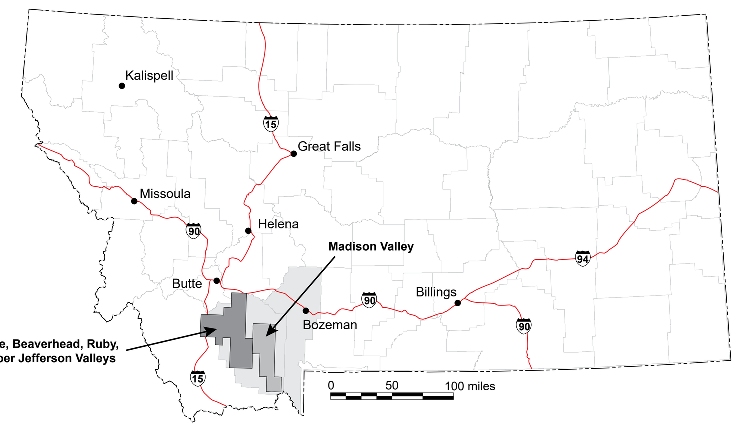
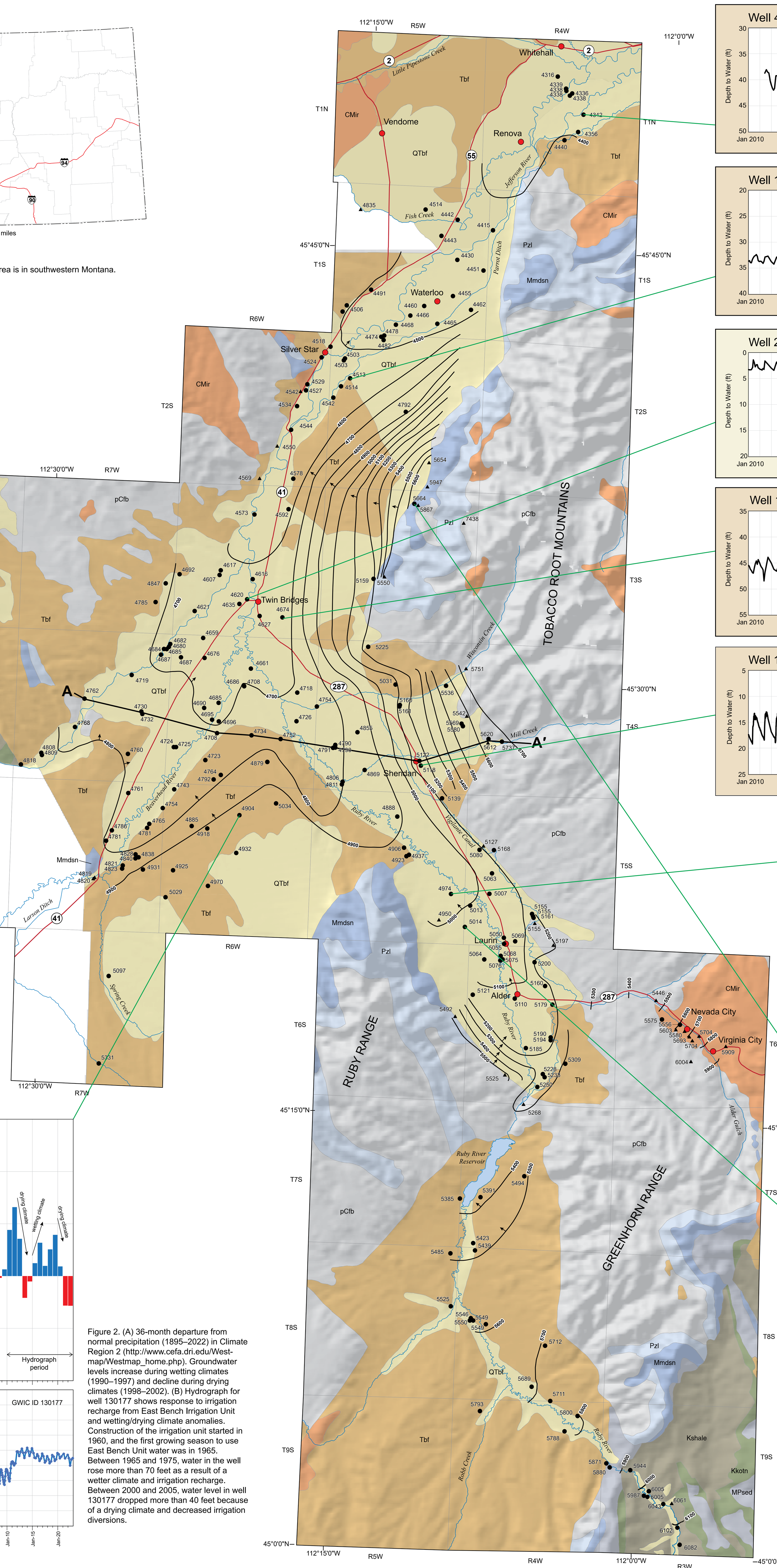
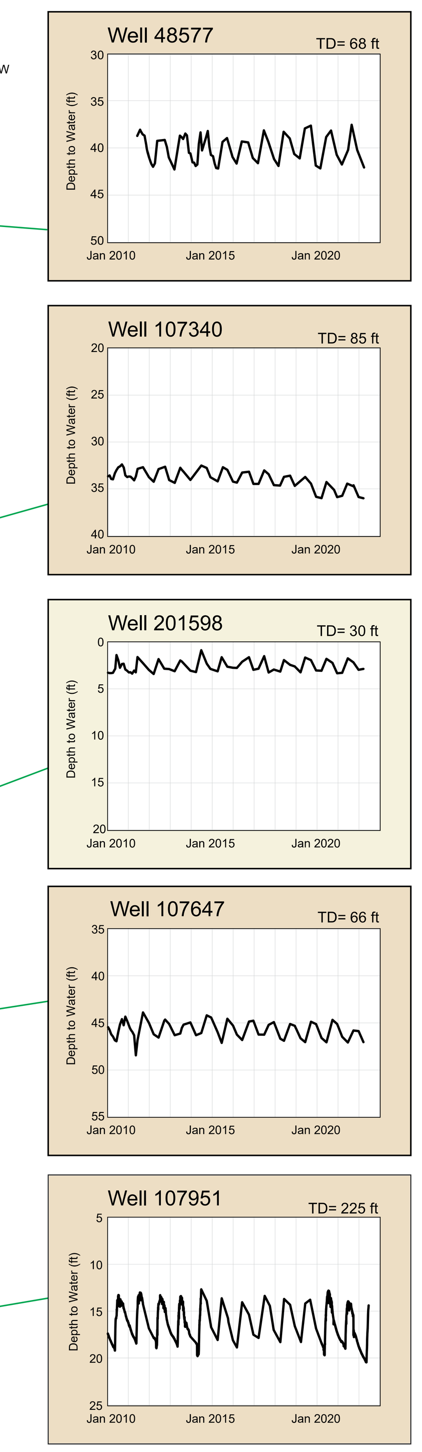


Figure 1. The Gallatin–Madison Groundwater Characterization Area is in southwestern Montana.



Big Hole, Beaverhead, Ruby, and upper Jefferson Valleys



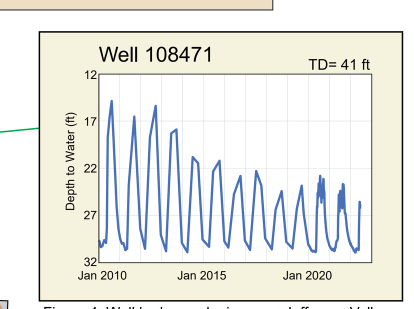


Figure 4. Well hydrographs in upper Jefferson Valley that reflect groundwater recharge from leaky irrigation conveyance structures (ditches, lateral, canals) and excess irrigation water to crops. Wells show higher water levels in the summer and fall and lower water levels in late winter/spring responding to irrigation recharge cycles.

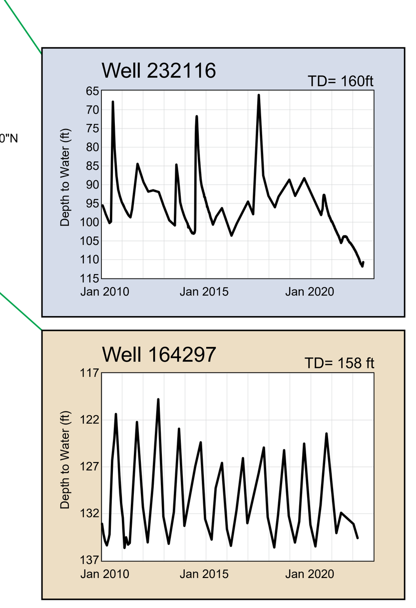


Figure 6. Well hydrographs in upper Jefferson Valley and major tributary valleys that reflect natural recharge sources and track climate trends. The hydrographs show a declining trend from 2010 to 2016, increasing from 2017 to 2019, and decreasing from 2020 to present. Wells show higher water levels in the summer and fall and lower water levels in late winter/spring, responding to natural recharge cycles.

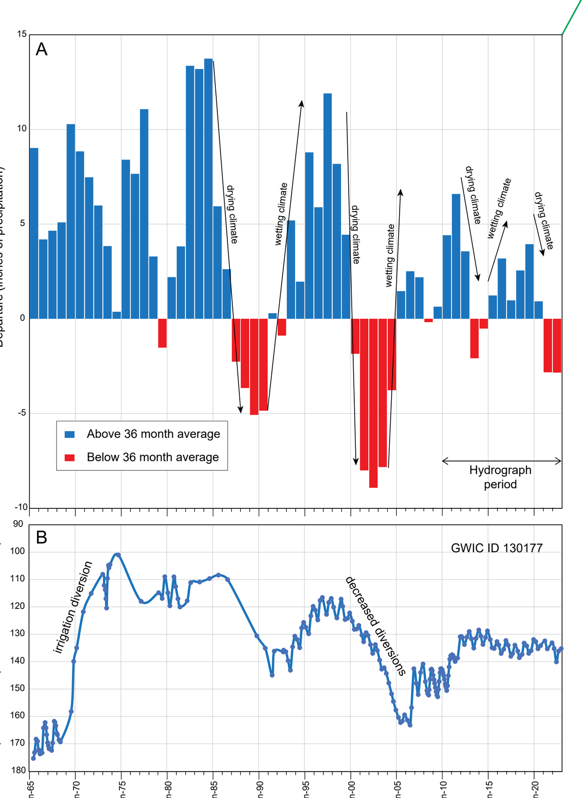


Figure 2. (A) 36-month departure from normal precipitation (1895–2022) in Climate Region 2 (http://www.cefa.dri.edu/Westmap/Westmap_home.php). Groundwater levels increase during wetting climates (1990–1997) and decline during drying climates (1998–2002). (B) Hydrograph for well 130177 shows response to irrigation recharge from East Bench Irrigation Unit and wetting/drying climate anomalies. Construction of the irrigation unit started in 1960, and the first growing season to use East Bench Unit water was in 1965. Between 1965 and 1975, water in the well rose more than 70 feet as a result of a wetter climate and irrigation recharge. Between 2000 and 2005, water level in well 130177 dropped more than 40 feet because of a drying climate and decreased irrigation diversions.

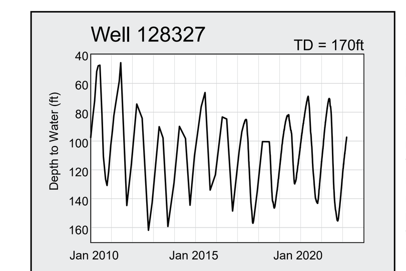
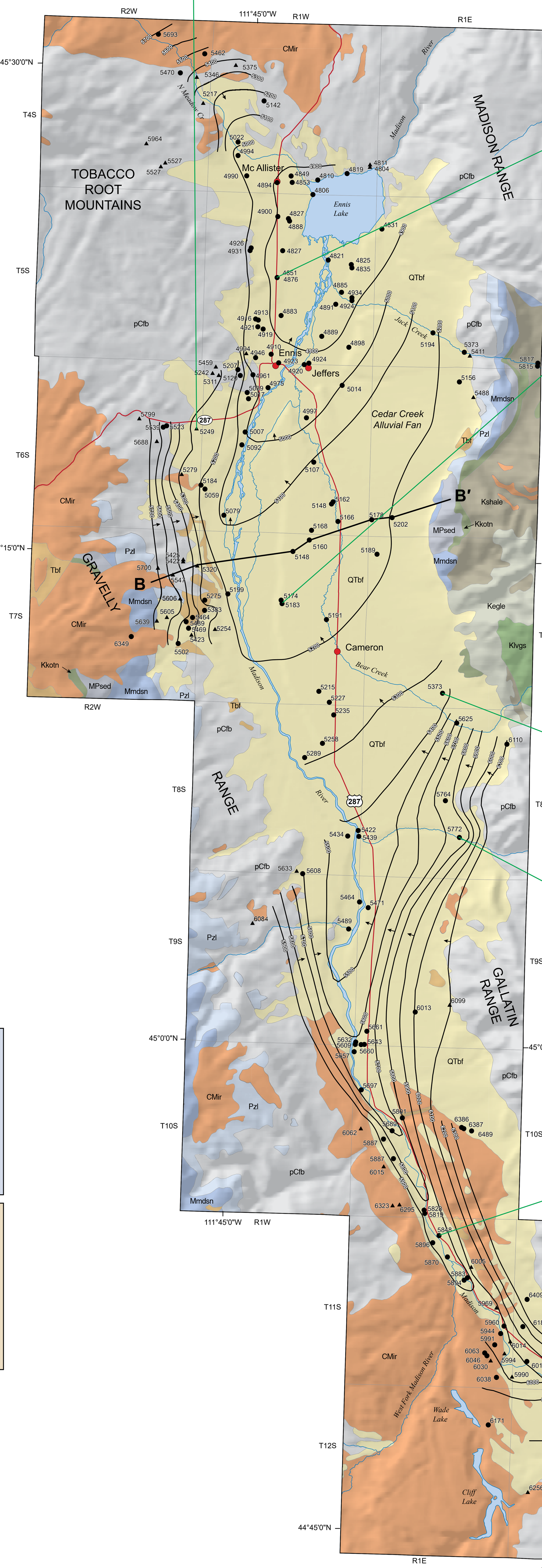


Figure 3. Water level in this well reflects local use from a bedrock aquifer with lower storage capacity and transmissivity than the subjacent sand and gravel basin-fill aquifer. About 8 mi^2 of land have been subdivided into several hundred lots, and about 200 residences individually withdraw water for domestic purposes. Most of the year, withdrawn groundwater is returned to the aquifer via the septic system and consumptive use is minimal. During summer months, many of the residences irrigate their lawns and most of the withdrawn water for lawn irrigation is consumed by the plants or evaporated. The water levels in the wells decline with the initiation of the irrigation season and continue to decline until the end of irrigation season in early fall. From fall to the next irrigation season, water level rises until the start of the next irrigation season. Compare with figures 6 and 7.



Madison Valley

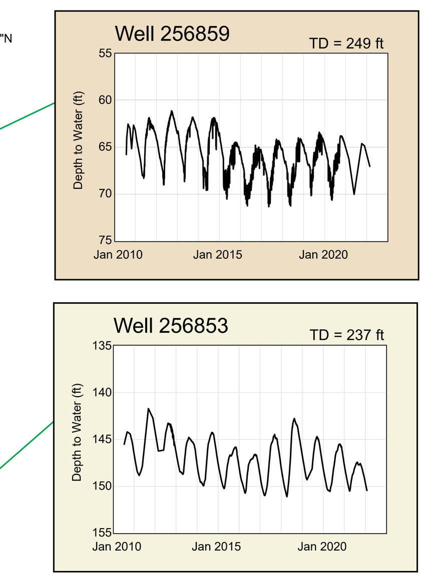
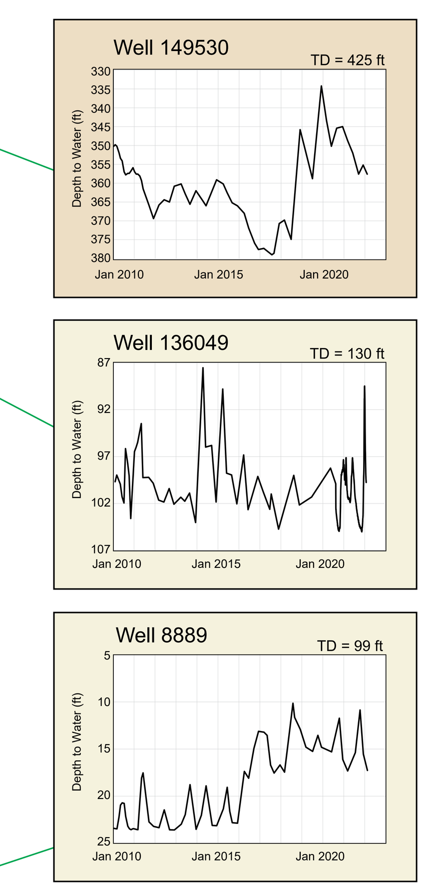


Figure 5. Well hydrographs in Madison Valley that reflect groundwater recharge from leaky irrigation conveyance structures (ditches, lateral, canals) and excess irrigation water to crops. Wells show higher water levels in the summer and fall and lower water levels in late winter/spring, responding to irrigation recharge cycles.



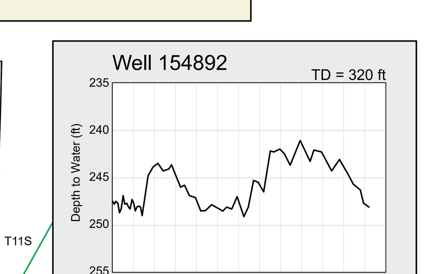


Figure 7. Well hydrographs in Madison Valley that reflect natural recharge sources and track climate trends (fig. 6). The hydrographs show a declining trend from 2010 to 2016, increasing from 2017 to 2019, and decreasing from 2020 to present. Wells show higher water levels in the summer and fall and lower water levels in late winter/spring, responding to natural recharge cycles.

0 2.5 5 10 Miles
0 2.5 5 10 Kilometers
Scale 1:150,000

Legend

- Town
- Road
- Stream

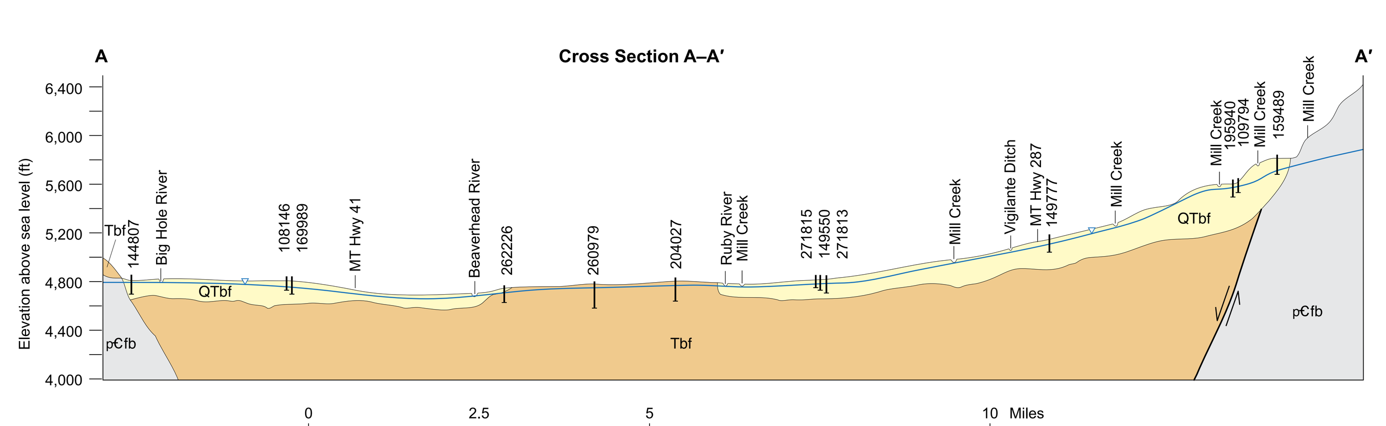
Inventoried well and measured altitude of water in feet above mean sea level.

- 4762 Basin-fill well
- 4792 Fractured-bedrock well

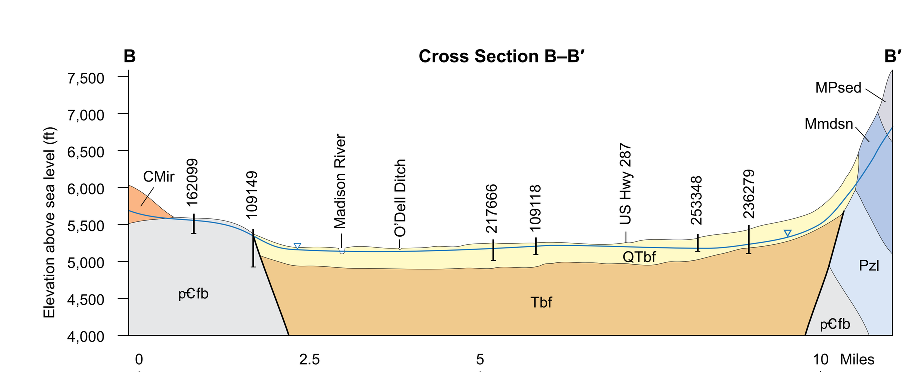
Generalized Potentiometric Contour—Shows altitude at which water would have stood in tightly cased well. Dashed where approximately located. Contour interval 100 ft. Datum is mean sea level. Arrow shows direction of groundwater flow.

Projection: NAD 1983 Lambert Conformal Conic

Cross Section A–A'



Cross Section B–B'



Hydrogeologic Framework

Regional Aquifers[1] | Regional Confining Units[2]

Unconsolidated to weakly consolidated basin-fill. Lenticular beds of clay, silt, sand, gravel. QTbf and Tbf are inter-connected and function as a valley-fill aquifer system.
- QTbf Cenozoic Basin-Fill/Alluvial Aquifer
- Tbf Tertiary Basin-Fill

Cretaceous sandstone beds within Kootenai, Eagle, and Fort Union Formations. Primary porosity and permeability in combination with secondary permeability along fractures.
- Kegle Cretaceous Eagle Aquifer
- Klvgs Cretaceous Livingston Group
- Kshale Claggett Fm
- Kkotn Cretaceous Kootenai Aquifer
- Kshale Colorado Group

- CMir Cenozoic and Mesozoic Igneous Rocks

Fractured bedrock with mostly secondary porosity and permeability along fractures and/or solution cavities.
- MPsed Mesozoic–Paleozoic Sedimentary Rocks
- Mmdsn Mississippian Madison Group Aquifer
- Pzl Lower Paleozoic Sedimentary Rocks
- pCfb Precambrian Fractured Igneous, Metasedimentary, and Metamorphic Rocks

Modified after Crowley and others, 2017. [1]Aquifer where saturated with water. [2]Locally may yield water to sandstone.

Maps may be obtained from:
Publications Office
Montana Bureau of Mines and Geology
1300 West Park Street
Butte, Montana 59701-8997
Phone: (406) 496-4167
http://mbmg.mtech.edu

Potentiometric Surface in the Madison, Upper Jefferson, Beaverhead, Big Hole, and Ruby River Valleys within Madison County, Southwest Montana

James P. Madison
2023

Author's Note: *This map is part of the Montana Bureau of Mines and Geology (MBMG) Groundwater Assessment Atlas for the Gallatin–Madison Area groundwater characterization. It is intended to stand alone and describe a single hydrogeologic aspect of the study area, although many of the area's hydrogeologic features are interrelated. For an integrated view of the hydrogeology of the Gallatin–Madison Area, the reader is referred to the other maps of Montana Groundwater Assessment Atlas 8. (http://mbmggwic.mtech.edu).*

Introduction

The map area covers parts of Madison County (fig. 1) and is characterized by intermontane basins delineated on the basis of topography. The basins generally trend north–northwest, encompass perennial streams with broad floodplains, and are bounded by mountain ranges. The basins contain several thousands of feet of unconsolidated to semi-consolidated Quaternary and Tertiary basin-fill deposits that form the major aquifer systems in the study area. The surrounding mountains consist of older sedimentary, igneous, and metamorphic rocks that also occur at depth below the basin-fill. Groundwater in the bedrock is contained in interconnected joints, fractures, and other forms of secondary porosity that serve as conduits for groundwater movement. (Briar and Madison, 1992; Kendy and Tresch, 1996; Thamke and Reynolds, 2000; Waren and LaFave, 2011). Water (fig. 2B) that infiltrates into the fractured bedrock percolates downward and then moves laterally outward from the mountains to the valleys. The lateral subsurface movement of groundwater to the valleys is a source of recharge to basin-fill aquifer systems. This map depicts the potentiometric surface for the unconsolidated basin-fill aquifer system and margins of the fractured-bedrock aquifer system in (1) the Madison, and (2) the upper Jefferson, Beaverhead, Big Hole, and Ruby River Valleys within Madison County (fig. 1). The Gallatin Valley potentiometric surface is presented in Madison (2022).

Potentiometric Surface

A potentiometric surface represents the altitude to which water levels rise in wells completed in an aquifer; it is useful for determining the general direction of groundwater flow and estimating depth to water at a given location. The potentiometric surface is generally a subdued representation of the regional topography; the highest groundwater altitudes coincide with the regional topographic highs and the lowest altitudes with the regional topographic lows. Groundwater flow is generally perpendicular to potentiometric contours from higher to lower altitudes. In this area, flow is away from mountainous recharge areas (regional topographic highs) towards and parallel to the major surface drainages (regional topographic lows). The potentiometric surface altitude at a site may be subtracted from the land-surface altitude at that location to yield depth to groundwater estimate.

Groundwater Fluctuations

Groundwater levels fluctuate in response to groundwater withdrawals (fig. 3), anthropogenic causes such as land use (figs. 4, 5), and natural causes (figs. 6, 7) such as wet or dry climate anomalies (Madison, 2016, 2022); (fig. 2). The fluctuations occur at seasonal, annual, or multi-year frequencies and provide insights on groundwater recharge and stresses acting on aquifers. Long-term (10+ year) hydrographs for 16 wells are included on the map to show representative groundwater-level fluctuations. Across the map area, annual groundwater fluctuations range up to 45 ft. There are two typical fluctuation patterns, and each reflect different recharge sources: (1) a "natural" pattern that reflects seasonal and interannual climate variability, and (2) an "irrigation" pattern that reflects recharge from leaky irrigation canals and excess infiltrating irrigation water not consumed by crops.

The natural (un-irrigated) pattern shows water levels generally rising in spring and early summer in response to snowmelt and increased precipitation, and then declining during the late summer and fall, reaching seasonal lows in the winter months (fig. 6 for wells in the Jefferson Valley and fig. 7 for wells in the Madison Valley). Extended droughts or wet periods manifest as multiyear water-level declines or increases (figs. 2, 6, 7).

The irrigation response is characterized by water levels rising sharply at the beginning of the irrigation season, in late spring (fig. 4 for wells in the Jefferson Valley or fig. 5 Madison Valley). Water levels remain elevated (a blunt peak or plateau) during the summer months while irrigation is ongoing, and sharply decline when irrigation water is "turned off." Water-level decline persists until the next irrigation period begins in the spring of the following year. The timing and magnitude of water-level fluctuation is consistent from year to year, reflecting irrigation practices.

Well 130177 in the Beaverhead Valley (fig. 2B) was installed to assess groundwater conditions prior to the installation of the East Bench canal; the canal delivers irrigation water from Clark Canyon Reservoir to about 50,000 acres of land including a terrace (the East Bench) flanking the Beaverhead River (Rogers, 2008). The long-term record from this well documents the significance of leakage from irrigation diversions (canals and excess irrigation water) to the groundwater system. With the onset of irrigation on the East Bench in 1965, the static water level in well 130177 rose about 70 ft (fig. 2A). The subsequent water-level response shows the annual irrigation cycle, in addition to multi-year increasing and decreasing trends caused by wetting and drying climate cycles (fig. 2B). During the drought of the early 2000's, irrigation diversions were severely diminished; in 2004 no water was diverted and the water level in 130177 approached pre-canal levels. Water levels recovered with the resumption of diversions in 2005.

Long-term hydrographs (figs. 3–5) do not show declining trends. In the Jefferson Valley near Whitehall, Bobst and Gebril (2021) documented land-use changes and conversion from flood to sprinkler irrigation that could alter groundwater recharge. Hydrograph for well 108471 is similar to well hydrographs on the Burton Bench where irrigation was converted from flood to sprinkler irrigation (Madison, 2004); because sprinkler irrigation is more efficient than flood, recharge is less and the hydrographs peaks are less than peaks when flood irrigating. Although such changes may cause decreased groundwater recharge, these hydrographs demonstrate that water levels have not changed appreciably over the past decade.

Map Construction

These maps are based on about 500 measured water levels gathered during site visits between January 2008 and December 2012, and water levels collected as part of the long-term statewide groundwater monitoring network (Carstarphen and others, 2015). Although the data were collected over a 4-year period, the long-term hydrographs for wells completed in the basin-fill and surrounding bedrock do not show changes or trends over that time period that would affect the configuration of the potentiometric contours, or introduce noticeable error in interpretation at the scale and contour interval presented.

This potentiometric surface map is a general interpretation of regional conditions and groundwater flow directions. Readers interested in site-specific interpretations should re-evaluate the data with an appropriate contour interval.

Water-level measurements and other site information are available from Montana Bureau of Mines and Geology's Ground Water Information Center (GWIC) database, http://mbmggwic.mtech.edu.

Acknowledgments

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