HYDROGEOLOGIC INVESTIGATION OF THE DEEP ALLUVIAL AQUIFER, FLATHEAD VALLEY, MONTANA

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Montana Bureau of Mines and Geology
Ground Water Investigation Program

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Front photo: Monitoring water levels at Jessup Millpond at Creston, Montana.

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PREFACE

The Ground Water Investigations 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, and commercial activity or changing irrigation practices. Additional program information can be accessed at http://www.mbmg.mtech.edu/ (see Ground Water Investigation Program).

The final products of this Flathead Valley Deep Alluvial Aquifer study include:

- A **Geologic Report** (Rose, 2018), which presents a three-dimensional model of the subsurface geology in the Flathead Valley. This model is based on interpretations of drillers' well logs, previous geologic maps and reports, gravity data, and seismic data. The publication includes electronic files depicting geologic contacts and each stratigraphic unit.
- This **Interpretive Report,** which presents data, addresses questions, offers interpretations, and summarizes project results within the focus area. A comprehensive data set is permanently stored in MBMG's Groundwater Information Center (GWIC) database (MBMG, 2022). The MBMG's Groundwater Monitoring and Assessment Program has monitored groundwater resources in the valley since the early 1990s, and much of these data are presented in this report.

The MBMG has two additional projects in the Flathead Valley (Bobst and others, in prep.). These include GWIP studies focused on the east side of the valley and an investigation of the thickness of the deep aquifer (Bobst and others, in review).

ABSTRACT

The Flathead Valley deep alluvial aquifer underlies an area from the north shore of Flathead Lake to near Whitefish and Columbia Falls. The aquifer is several hundred feet thick, generally confined, and composed of glaciofluvial sand and gravel overlain by a confining unit of glacial till and lake sediments. This aquifer is the most productive source of groundwater in the valley, supplying high-capacity municipal and irrigation wells in addition to thousands of domestic wells. Groundwater, primarily from the deep aquifer, supplies all domestic needs except those served by the public water supply at Whitefish. The largest users of water in the valley are public water supply systems and irrigators.

This study of the deep alluvial aquifer, focused in the central and eastern Flathead Valley, was motivated by concerns that pumping from the deep alluvial aquifer could exceed its capacity to recover. The purpose of this investigation was to determine: (1) whether withdrawals from the deep aquifer affect surface-water resources and (2) whether water levels in the deep aquifer are declining.

The lacustrine-till aquitard that confines the deep aquifer is present throughout most of the valley. The aquitard varies in thickness but thins along the valley margins. Water can move vertically through the confining unit, but extremely slowly, due to its low hydraulic conductivity (about 0.0007 ft/d at the one test site of the lacustrine sediments). Therefore, throughout much of the valley, withdrawals from the deep aquifer are unlikely to directly affect surface-water sources. A companion report (Rose, 2018) presents a three-dimensional geologic model of the Flathead Valley that includes the location and thickness of the lacustrine-till aquitard interpolated from drillers' logs.

The deep aquifer is heterogeneous in aquifer properties and thickness. Two aquifer tests completed for this study yielded transmissivity estimates of 35,000 and 17,000 ft^2/d, with storativities of 5.2×10^{-4} and 7.6×10^{-3}, respectively. Records compiled from a variety of sources report transmissivity values ranging from 100 ft2/d to nearly 100,000 ft^2/d, with lower values in the upper 50 to 100 ft of the aquifer due to higher concentrations of silt and clay. Deep aquifer well yields range up to several thousand gallons per minute.

Recharge to the deep alluvial aquifer occurs primarily along mountain fronts surrounding the valley, likely augmented by vertical seepage through the aquitard. Discharges from the aquifer are to pumping, groundwater outflow to the south, and upward flux across the aquitard. Vertical groundwater gradients across the aquitard are generally downward in the northern portion of the valley and upward in the southern area.

Long-term (1996–2017) monitoring of groundwater elevations in the western and southern portions of the focus area generally shows statistically significant decreases. With no statistical decline in the amount of precipitation during this period, pumping from the deep aquifer likely causes these groundwater-level declines. In the northern and eastern areas there are no statistically significant increasing or decreasing trends. Proximity to recharge may explain the relatively stable water levels in these areas.

INTRODUCTION

The deep alluvial aquifer in the Flathead Valley is generally confined and composed primarily of sand and gravel (LaFave and others, 2004). It is the most utilized aquifer in the valley, supplying high-capacity municipal and irrigation wells and thousands of domestic wells. Continued population growth and observations of water-level declines in the deep alluvial aquifer (LaFave and others, 2004) raised concern about the potential effect of further groundwater development.

Historically, land use in the valley has been dominated by agriculture, including irrigated crops that can require large volumes of water. However, the population in the Flathead Valley has increased during the past several decades. The population of Flathead County grew by 180 percent between 1960 (33,000) and 2014 (95,000; U.S. Census, 1960, 2014). Groundwater, primarily from the deep alluvial aquifer, supplies all domestic needs in the valley except those served by the public water supply at Whitefish, which relies on surface water from the Haskill Basin watershed and from Whitefish Lake. Within the study area, public water supplies from groundwater serve the communities of Columbia Falls, Evergreen, Kalispell, and Bigfork.

Purpose and Scope

The purpose of this Ground Water Investigation Program (GWIP) study was to determine: (1) whether withdrawals from the deep alluvial aquifer affect surface-water resources and (2) whether water levels in this aquifer are declining.

The project included the following three objectives:

- Investigate the geologic and hydrogeologic characteristics of the lacustrine-till aquitard, because the aquitard affects the degree of hydrologic connection between the deep aquifer, the shallow aquifer, and surface-water resources. A companion report (Rose, 2018) describes a three-dimensional hydrogeologic model of the area.
- Identify possible sources and mechanisms of recharge and discharge in the deep alluvial aquifer.
- Analyze seasonal and long-term water-level trends in the deep alluvial aquifer.

To meet these objectives, the scope of the project included extensive data collection efforts. Fieldwork included several aquifer tests, monitoring water levels in wells across the study area, and an assessment of groundwater quality. These data were collected primarily from 2010 through 2012. We also relied on long-term records of groundwater levels dating from the mid-1990s, collected by the MBMG's Groundwater Monitoring Program (MBMG, 2022).

Location

The larger study area of this report extends across much of the Flathead Valley, a north–northwest-trending intermontane basin north of Flathead Lake (fig. 1). The valley encompasses nearly 200,000 acres (312 mi^2) and includes the communities of Kalispell, Evergreen, Bigfork, Columbia Falls, and Whitefish. The focus area of this work, where most of the data collection occurred, lies in the central and eastern two-thirds of the valley, an area of about 121,000 acres (189 mi^2; red outline in fig. 1). This focus area was chosen because of its high population density.

Climate

Annual total precipitation in the valley from 1896 to 2017 averaged 15.9 in. More recently, notable wet intervals occurred during the 1990s and 2010s, while dry years prevailed from 2000 to 2009 (fig. 2). Maximum and minimum annual precipitation totals were 25.2 in (1996) and 8.1 in (1949).

More precipitation falls in the mountains surrounding the valley floor than at lower elevations (table 1). Annual precipitation during 2011 was 16.2 in at the Glacier Park International Airport near Kalispell (DRI, 2022) in the valley bottom, at an elevation of 2,977 ft above mean sea level (ft amsl). In the Swan Range to the east, the Noisy Basin SNOTEL site (elevation 6,040 ft amsl) recorded 90.5 in of precipitation in 2011 (USDA, 2022b). To the west in the Salish Mountains, 31.2 in of precipitation was recorded in 2011 at the Blacktail Mountain SNOTEL site (elevation 5,650 ft amsl; table 1; USDA, 2022a).

Physiography

The Flathead Valley extends north from the shore of Flathead Lake and includes Whitefish and Columbia Falls (fig. 1). The Flathead, Stillwater, and Whitefish Rivers flow roughly from north to south through the length of the valley. Ashley Creek flows into the valley from the west. These streams merge near Ka-

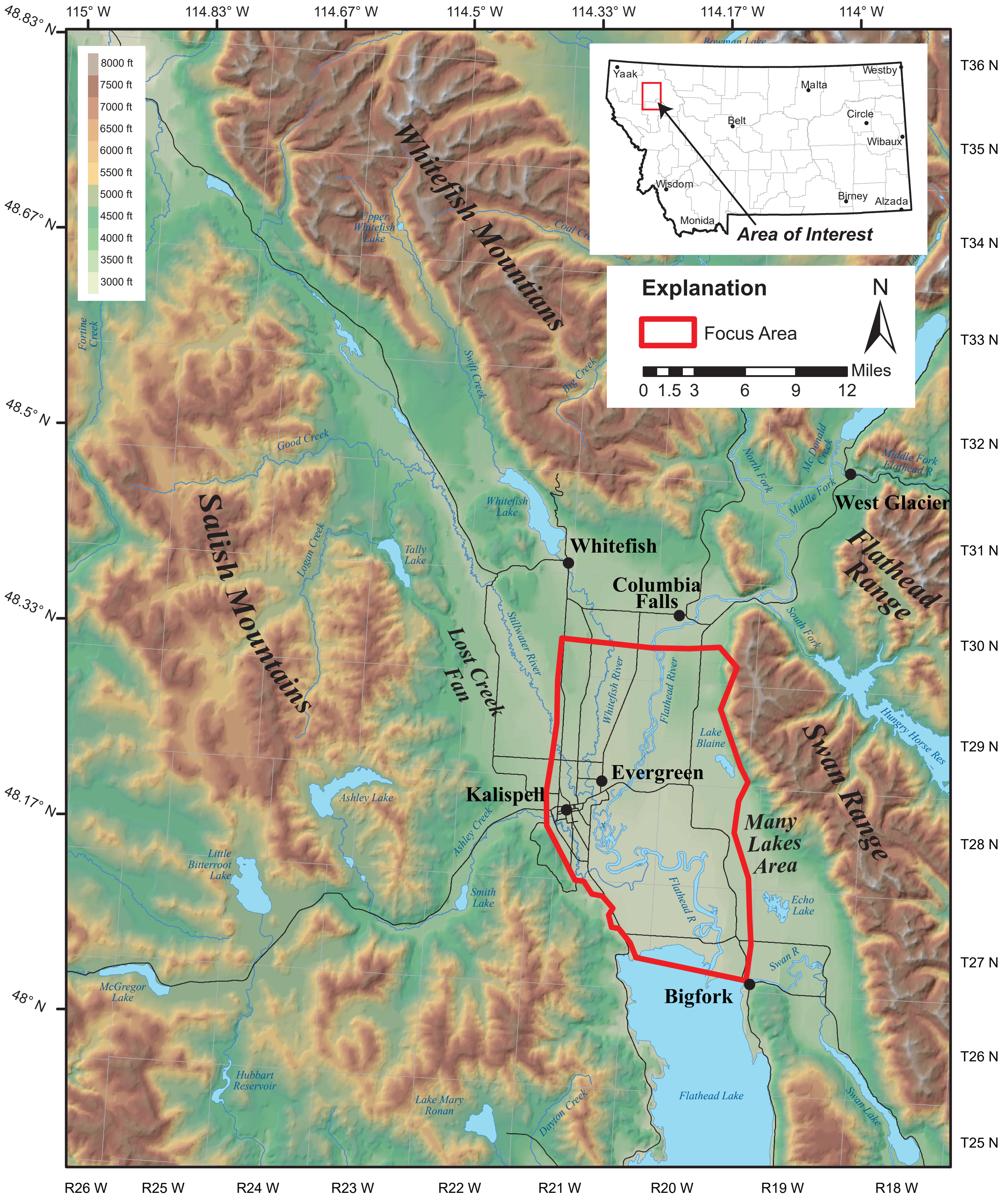

Figure 1. The study and focus area in northwest Montana.

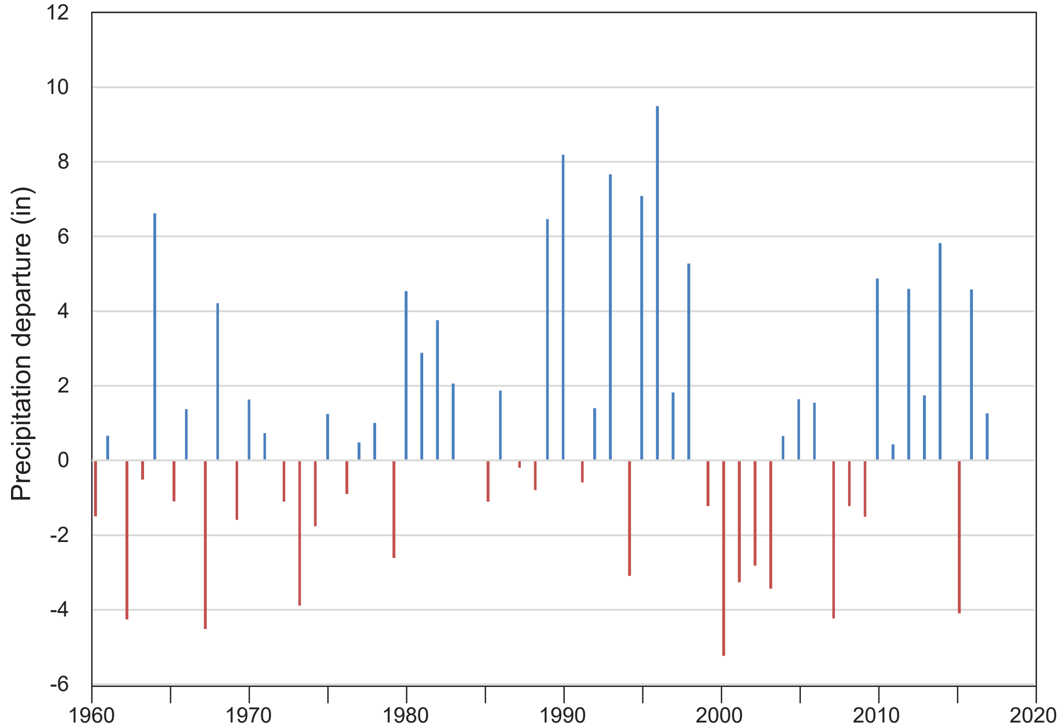

Figure 2. Annual departure from average precipitation at the Kalispell Glacier Airport (DRI, 2022). Average precipitation was based on records from 1896 to 2017.

lispell and flow into Flathead Lake near the town of Bigfork. The Swan River flows from the southeast and discharges to Flathead Lake at Bigfork. Lake levels are controlled by the operation of Seli'š Ksanka Qlispe' (Kerr) Dam near Polson.

The altitude of the valley floor ranges from about 2,900 ft above mean sea level (ft amsl), where the Flathead River enters Flathead Lake, to around 3,100 ft amsl around the valley edges (higher on terraces). Mountain ranges surround the valley on three sides: the Swan Range along the east, the Whitefish Range to the north, and the Salish Mountains to the west (fig. 1).

Previous Investigations

There have been several studies of the geologic and hydrogeologic conditions in the Flathead Valley. Alden (1953) provided the first geomorphic interpretation of the valley and provided insight into its geology. Witkind (1977) mapped major active faults and seismicity in and near Bigfork. Detailed surface geology and structure for the Kalispell 1 x 2 degree quadrangle were mapped by Harrison and others (1992). This map was rereleased in 2000 as a digital database (Harrison and others, 1992, 2000). Smith (2004) describes in great detail the subsurface geology, relationships of

Table 1. Monthly total inches of precipitation and estimated crop water use during 2011.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Noisy Basin SNOTEL Swan Range	16.4	8.5	9.4	14.9	9.1	11.6	2	0.4	1.7	7	5.6	3.9	90.5
Blacktail Mountain SNOTEL Salish Mountains	3.9	3.2	3.2	4	3	5.1	0.7	0.1	1.2	2.9	2.5	1.4	31.2
Kalispell Glacier Airport	2.39	1.16	1.12	1.84	1.85	3.16	0.69	0.47	0.47	1.86	0.42	0.74	16.17
Crop water use Creston AgriMet	0	0	0.02	0.5	2.3	3.5	6.7	5.6	2.4	0	0	0	21

Note. Noisy Basin, Swan Range (USDA, 2022b); Kalispell Glacier Airport (DRI, 2022); Blacktail Mountain, Salish Mountains (USDA, 2022a); Evapotranspiration Creston AgriMet (U.S. BOR, 2022b).

specific geologic features, and geologic timeline of the formation of the valley.

Konizeski and others (1968) described the hydrogeology of the Flathead Valley prior to widespread drilling and adoption of irrigation wells. Noble and Stanford (1986) described the unconfined aquifers in the valley in detail. Briar and others (1996) included the Flathead Valley in their map and discussed groundwater flow directions in the intermontane basins of the northern Rocky Mountains. In this broad regional overview, they briefly discussed decreasing permeability with depth in the unconsolidated sediments. Uthman and others (2000) described the subsurface geology and installed monitoring wells along a transect in the northern portion of the valley, some of which are still monitored.

MBMG hydrogeologists conducted a regional hydrogeologic characterization of the valley north and south of Flathead Lake. This study produced multiple publications about the area's hydrogeology and geology (LaFave, 2004a,b; Smith, 2004a–g; Smith and others, 2004a,b; Patton and others, 2003; McDonald and LaFave, 2004; Waren and Patton, 2007). Declining groundwater levels reported by LaFave and others (2004) spurred the research into the deep aquifer presented in this report.

Hydrostratigraphy

As part of this study, Rose (2018) published a three-dimensional model of the valley subsurface geology. That report presents descriptions of the geologic forces that formed the valley, the valley's erosional and depositional history, and the geologic setting (fig. 3) of the hydrogeologic systems. The hydrostratigraphy is summarized below.

The Flathead Valley is formed in a structural bedrock depression along the western flank of the Swan Range. Precambrian Belt Supergroup metasediments form the sides and basement floor of the valley. The basement floor dips from west to east (Smith, 2004b). The top of the Belt bedrock is as much as 1,500 ft below ground surface to the west and up to 3,000 ft below the surface to the east (Smith, 2004a; Konizeski and others, 1968; R.I. Gibson, oral commun., 2012). Gravity data show the top of the bedrock, in the lowest locations, is near sea level elevation (Smith, 2004a).

An unknown thickness of semi-consolidated Tertiary mudstone, sandstone, and conglomerate probably lies on top of the bedrock. This unit would likely be the Kishenehn Formation (Smith, 2004a). No wells drilled in the valley extend to Tertiary sediments, so interpretations are based on observations of this material in other locations. Smith (2004a) describes these sediments as stream-laid, basal, valley-fill units that lie directly above the Belt bedrock. Pleistocene glaciation within the Flathead Valley presumably removed some portion of this unit. Where present, the top of the Tertiary interval must be below the depth of the deepest wells on record in the valley (about 800 ft below the land surface).

The deep alluvial aquifer is likely composed of both alluvial and glaciofluvial material. This aquifer consists of a sequence of unconsolidated Pleistocene sand and gravel that lies on top of the Tertiary sediments (table 2). Likely deposited before and during glacial advances (Smith 2004d), the deep aquifer is largely composed of thick layers of coarse-grained sand and gravel with little fine material that is thought to be glacial outwash (Smith, 2004a). In most of the study area, an upper zone up to 100 ft thick at the top of the deep aquifer contains a higher proportion of silt and clay (Rose, 2018; figs. 4, 5).

The thickness of the deep aquifer is unknown because no wells have penetrated the base, and remote sensing methods, such as gravity measurements, cannot differentiate between Pleistocene and Tertiary alluvial deposits. Estimates of total thickness from previous work have ranged from greater than 364 ft (Konizeski and others, 1968) to greater than 460 ft (Smith, 2004c), to as much as 1,000 ft (Alden, 1953). The MBMG is investigating the thickness of the deep aquifer through the installation of a deep well in the southern Flathead Valley; this work will conclude in 2022 (Bobst and others, in review).

The lacustrine-till aquitard is formed by glacial till and lake deposits that overlie the deep aquifer. The lacustrine-till aquitard includes material from two depositional settings: till and lake sediments (fig. 4, table 2). While this unit is less permeable than the overlying and underlying deposits, it is heterogeneous and is not impermeable. This unit is up to 790 ft thick (Rose, 2018). Where the aquitard is not identified in well logs, it may have been removed by erosion (Smith, 2004a) or drillers may not have recognized and described it (Rose, 2018).

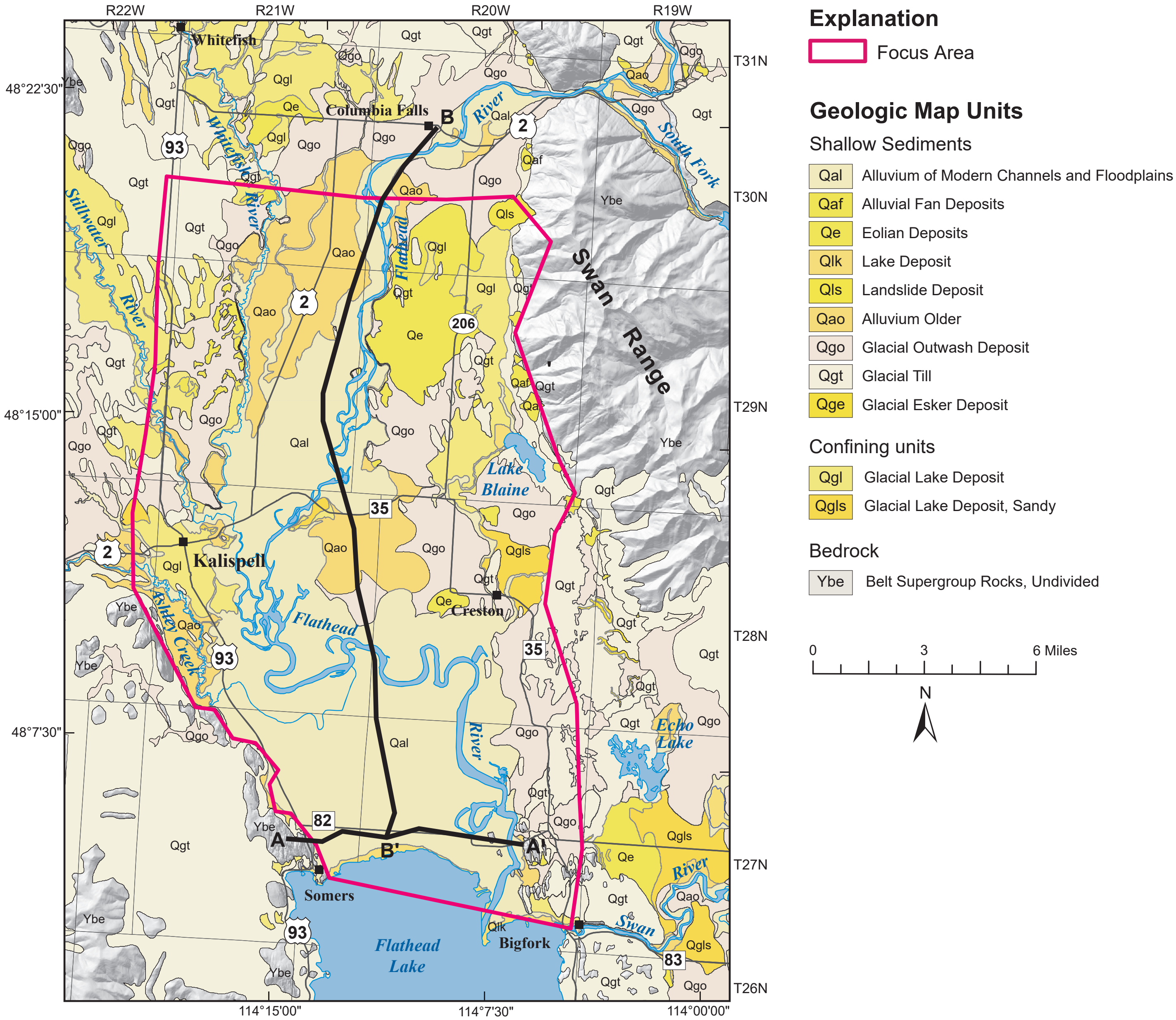

Figure 3. The surface geology of the study area is dominated by Quaternary glacial and alluvial deposits with pre-Cambrian Belt Supergroup rocks in the surrounding highlands (modified from Smith, 2004a). Black cross-section lines indicate locations of cross sections shown in figures 4 and 5.

The bottom of the lacustrine-till aquitard is identified almost everywhere in the focus area as a compacted and dense till, or lacustrine sediment where the till is absent. The till is composed of a mixture of boulder, gravel, sand, and silt compacted in a clay matrix. The till provides a clear lithologic contact at the change in depositional environments where the till overlies the coarse-grained sand and gravel of the deep alluvial aquifer (Rose, 2018).

During and after glacial retreat (late Wisconsinage), a lake filled the valley from Polson to Whitefish and Columbia Falls (Smith, 2004a). The lake receded as the moraine near Polson was eroded. Over time, a relatively thick and continuous layer of fine-grained lake sediments accumulated directly on top of the till in most of the valley. Water wells drilled throughout the valley show an interval of dominantly fine-grained lake-deposited material, described as tan, yellow, light brown or gray silt, or silt with clay.

A number of north–south-trending deep troughs were carved through the till into the surface of the deep sand and gravel (Rose, 2018; Smith, 2004a). The troughs are up to about 1 mi wide and 3 to 4 mi long. In places, the deep portions of the troughs contain alluvial deposits of silt, sand, and gravel. Fine-grained silt and clay lacustrine deposits from ancestral Flat-

Table 2. Hydrostratigraphic units.

Age	Hydrostratigraphic Unit	Geologic Unit	Unit Thickness (ft)	Material Description	Aquifer Character
Quaternary (Holocene–present)	Shallow aquifers	Surficial deposits	0–200	fluvial alluvium and delta sediments of gravel, sand, silt and clay	Shallow aquifers, well yield average 30 gpm
Quaternary (Pleistocene–Holocene)	Lacustrine-till aquitard	Lacustrine deposits	<10–790	Ancestral Flathead Lake deposits of silt and clay	Aquitard that separates shallow and deep groundwater systems and controls recharge confines pressure in the deep aquifer
		Till		Sand and gravel embedded in clay	
Quaternary (Pleistocene)	Deep alluvial aquifer	Deep alluvium	~ 1,000–1,500	Glaciofluvial material: outwash, clean, coarse gravel, and sand with occasional silt or clay-rich intervals near top	Confined unconsolidated aquifer, on record well yields reach 100s of gpm, max 3,500 gpm. Lower yield zone near top in some areas.
Tertiary	Tertiary Sediments	Tertiary sediments	~ 1,500	Preglacial fluvial deposits of semi-consolidated, fine-grained, silty-sand, sand and gravel, shale, and conglomerate	Unknown in the valley
Precambrian	Bedrock aquifer	Belt Supergroup bedrock		Medisedimentary deposits of argillite, siltite, mudstone, marble, dolomite, and some igneous rocks	Flow in fractures, lower yields to wells averages 30 gpm

Note. Modified from Rose (2018) and Smith, 2004d.

head Lake overlie these alluvial sediments and fill most of the troughs. The troughs are considered a part of the lacustrine-till aquitard because of this fine-grained fill material. The bottom surface of the confining unit is at a much lower elevation at the troughs.

Holocene alluvium lies on top of the lacustrine-till aquitard in the valley (Smith, 2004e,f). This shallow alluvium consists of terrace sand and gravels, modern river channel sand and gravels, and river delta sediments (fig. 3). Holocene alluvium and delta sediments form the majority of the surficial deposits in the Flathead Valley (Smith, 2004b). The river alluvium is composed of sand and gravel, and in some areas contains silt and clay. Modern river alluvium north of Kalispell is generally less than 50 ft thick and, in many places, is less than 20 ft. Where these unconsolidated sediments are saturated they form shallow aquifers such as the Evergreen Aquifer north of Kalispell and between the Flathead and the Whitefish Rivers (Noble and Stanford, 1986).

The Flathead River deposited sediments into ancestral Flathead Lake and formed a delta that filled the northernmost area of the lake. The formation of the delta effectively moved the north shoreline from near Kalispell to its present location. Well logs report the delta sediment as medium- to fine-grained sand and gravel with varying amounts of silt or clay. This material can be up to 200 ft thick; although it contains abundant fine-grained sediment, it is permeable enough in many locations to yield water to wells. These sands and gravels form several discontinuous shallow aquifers in the valley. In some areas the water quality in these units is poor (Konizeski and others, 1968).

Groundwater Use

The quantity of groundwater withdrawn from the deep alluvial aquifer was estimated for this study from water-rights records maintained by the Montana State Library (MSL, 2013). Groundwater rights in the focus area totaled 5,951 acre-ft per year (acre-ft/yr) in 1960 (table 3). By 2017, groundwater rights increased to 69,284 acre-ft/yr, of which 42,820 acre-ft/yr identified the source as the deep alluvial aquifer. Annual maximum allowable diversion volumes are listed for

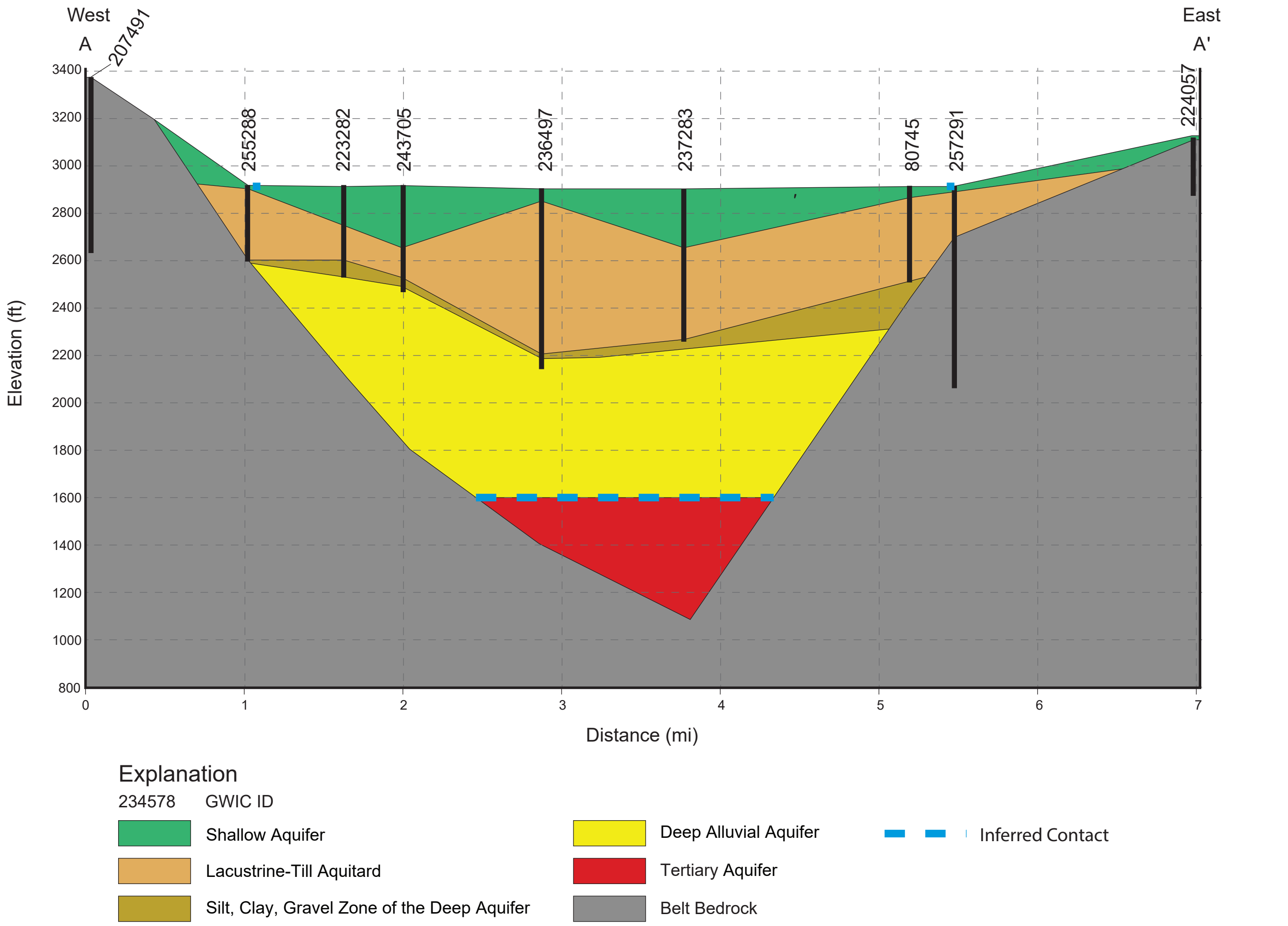

Figure 4. The Flathead Valley conceptual hydrogeologic model includes Belt Supergroup as the bedrock valley bottom (based on geophysical interpretations), Tertiary sediments, deep alluvial aquifer, and lacustrine-till aquitard (Rose, 2018). Black vertical lines represent wells identified by their GWIC ID number. Cross section location shown in figure 3.

2,120 of the 2,710 water rights associated with the deep aquifer. The annual individual diversions of these groundwater rights ranged from 0.03 acre-ft/yr to 4,344 acre-ft/yr and averaged 20 acre-ft/yr. The listed diversion rates ranged up to 3,000 gpm and averaged approximately 40 gpm.

Groundwater use, as represented by water-rights records, has changed over the past half century. Based on water allocations, municipal water and fisheries were the largest categories in 1960 (table 3). From 1960 to 2017, the largest increases in both percent and volume of diversion were in municipal and irrigation categories (table 3, fig. 6).

The rate of well installations each year began increasing in the early 1970s (fig. 7). Several factors contributed to this increase in demand for groundwater: the availability of modern and more efficient water-well drilling methods and pumps; population growth; economic development; and changes in irrigation methods and crop types. The rate of water-well drilling declined slightly beginning in 2008.

Not all water pumped from the deep aquifer leaves the valley hydrologic system; however, little of the pumped water is expected to return to the deep aquifer. Water applied to irrigated fields and lawns that is evapotranspired is lost to the atmosphere. However, irrigation application in excess of evapotranspiration either recharges the shallow aquifer or discharges to surface water. Similarly, much of the water diverted from the deep aquifer for in-home uses returns to shallow aquifers via septic and treatment systems.

METHODS

Data Management

Monitoring sites are listed in appendix A. All water-level and water-quality data are hosted on the MBMG Ground Water Information Center (GWIC) database (MBMG, 2022).

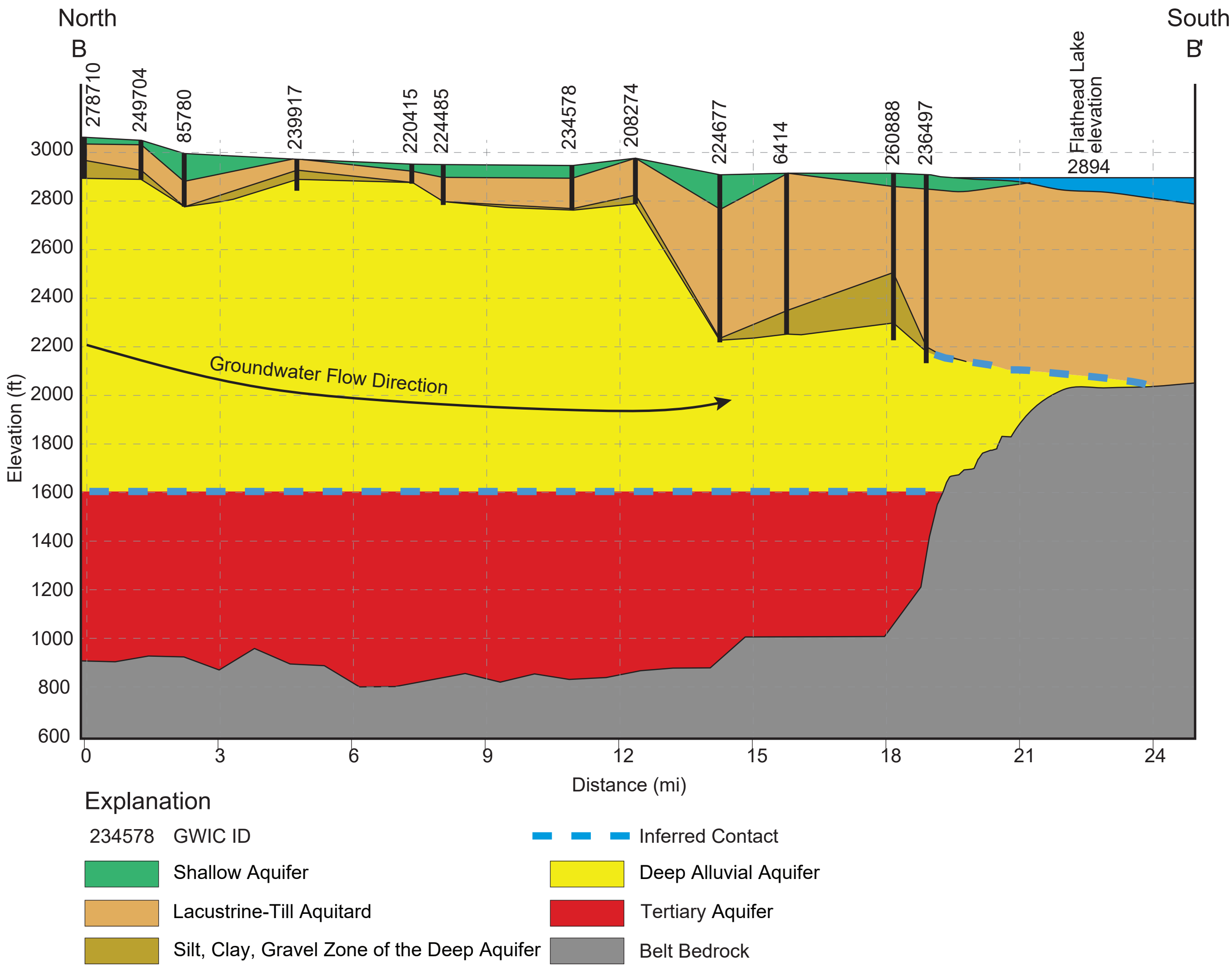

Figure 5. The deep alluvial aquifer in the Flathead Valley presumably thins from north to south, toward the shore of Flathead Lake as the confining unit thickens (Rose, 2018). Cross section location shown in figure 3.

Table 3. Groundwater rights in focus area (acre-ft/yr).

Use	1960 Annual Maximum Diversion All Groundwater Sources	2017 Annual Maximum Diversion All Groundwater Sources	2017 Annual Maximum Diversion Deep Alluvial Aquifer
Fire Protection		6	6
Other Purpose		58	12
Recreation		168	13
Industrial	230	2,304	466
Commercial	420	3,192	538
Institutional	785	837	797
Fishery	959	2,213	1,056
Stock	57	1,774	1,119
Multiple Domestic	338	2,702	1,739
Lawn and Garden	100	3,653	2,517
Geothermal		3,689	3,288
Domestic	556	6,598	4,046
Irrigation	140	18,057	11,940
Municipal	2,366	24,033	15,282
TOTAL	**5,951**	**69,284**	**42,820**

Note. Data source Montana State Library (2022).

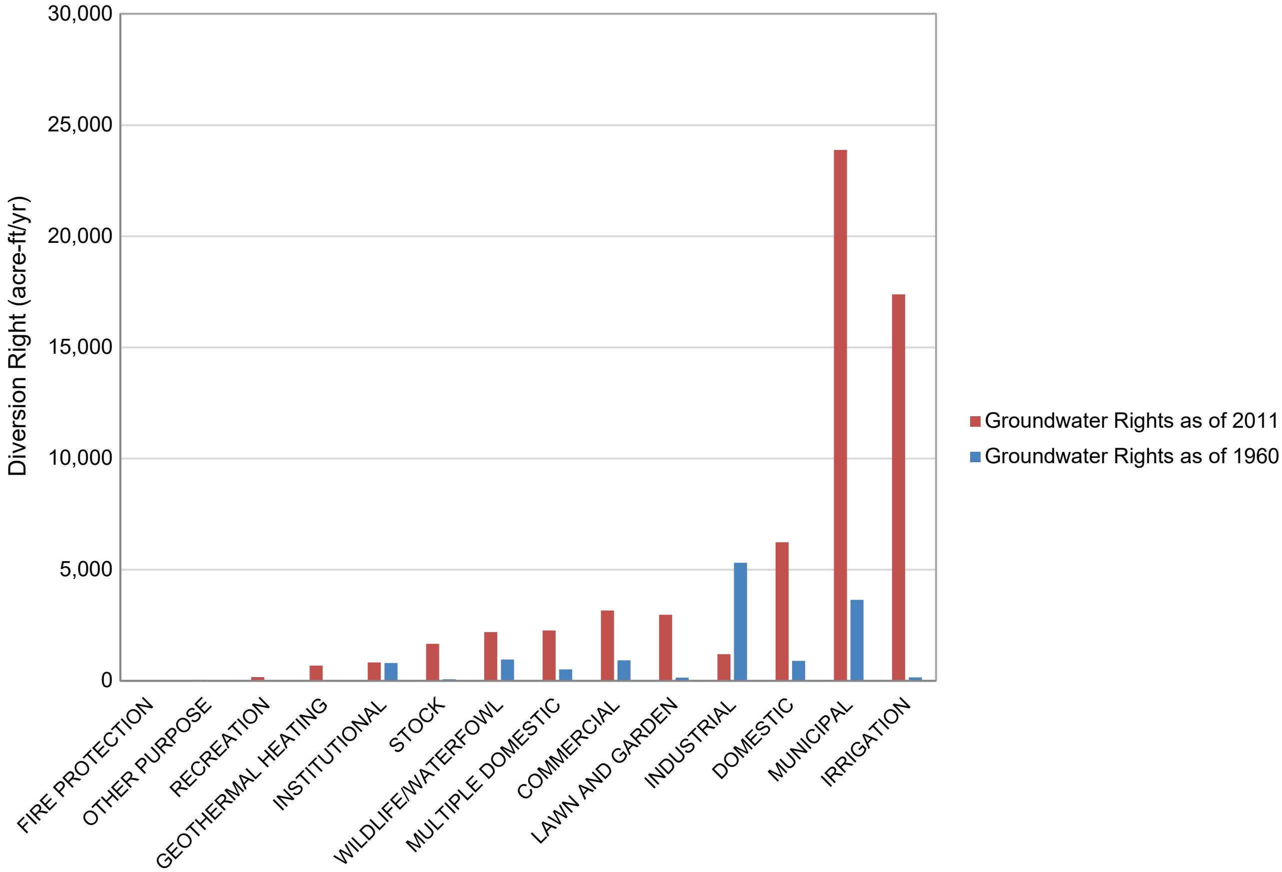

Figure 6. The volume of allowable annual groundwater diversions from all aquifers by water-use category within the focus area, in acre-feet per year for 1960 and for 2017, based on water-rights records. Data source: Montana State Library (2022).

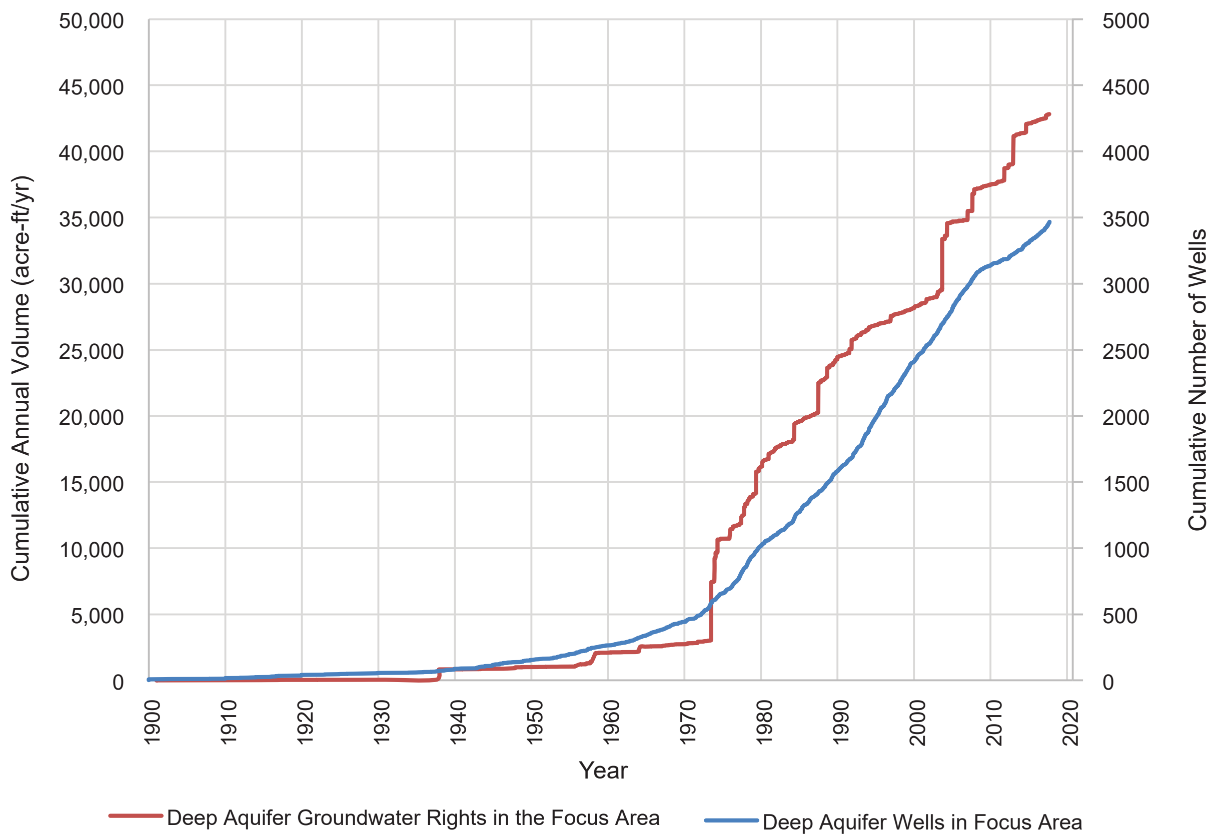

Figure 7. Within the focus area, the number of wells and the cumulative annual volume of groundwater rights from the deep alluvial aquifer increased sharply in the mid-1970s. About 60 percent of all groundwater rights in the study area are drawn from the deep alluvial aquifer. Data source: Montana State Library (2022).

Groundwater and Surface-Water Monitoring

Most data presented in this report were collected from 2010 to 2012. The primary year for monitoring was 2011. Water levels were measured in 88 wells (fig. 8, appendix A). Surface-water stage and discharge were monitored at 3 sites, and one-time site visits were made to 10 sites during 2010 through 2014 (fig. 8, appendix A). Well locations and elevations were surveyed by a licensed professional land surveyor. In addition to these data, we compiled historical records of groundwater levels collected by the MBMG's Ground Water Monitoring Program that are stored in GWIC.

Aquifer Characteristics

Constant discharge aquifer tests were conducted at two sites (pumping wells were 260892 and 82279) to provide site-specific evaluations of transmissivity and storativity. Aquifer test data for wells 260892 and 82279 are available on GWIC (MBMG, 2022). For details on aquifer test analysis for wells 260892 and 82279, see Bobst and others (in review) and Myse and others (in review), respectively.

At well 260892, a 168-h, constant discharge aquifer test and subsequent recovery test were performed by pumping from a well completed in the deep aquifer. The well was pumped at an average rate of 485 gpm. Groundwater-level responses were monitored in six deep aquifer wells located from 55 to 11,400 ft from the pumping well, five shallow aquifer wells located from 17 ft to 8,480 ft, and one well completed in the confining unit 35 ft from the pumping well. A single-well slug test of the lacustrine-till aquitard was conducted at this well (260889), the only known hydraulic test of the lacustrine-till aquitard in the Flathead Valley.

Well 82279 was pumped at an average rate of 538 gpm for 49 h. Groundwater responses were monitored in five wells completed in the deep alluvial aquifer at distances of 40 ft to 2,500 ft from the pumping well, and one well completed in the shallow aquifer located 24 ft from the pumping well.

Aquifer tests have been performed for water-right permitting and for previous research in the valley. During this study, we compiled and utilized results from the available aquifer tests in the area (MT DNRC file data; appendix B).

Groundwater-Level Trends

Long-term and seasonal trends in groundwater levels were assessed for the period 1996 through 2017 and for the year 2011, respectively. We analyzed long-term groundwater-level trends with the non-parametric seasonal Mann–Kendall method (Helsel and Hirsch, 1992). Our null hypothesis was that there were no water-level trends during the period of analysis. A statistically significant trend (increasing or decreasing) is detected when the null hypothesis can be rejected with 95 percent or greater certainty (i.e., $\alpha = 0.05$; p-value <0.05). This approach has an advantage over simple linear regression because it does not require a normal distribution and is less sensitive to outliers. For records with a significant increasing or decreasing trend, the magnitude of that trend was determined using the Sen (a.k.a. Theil or Theil–Sen) slope, the median of all the pairwise slopes between observations. The pairwise slope is the change in depth to water divided by the time between successive measurements (Helsel and Hirsch, 1992).

The influence of pumping water levels was reduced from the long-term data sets by selecting the highest water level recorded during each month. The water level measured on the day nearest the middle of each quarter of every year was selected from this monthly data set. These quarterly measurements were then used as inputs for the Mann–Kendall test to evaluate statistically significant trends in water levels.

Monthly precipitation totals from the Glacier Park International Airport at Kalispell (DRI, 2022) were converted to Standardized Precipitation Index (SPI) values (Svoboda and others, 2012; Heim, 2002). The SPI values were calculated on 24-mo durations and plotted on either 3-mo or 12-mo intervals, depending on the duration of the hydrograph at each well. The Mann–Kendall method was applied to the SPI data set to recognize long-term increasing or decreasing trends in the precipitation record that might be reflected in hydrographs. The SPI data were also plotted with the hydrographs to identify changes in water levels that might relate to climate.

Components of Deep Aquifer Flow

To quantify components of flow into and out of the deep alluvial aquifer, we estimated vertical leakage across the lacustrine-till aquitard and pumping withdrawals from the deep aquifer in the focus area. A

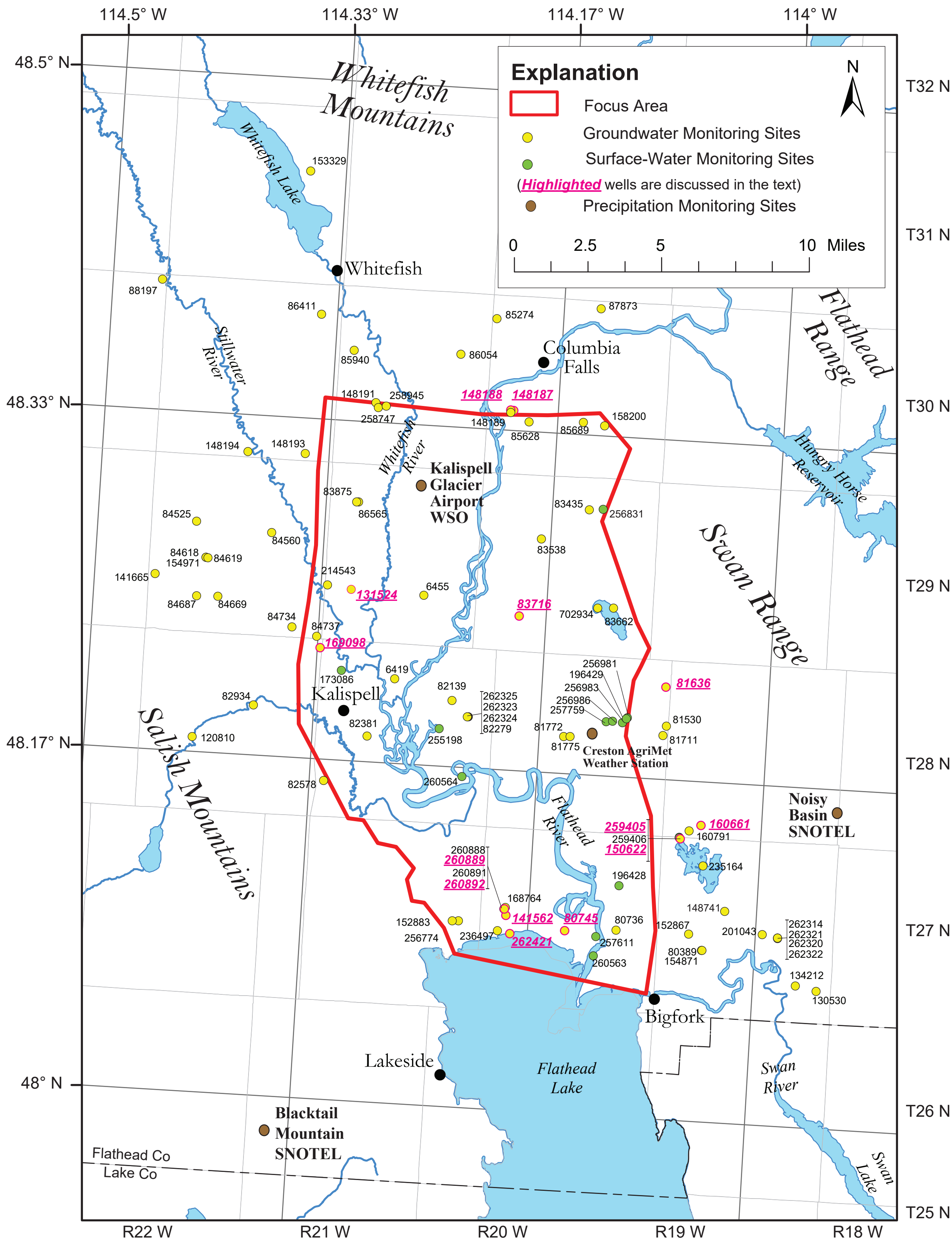

Figure 8. Data were collected at groundwater and surface-water monitoring sites across and outside the focus area.

large amount of uncertainty associated with the thickness, and therefore transmissivity, of the deep aquifer affected estimates of other components of the groundwater budget. Neither inflow to the focus area (including mountain front recharge) nor groundwater outflow toward the south could be approximated with a reasonable degree of confidence.

Vertical Seepage through the Aquitard

Downward vertical seepage of groundwater through the lacustrine-till aquitard occurs where the hydraulic head in the shallow aquifer exceeds that in the deep aquifer. Upward vertical seepage occurs where the hydraulic head of the deep aquifer exceeds that of the shallow aquifer.

Vertical seepage (V) through the lacustrine-till aquitard was estimated using Darcy's Law (eq. 1).

$$V = KiA, \qquad \text{(eq. 1)}$$

where V is volumetric seepage (ft^3/d); K is hydraulic conductivity (ft/d); i is hydraulic gradient, change in head over distance (ft/ft; dimensionless), negative value indicates an upward gradient; and A is cross-section area perpendicular to groundwater flow (ft^2).

Pumping Withdrawals

Groundwater used from the deep alluvial aquifer in the focus area was divided into the following categories: irrigation, public water supplies, self-supplied domestic and multi-family domestic indoor water use, self-supplied institutional/commercial/industrial, stock water, and fisheries. Data specific to the year 2011 were preferred. Where those data were not available, we used the best available information. For example, water rights were used to approximate pumping volumes as described below, though they are not specific to a year. Population from the 2010 census was used to estimate domestic withdrawals.

<u>Irrigation use.</u> There is no consolidated recordkeeping or reporting on groundwater use for agricultural irrigation in Montana. Minimum, mid-range, and maximum estimates of irrigation pumping were arrived at as follows:

1. The minimum is based on estimated evapotranspiration and the number of irrigated acres;
2. The mid-range includes the volume of water rights for irrigation allocated outside of irrigated areas identified in (1) above, plus the minimum estimate;
3. The maximum includes drillers' well logs that specify irrigation use at wells that were not accounted for in (1) or (2) above, plus the mid-range estimate.

We compiled information on the irrigation method used at individual fields from Montana Department of Revenue, Final Land Unit Classifications (FLU) data (MT DOR, 2015). The source of water at each field was assigned using the FLU data and satellite imagery. We assumed that surface water was used where fields were serviced by a ditch, flood irrigated, or had sprinkler or pivots serviced by a ditch. Groundwater use was assumed at all other fields. Pumping was assigned to the shallow or deep aquifer based on the site geology and hydrogeology as described by Rose (2018), MBMG Ground Water Assessment Atlas maps (LaFave, 2004a; Smith, 2004b,d), or based on well logs.

1. Minimum Estimate of Irrigation Pumping

We calculated irrigation pumping rates from the deep aquifer for 2011 based on daily crop water requirements and adjusted for application system efficiencies. Irrigated land areas were provided by the Montana Department of Natural Resources and Conservation (MT DNRC; Water Rights Bureau, file data). We compared individual fields to water-well and water-rights records to identify fields that are likely irrigated from the deep aquifer. The area of each irrigated field was estimated using polygons created in GIS to outline fields identified in satellite images. The Creston AgriMet station (U.S. BOR, 2022a,b) lists water requirements for multiple crop types for the focus area and archives precipitation records. The average evapotranspiration for all crop types during the 2011 growing season was 1.7 ft per year. Precipitation totaled 0.9 ft over that period, resulting in a net irrigation requirement of 0.8 ft.

Different irrigation systems have different efficiencies (the ratio of consumptive water use by plants to the total water applied). We identified the type of irrigation system used for each field from satellite imagery. To allow for application efficiencies, the net estimated irrigation requirement of 0.8 ft was multiplied by a factor of 2 for flood irrigation, 1.43 for sprinkler application, and 1.18 for pivot systems. The average of these values, 1.54, was used for fields where the application method was unknown. These multipliers were based on the Administrative Rules of Montana (ARM, 2022).

2. Mid-Range Estimate of Irrigation Pumping

We attained water-rights records from the MT DNRC database (MT DNRC, 2022). Groundwater rights in the focus area that were not clearly associated with the irrigated fields identified above were assigned to the shallow or deep aquifer, as described above. The mid-range estimate is the sum of the evapotranspiration-based estimate of pumping withdrawal and the water-rights withdrawals for parcels identified as points of use in the water rights, but not included in the evapotranspiration-based estimate.

3. Maximum Estimate of Irrigation Pumping

We compared well logs that specify irrigation water use to the evapotranspiration data and the groundwater-rights map developed in (1) and (2) above. Records for irrigation wells that were not clearly associated with either were added to the irrigation pumping estimate. Pumping rates for these wells were based on the reported well yield and a 4-mo irrigation season. This value was added to the mid-range value to arrive at a maximum estimate of deep aquifer pumping for irrigation.

Public water systems. Public water systems (PWS) in the focus area were identified from records at the Montana Department of Environmental Quality (MT DEQ, 2022) and the U.S. Environmental Protection Agency Safe Drinking Water Initiative (U.S. EPA, 2022).

Two public systems, Bigfork and Kalispell, provided their pumping rates and population served for 2011. The per capita withdrawal rate for Bigfork PWS, without industry, was applied to the reported population served by all public water systems in the focus area. A list of all PWS was retrieved from the Montana State Library (MSL, 2013).

Public water systems draw from four potential water sources in the valley: surface water, shallow alluvial aquifers, the deep alluvial aquifer, or the bedrock aquifer. We were able to determine the source aquifer for approximately half of the PWS that rely on groundwater in the focus area, based on GWIC records, well locations, and the geologic model of Rose (2018). We assumed that pumping from the deep aquifer was 99 percent of the total PWS pumping, based on the available PWS well construction records. The maximum public water supply withdrawal rate was set at the total groundwater rights allocated to each PWS. The mid-range estimate was approximately half the amount allocated in water rights. The minimum estimate of PWS was based on a per capita rate of 158 gallons per day for the population served by PWS.

Self-supplied single and multi-family domestic. We estimated groundwater pumping for self-supplied domestic indoor and for self-supplied outdoor water use and present these estimates as a combined value. Per capita indoor usage was based on the Bigfork PWS pumping rates during non-irrigation months of 2011. Bigfork has little industry and the per-capita pumping rate during the winter is a reasonable proxy for self-supplied indoor water use. This value is different than the per capita value estimated for other PWS because most PWS serve both commercial and residential users. The population that relies on private wells was determined by subtracting the number of people served by PWS from the total population.

Domestic lawn and garden. To estimate deep aquifer withdrawals for lawn and garden watering from self-supplied domestic wells, we analyzed a random selection of 189 wells from the 2,650 deep aquifer domestic well records. Wells were spatially located and, using LandSat images, green areas on the property were assumed to be watered. Of the 189 wells, watered areas ranged from 0 to 5 acres, with a mean of 0.48 acres. This value was multiplied by the total number of domestic wells completed in the deep aquifer for the total area watered. The water consumption derived from AgriMet data for the Creston station (U.S. BOR, 2022a,b) for lawns was 25 in per year, or approximately 1 acre-ft/yr per well. This served as the mid-range estimate for domestic outdoor water use. Maximum rate was based on evapotranspiration estimate of 2 acre-ft/yr.

The total water-rights allocations for single and multiple-family domestic exceeded the estimated consumption rate. The water-rights allocation served as a maximum estimate of domestic and multi-family domestic indoor and outdoor water use. We did not estimate a minimum amount of self-supplied domestic water use.

Self-supplied commercial and industrial. In this report, water rights include commercial, fire protection, fisheries, parks, geothermal, industrial, institutional, and pollution abatement. Estimated self-supplied commercial and industrial withdrawal rates were based on groundwater rights from the MT DNRC database (MT DNRC, 2022).

The total of all annual water-rights allotments provided a maximum withdrawal rate. A reasonable mid-range estimate accounted for water rights that are not fully utilized by using half of the maximum. We made no attempt to estimate the minimum.

Stock water. We estimated the minimum withdrawal rates for livestock within the focus area based on animal consumption reports. Countywide livestock counts and daily water requirements for individual animals came from the 2012 Montana Agricultural Statistics report (MT DOA, 2012). The water requirements for each type of livestock were multiplied by the head counts to estimate total annual water requirements and pumping rates. The animal units for the focus area were estimated as a percent of head counts in Flathead County. This percent was the ratio of agricultural land within the area to that for the county, based on Final Land Unit classifications from the Montana Department of Revenue (MT DOA, 2012). Some reported agricultural land classifications were not used because they include urban areas, parking lots, and airports. Animal unit daily consumption was taken from the Clark Fork and Kootenai River Basins Water Plan 2014 (MT DNRC, 2014). The water source for livestock was split between surface water (68 percent) and groundwater (32 percent; Cannon and Johnson, 2004). Groundwater supplies were assigned to the deep or shallow aquifer based on the ratio of deep and shallow aquifer wells (55 percent deep, 45 percent shallow).

The estimated maximum livestock withdrawal was based on the total water rights on record in the focus area that were interpreted to come from the deep aquifer. The mid-range estimate was set at the mid-point between the minimum and maximum estimates.

Groundwater and Surface-Water Chemistry

Water chemistry was evaluated to help identify possible sources of groundwater recharge and flow paths to the deep aquifer. Water-quality samples collected during this and previous studies (e.g., Smith and others, 2004b) were included in the analyses (fig. 9). Between 1983 and 2013, 190 samples for inorganic constituents were collected from 156 wells, seven springs, one pond, and five streams in the Flathead Valley. This project sampled 35 sites for tritium analysis: five springs, one stream, and 29 groundwater sites.

Groundwater-quality samples were collected after purging wells of a minimum of three-casing volumes and waiting for measured field parameters to stabilize. Samples from private wells were collected from dedicated, in situ pumps; samples from monitoring wells were collected from sampling pumps. Two methods were used to sample surface water; sample collection method is documented for each sample in the GWIC database. These included collecting grab samples or by depth and width integrating the stream channel, depending upon the size of the stream. Samples for inorganic constituents, isotopes, noble gases, and organic waste/endocrine analyses were collected, preserved, and stored according to protocols suggested by each laboratory (see below). Field parameters [specific conductance (SC), temperature, and pH] were measured using handheld field meters. Meters and probes were calibrated daily according to manufacturer's recommendations.

Inorganic analyses, including nutrients (nitrate and phosphorus), were performed by the MBMG Analytical Laboratory in Butte, Montana. Tritium analyses were conducted by the University of Utah Dissolved and Noble Gas lab. Samples for organic waste/endocrine analyses were collected by a single technician who wore a Tyvek suit, single-use powderless gloves, and avoided any sunscreen, perfumed skin products, bug spray, and any compounds that might be detected in the sample. Analyses were done by Columbia Analytical Services in Kelso, Washington. Quality assurance for organic wastewater sampling included a triplicate sample (three identical sample bottles filled in succession) and a field blank using deionized water provided by the MBMG Analytical Lab.

RESULTS AND DISCUSSION

Aquifer Physical Characteristics

This section presents the hydrostratigraphic interpretation for the focus area along with estimates of hydraulic parameters, including hydraulic conductivity and storage. Table 2 lists the sequence of hydrogeologic units. Transmissivity values are summarized in table 4. Appendix B contains a summary of aquifer

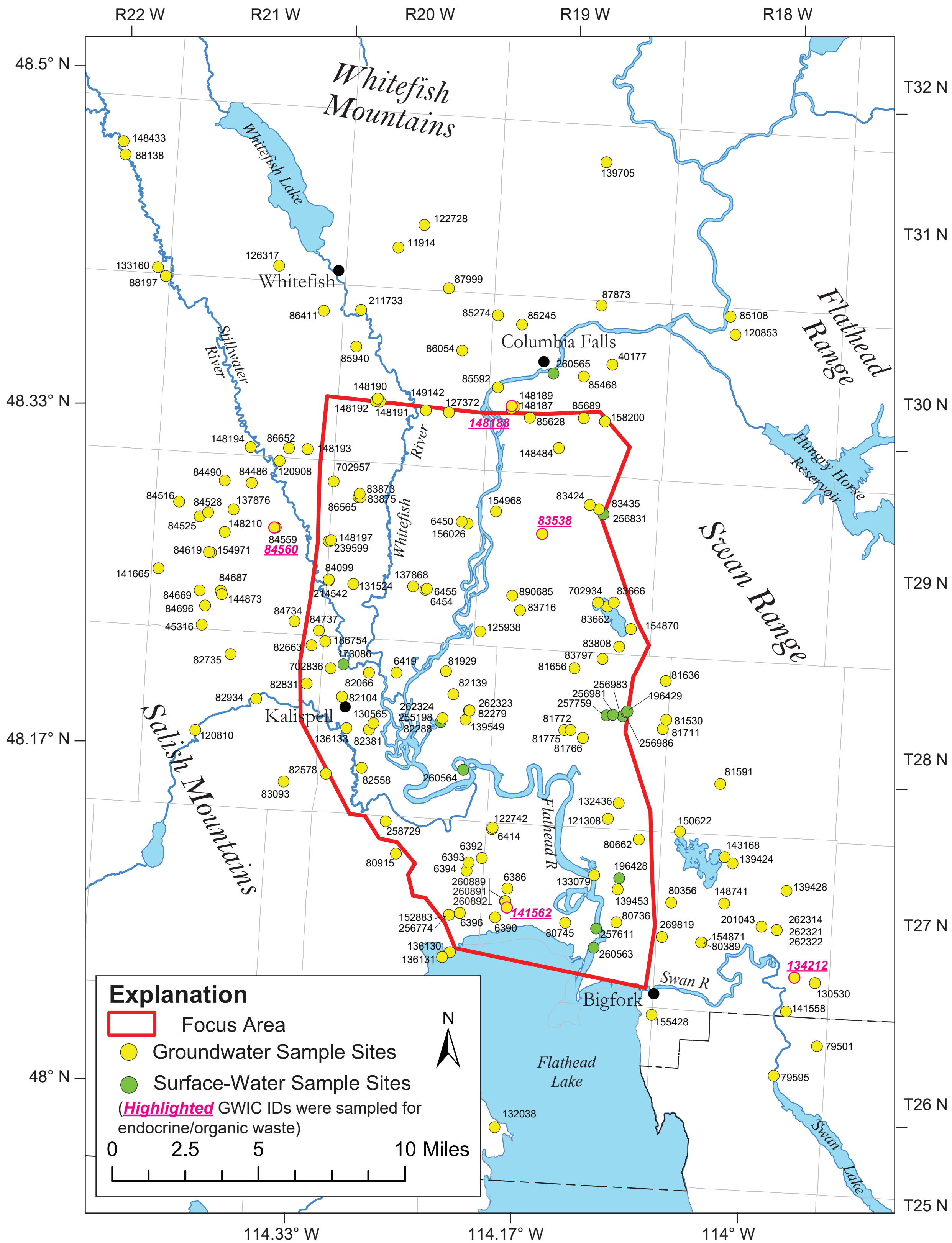

Figure 9. Water-quality samples were collected at groundwater and surface-water monitoring sites across and outside the focus area.

Table 4. Transmissivity summary statistics for focus area aquifers.

Transmissivity	Shallow Alluvial Aquifer	Confining Unit	Deep Alluvial Aquifer	Bedrock
Maximum (ft^2/day)	174,200	0.2	98,172	13,480
Geometric mean (ft^2/day)	3,174	0.2	4,622	628
Minimum (ft^2/day)	1	0.2	36	29
Number of tests	8	1	117	9

Note. See appendix B for aquifer test details and references.

test results. Transmissivity typically has a log-normal distribution within any specific aquifer and is described with the minimum, maximum, and geometric mean (Neuman, 1982). The arithmetic mean, and minimum and maximum values, characterize the range in storativity.

Bedrock Aquifer

Metasedimentary units of the Belt Supergroup have very low primary porosity and hydraulic conductivity. Water movement through and water production from the bedrock aquifer occurs through fractures formed by faulting and weathering.

GWIC records show the 237 reported bedrock wells in the focus area have a median depth of 215 ft, with a range of 21 to 1,026 ft. Reported well yields range from 0 to 600 gpm, with a median value of 25 gpm. We compiled results of nine tests of the bedrock aquifer from the area (appendix B), with transmissivity values ranging from 29 to 13,480 ft^2/d and a geometric mean of 628 ft^2/d. Storativity ranged from 9 x 10^{-5} to 8.7 x 10^{-3}, with a mean of 3 x 10^{-3}. The range of values suggests that the fractures are not evenly distributed across the aquifer, or that the connectivity of fracture networks varies widely.

Deep Alluvial Aquifer

The deep alluvial aquifer, which underlies nearly all of the Flathead Valley, is the area's most utilized aquifer. It is assumed to lie on top of Tertiary sediments in most of the valley and directly on Belt bedrock near the valley margins. The aquifer is composed of unconsolidated, coarse-grained sand and gravel, and displays confined characteristics in most of the valley. The aquifer is more than 500 ft thick in the center of the valley, but its total thickness is unknown because wells only penetrate its full thickness where it is thin near the valley margins. Because the aquifer is highly transmissive, desired well yields can be achieved with partial penetration.

Based on subsurface mapping and modeling, the top surface of the deep aquifer appears to be undulating and eroded by numerous streams when the sand and gravel layers were exposed at the land surface (Rose, 2018). The top surface generally dips to the south at an average slope of about 19 ft per mile. The depth to the top of the deep aquifer ranges from less than 100 ft below the land surface to 790 ft beneath the trough-cut features.

In some areas, the lithology near the top of the deep aquifer is silt and clay-rich coarse-grained sand and gravel and is referred to as the silt, clay, gravel zone by Rose (2018). Due to the higher percentage of silt and clay, wells completed in this part of the deep aquifer are less productive than those in deeper sections. Although not present across the entire valley, the silt and clay-rich interval ranges up to 100 ft in thickness (Rose, 2018). Though lithologically distinct, the upper silt, clay, and gravel zone and the underlying coarse-grained sediment form a single, heterogeneous aquifer. The material reported in well logs from about 100 ft to 400 ft below the top of the deep aquifer is similar throughout the valley, with only minor variations in sand and gravel ratios and silt or clay content.

Records indicate that 3,276 wells are completed in the deep aquifer within the focus area. Their depths range from about 100 ft up to 840 ft, with a median depth of 206 ft. The median reported well yield is 30 gpm with a minimum of less than 10 gpm and a maximum of 3,500 gpm (MBMG, 2021).

Transmissivity values reported from 117 aquifer tests conducted in the deep aquifer ranged from 36 to 98,172 ft²/d (table 4, appendix B). The geometric mean was 4,622 ft²/d. Storativity values from 72 aquifer tests that included an observation well ranged from 10^{-6} to 0.39 and averaged 0.014. These storativity values suggest that while the deep alluvial aquifer is typically confined, there may be some leaky confined or unconfined conditions in some locations. The spatial distribution of transmissivity from deep aquifer tests is shown in figure 10.

This study included two aquifer tests of the deep alluvial aquifer (appendix B, figs. B-1, B-2). Pumping

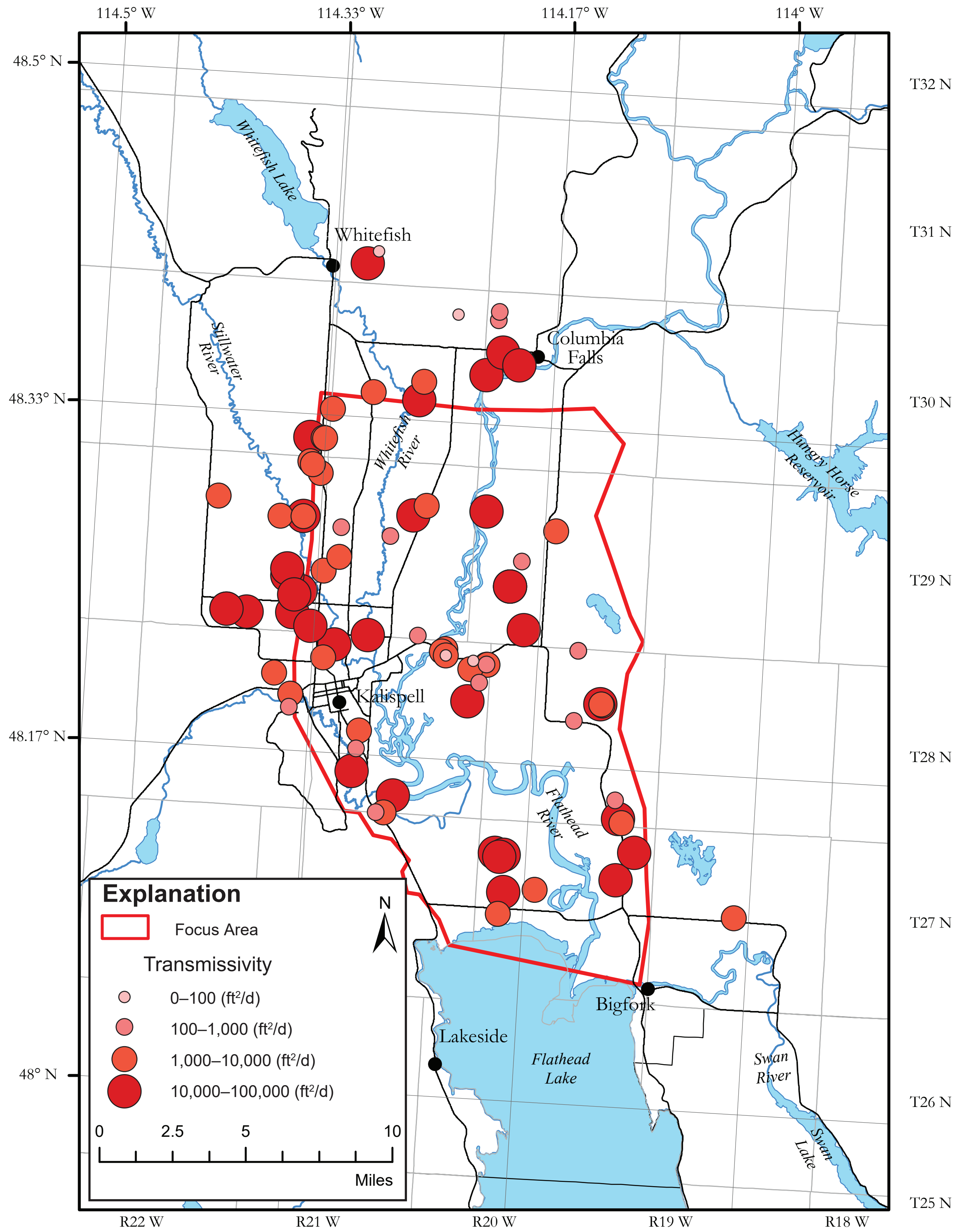

Figure 10. Distribution of transmissivity estimated from tests of the deep aquifer does not show spatial trends.

wells for the aquifer tests were well 260892, near the north shore of Flathead Lake, and well 82279, near the middle of the valley.

The maximum drawdown during the 168-h pumping test at well 260892 was 23.83 ft (average pumping rate was 485 gpm). An observation well 55 ft from the pumping well showed a maximum drawdown of 5.18 ft. Measurable drawdown was recorded in all of the deep aquifer observation wells (maximum distance 11,400 ft). No drawdown was observed in any shallow observation wells nor was drawdown detected in the well completed in the confining unit.

Interpretation of the aquifer test data indicates that the deep aquifer at this location is confined, with minimal leakage through the confining unit. No hydrologic boundaries were apparent in the data. Transmissivity and storativity were calculated at 35,000 ft^2/d and 5.2 x 10^{-4}, respectively.

Maximum drawdown at well 82279 was 119.68 ft. At distances of 40 ft to 2,494 ft from the pumping well, drawdown ranged from 25.02 ft to 0.49 ft. No drawdown was detected in the shallow aquifer. Based on this test, transmissivity was estimated at 17,000 ft^2/d, with a storativity of 7.6 x 10^{-3}. The data indicated a vertical anisotropy ratio of 0.025, or 40:1, and a leakage coefficient of 7.4 x 10^{-4} within the deep aquifer.

Lacustrine-Till Aquitard

The lacustrine-till aquitard limits vertical seepage of groundwater between the shallow aquifers and the deep alluvial aquifer. Well records from throughout the focus area indicate the thickness of the lacustrine sediment averages about 200 ft and ranges up to 500 ft (Rose, 2018). The aquitard is thickest where the sediment fills topographic lows in the surface of the deep aquifer.

Well construction records from within the focus area document 17 wells completed within the lacustrine-till aquitard. These wells average 205 ft in total depth with minimum and maximum depths of 47 and 380 ft, respectively. The reported well yields ranged from 0 to 10 gpm with an average of 4 gpm.

A slug test performed on well 260889, completed within the lacustrine-till confining unit, showed a recovery time of several months (fig. 11; appendix B, fig. B-3). Transmissivity was estimated at 0.2 ft^2/d at this well, about six orders of magnitude less than the deep aquifer at this location. Hydraulic conductivity is about 0.0007 ft/d, based on the transmissivity of 0.2 ft^2/d and an estimated saturated thickness of 300

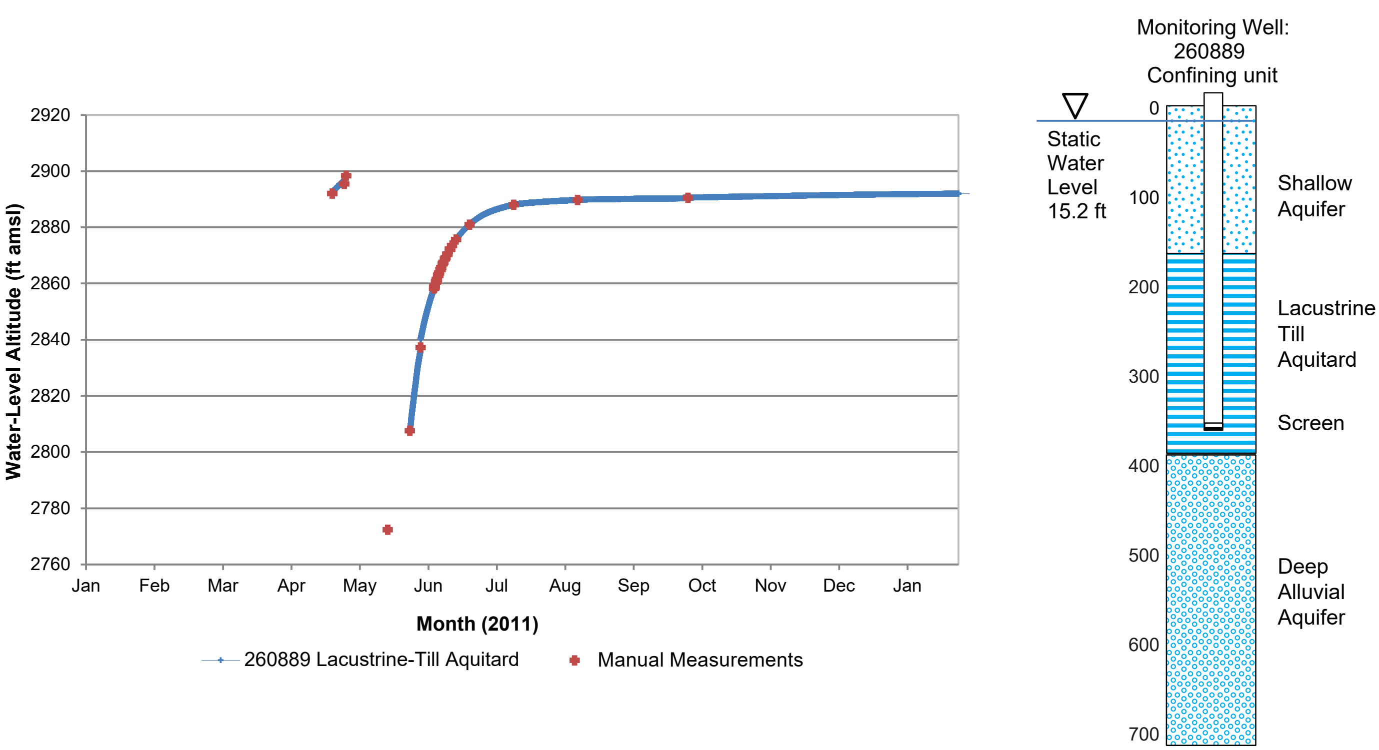

Figure 11. Well 260889, completed in the lacustrine-till confining unit, shows water-level recovery over 2 mo following the slug test on May 17, 2011. This record shows no response to an extensive pumping test of the deep aquifer at a nearby well that occurred the second week of June, 2011. Well location shown in figure 8.

ft. This is the only known hydraulic test of the confining unit. The reported well yields of up to 10 gpm for wells completed in this material are not possible with a transmissivity of 0.2 ft/d, suggesting that the aquitard is spatially heterogeneous, with areas of higher conductivity. There are likely intermediate aquifers (discontinuous lenses of higher-conductivity material) within the confining layer in some areas (LaFave and others, 2004).

Groundwater Levels in the Shallow and Deep Groundwater Systems

Deep Alluvial Aquifer Potentiometric Surface

The potentiometric surface map, created from June 2011 water-level measurements of the deep aquifer (fig. 12), shows groundwater flow from the Swan River Valley in the southeast, along the eastern (Swan Range), northern (Whitefish Mountains), and northwest margins, and from the Ashley Creek area in the Salish Mountains. Groundwater flows from these areas toward the center of the Flathead Valley, then south toward Flathead Lake. Groundwater flow directions are similar to those mapped by Konizesko and others (1968) and LaFave and others (2004).

The steepest horizontal gradients in the Flathead Valley are along the Swan Range front. For example, north of Echo Lake the gradient is 0.01 ft/ft. The potentiometric surface flattens toward the center of the valley, reaching a gradient of about 0.0002 ft/ft near the north shore of Flathead Lake. Although the deep aquifer potentiometric surface indicates flow towards the south, groundwater discharge to the lake has not been documented, and the aquifer is projected to be on the order of 800 ft (e.g., at well 236497) below the lake bottom. As illustrated in figure 5, there are no wells completed in the deep aquifer in what may be a groundwater discharge area to Flathead Lake (see Deep Aquifer Discharge section).

Variation in Water Levels during 2011

In general, groundwater levels rise and fall seasonally in response to recharge or inflow to the area and discharge, either from groundwater outflow or stresses such as pumping. Water levels in most wells in the deep aquifer in the Flathead Valley show seasonal variations related to recharge and discharge patterns. Seasonal discharge at most deep alluvial aquifer wells coincides with summertime irrigation. Hydrographs from wells completed in the shallow aquifer are included here to illustrate the groundwater dynamics near Flathead Lake and small, groundwater-fed lakes. Figure 8 shows the locations of wells referred to in this and the next section.

At the base of the Swan Range, water levels in well 81636, completed in the fractured bedrock, rose about 8 ft from March through June 2011 (fig. 13). This rise corresponds to springtime conditions, including warmer temperatures, precipitation, and snowmelt in the Swan Range. Though there is a break in the record, the available data show the lowest levels in the late winter of 2011, before a springtime rise of about 9 ft. As demonstrated by the 5 ft difference in water levels between January 2011 and January 2012, the range in groundwater minimum and maximum levels generally vary from year to year, which we attribute to variation in the amount of recharge received each year.

About 8,500 ft west of the base of the Swan Range front, water levels at deep aquifer well 160661 began rising in early April in response to precipitation and low-altitude snowmelt (fig. 13). The rate of water-level rise increased mid-May, with additional precipitation and snowmelt at progressively higher altitudes. Water levels peaked in mid-July at approximately the same time that the snow-water equivalent was approaching zero for the year at the Noisy Basin SNOTEL site (DRI, 2022). The spring rise in this well was about 10 ft. Spring recharge began about 2 weeks later at this well than at well 81636.

Deep aquifer well 83716 is about 18,000 ft from the base of the Swan Range front. Water levels in this well (fig. 13) show an annual cycle that differs from the other hydrographs. Water-level rise in well 83716, beginning in May, was truncated by seasonal pumping that lowered water levels while groundwater levels nearer the mountain front continued to rise through mid-summer. The hydrographs in figure 13 illustrate the contrast in groundwater responses with distance from the mountain front. The bedrock aquifer is subject to mountain front recharge dynamics, and it responds quickly to spring snowmelt. The deep alluvial well close to the mountain front (well 160661) shows a similar response, but further from the mountain front, summertime pumping affects groundwater levels in the deep alluvial aquifer (well 83716). Farther from the mountain front, well 150622 shows a delayed response to spring recharge in the shallow aquifer.

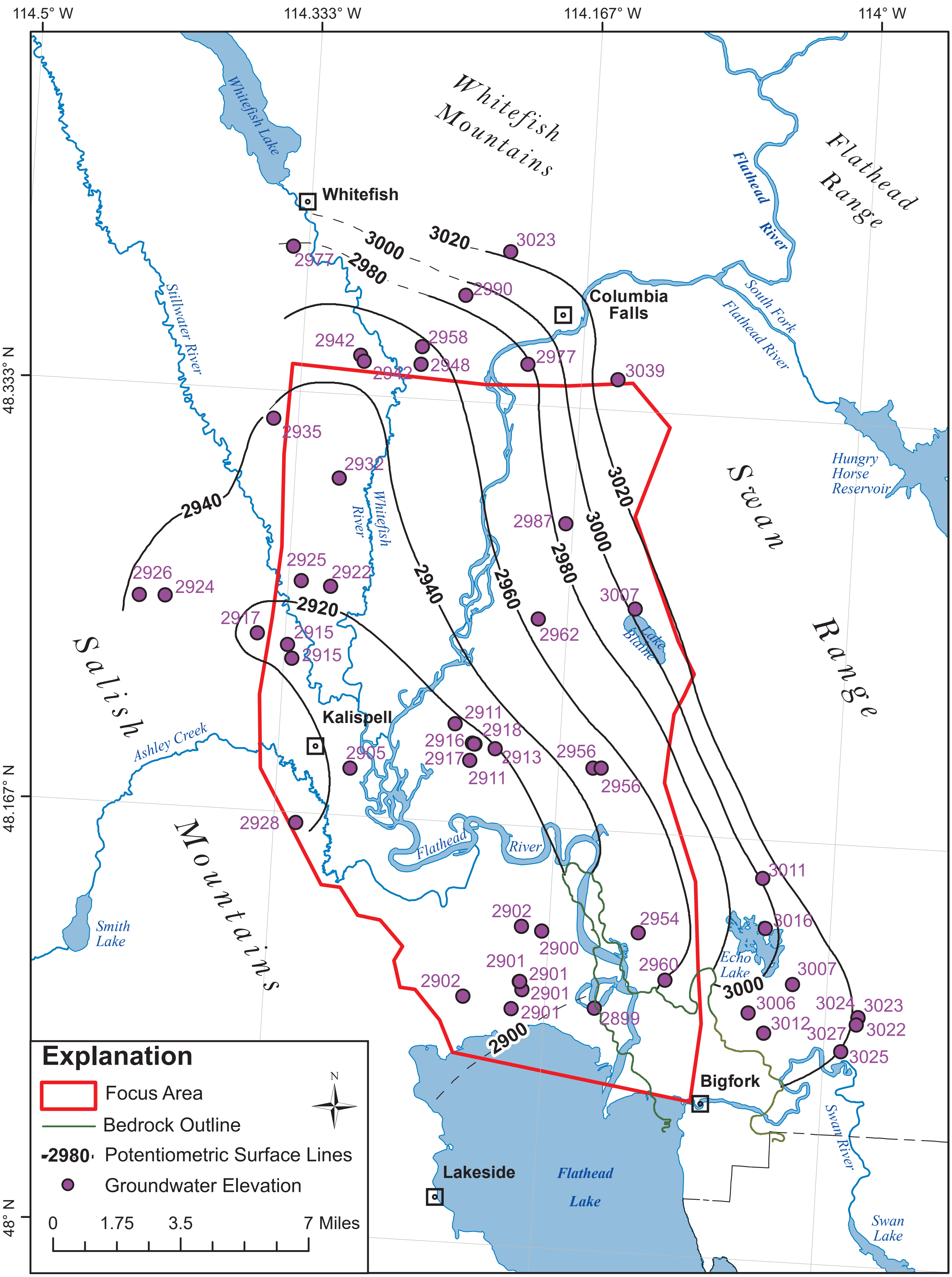

Figure 12. The potentiometric surface for the deep aquifer (June 2011) shows that groundwater flows generally away from the surrounding mountains and toward Flathead Lake. The bedrock outline is a topographic high in the bedrock surface that intersects the deep aquifer near the Swan River Valley (Rose, 2018).

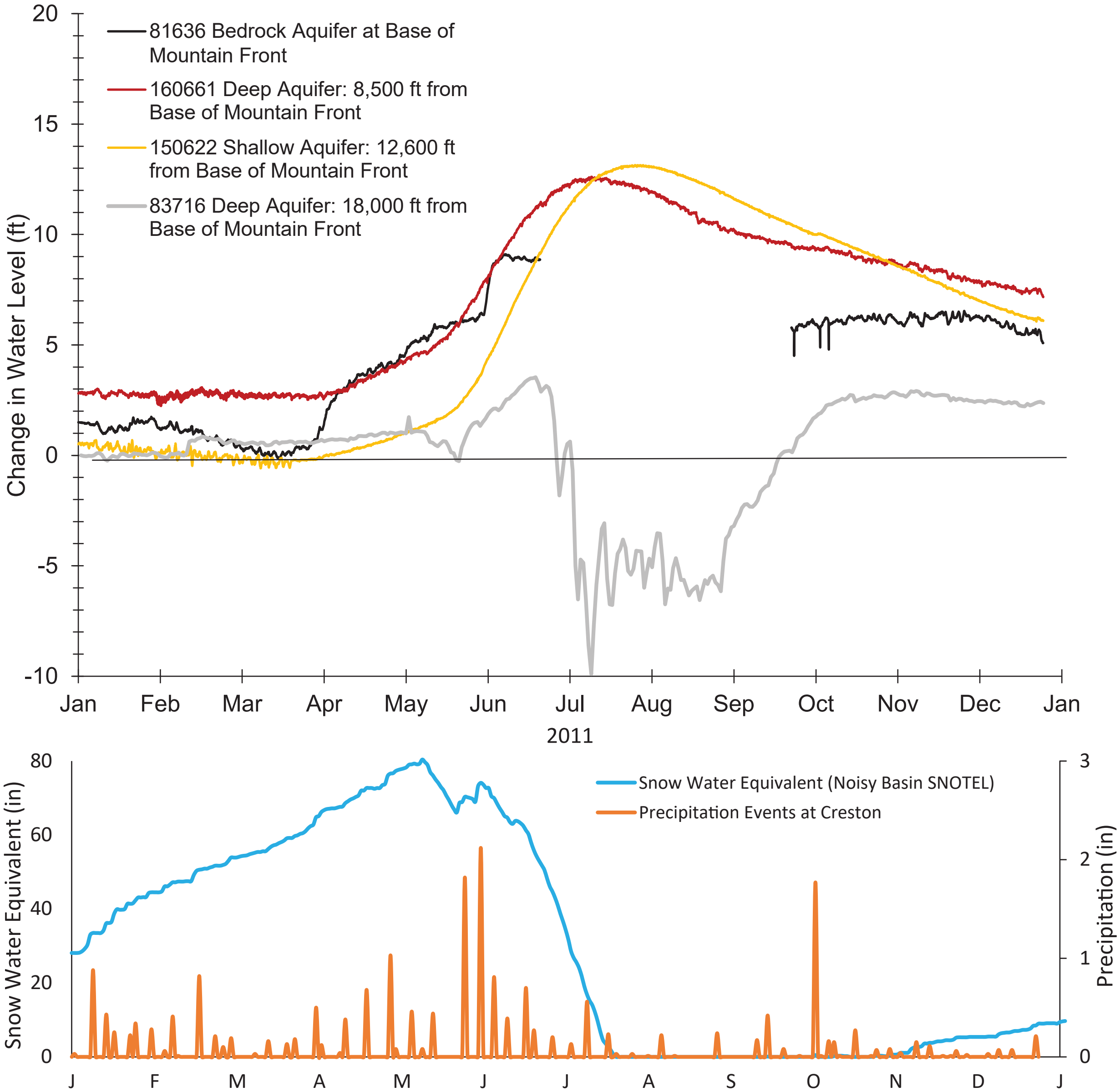

Figure 13. Groundwater hydrographs at various distances from the Swan Range. The bedrock aquifer responds quickly to spring snowmelt events. The deep alluvial aquifer shows a similar response close to the mountain front (well 160661); however, the influence of summer pumping dominates the deep alluvial aquifer hydrograph in well 83716 located 18,000 ft from the mountain front. Farther from the mountain front, the recharge timing in the shallow aquifer is shifted later in the season (well 150622). Well locations are highlighted in figure 8.

Well 150622, located about 12,600 ft from the Swan Range front, is completed in a shallow aquifer adjacent to Lake of the Woods. With additional distance from the mountain front, the groundwater-level peak at well 150622 occurs around 3 weeks after the peak in the deep alluvial aquifer well, 160661 (fig. 13). Long-term hydrographs for shallow well 150622 and the lake are nearly identical (fig. 14). In response to spring precipitation and snowmelt, groundwater levels (well 250622) and lake levels (site 259405) rise in late March. The highest water levels occur in mid-summer. We interpret the lake hydrology to include inflows from direct precipitation and submerged and on-shore springs, and outflows to evapotranspiration and possibly seepage to groundwater.

South of Columbia Falls, groundwater levels in the deep alluvial aquifer reflect pumping stresses from the nearby area (well 148187, fig. 15). Well 148187 is a monitoring well and is not subjected to routine pumping, so short-term variation in the hydrograph indicates a response to nearby pumping. Water levels at this well show seasonal recharge through the spring until drawdown begins in late June. The initial rate of drawdown is rapid (0.6 ft/d in the first week of July) and decreases through the summer. From late August

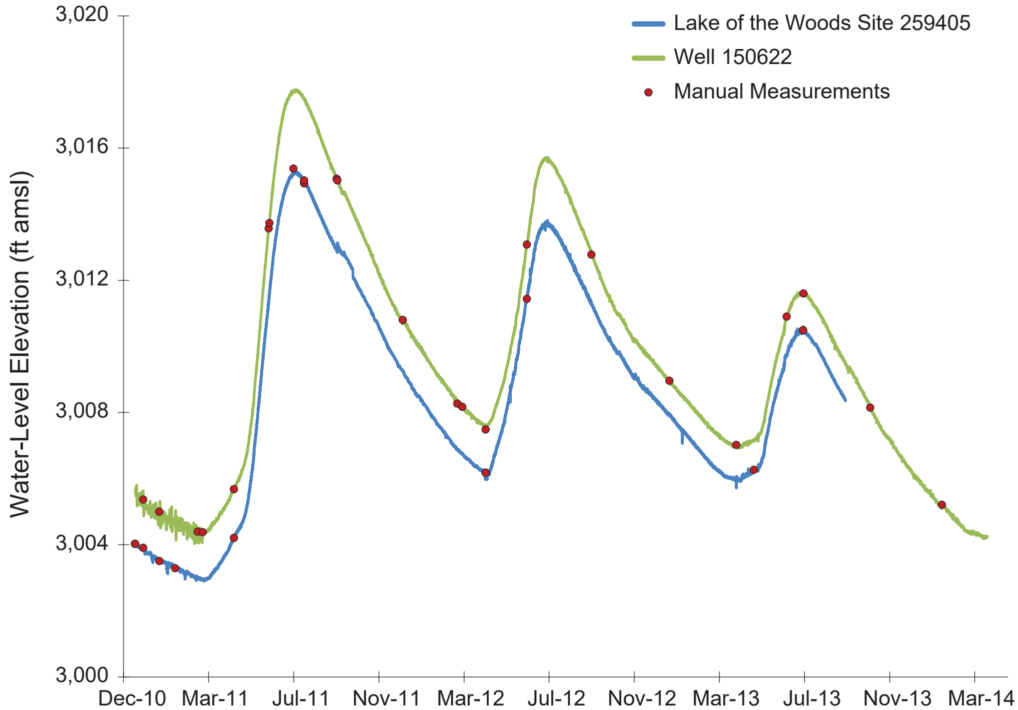

Figure 14. These hydrographs show that the stage in Lake of the Woods (site 259405) correlates to groundwater levels in the shallow aquifer (well 150622). Lake levels mirror groundwater levels, increasing through spring and early summer and dropping the rest of the year. Groundwater elevation is consistently higher than the lake level, indicating that groundwater discharges to the lake. The locations of these sites are highlighted in figure 8.

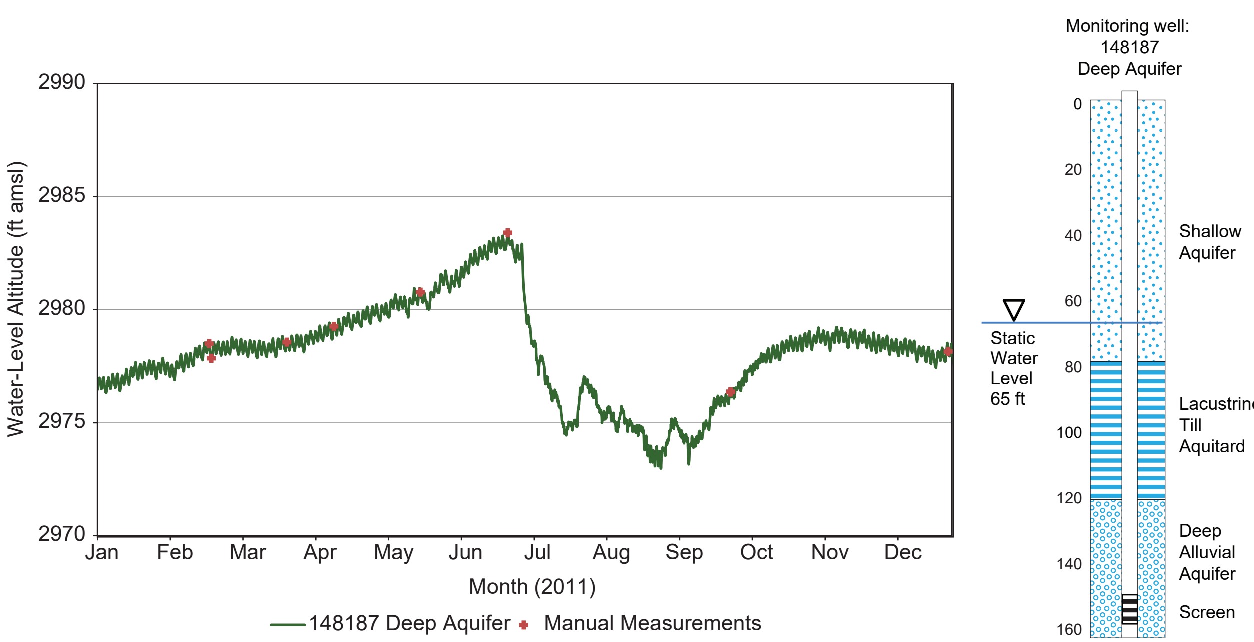

Figure 15. The hydrograph from well 148187, completed in the deep alluvial aquifer, shows springtime recharge followed by a response to pumping from nearby wells. Water-level recovery begins as the pumping season ends in late summer through the fall.

through early September, drawdown averages about 0.03 ft/d. Seasonal recovery begins in late September and continues until November. By the end of 2011, groundwater recovered to a similar elevation as at the beginning of the year.

Water levels from shallow alluvial well 262421, about 0.4 mi from the north shore of Flathead Lake, reflect precipitation events and regional, seasonal pumping. The groundwater level was independent of the lake level, with groundwater lows in the summer when the lake was high. Groundwater levels were higher during the winter and spring when the lake was low (fig. 16).

Both wells 80745 (fig. 17) and 260892 (fig. 18), completed in the deep alluvial aquifer, show seasonal trends typical throughout the valley of spring recharge followed by water-level declines due to summertime irrigation. The groundwater elevation of both wells is higher than that of the lake level throughout the year, and therefore the deep aquifer has the potential to discharge to the lake; however, 250 ft (fig. 18) to 350 ft (fig. 17) of confining unit between the lake bottom and the aquifer suggest low rates of flux from the aquifer to the lake.

Long-Term Water-Level Trends

Trends in groundwater levels that persist over several years generally indicate that some change, or stress, is affecting an aquifer. Stresses that can cause long-term declines or rises in water levels include cumulative effects of pumping that exceed recovery; land-use changes that alter recharge; climatic trends, including an increase or decrease in total precipitation; or changes in the timing, magnitude, or duration of precipitation. Representative hydrographs discussed below show several types of long-term groundwater response throughout the valley.

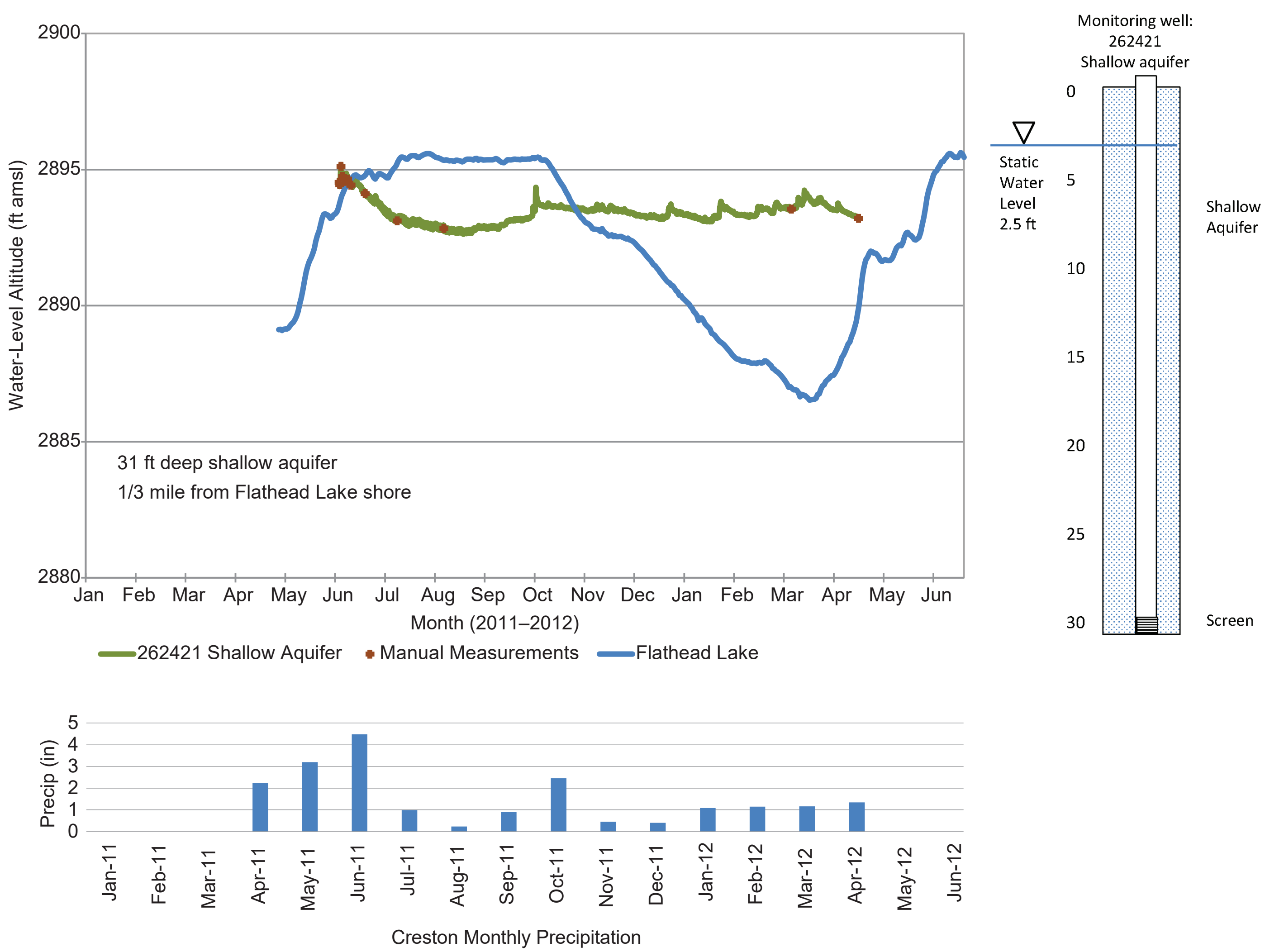

Figure 16. Groundwater levels in the shallow aquifer approximately 1/3 mile north of Flathead Lake (well 262421) do not correlate with the lake level.

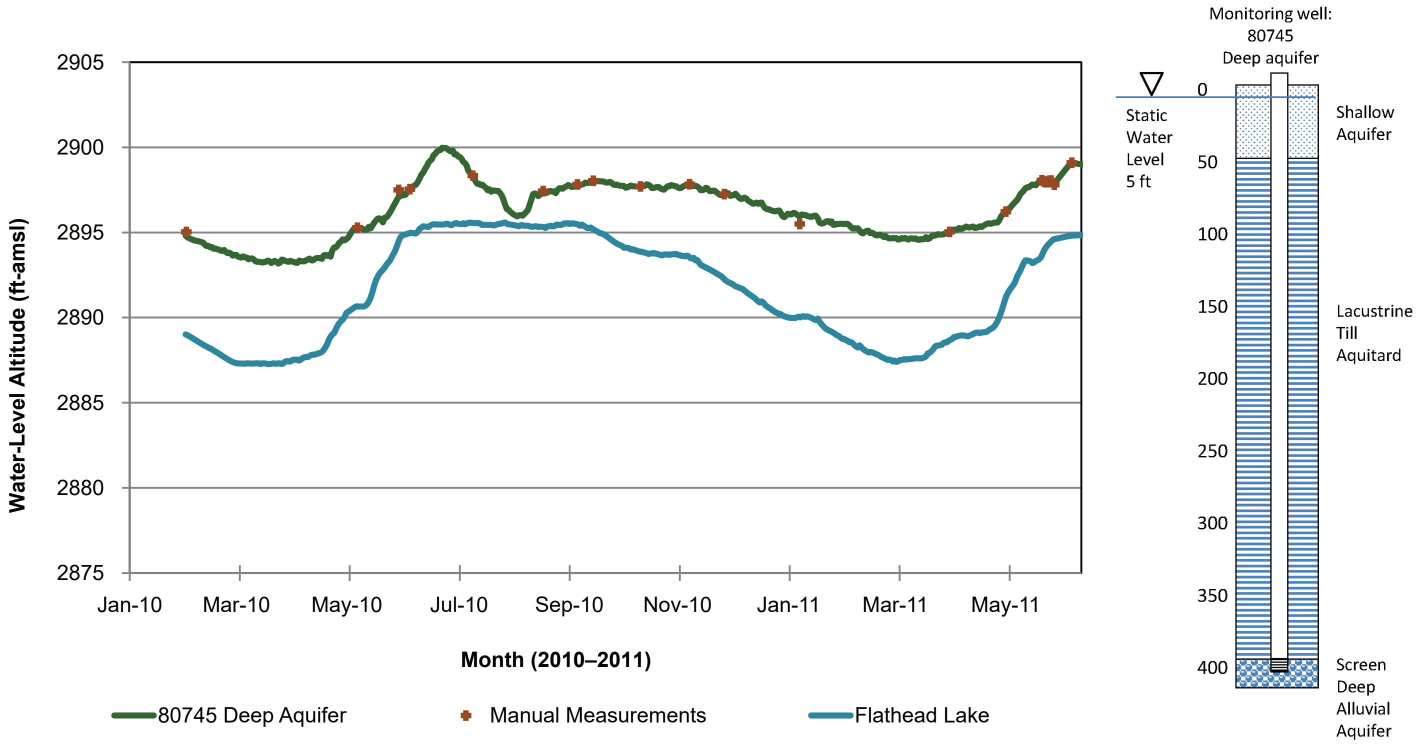

Figure 17. Groundwater levels in the deep alluvial aquifer at well 80745 exceed the Flathead Lake stage, indicating upward vertical gradients from the aquifer to the lake.

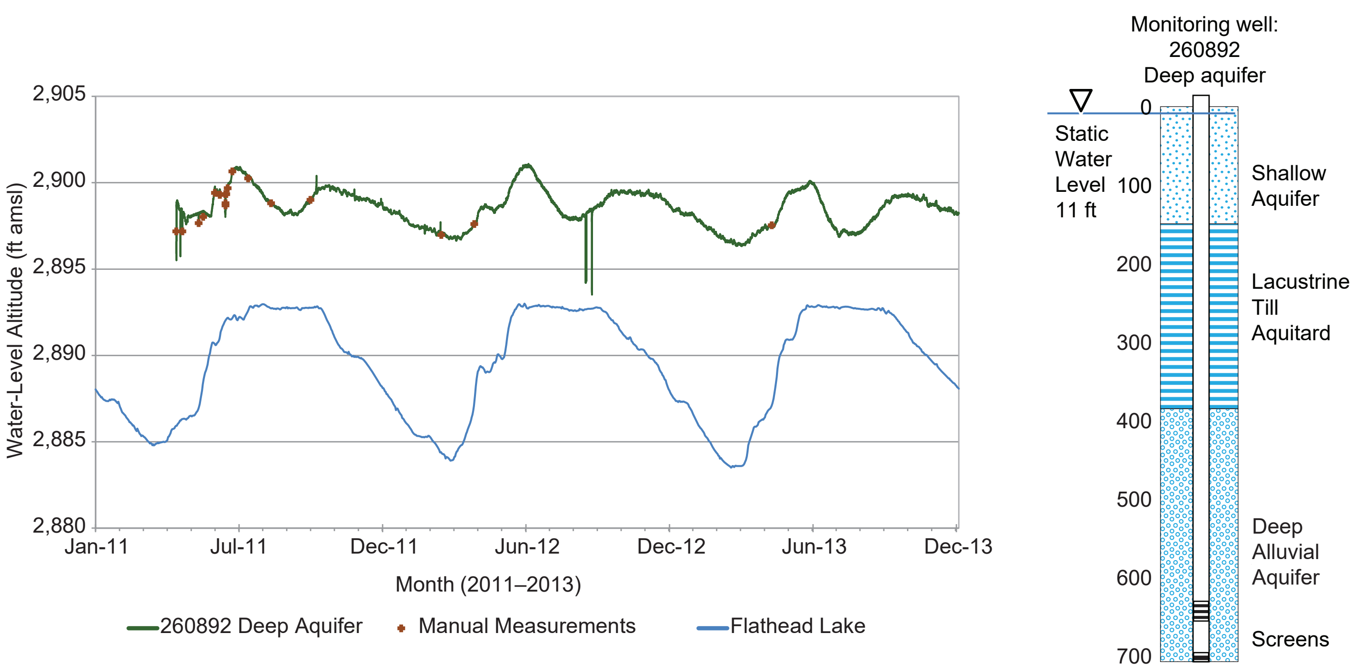

Figure 18. Groundwater levels in the deep alluvial aquifer at well 260892 are higher than the Flathead Lake stage.

Table 5. Long-term water-level trends.

GWIC	Latitude	Longitude	Beginning Year	Ending Year	Time Steps	*p*-value	Statistically Significant Trend	Change in Water Level (ft)	Slope (ft/yr)
80389	48.08882	-114.03589	1996	2017	Quarterly	0.225	None	0	NA
80745	48.09470226	-114.1368116	1996	2015	Quarterly	**0.013**	Decreasing	-2	-0.11
81530	48.19763974	-114.0711319	1996	2017	Quarterly	0.411	None	0	NA
82139	48.2040922	-114.2293022	1996	2017	Quarterly	**0.039**	Decreasing	-4	-0.18
82381	48.18404796	-114.2900642	1996	2016	Quarterly	**0.001**	Decreasing	-6	-0.28
82934	48.19602825	-114.3747948	1996	2017	Quarterly	**<0.0001**	Decreasing	-5	-1.38
83716	48.24751238	-114.1838282	1996	2017	Quarterly	0.248	None	0	NA
83875	48.29854199	-114.3068833	1995	2017	Quarterly	**<0.0001**	Decreasing	-12	-0.55
84560	48.28085751	-114.3691229	1996	2017	Semi-annual	0.189	None	0	NA
84669	48.24797	-114.40579	1996	2017	Quarterly	**<0.0001**	Decreasing	-19	-0.92
84687	48.24765243	-114.4211841	1996	2017	Quarterly	**<0.0001**	Decreasing	-15	-1.10
85274	48.39235109	-114.2133101	1996	2017	Quarterly	0.497	None	0	NA
85628	48.34286743	-114.1851764	1996	2016	Quarterly	0.596	None	0	NA
85689	48.34416534	-114.1449769	1996	2016	Quarterly	0.426	None	0	NA
85940	48.37263732	-114.3169359	1996	2017	Quarterly	0.099	None	0	NA
86411	48.38930306	-114.3424642	1996	2017	Quarterly	0.986	None	0	NA
120810	48.17860652	-114.4182179	1996	2017	Quarterly	**<0.0001**	Decreasing	-27	-1.41
131524	48.25545861	-114.3081896	1996	2017	Quarterly	**0.0005**	Decreasing	-6	-0.25
141562	48.10042473	-114.1803348	1996	2017	Quarterly	**0.016**	Decreasing	-2	-0.07
148187	48.34806329	-114.1969264	1996	2017	Quarterly	0.357	None	0	NA
148188	48.34820738	-114.1990453	1996	2017	Quarterly	0.449	None	0	NA
148189	48.34691179	-114.1991149	1996	2016	Quarterly	0.961	None	0	NA
148191	48.34778419	-114.2984953	2004	2017	Quarterly	**0.020**	Increasing	2	0.14
148193	48.32062	-114.34792	1996	2016	Quarterly	**0.0002**	Decreasing	-1	-0.21
152883	48.09639039	-114.2149164	1996	2017	Quarterly	**<0.0001**	Decreasing	-5	-0.26
169098	48.22613844	-114.3283472	1998	2017	Quarterly	**<0.0001**	Decreasing	-21	-0.50
702934	48.25367	-114.12665	1996	2017	Quarterly	**0.019**	Increasing	3	0.21
Precipitation (SPI)	48.30809	-114.25187	1996	2017	Quarterly	0.430	None	0	NA

Note. *p*-values **<0.05** are considered to be statistically significant.

Twenty-seven wells completed in the deep aquifer have long-term water-level records of 13 or more years (table 5). As indicated in table 5, for most wells we used the period from 1996 through 2017 to develop comparable data sets for trend analysis with the Mann–Kendall method. Table 5 summarizes results of the analyses, including period of record, *p*-values, and trend direction and magnitude. The null hypothesis, that there is no trend in water levels during the period of evaluation, was rejected for *p*-values less than 0.05.

Hydrographs and trend lines for these monitoring wells, and the SPI to illustrate precipitation, are in appendix C. Figure 19 illustrates the spatial distribution of trend-analysis results, indicating areas in the west and south of the study area where groundwater levels are decreasing. Density of water rights indicate areas where groundwater pumping may influence groundwater levels and are shown in figure 19.

Analysis of the monthly precipitation record, applied to SPI values, shows no statistically significant trend in precipitation from 1996 through 2017 (table 5, appendix C).

Near the center of the valley, water levels measured quarterly in well 83716 correlate to changes in precipitation (converted to the SPI; fig. 20, appendix C). This long-term record indicates that while pumping generally lowers the deep aquifer hydraulic head in this area by 10 to 20 feet, water-levels recover each year. The data at this well do not demonstrate a statistically significant trend and do not show long-term effects from pumping.

The longest continual water-level record (1963 through 2017) in the valley is from well 131524 (fig. 21, appendix C). Water levels measured in this well dropped from the mid-1970s through the early 1990s. A statistically significant decline of approximately

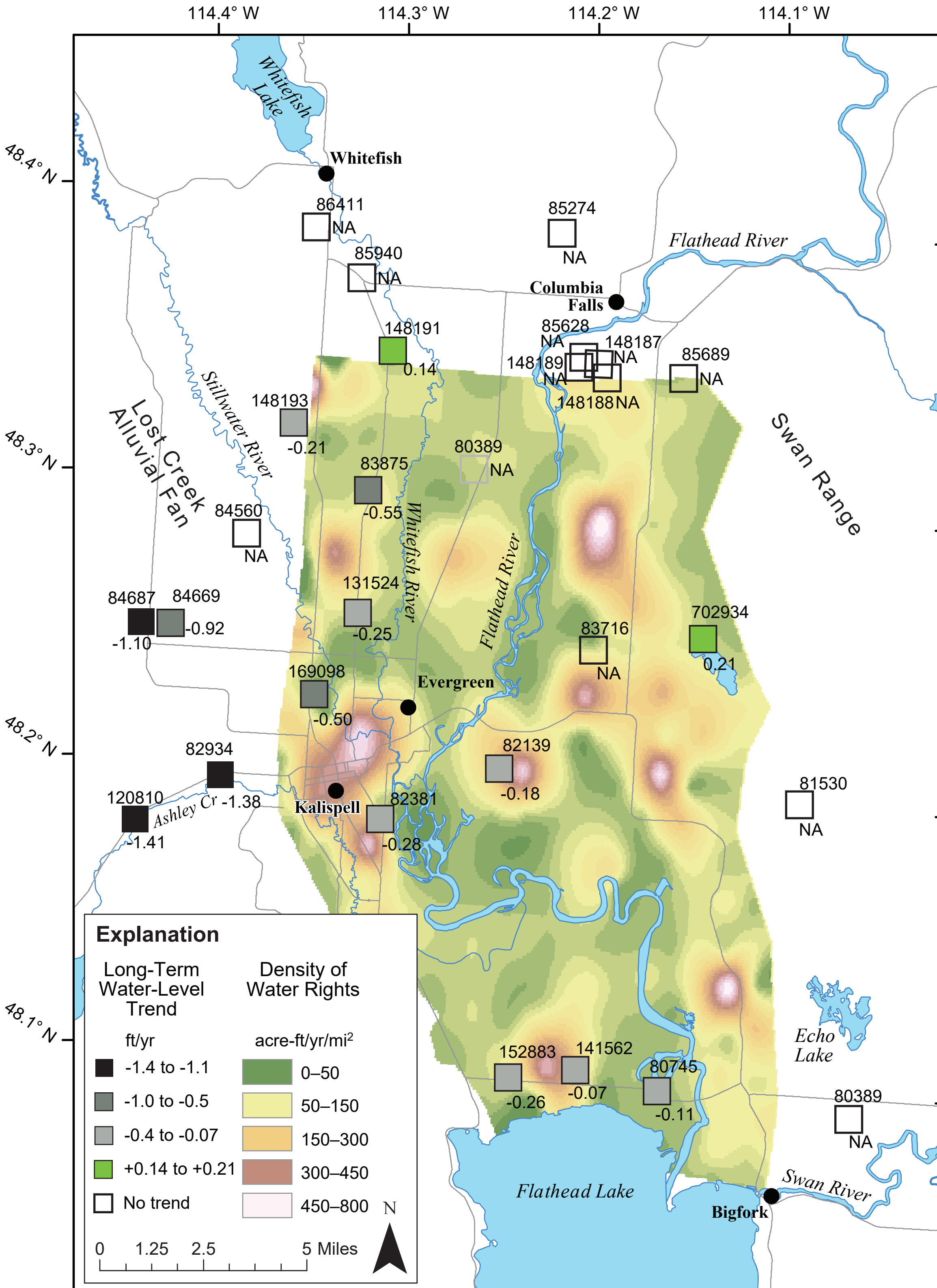

Figure 19. Trends in deep alluvial aquifer hydrographs, based on data from 1996 through 2017, indicate declining groundwater levels in the central and west areas in the valley. Other areas show no statistically significant trend.

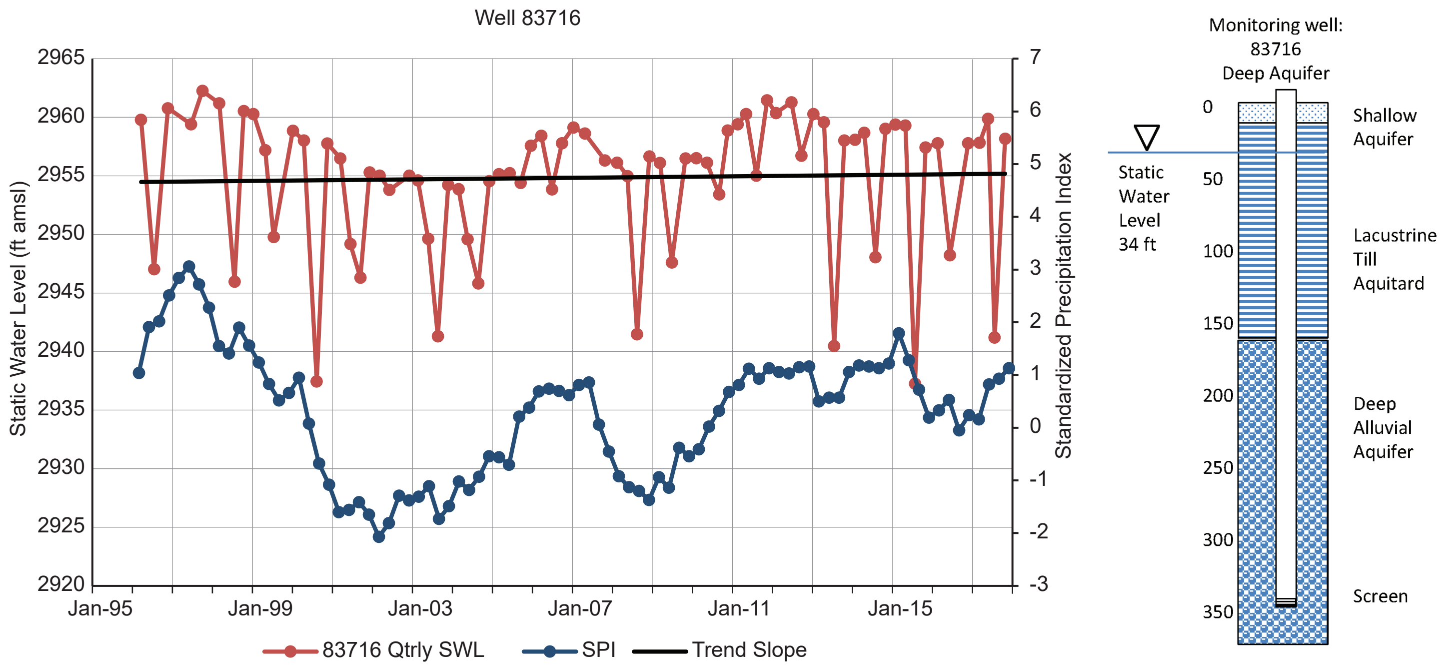

Figure 20. Since 1996, water levels at well 83716 follow precipitation trends (Kalispell Glacier Airport; DRI, 2022). High groundwater levels occur during periods of higher precipitation and groundwater levels decline during periods of low precipitation.

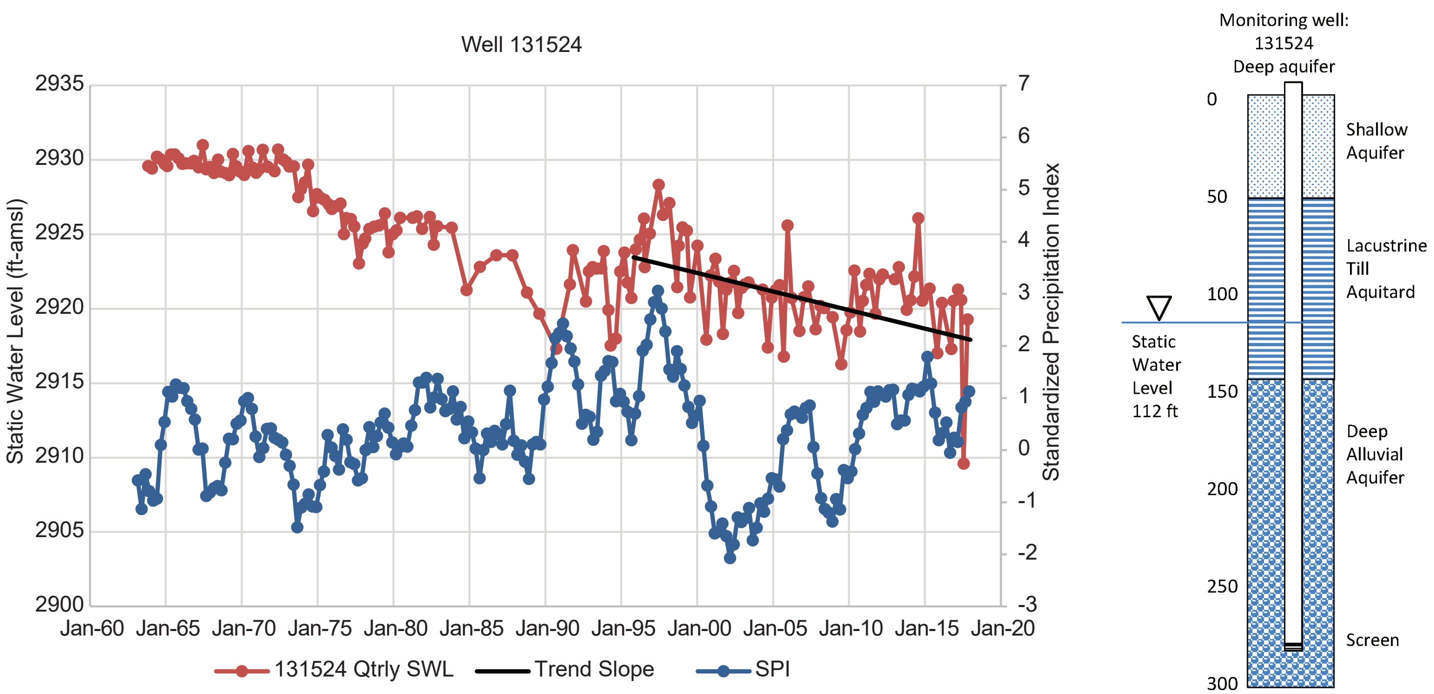

Figure 21. Groundwater levels in well 131524 have declined since the mid-1970s. Since 1996, the rate of decline has been about 0.25 ft per year.

-0.25 ft per year occurred from 1996 through 2017. The water-level decline at this well occurred when most years had an SPI greater than zero. This suggests that the decrease is related to increased pumping. The declines in water levels at this well since the mid-1970s coincide with installation of more high-capacity irrigation wells in the deep aquifer (fig. 7).

Just north of Kalispell, data from well 169098 show seasonal effects of pumping on an annual timescale and a long-term water-level decline that we also attribute to pumping (fig. 22, appendix C). These groundwater levels do not follow annual precipitation patterns. Water levels drop each spring and recover in late summer or fall. Water levels continue to rise until the next spring and summer pumping cycle. The water level does not fully recover between annual pumping cycles; pumping begins during water-level recovery, indicating depletion of aquifer storage. The statistically significant downward trend is approximately -0.5 ft/year.

In the southern part of the focus area, near Flathead Lake, deep alluvial aquifer well 141562 shows some influence from annual precipitation, but the overall trend is a statistically significant decrease of about -0.07 ft/year (fig. 23, appendix C). Other wells along the north shore of Flathead Lake also show downward-trending water levels (e.g., wells 152883 and 80745 in appendix C).

Of 27 wells with long-term data, 13 show decreasing water levels. Declines ranged from 1 ft to 27 ft, with a median value of 6 ft (table 5). The spatial distribution of these wells (fig. 19) shows downward trends in all but well 84560 (near the Stillwater River) in the southwest half of the focus area and west to Ashley Creek and the Lost Creek Alluvial Fan. East of the Flathead River, toward the Swan Range front, and north toward the Whitefish Range, water levels generally show no significant trend; however, two wells show increasing water levels.

The density of groundwater-rights annual pumping volumes from the deep aquifer represents the spatial distribution of withdrawals (fig. 19). The highest density extends along the eastern part of the focus area, near the Swan Range front. The cumulative volume near Kalispell is also high. However, the area showing no trends or upward trends in long-term water levels is near the higher density of water rights west and south of the Swan and Whitefish ranges, indicating that head loss due to pumping may be offset by induced recharge along this side of the valley, near the mountain front. Alternatively, these wells may be too distant from the highest density of groundwater use to ad-

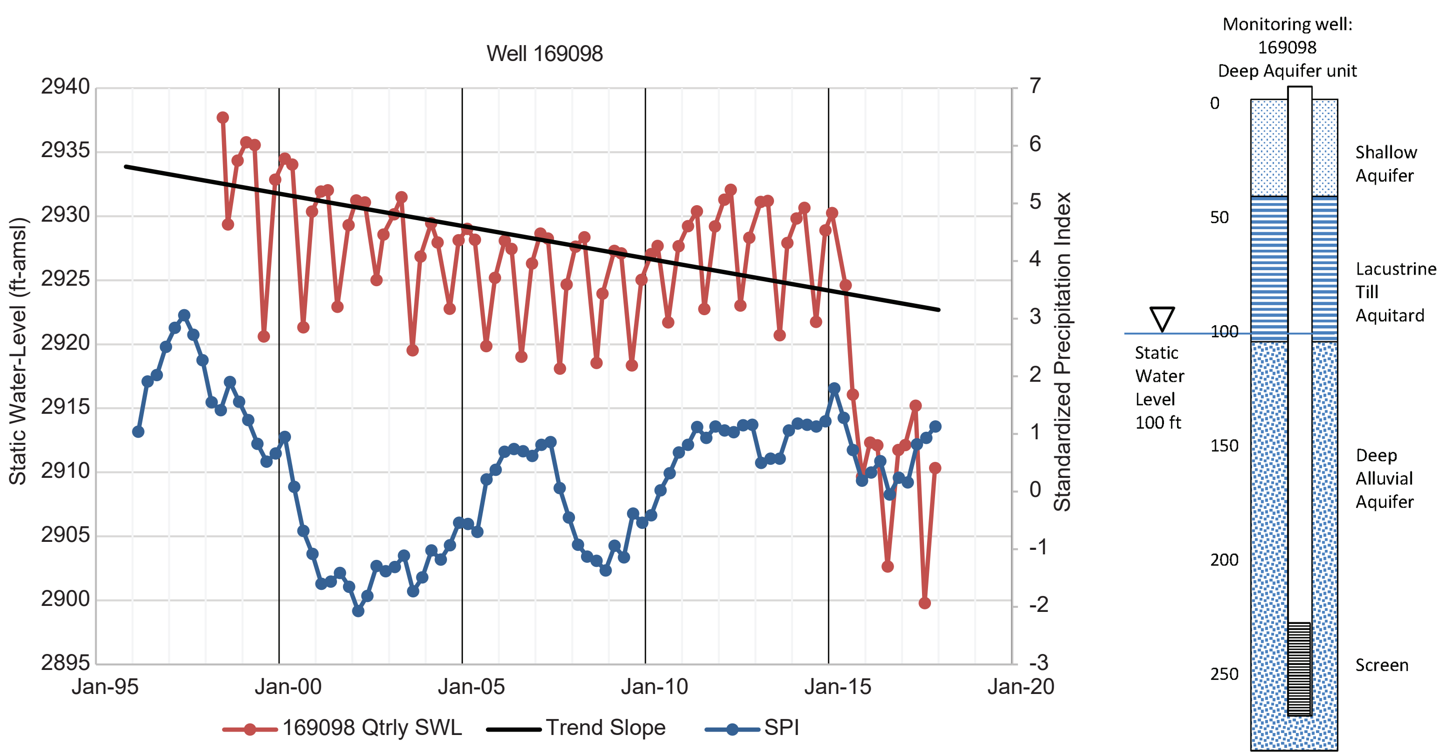

Figure 22. Groundwater levels in well 169098 do not fully recover after the summer pumping period. The average rate of decline in groundwater levels is about 0.5 ft per year from 1996 through 2017.

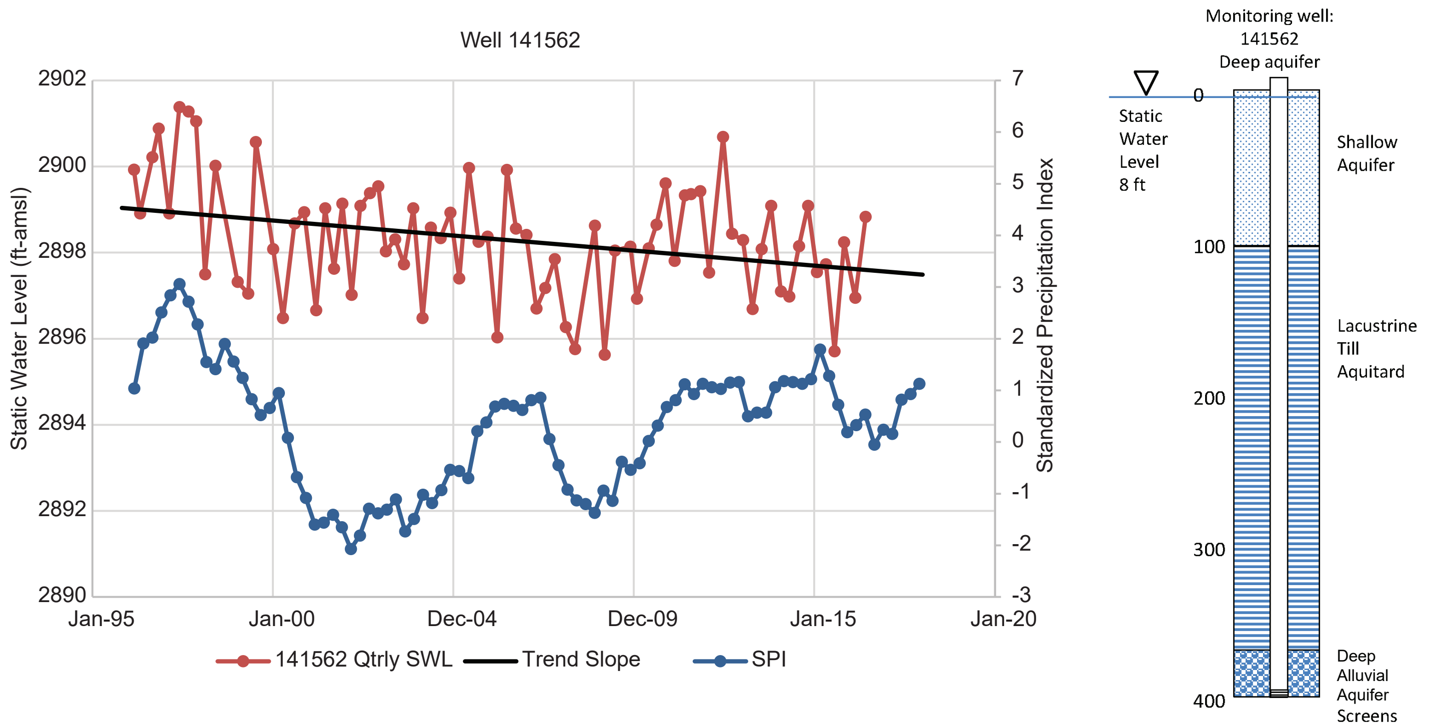

Figure 23. Groundwater levels in well 141562, 0.4 mi north of Flathead Lake, are declining.

equately capture the effects of pumping. Although the wells that show decreasing water levels are near the Salish Mountains, the distance between the wells and areas of possible mountain front recharge is greater than on the east side of the valley. Here, recharge does not appear to be adequate to offset drawdown from pumping, and therefore groundwater levels are declining.

Deep Aquifer Recharge

Mountain Front Recharge

Along the margins of the valley floor, the shallow, presumably fractured bedrock of the mountain blocks are potential recharge paths for the snowmelt and rainfall in the high elevations. As reported in table 1, annual precipitation in the Swan and Salish Mountains exceeds that in the valley. Some precipitation runs off to streams; where mountain streams flow onto the more permeable material on the valley floor, the streams may recharge the water table. On the mountain slopes, infiltration of rain and snowmelt can flow through fractures and recharge both the shallow and the deep aquifers. Mountain-front recharge is likely the primary means of recharge to the deep aquifer, as indicated by previous work (LaFave and others, 2004) and supported by this study.

Vertical Recharge through the Lacustrine-Till Aquitard

Due to low hydraulic conductivity of the lacustrine-till aquitard, volumetric flux between the shallow and deep aquifers is small. However, the aquitard covers a large area, and the total seepage volume represents a source of recharge to the deep aquifer. Based on 2011 water levels in the shallow aquifer and the estimated potentiometric surface of the deep aquifer in that location, we estimated magnitude and direction of vertical gradients (dimensionless term i in eq. 1) across the aquitard at locations shown in figure 24. The magnitude of the vertical gradients are approximate, given the level of accuracy of the potentiometric map; however, in general, this analysis indicates downward gradients to the north and east in the focus area and flat to slightly upward in the southern half (fig. 24). The average vertical gradients were 0.17 (downward) in the northern area (about 65,800 acres) and -0.07 (upward) in the southern area (about 55,000 acres).

Results from the slug test conducted in the confining unit indicate the hydraulic conductivity is about 0.0007 ft/d. Applying Darcy's Law with an average vertical gradient and this estimate of hydraulic conductivity, we find that the vertical seepage through the confining unit in the northern area provides about 2,800 acre-ft per year of recharge to the deep aquifer.

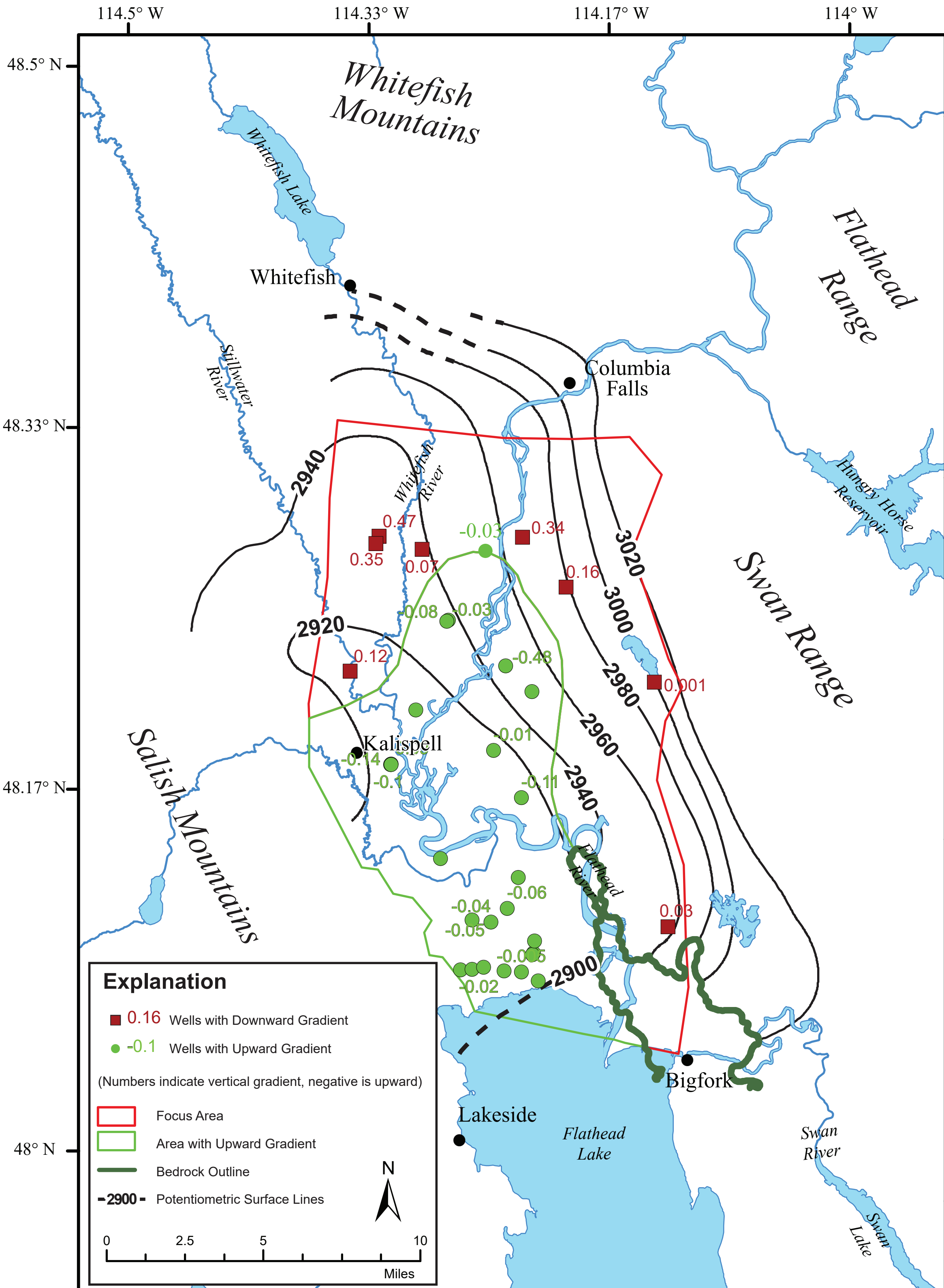

Figure 24. Vertical hydraulic gradients across the lacustrine-till aquitard are downward in the north and east of the focus area and upward in the central and southern areas. The bedrock outline shows a bedrock high that borders the deep aquifer near the Swan River Valley (Rose, 2018).

This estimate assumes homogenous properties; however, hydraulic conductivity and vertical seepage of the aquitard vary spatially.

Based on the potentiometric map and the geology model from Rose (2018), the aquifer is confined, indicating the aquitard appears to be continuous across the area. We found no pathway for precipitation falling directly on the valley floor, or losing reaches of rivers flowing across the valley, to directly recharge the deep aquifer. Precipitation and stream loss on the valley floor does recharge the shallow aquifer. Recharge from the shallow aquifer to the deep aquifer occurs through downward vertical seepage across the confining unit in the northern half of the focus area.

Deep Aquifer Discharge

Outflow from the deep aquifer occurs from pumping withdrawals, vertical seepage upward through the aquitard, and groundwater discharge to the south. Groundwater outflow to the south is not estimated here due to uncertainty about aquifer thickness.

Pumping Withdrawals

Estimates of pumping from the focus area and summary results for each category of water use are listed in table 6. We developed ranges of values for some, but not all, categories. Groundwater withdrawals are dominated by irrigation, public water supplies, lawn and garden, and self-supplied industrial uses.

Estimates made for this study were compared to those by the U. S. Geological Survey (USGS) for 2015 (Dieter and others, 2018). The USGS estimates are countywide, and combine groundwater pumping from all aquifers and well depths. Although estimated using different methods, the USGS values are consistent with those developed during this study.

Irrigation. The estimated annual withdrawal from the deep aquifer for irrigation ranged from 5,000 to 11,600 acre-ft/year.

Public water systems. Within the focus area, 98 PWS serve approximately 40,000 people (table 6). The estimated minimum PWS use was 2,500 acre-ft/yr, assuming a per capital rate of 158 gallons per day. Mid-range annual consumption from these systems was estimated at 7,000 acre-ft/yr. This estimated maximum use is the reported PWS water rights of 15,000 acre-ft/yr.

Self-supplied single and multi-family domestic. Self-supplied domestic and multi-family wells serve an estimated 8,500 people from 2,650 private wells completed in the deep aquifer (table 6). Based on Bigfork PWS records, per capita consumption was

Table 6. Estimated annual pumping volume from the deep aquifer in the focus area during 2011.

Pumping Withdrawals: Water-Use Category	Estimated Minimum (acre-ft/yr)	Estimated Mid-Range (acre-ft/yr)	Estimated Maximum (acre-ft/yr)	Resident Population Served by Deep Aquifer Sources (individuals)	Per capita (gallons per day)	Water Rights, Wells, or Systems (count)
Irrigation	5,000	10,000	11,600	—	—	—
Public water supply	2,500	7,000	15,000	40,000	158	98 systems (148 diversions)
Self-supplied single- and multi-family domestic	—	600	—	8,500	65	2,650
Domestic lawn and garden	—	2,600	7,200	—	—	2,650
Self-supplied commercial and industrial	—	1,700	3,000	—	—	157
Stock water	25	500	1,000	—	—	—
Total pumping	—	**22,400**	**37,800**	—	—	—

Note. Derivation of estimated values is outlined in Methods, Pumping Withdrawals, Results, Discussion, and Deep Alluvial Aquifer Discharge.

estimated at 65 gpd for indoor use, including washing, cooking, and other year-round daily needs. Annual mid-range, deep aquifer withdrawal in the focus area by private domestic wells for household use was therefore estimated at 600 acre-ft/yr. Groundwater withdrawn for domestic wells is either consumed or discharged to the shallow aquifer through septic systems; none of it returns to the deep aquifer.

Lawn and garden watering only occurs during the summer growing months and requires far more water than in-house use. Each well produces an estimated 1 acre-ft/yr for outdoor watering. Total lawn and garden watering consumes an estimated 2,600 to 7,200 acre-ft/yr.

Total annual withdrawals for private domestic wells (the combination of in-house use and lawn and garden watering) was estimated at 3,200 acre-ft/yr. We did not estimate minimum annual use because it would be arbitrary. The maximum estimated use from domestic wells was set equal to total domestic well water rights on file: 7,200 acre-ft/yr.

Self-supplied commercial and industrial. Withdrawal from the deep aquifer by self-supplied commercial and industrial uses was likely less than the 3,000 acre-ft/yr allocated to 155 groundwater rights (table 6). Our mid-range estimate was 1,700 acre-ft/yr.

Stock water. The estimated total water requirement for livestock in the focus area is included in table 6. The focus area represents about 4 percent of the county. However, the county is heavily timbered and stock areas are concentrated in the valley. The focus area includes about 60 percent of the county's non-irrigated agricultural areas. Using 60 percent as a basis of the distribution of livestock within the county, we estimated stock water requirements at 25 acre-ft/yr (MT DOA, 2012). The total water rights for livestock water within the focus area are 1,038 acre-ft/yr.

Vertical Discharge through the Lacustrine-Till Aquitard

Vertical seepage upward from the deep aquifer through the lacustrine-till aquitard occurs where the hydraulic heads in the deep aquifer are higher than those in the shallow aquifer (fig. 24). The area of upward gradients covers about 55,000 acres. Using the method described above, upward vertical seepage was estimated at 1,000 acre-ft/yr (appendix D).

Some water may also discharge through upward flow to springs in areas where the confining layer is thin and the vertical gradient is upward; however, we have not identified such areas.

Groundwater Chemistry

Major and Minor Ions

Major ion chemistry, displayed as percent composition on Piper diagrams, is similar among the aquifers in the Flathead Valley (fig. 25). Samples from shallow and deep unconsolidated aquifers and bedrock aquifers were all predominantly calcium–magnesium–bicarbonate type. A few samples from the deep aquifer and bedrock were sodium–bicarbonate type, indicating more variability in water quality than in the shallow system and potentially pointing to bedrock as a source of recharge to the deep aquifer. The sodium-dominated samples from the deep alluvial aquifer are concentrated along the eastern edge of the valley at the base of the Swan Range and where the bedrock is near the surface near the north shore of Flathead Lake (fig. 4). This suggests bedrock aquifer recharge to the deep aquifer may influence the geochemistry near the alluvial/bedrock contact.

Tritium

Stream samples from site 256831 were used to characterize the tritium level in precipitation in the Flathead Valley: around 7 tritium units (TU; appendix E). Surface water, such as stream site 256831, can only approximate the TU in precipitation because surface water may include a component of old water (such as groundwater baseflow) that would reduce the average TU value of the stream. The value of 7 TU is an approximate lower limit of modern atmospheric TU values in the focus area, which is consistent with the Clark and Fritz (1997) interpretation of 5 to 15 TU for modern water. Clark and Fritz (1997) generalize the tritium values in groundwater for continental regions as:

- <0.8 TU, old water recharged prior to 1952;
- 0.8–4 TU, a mixture of old and modern water;
- 5–15 TU, modern water; and
- >15 TU, water that was recharged during nuclear bomb testing in the 1960s.

Other surface-water sample sites (fig. 26) include four springs with modern water tritium values close

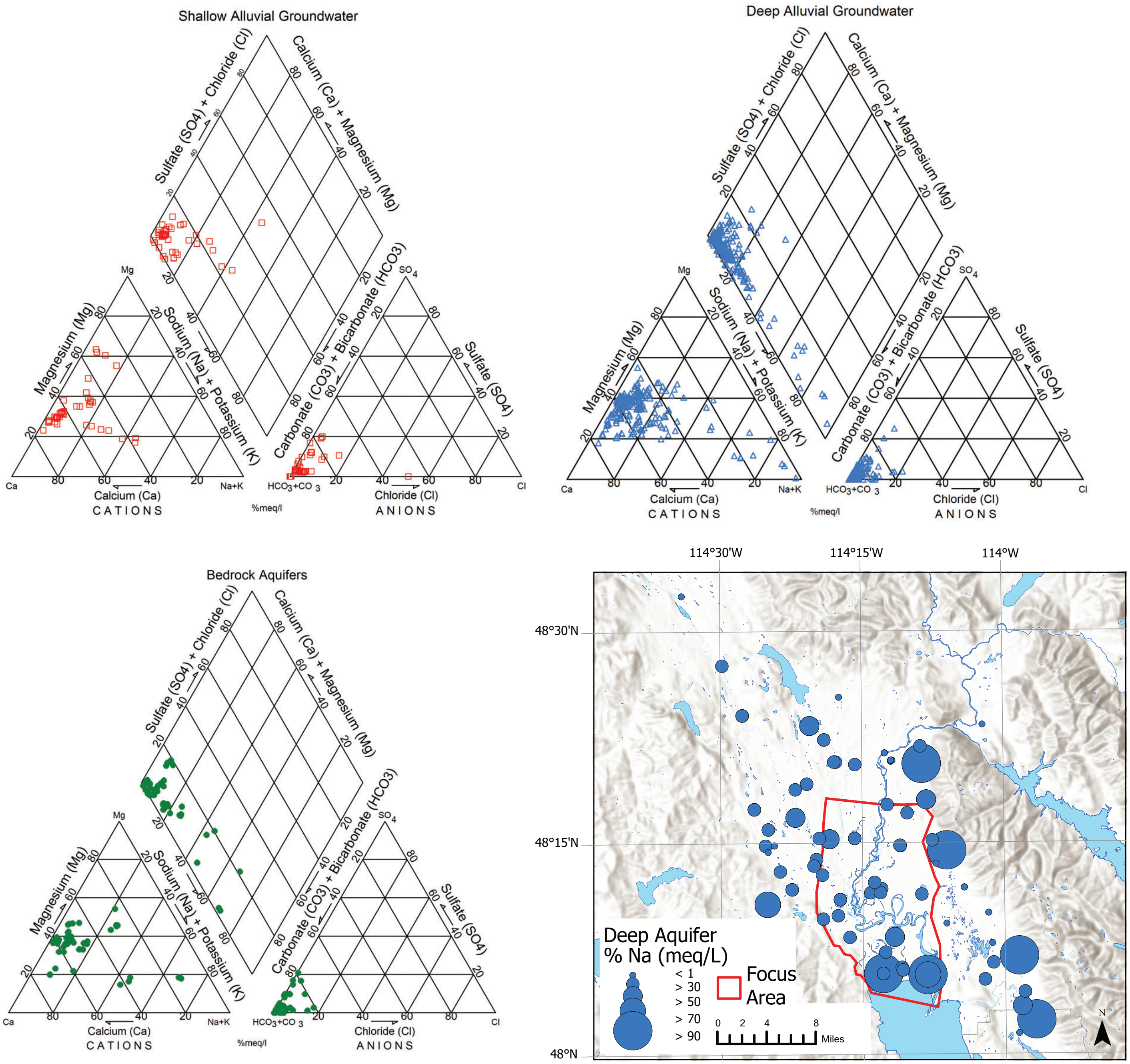

Figure 25. The groundwater geochemistry in all aquifers in the study area was predominantly calcium–magnesium–bicarbonate; however, some samples in the deep alluvial aquifer and the bedrock aquifers were sodium–bicarbonate. The sodium-dominated samples from the deep alluvial aquifer are concentrated along the eastern edge of the valley at the base of the Swan Range and along the north shore of Flathead Lake. This suggests bedrock aquifer recharge to the deep alluvial aquifer influences the geochemistry near the alluvial/bedrock contact.

to 7 TU (256983, 256981, 196428, and 173086) and one spring with a mixture of old and modern water (255198).

Samples collected from wells completed in the deep aquifer in the Swan River Valley indicate the potential for modern recharge to the deep aquifer in this watershed (fig. 26). Along the deep aquifer flow path from the Swan River Valley to the eastern study boundary, a series of three wells have TU values consistent with modern water (well 79595) and water that is a mixture of modern and old (wells 80289 and 139453). These wells are completed in the upper part of the deep aquifer. Total depths range from 125 ft near Swan Lake (well 79595) to 247 ft (80389) and 310 ft (139453) toward the eastern edge of the study boundary. The groundwater sampled from these sites all has calcium–bicarbonate quality and total dis-

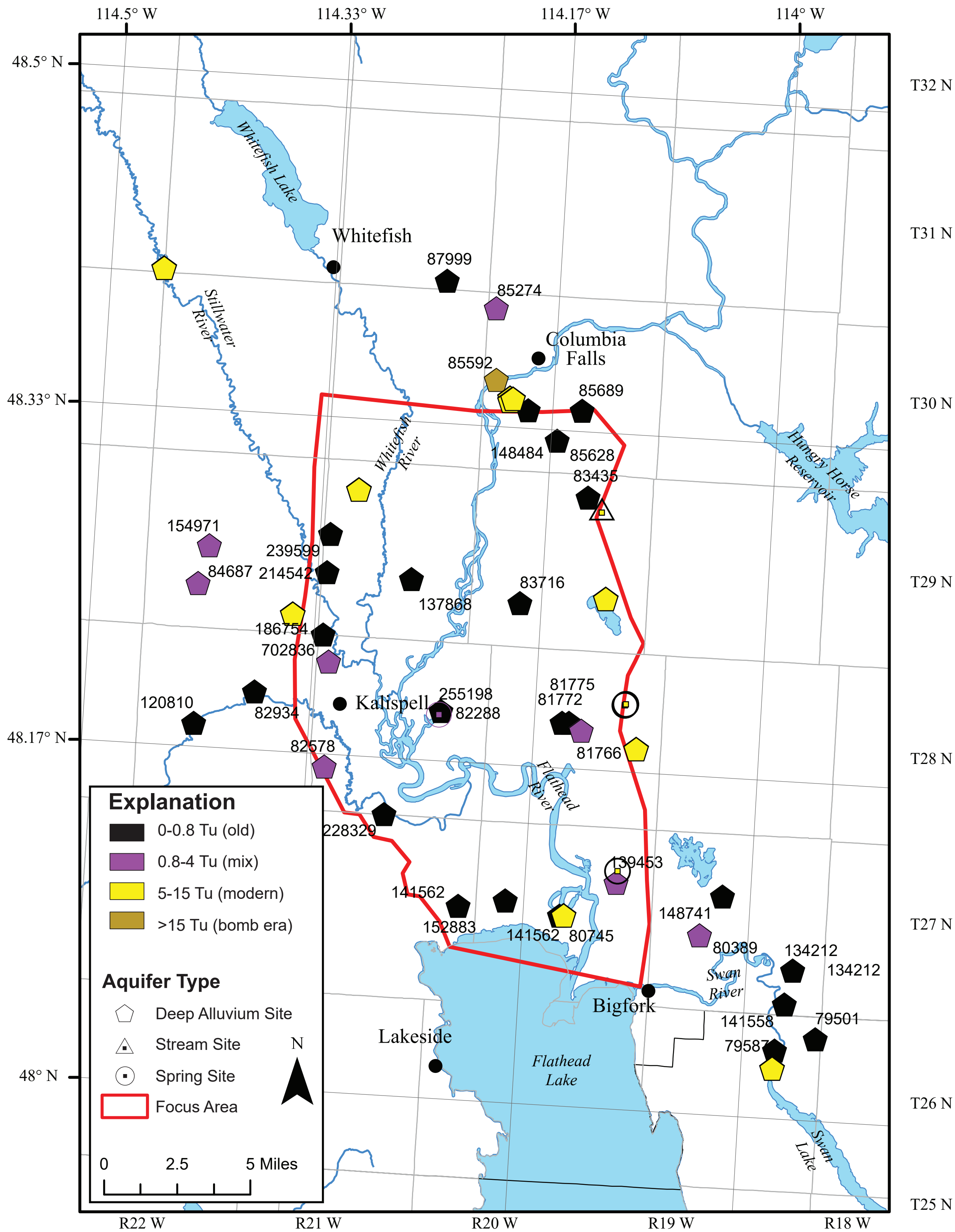

Figure 26. Tritium analyses indicate predominantly old water in the deep alluvial aquifer within the study area.

solved solids around 250 mg/L. Samples collected from nearby deep aquifer well 79501 (1,085 ft deep) has sodium–bicarbonate water quality and TU values consistent with old water, implying stratification or incomplete mixing of the aquifer. While the other four groundwater samples from the deep aquifer in this area of the Swan Valley have TU values that indicate old water, the presence of young water indicates that the modern precipitation recharges the deep aquifer at some locations and depths.

Overall, samples from wells completed in the deep aquifer are predominantly old water with no measurable tritium or a mixture of old water and some modern water (fig. 26). Well 80745 was sampled twice, resulting in two TU values: 7.12 (modern water) and <0.8 (old water; fig. 26). This well is 400 ft deep and near the center of the valley by Flathead Lake. The likelihood of modern groundwater recharging this site is low. However, a failure in the casing at a shallow depth could introduce modern water. This well could be resampled to determine repeatability of these conflicting results.

Nitrate

While concentrations are generally low, nitrate was detected in many wells completed in the shallow alluvial aquifer. Of the 19 sampled shallow-aquifer wells, 14 had measurable nitrate (73 percent); the highest concentration was 11.4 mg/L and the median value of those samples with detectable nitrate was 1.65 mg/L (detection limit varied from 0.05 to 0.5 mg/L). In contrast, of the 126 sampled deep-aquifer wells, 69 had detectable nitrate (54 percent). The highest concentration in the deep aquifer wells was 32.9 mg/L and the median value of those samples with detectable nitrate was 0.50 mg/L. For wells sampled multiple times, the highest result was included in these calculations. Elevated nitrate in the area is likely due to agricultural practices or septic systems. No samples had detectable amounts of nitrite, as is expected in most groundwater systems.

Nationally, background nitrate concentrations in groundwater are 1 mg/L, and concentrations that exceed this level may indicate nitrate contributions from human activities (Dubrovsky and others, 2010; U.S. EPA, 2021). Nitrate concentrations above background levels in the deep alluvial aquifer may indicate locations where nitrate-impacted shallow groundwater has migrated to the deep aquifer. Although outside of the focus area of this study, earlier work at a group of wells near Lost Creek Fan (fig. 27) showed elevated nitrate concentrations (LaFave and others, 2004). The lacustrine-till aquitard thins near Lost Creek Fan and the deep aquifer is nearer to the surface (Rose, 2018). The deep aquifer has greater vulnerability to contamination where the lacustrine-till aquitard is thin. Nitrate is very low or less than detection across most of the deep aquifer. In comparison to the Lost Creek Fan area, this indicates that the aquitard provides more protection from surface contamination, that less nitrogen is being added to the shallow aquifer, or that upward vertical hydraulic gradients prevent migration from the shallow system.

Organic Wastewater Chemicals

Organic wastewater chemicals are introduced to groundwater through septic and wastewater treatment. Because these chemicals are introduced from the surface and near-surface (e.g., septic systems), their presence in deep aquifers can indicate communication between shallow and deep aquifers.

Samples for organic wastewater chemicals were collected from five wells (fig. 9) completed in the deep aquifer. Thirty-two analytes were measured, including pharmaceuticals, plastics, and aromatic hydrocarbons (appendix E). Triplicate samples collected from well 148188 had measurable bisphenol A (BPA, a plastic) in two of the three samples. The two positive results, 12 and 15 ng/L, were above the reporting limit of 9.5 ng/L. Samples from wells 83538 and 84560 had measurable amounts of salicylic acid, 27 and 22 ng/L, respectively, values above the reporting limit of 19 ng/L. Salicylic acid is in pharmaceuticals (aspirin) and skincare products but also occurs naturally as a plant hormone. Tappenbeck and Ellis (2011) sampled the shallow aquifer for organic wastewater chemicals. Their results show wastewater compounds in shallow groundwater that we did not find in the five deep aquifer wells. During our study, the few detections of salicylic acid and bisphenol A in the deep wells suggests that at some locations, shallow groundwater reaches the deep alluvial aquifer.

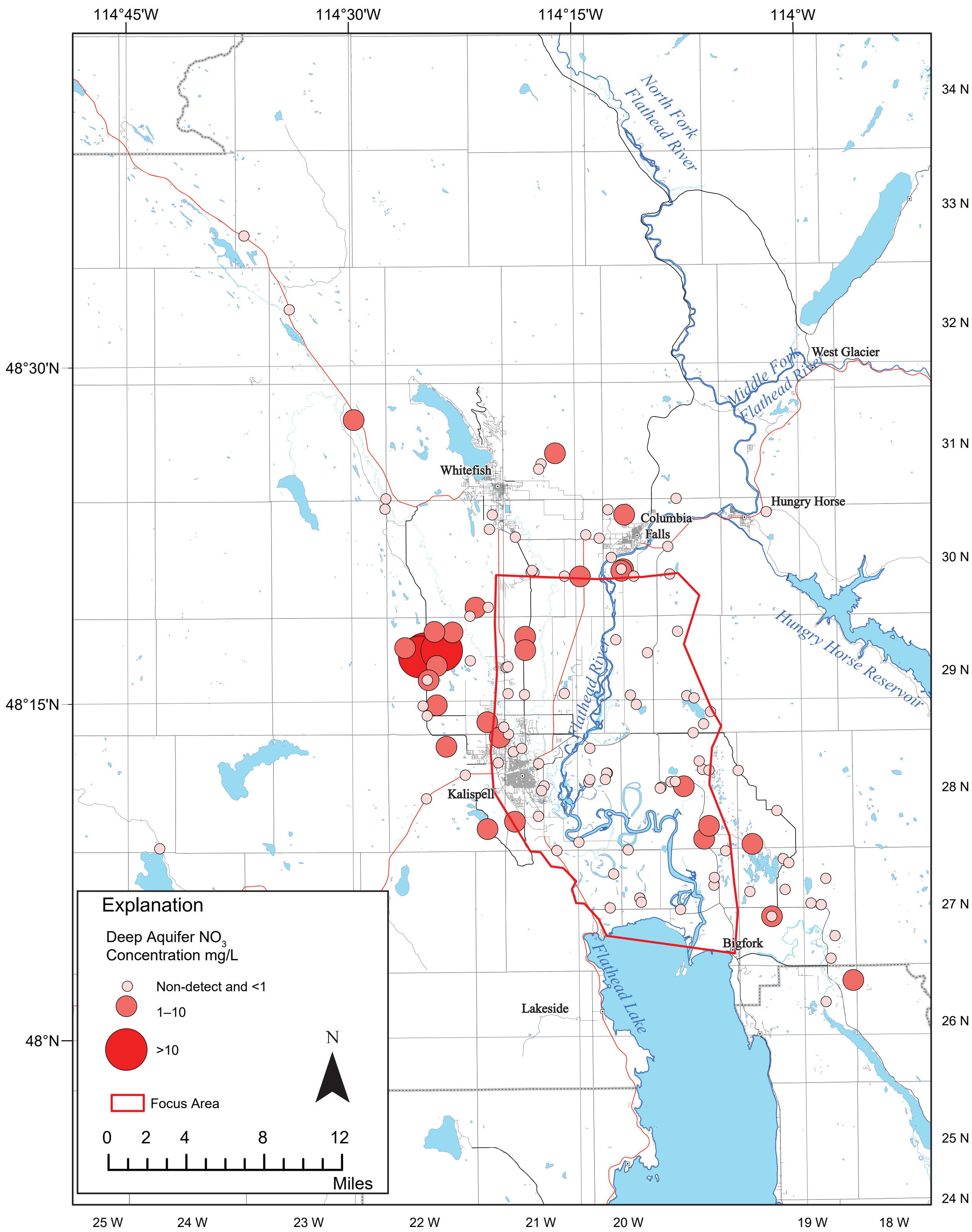

Figure 27. Several wells completed in the deep alluvial aquifer have nitrate concentrations that indicate some modern recharge flows to these wells.

SUMMARY

Aquifer Characteristics

The Flathead Valley deep alluvial aquifer underlies an area from the north shore of Flathead Lake to near Whitefish and Columbia Falls. The aquifer, composed of glaciofluvial sand and gravel, is overlain by a confining unit of glacial till and lake sediments. The deep aquifer is the most productive source of groundwater in the valley, supplying high-capacity municipal and irrigation wells in addition to thousands of domestic wells. Groundwater, primarily from the deep alluvial aquifer, supplies all domestic needs except those served by the public water supply at Whitefish, which relies on surface water. The largest users of water in the valley are public water supply systems and irrigators.

The top of the deep aquifer lies 100 to 790 ft below the land surface (Rose, 2018). The altitude of the bottom of the deep alluvial aquifer is not known because no wells have penetrated the base and remote sensing methods such as gravity measurements cannot differentiate between Pleistocene and Tertiary alluvial deposits. The maximum thickness of the aquifer penetrated by drilling is 500 ft (Rose, 2018). Total thickness estimates from previous work have ranged up to 1,000 ft (Alden, 1953).

The deep aquifer is heterogeneous in both spatial and vertical extent. Two aquifer tests completed by the MBMG for this study yielded transmissivity estimates of 35,000 and 17,000 ft^2/d, with storativities of 5.2×10^{-4} and 7.6×10^{-3}, respectively. Records compiled from a variety of sources report transmissivity values ranging from 100 ft^2/d to nearly 100,000 ft^2/d, with relatively lower values in the uppermost portion of the deep aquifer due to variations in silt and clay content in some areas.

The lacustrine-till aquitard overlies the deep alluvial aquifer throughout most of the study area. North of Kalispell the aquitard consists of clay to silt-sized lacustrine sediments overlying the poorly sorted clay-with-gravel till. The till is locally absent where sub-glacial troughs cut through the unit and into the deep alluvial aquifer. These troughs were filled by the overlying lacustrine sediments. South of Kalispell, the lacustrine-till aquitard contains some till at the bottom, but is dominated by fine-grained lacustrine lake deposits that appear to extend continuously under the north shore of the lake. Water can move vertically through the confining unit, but slowly, due to the low hydraulic conductivity (about 0.0007 ft/d). The aquitard appears to be present across most of the focus area, but it thins along the margins of the valley (Rose, 2018). Some storativity values from aquifer tests indicate unconfined condition in some areas.

The lacustrine-till aquitard generally protects the deep alluvial aquifer from contamination from surface sources. Detections of low concentrations of nitrate and trace concentrations of two wastewater compounds in deep alluvial aquifer wells, as well as tritium values consistent with young water, may indicate locations where some modern recharge reaches the deep aquifer.

Recharge and Discharge

Recharge to the deep alluvial aquifer primarily occurs along the valley edges as mountain front recharge. Snowmelt, precipitation, and streams enter fractures in the Belt bedrock on mountain slopes. Two young tritium dates, the steep gradient in the potentiometric surface, and stable long-term water levels in the east part of the focus area support the conclusion that recharge occurs along the Swan Range front. Our geologic model (Rose, 2018) suggests the lacustrine-till aquitard is present across most of the valley. The aquitard limits vertical infiltration of recharge to the deep aquifer within the focus area. Based on a map of vertical hydraulic gradients between the shallow and deep groundwater systems (fig. 24), we estimate less than 3,000 acre-ft/yr of groundwater recharges the deep alluvial aquifer in areas of downward flow across the aquitard.

Discharge from the deep alluvial aquifer in the focus area includes pumping (estimated at 20,000 to 40,000 acre-ft/yr) and upward vertical flux through the lacustrine-till aquitard (estimated at about 1,000 acre-ft/yr). Flathead Lake likely receives some groundwater discharge, based on the gradient between deep wells at the north end of the lake and lake stage. However, the volumetric flux from the deep aquifer to the lake is expected to be very low because the intervening aquitard is hundreds of feet thick with an estimated hydraulic conductivity of 0.0007 ft/d.

In addition to pumping and upward flux to the shallow system, groundwater discharge from the deep alluvial aquifer may include a component of groundwater flow out of the valley, as the potentiometric surface shows flow to the south (fig. 12). However, little is known about the geometry of the aquifer under, and to the south of, Flathead Lake. The low horizontal gradient in the aquifer between Kalispell and the lake suggests that aquifer transmissivity generally increases to the south. Although the subsurface interpretation presented in figure 5 suggests the thickness of the deep alluvial aquifer decreases to the south, the low gradient may be the result of an increase in hydraulic conductivity of aquifer sediment. The potentiometric surface map developed during the 1960s (Konizeski and others, 1968) is similar to that compiled for this study, indicating that drawdown related to increased pumping (discussed below), while observed in individual wells (table 5), is not evident at the map scale.

Seasonal and Long-Term Water-Level Trends

Water levels in the deep aquifer have an annual cycle of base levels, spring recharge, and summer pumping-induced drawdown. Through the winter and spring, groundwater levels return to, or near, pre-pumping levels at many wells (for example, fig. 20).

Many deep alluvial aquifer wells in the west and south of the valley show declining trends in groundwater levels from 1996 through 2017 (fig. 19). Water levels in the east half of the focus area did not show downward trends. Downward trends are as much as -1.4 ft per year in the Ashley Creek area. Precipitation data do not show a decrease during the period of record and therefore are not interpreted as the cause of groundwater-level declines.

Based on the increasing number of water rights and wells completed in the deep alluvial aquifer (fig. 7), we attribute the downward trend in water levels to pumping. This is supported by the timing of water-level decline in well 131524 (fig. 21). The period of record at this well dates back to the early 1960s, and shows the downward trend began in the mid-1970s.

Though the groundwater-level declines identified since 1996 are a small percent of available head, a decline in water levels represents a reduction in the volume of water in storage. Although effects to surface water from development of the deep aquifer have not been documented, the declines highlight the importance of continued monitoring at these wells.

The long-term data from the eastern half of the valley do not show downward trends in water level. Based on the density of water rights, this area experiences high pumping volumes, but there are not many long-term records from wells in this area (fig. 19). The proximity of this area to the Swan Range may result in these wells receiving more recharge than the western side of the valley. Drawdown from pumping may reach the recharge area near the mountain front and induce recharge, partially offsetting any change in storage caused by pumping.

RECOMMENDATIONS

Appropriate water management decisions can help balance conservation with utilization of the deep aquifer. These recommendations identify technical information useful to support aquifer management; however, to implement these recommendations and address future challenges, residents and local governments should consider the formation of a consolidated local water management organization. An example of a district formed through local government is the Lewis and Clark County Water Quality Protection District (Lewis and Clark County, 2022).

Long-term groundwater monitoring should be continued and possibly expanded in areas along the east side of the valley. The declining water levels identified in this report show the value of long-term data collection. The MBMG Ground Water Assessment Program both monitors and maintains data for many of these wells; however, local government entities or interested groups could expand these efforts. Some water quality and conservation districts partner with the MBMG to ensure data collection and data storage protocols result in credible and useful data sets over long time periods (decades).

The thickness of the deep aquifer and confirming its presence/thickness south of Flathead Lake should be determined, at least in a few key locations. The potential for deep aquifer discharge to Flathead Lake could be directly investigated using tracers such as radon or temperature.

A robust three-dimensional groundwater flow model should be developed for the valley. Many of the necessary model inputs were measured or derived during this study, including: lithologic characterization (Rose, 2018), water levels, vertical gradients, and hydraulic conductivity. The model will be a useful tool to evaluate potential consequences, if any, of the observed declines in groundwater levels and to forecast effects of additional groundwater pumping from the deep alluvial aquifer.

Protection should be considered for recharge areas along the mountain fronts where stream channel manipulation or land-use changes might decrease recharge to the deep aquifer. The southeast portion of the Flathead Valley, in the general area of Echo Lake, could not be addressed in detail during this project. A detailed project along the east side to further delineate recharge would be beneficial.

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