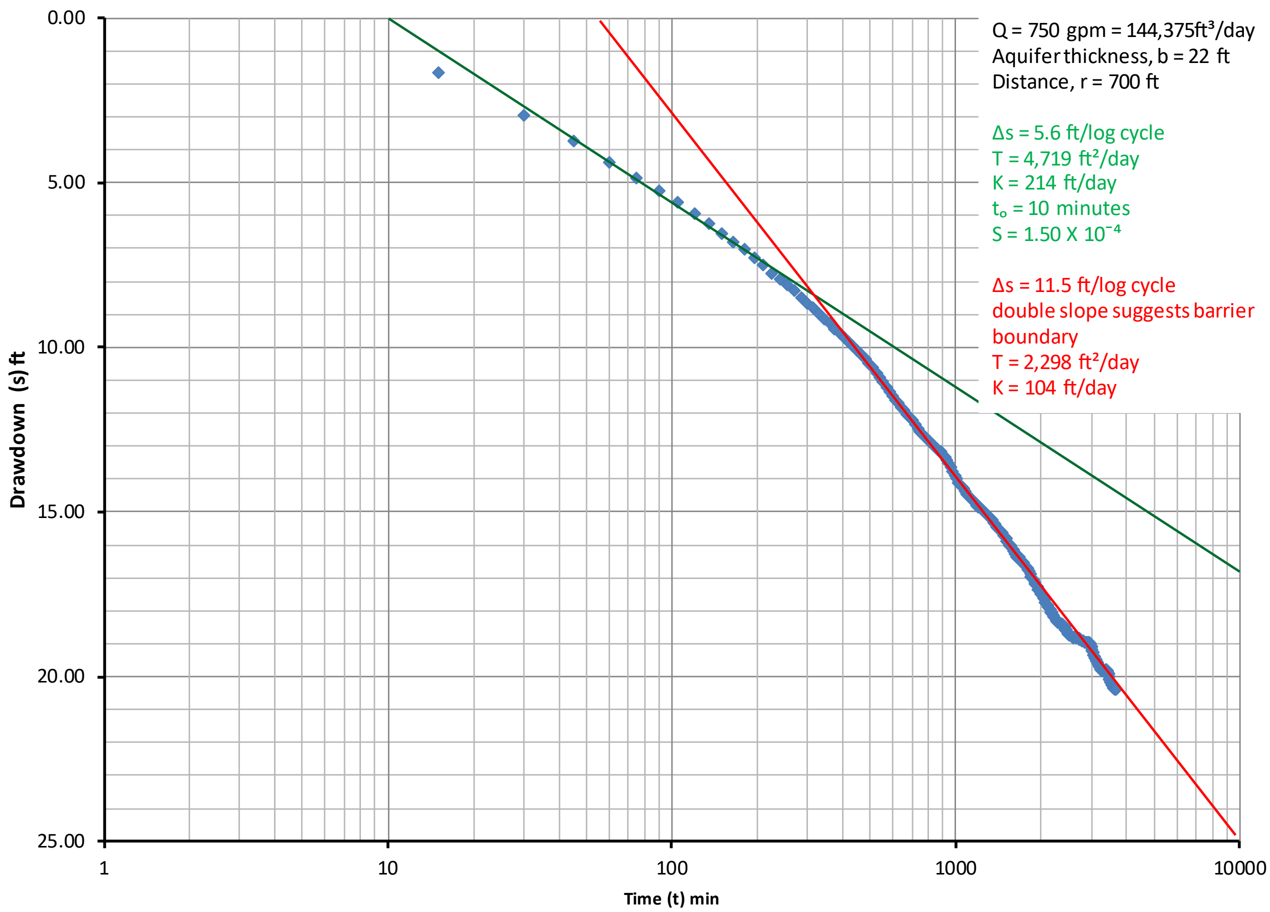


Figure C2-5. Results of Nelson 2 aquifer test #4.

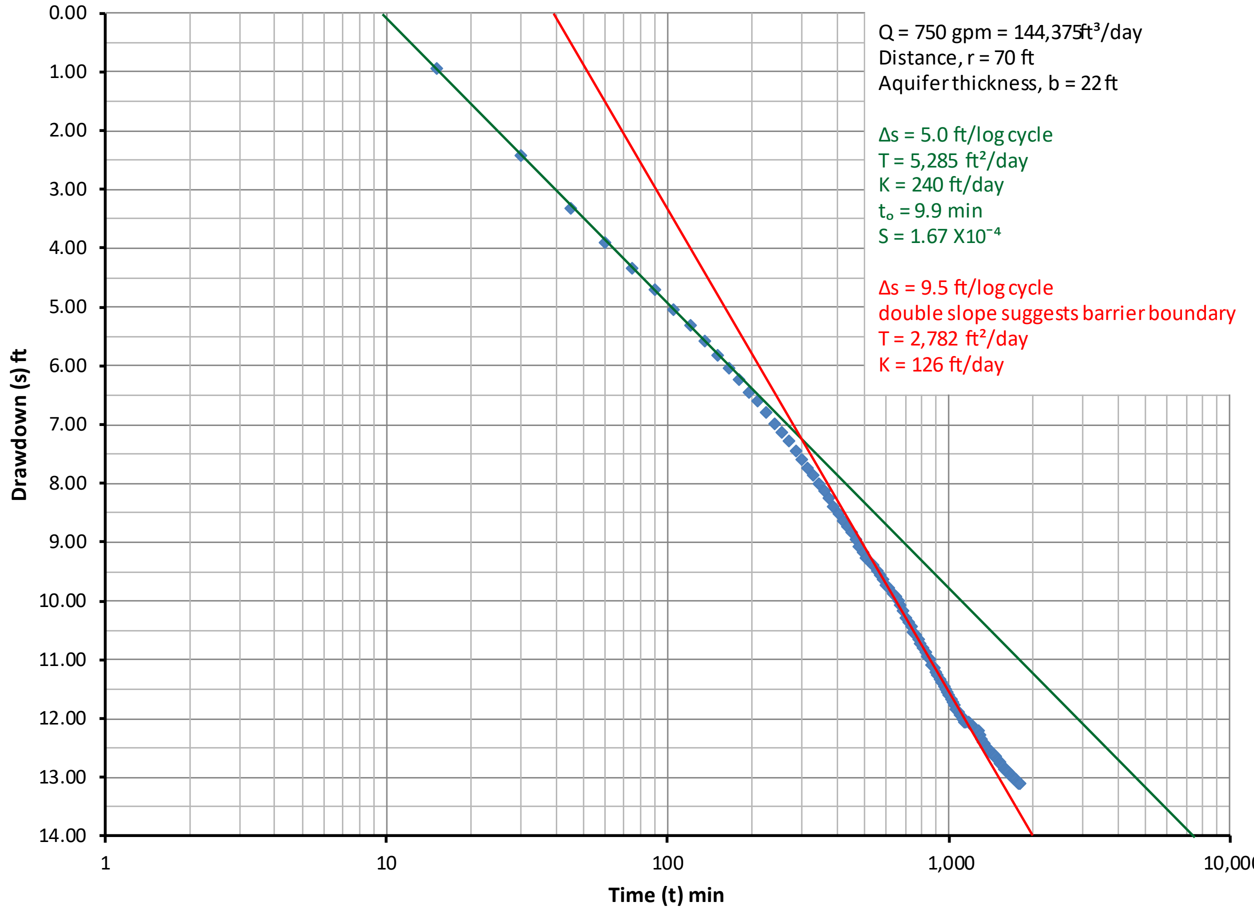


Figure C2-6. Results of Nelson 2 aquifer test #5.

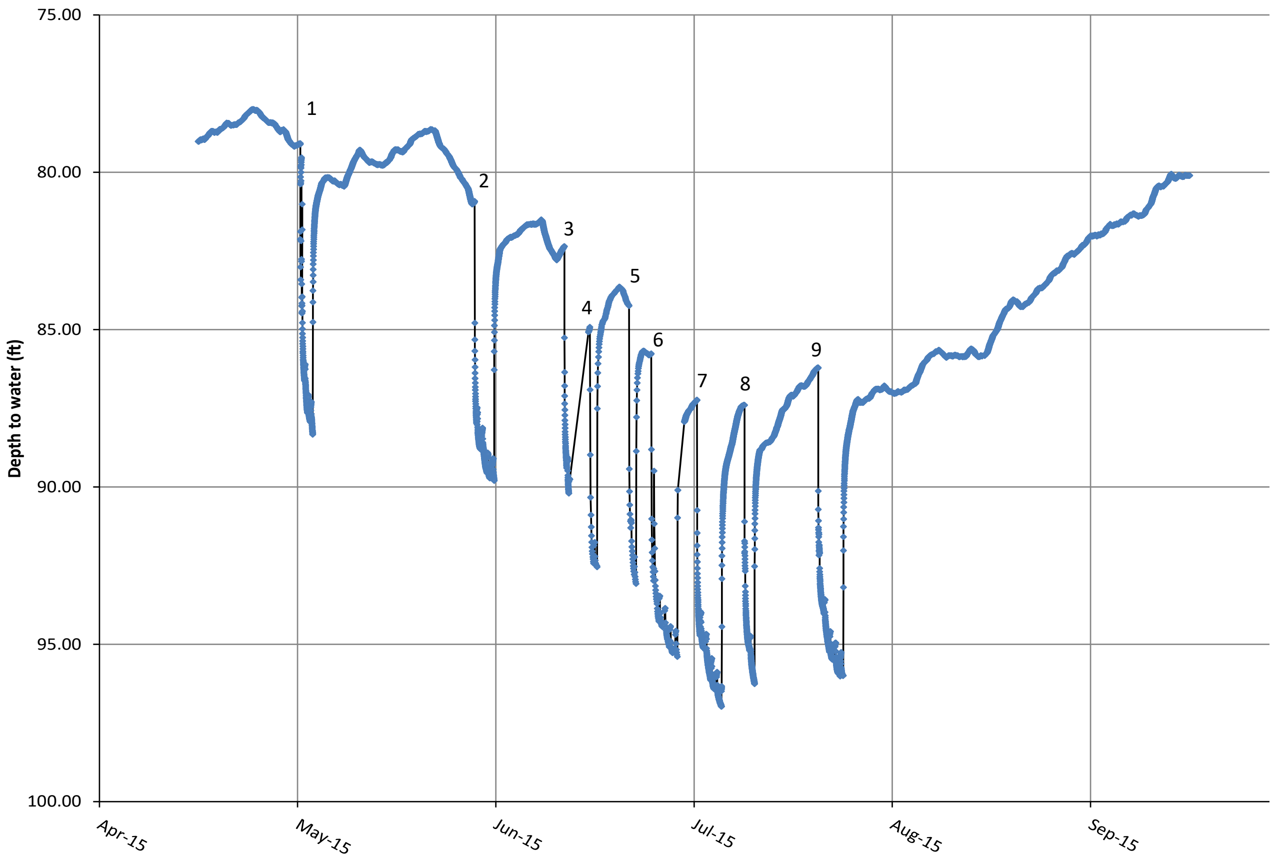


Figure C3-1. Timing of nine aquifer tests at Nelson 3, pumping irrigation well 212128 and monitoring drawdown at well 169217 located 230 ft away from the irrigation well.

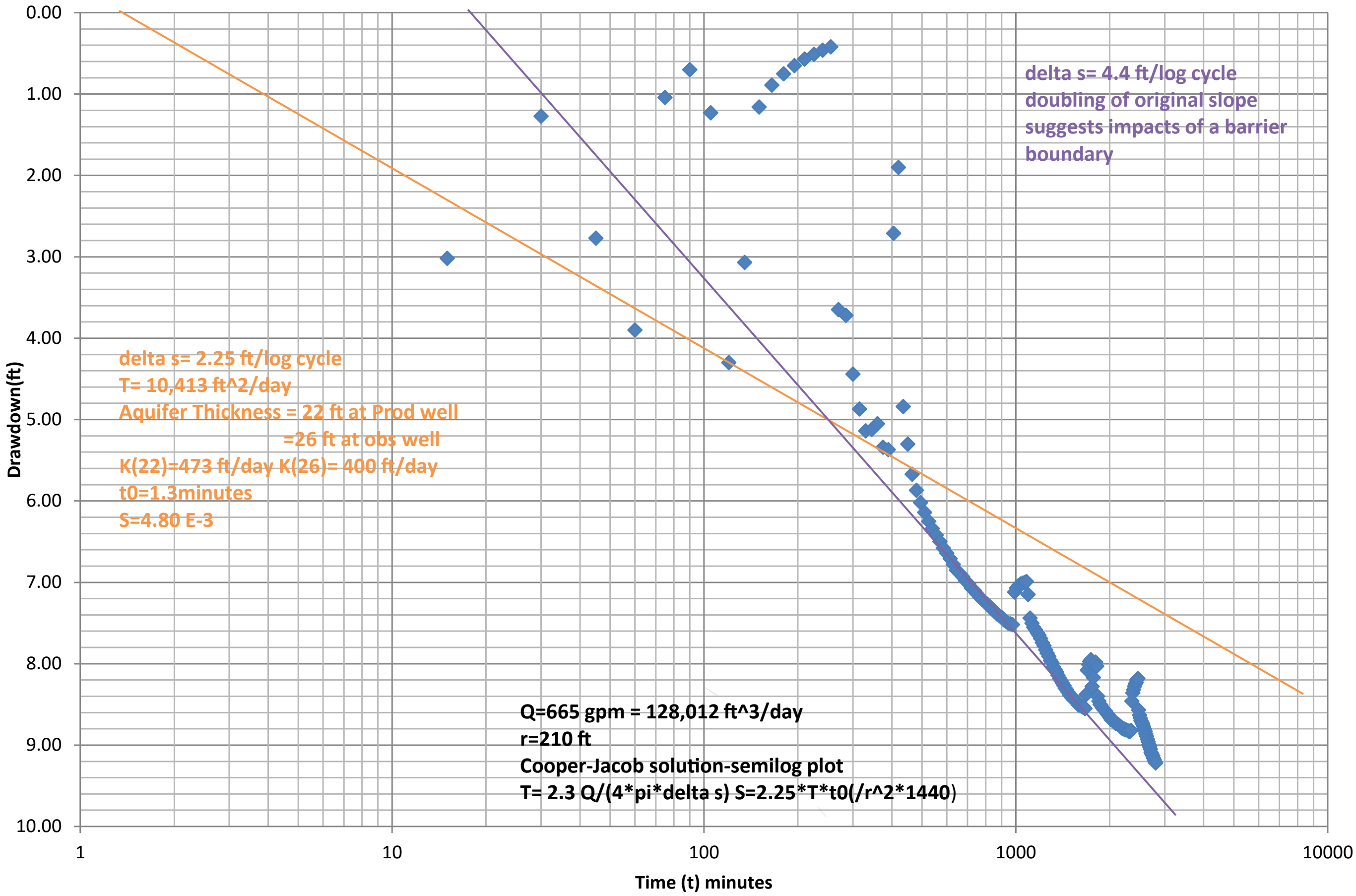


Figure C3-2. Results of Nelson 3 aquifer test #1.

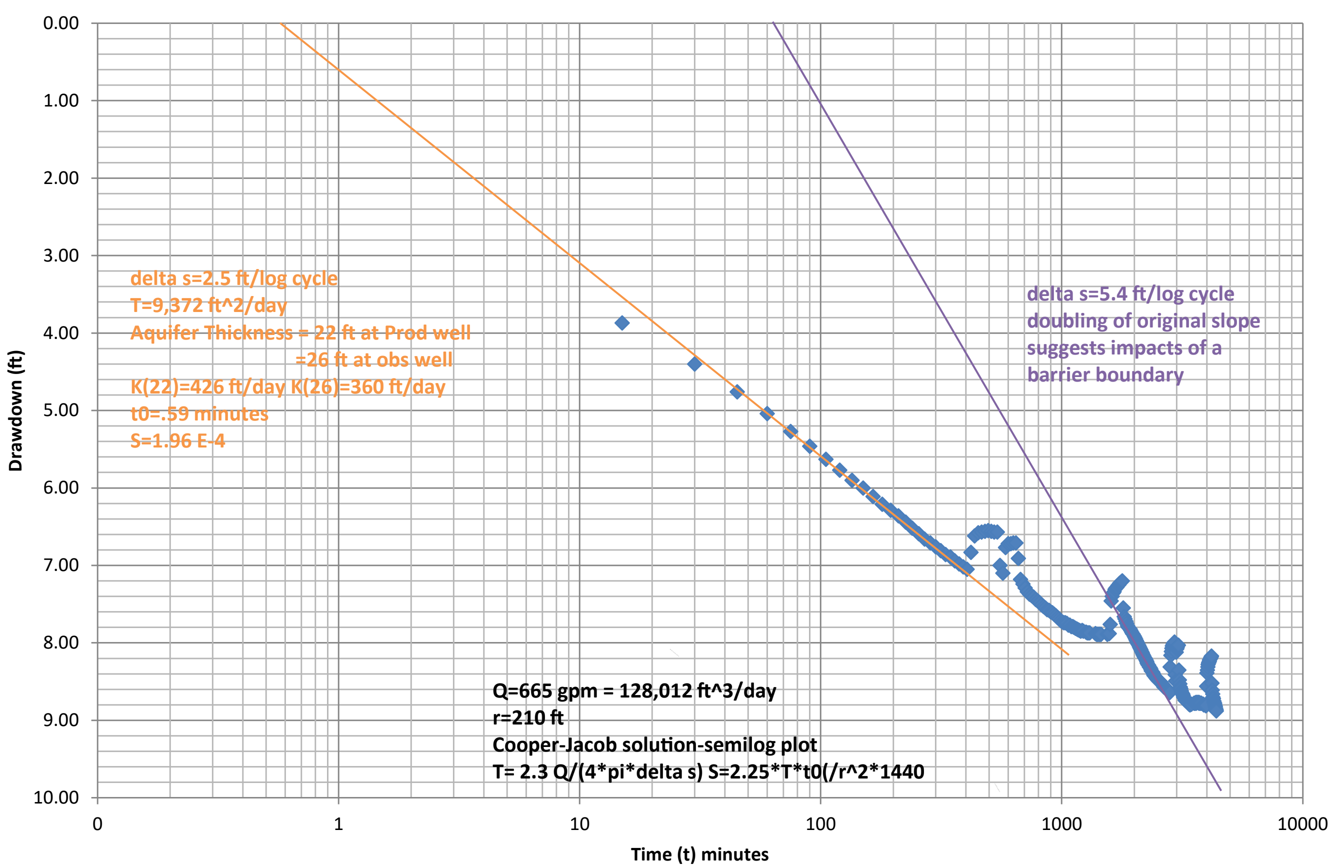


Figure C3-3. Results of Nelson 3 aquifer test #2.

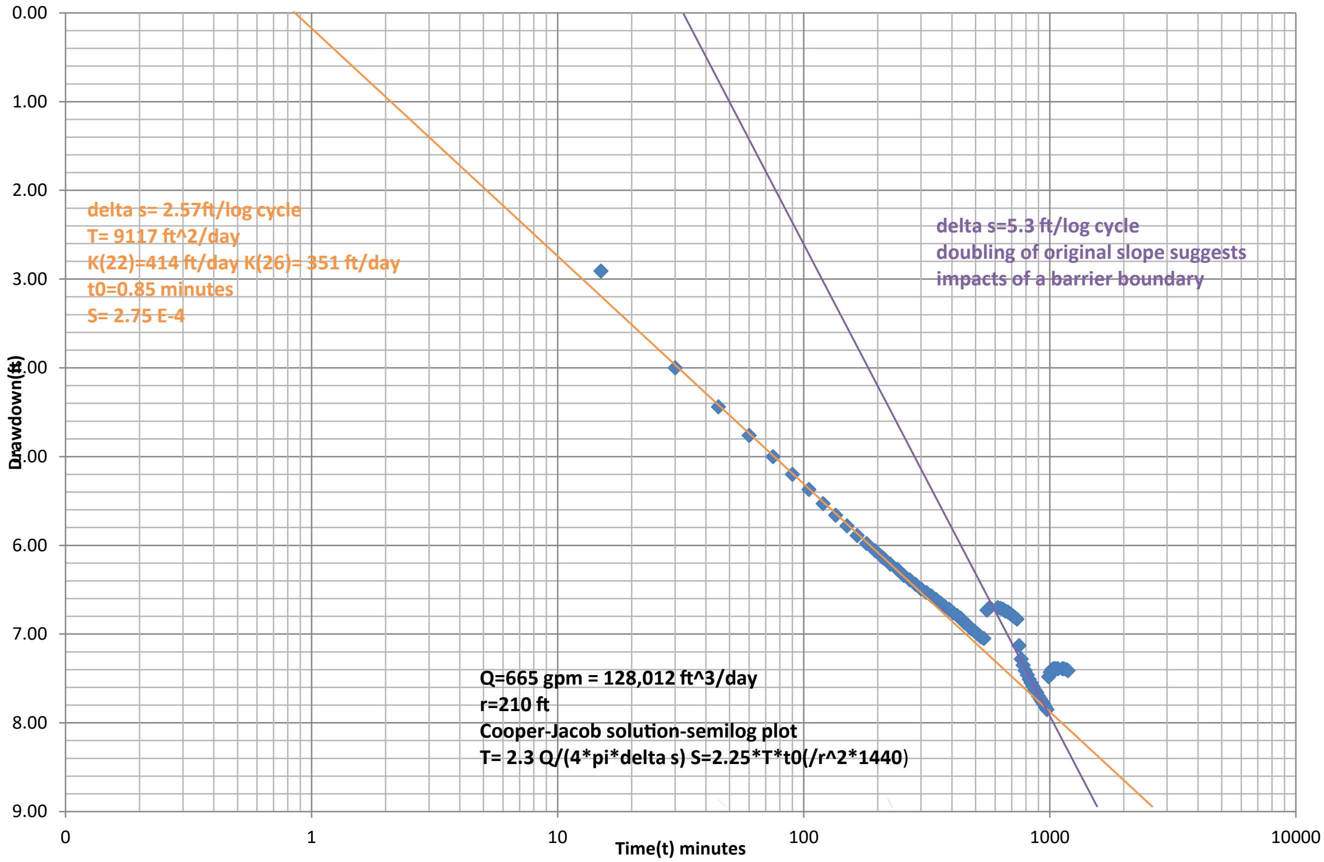


Figure C3-4. Results of Nelson 3 aquifer test #3.

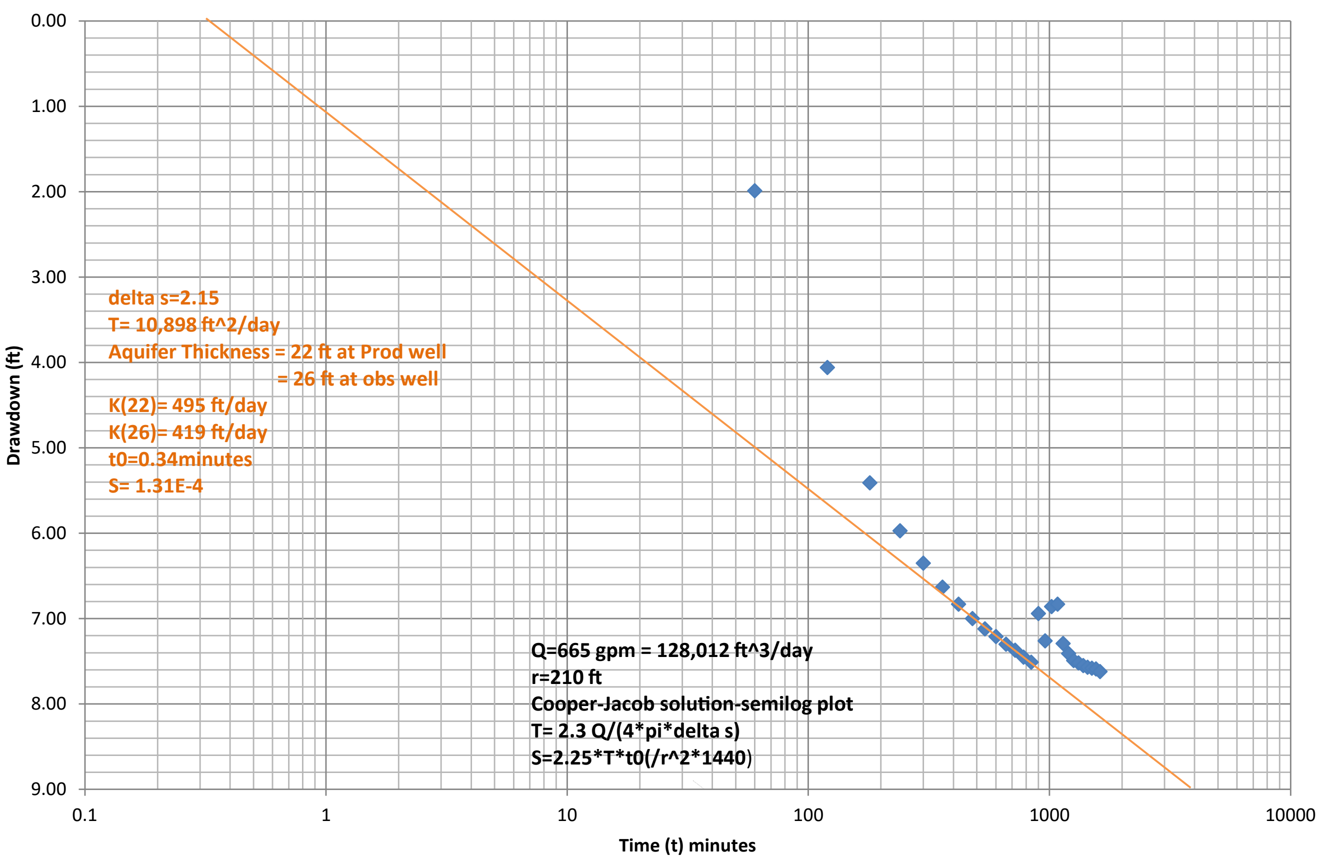


Figure C3-5. Results of Nelson 3 aquifer test #4.

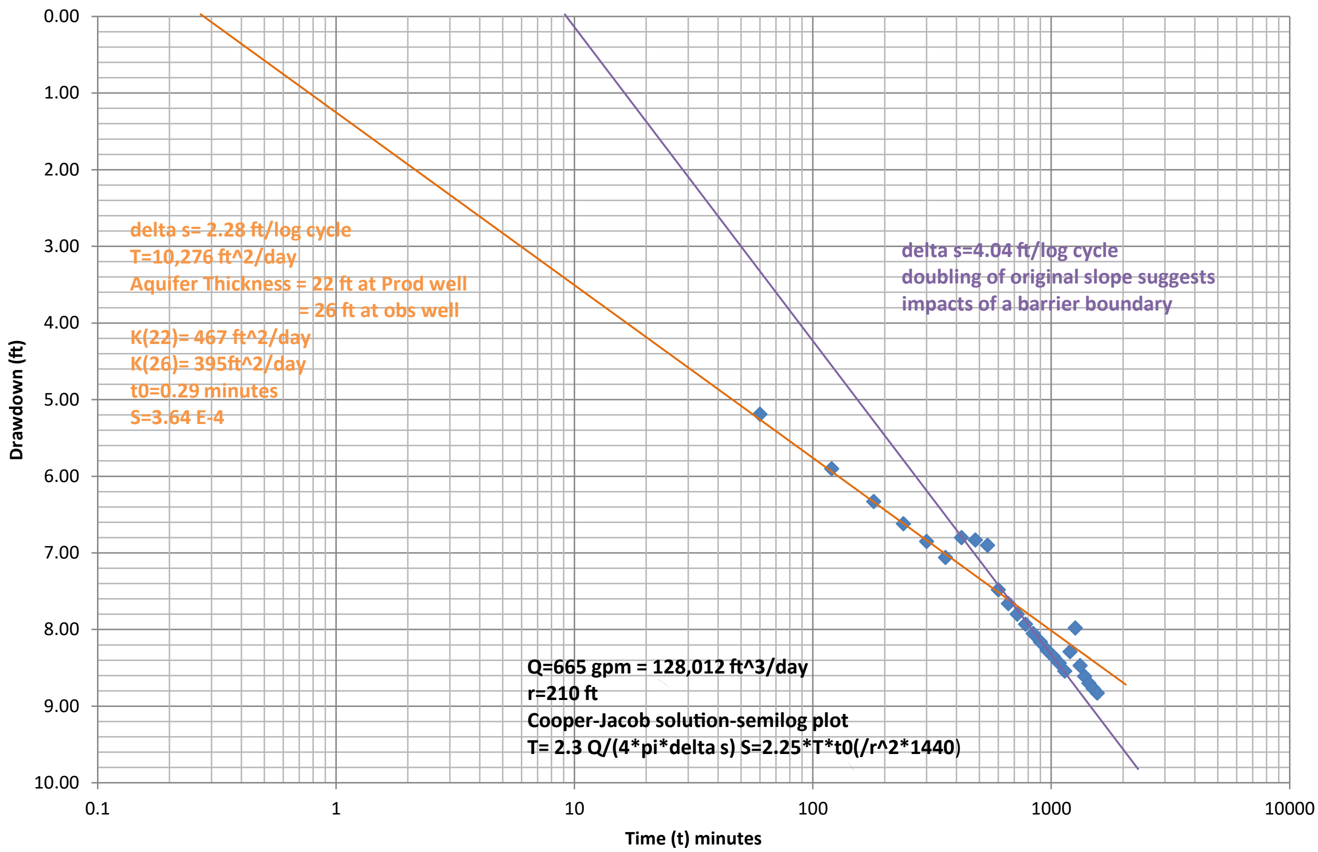


Figure C3-6. Results of Nelson 3 aquifer test #5.

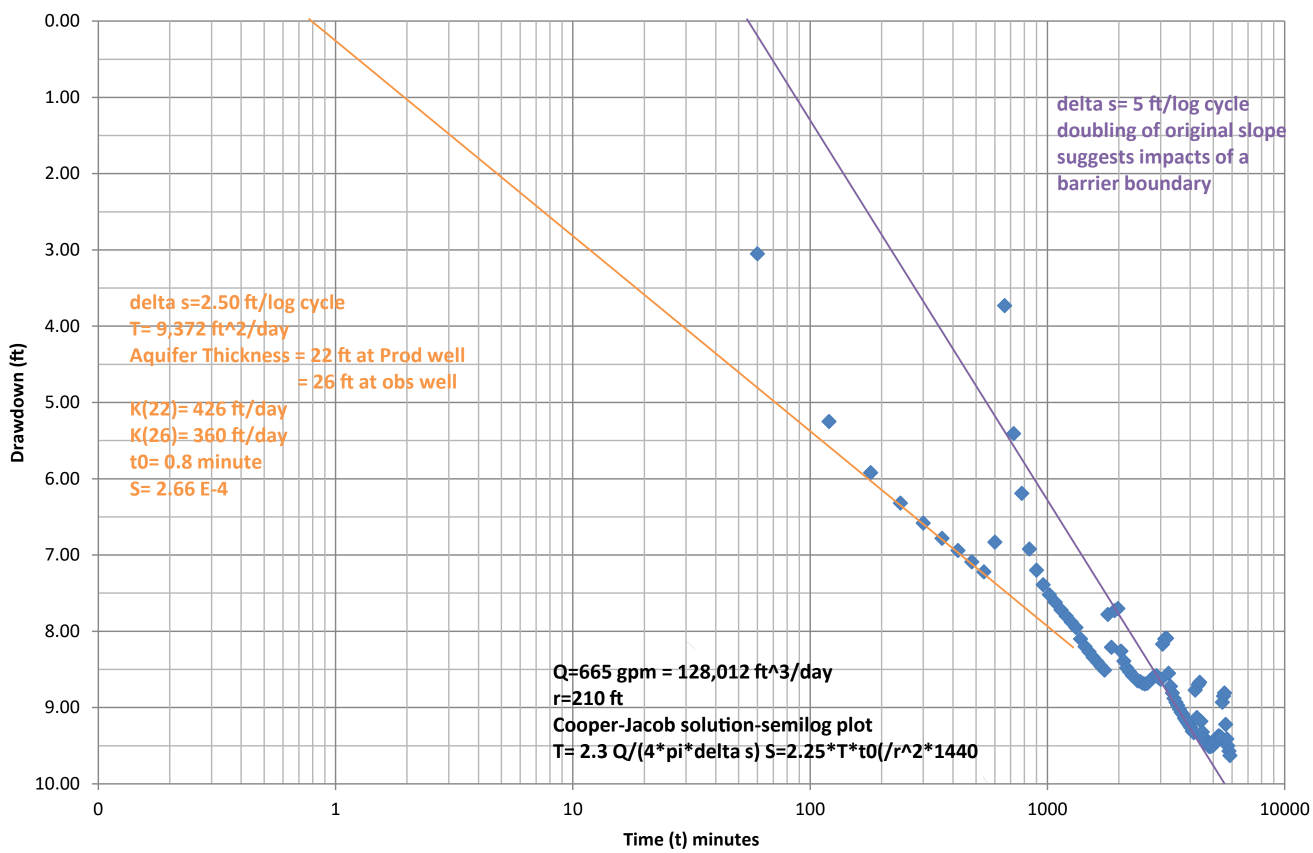


Figure C3-7. Results of Nelson 3 aquifer test #6.

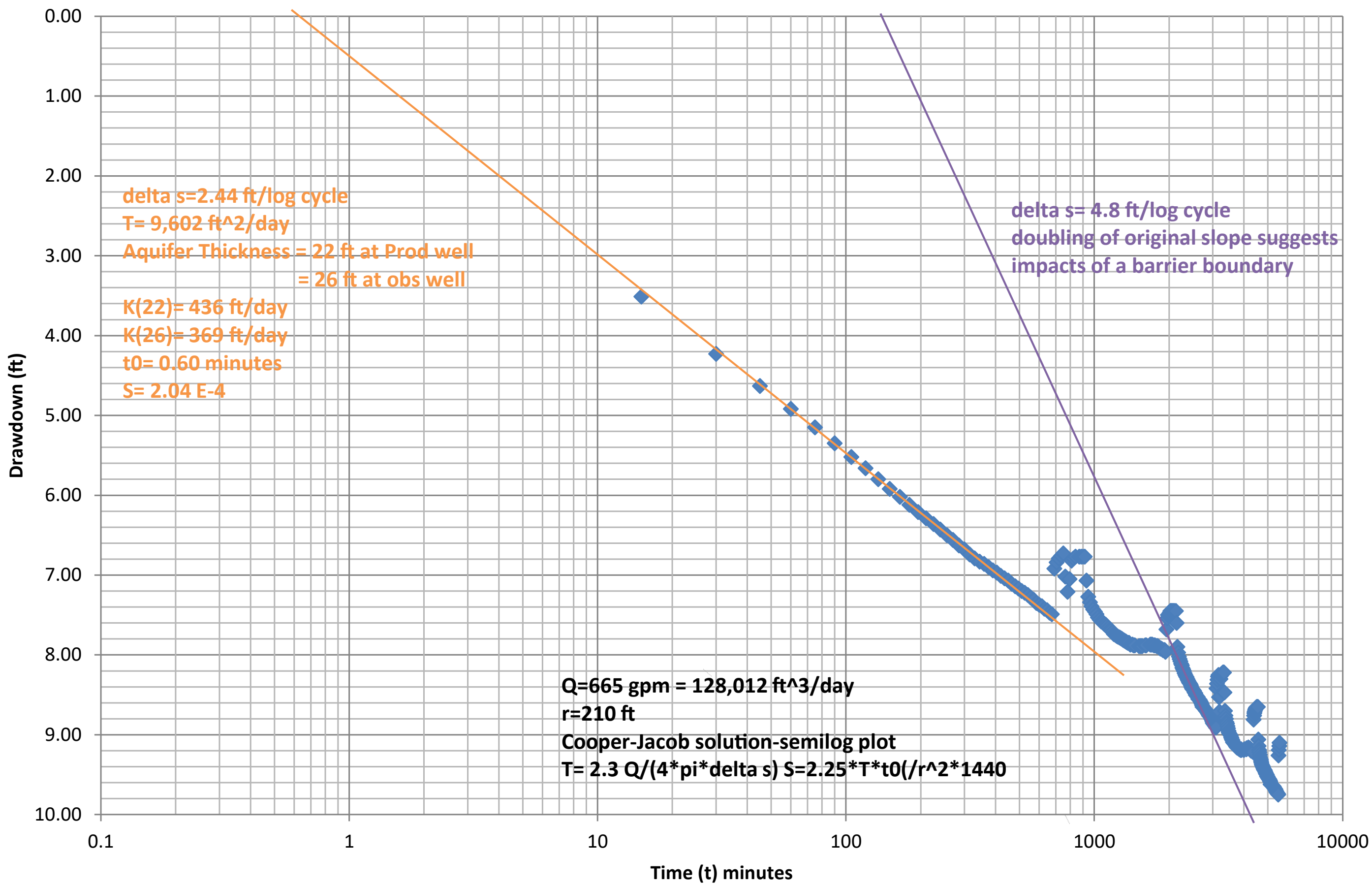


Figure C3-8. Results of Nelson 3 aquifer test #7.

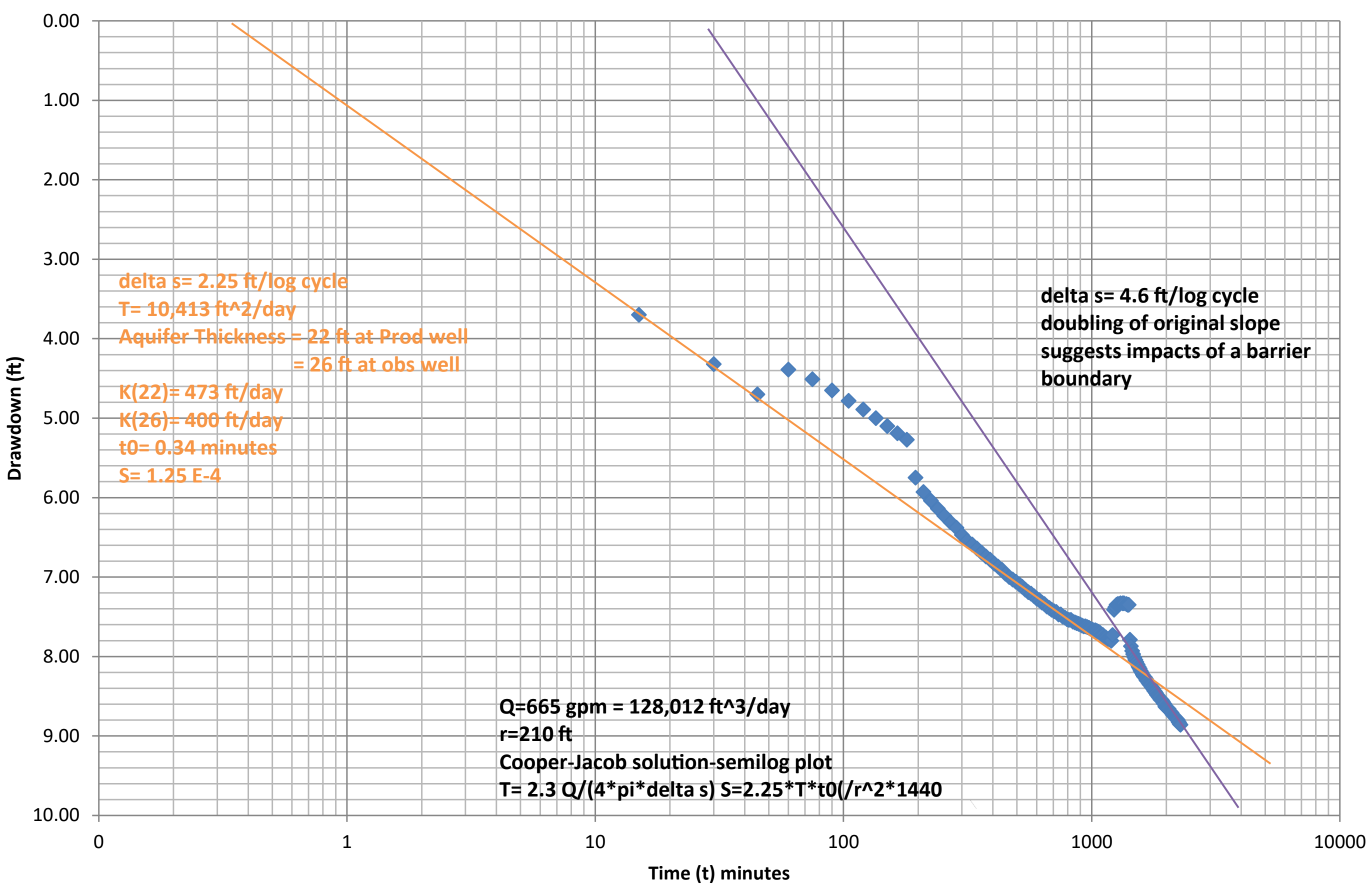


Figure C3-9. Results of Nelson 3 aquifer test #8.

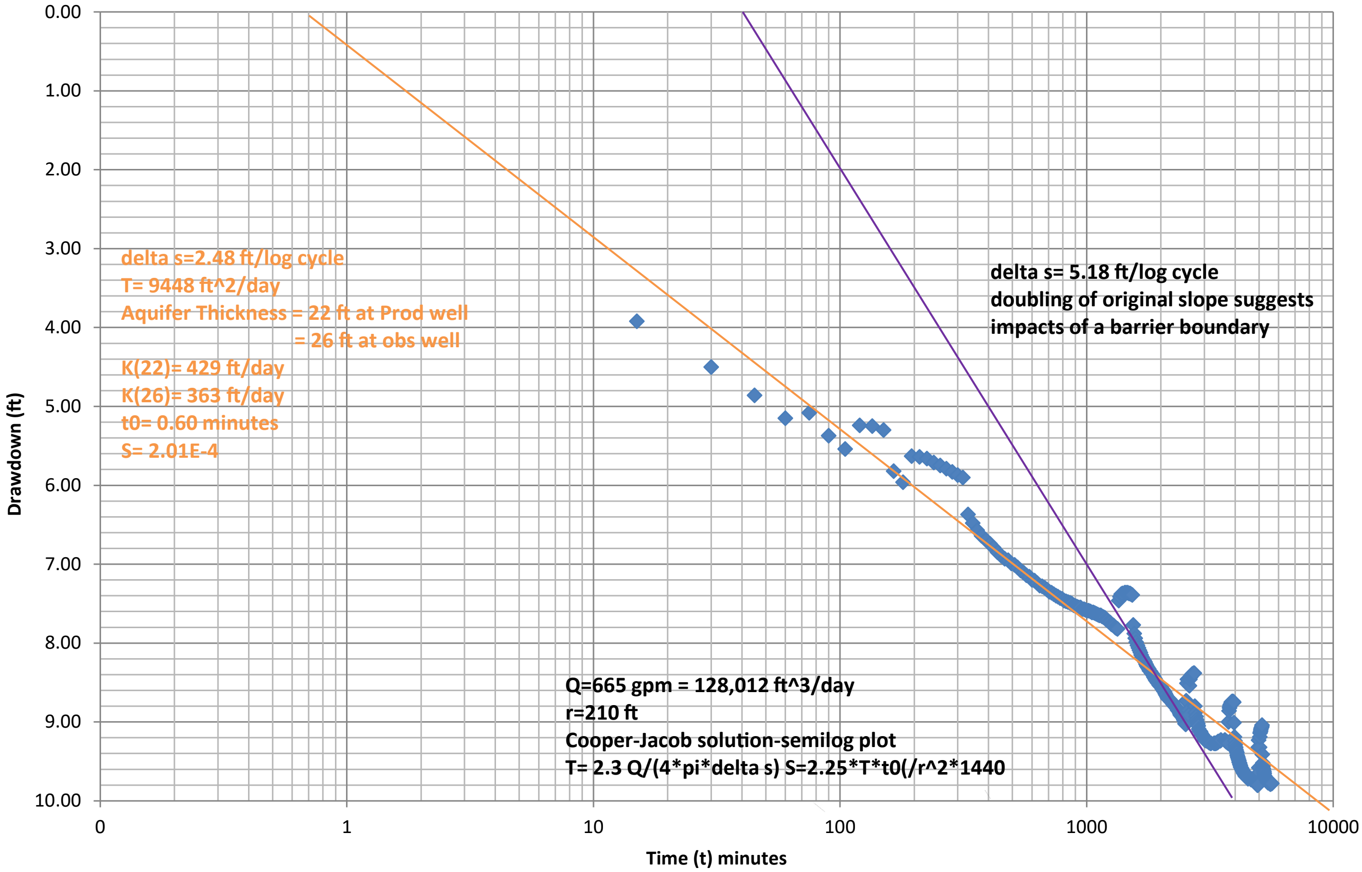


Figure C3-10. Results of Nelson 3 aquifer test #9.

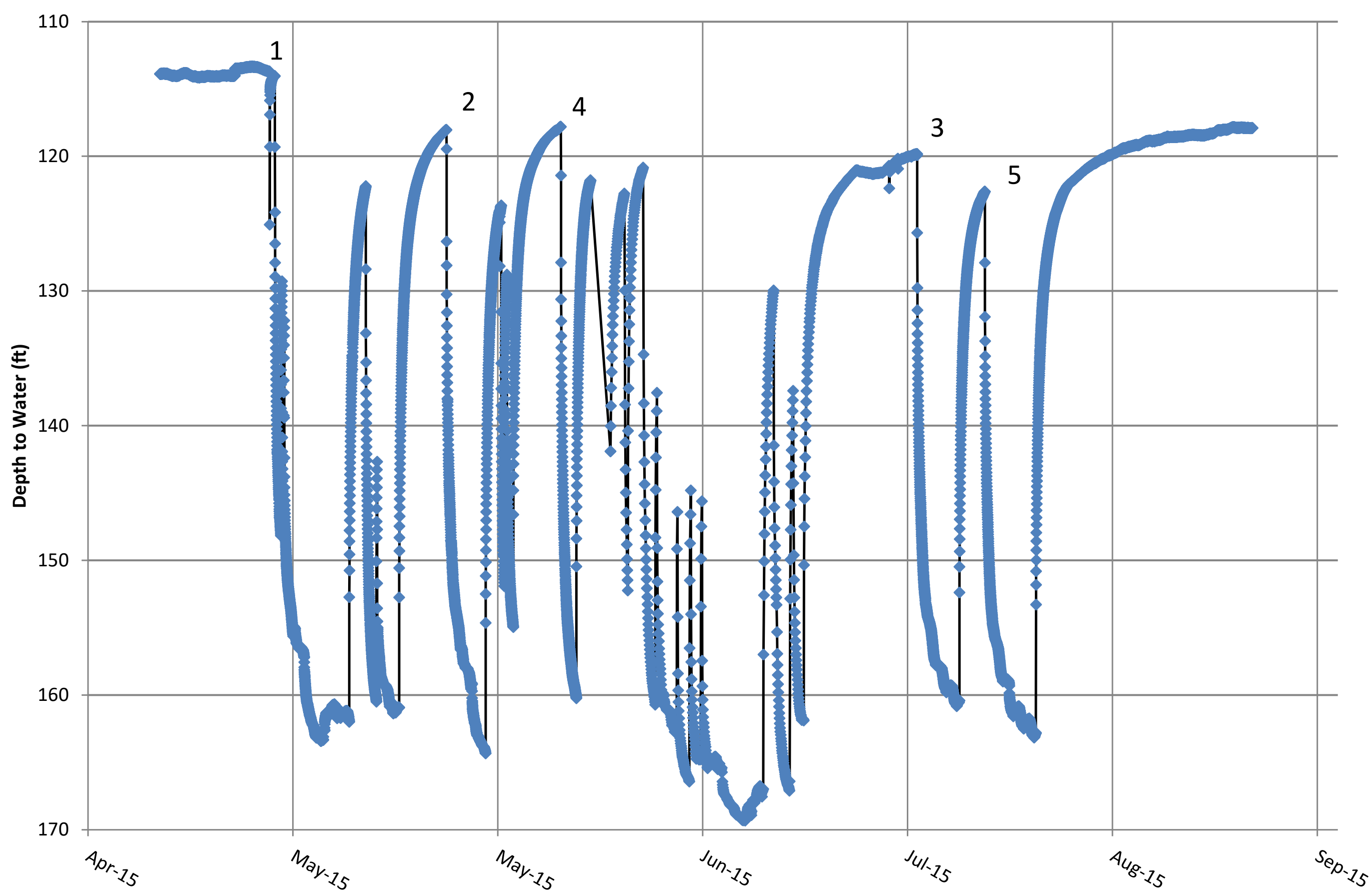


Figure C4-1. Timing of five aquifer tests at Bolstad 1, pumping irrigation well 175651 and monitoring drawdown at well 43116 located 20 ft away from the irrigation well.

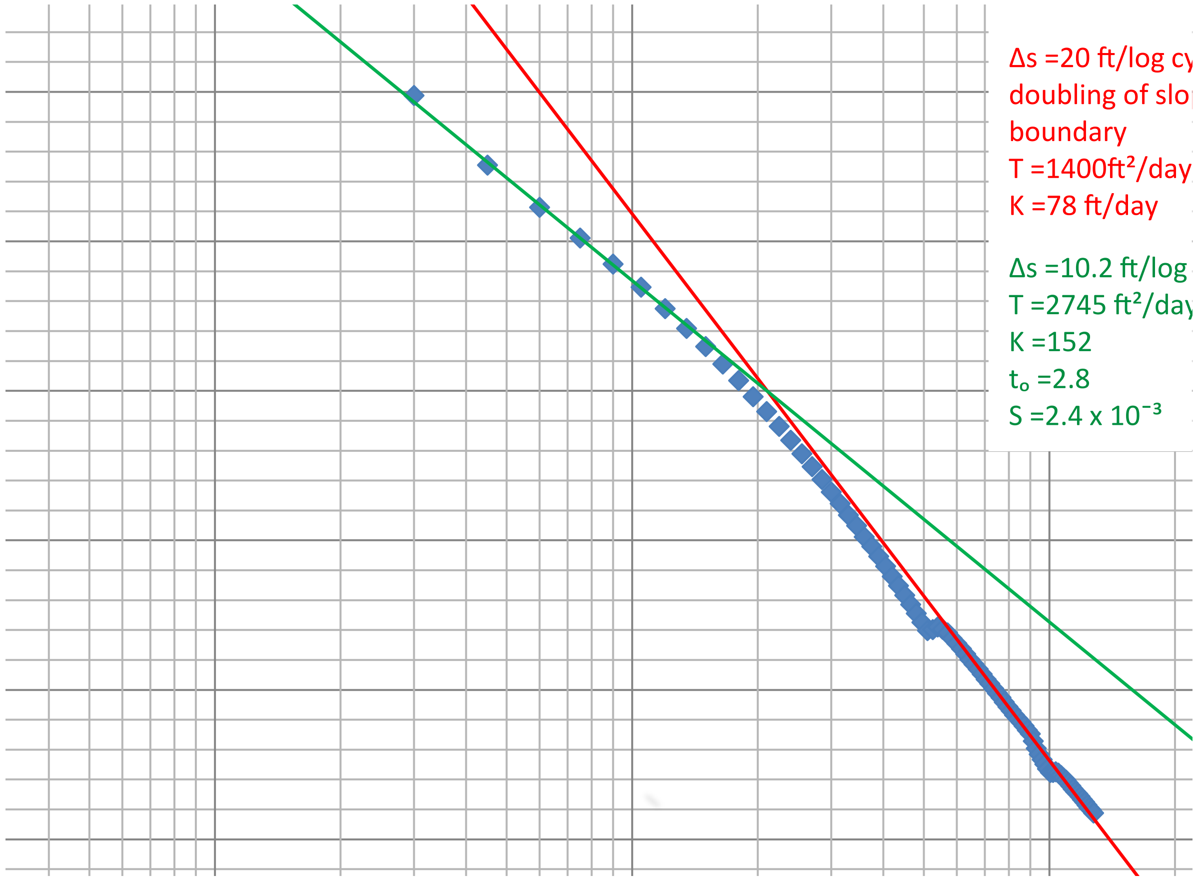


Figure C4-2. Results of Bolstad 1 aquifer test #1.

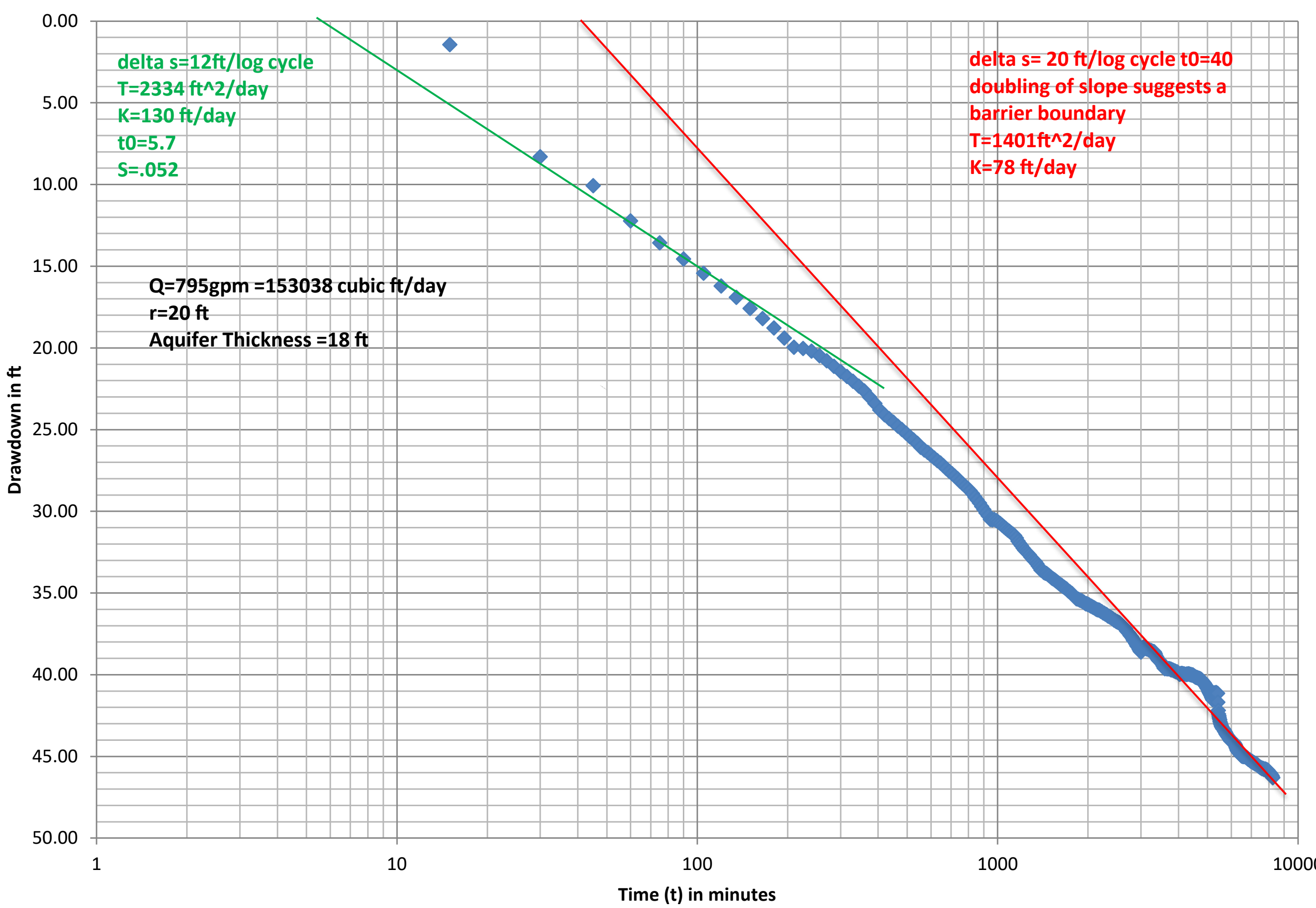


Figure C4-3. Results of Bolstad 1 aquifer test #2.

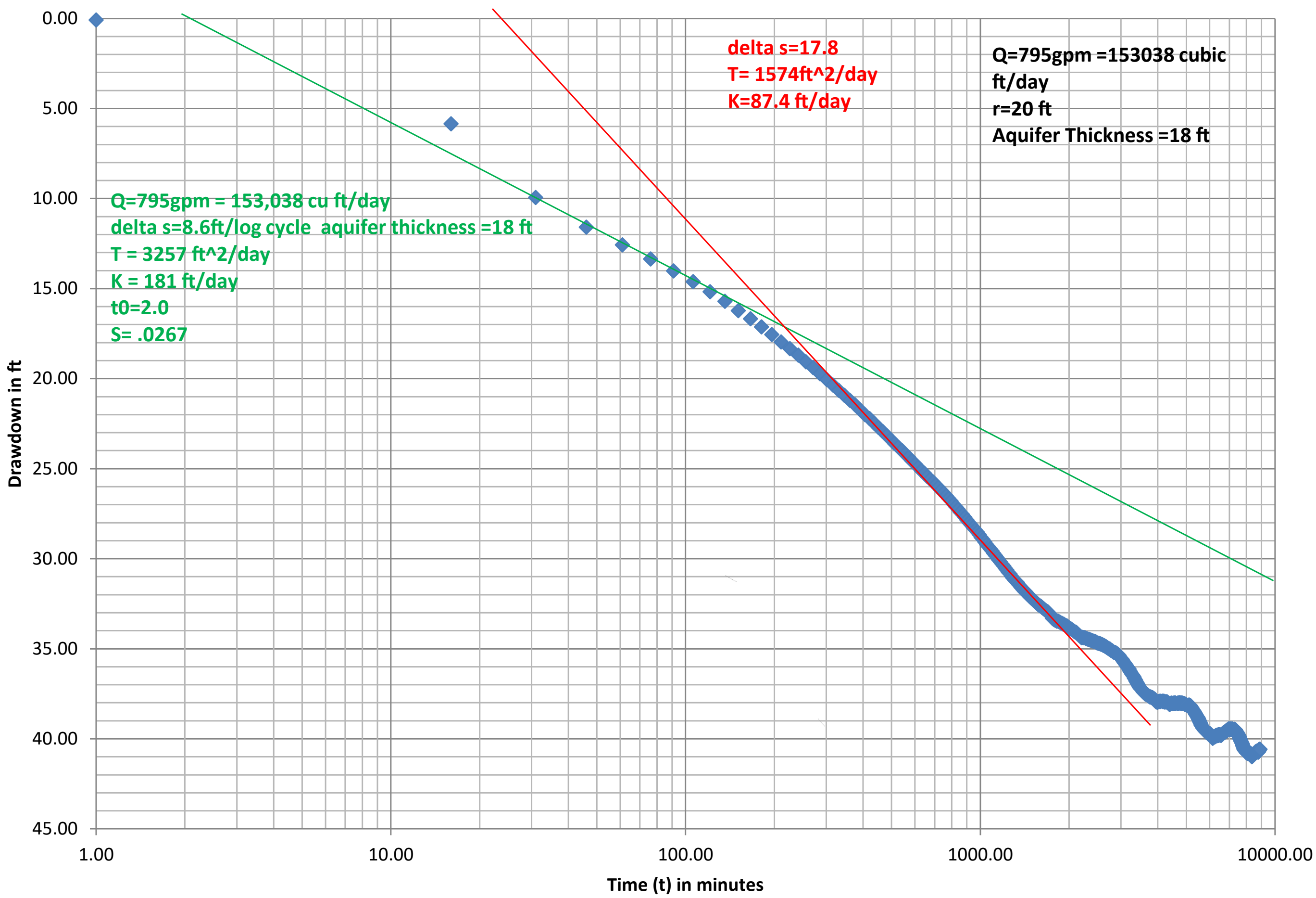


Figure C4-4. Results of Bolstad 1 aquifer test #3.

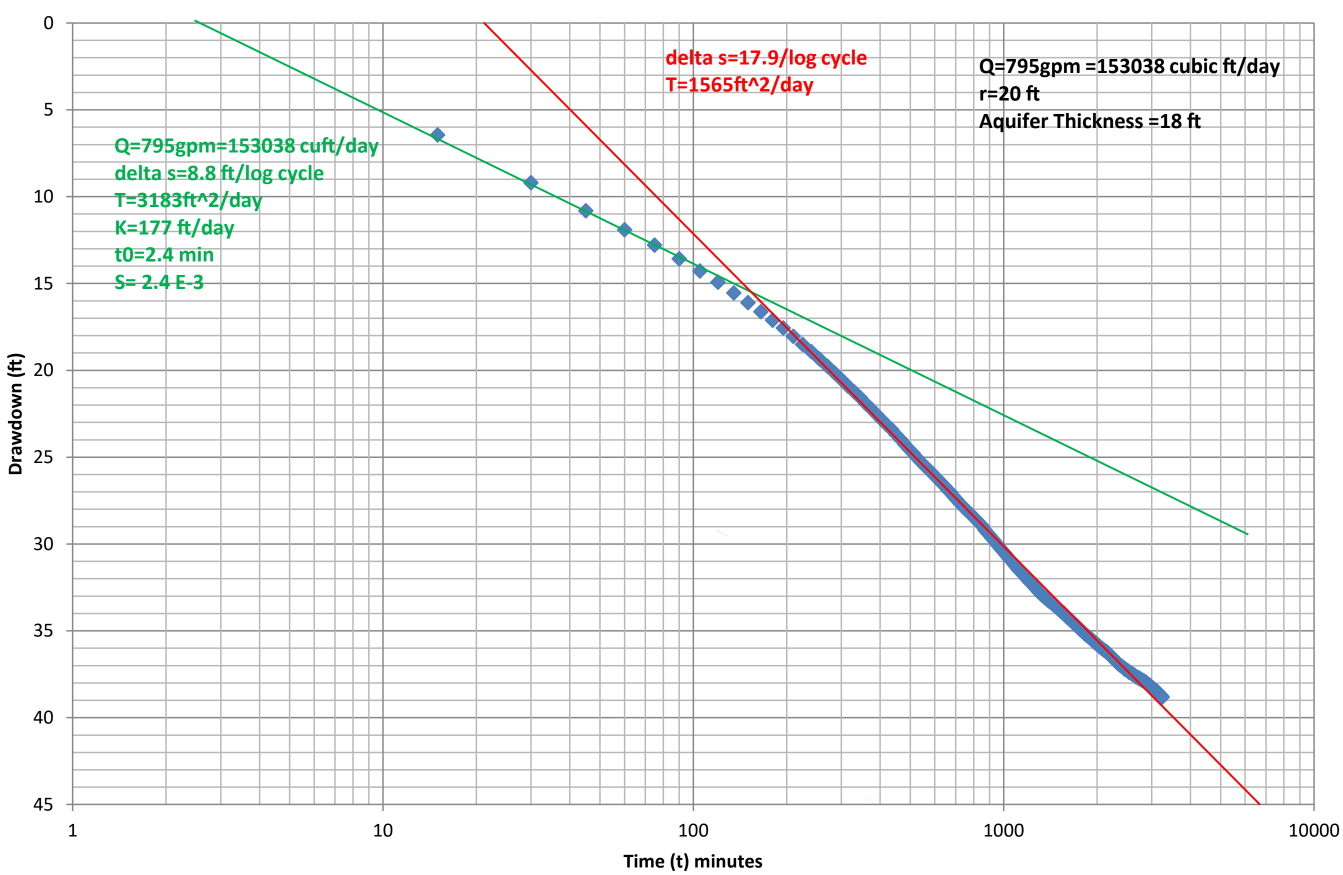


Figure C4-5. Results of Bolstad 1 aquifer test #4.

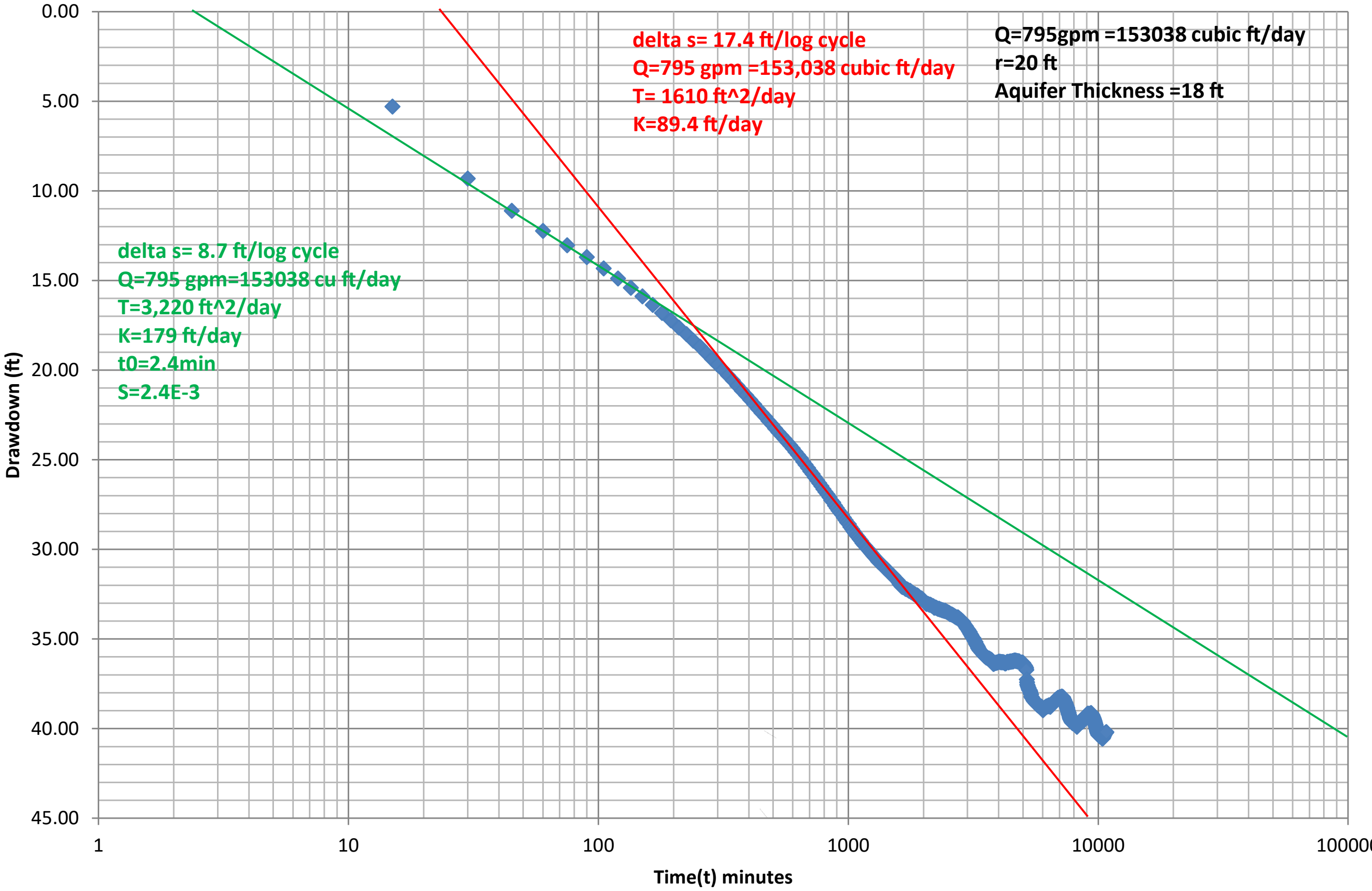


Figure C4-6. Results of Bolstad 1 aquifer test #5.