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GROUNDWATER RECHARGE IN FLOOD TO PIVOT IRRIGATION CONVERSIONS

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INTRODUCTION

The economic and conservation benefits of pivot irrigation are convincing many Montana irrigators to install sprinkler irrigation systems. Such systems allow for more precise management of water and require significantly less operator time and labor. However, an unintended consequence of converting flood-irrigated agricultural land to sprinkler irrigation can be reduced aquifer recharge. Many rural residents rely on irrigation-recharged groundwater for their domestic water supply and reduced recharge may also impact baseflow to streams.

For this project, groundwater-level data were collected from three fields in Yellowstone and Carbon Counties undergoing irrigation method changes (fig. 1). Each site and aquifer are unique, but they all receive recharge through infiltration of irrigation water.

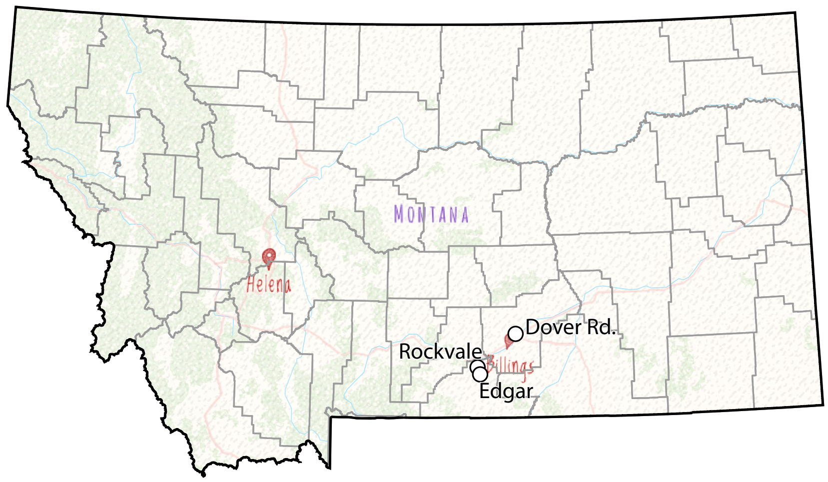

Figure 1. The Montana Bureau of Mines and Geology has instrumented three field sites in south-central Montana to measure the groundwater response where flood irrigation is being replaced by pivot irrigation.

DOVER ROAD SITE

The Dover Road site is located in the Yellowstone River Valley near Billings, Montana (fig. 2). Four monitoring wells were installed in the alluvial sand and gravel aquifer, with total depths ranging from 26 to 45 feet. The wells were positioned to monitor groundwater levels beneath flood- and pivot-irrigated fields that undergo crop rotations of sugar beets, barley, and corn. A control well was positioned in a field that remained under flood irrigation (well 297630). Figure 2 shows the extent of the center pivot that was installed in 2019 (outlined in orange). Flood irrigation through gated pipes is still used on the other fields (gated pipe locations are shown as blue lines on fig. 2).

Water levels measured before irrigation began in 2019 were used to map the groundwater flow direction, which is east–southeast toward the Yellowstone River. The highest water levels are where the ephemeral Sevenmile Creek enters the valley near well 297631, indicating stream loss recharging the aquifer (fig. 3). A constructed underground drain (e.g., a tile or French drain) passes near well 297633, which may be why the groundwater response to recharge is more muted than in nearby wells (fig. 3).

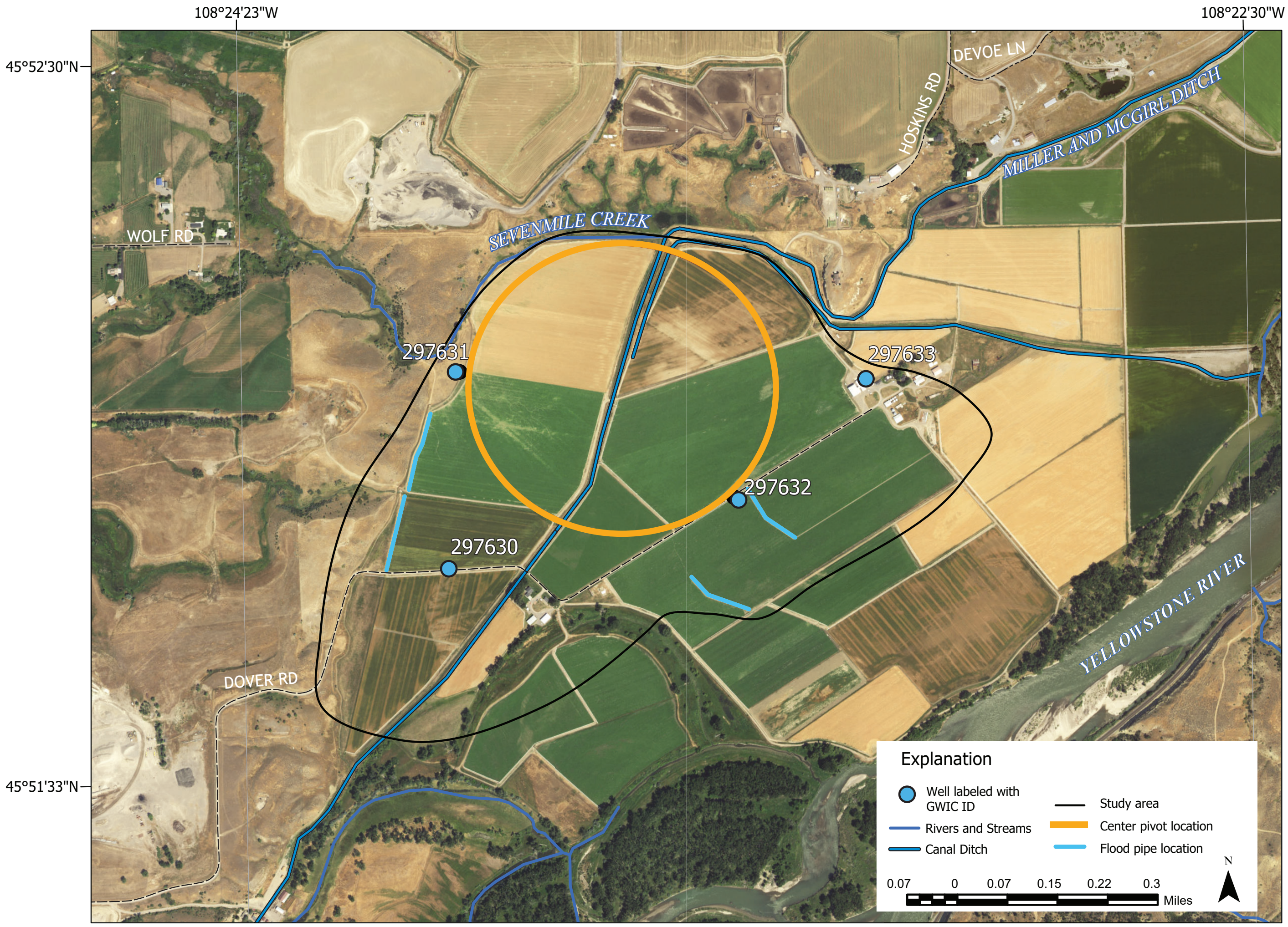

Figure 2. The center pivot at the Dover Road site was installed in 2019; the other fields in the study area remain under gated-pipe irrigation. The groundwater flows southeast toward the Yellowstone River.

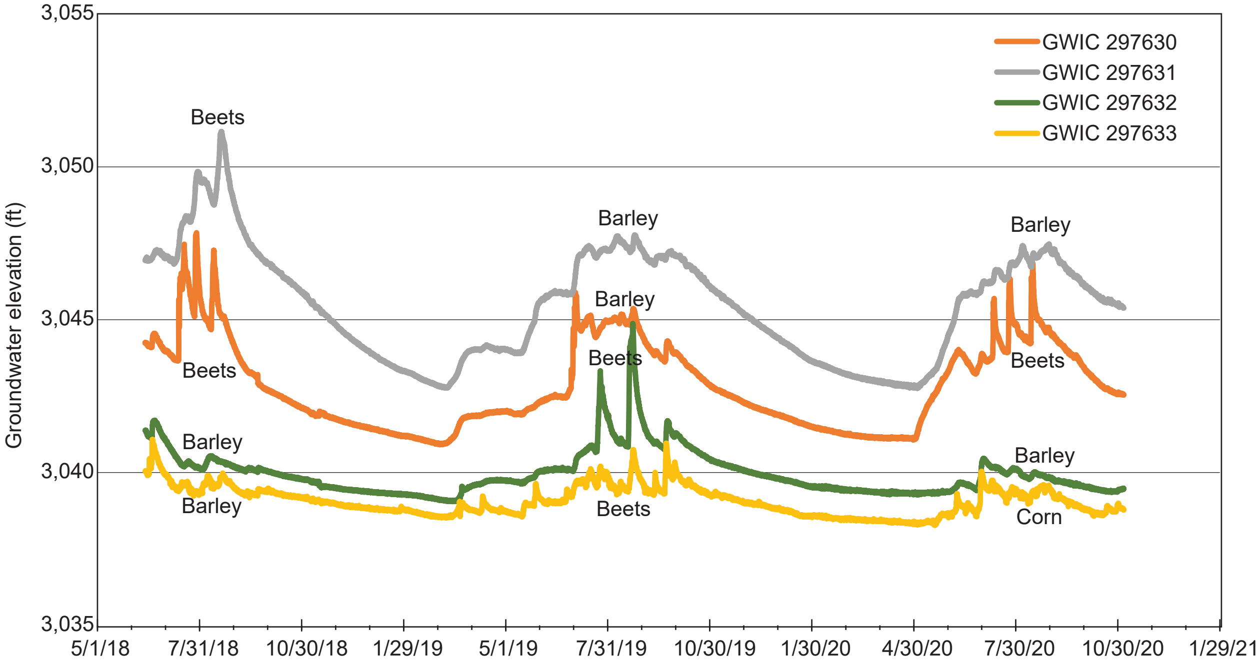

Figure 3. Groundwater levels are controlled by the timing and volume of irrigation applications specific to each crop type.

The hydrographs for all the wells (fig. 3) shows continuous water-level elevations for 3 years (2018–2020) under different irrigation methods and crop rotations. The difference in timing and duration of irrigation application for the three crop types is evident in the groundwater response. The greatest water-level fluctuations occur during beet rotation; groundwater below fields cultivated in sugar beets show three distinct spikes in response to separate applications of irrigation water. In contrast, groundwater levels below fields cultivated in barley and corn are relatively stable during the irrigation season. No difference in groundwater elevation was observed after the center pivot was installed in 2019, indicating this conversion has not measurably affected the aquifer.

This project illustrates how crop-specific irrigation practices can alter groundwater recharge. In this setting, the conversion from flood irrigation and center pivot irrigation did not significantly impact groundwater levels because of other factors influencing recharge, such as subsurface flow from Sevenmile Creek and constructed underground drains.

EDGAR SITE

The Edgar site (fig. 4) includes monitoring wells installed in the alluvial sand and gravel aquifer with total depths ranging from 37.5 to 63.5 feet. The pivots highlighted on figure 4 were installed in 2017 and 2020 and use water from the East Elbow ditch.

Water levels measured before irrigation began in spring 2019 were used to determine the groundwater flow direction, which is northeast toward the Clarks Fork River. Continuous water-level measurements show the flood-irrigation and pivot-irrigation water-level responses (fig. 5). Groundwater levels indicate recharge is predominantly from infiltration of flood irrigation and ditch leakage (fig. 5). The upward adjacent pastures were recently removed from flood irrigation, and East Elbow Ditch is transporting minimal water (oral communication, M. Robertus, November 29, 2023); both changes result in less groundwater recharge. The alluvial groundwater response near East Elbow Ditch (fig. 6) illustrates the important role ditch leakage and flood infiltration have on groundwater recharge. The water levels respond closely to the ditch stage; years with higher groundwater levels correspond to years with higher ditch stage, indicating that ditch stage is an important control on groundwater recharge.

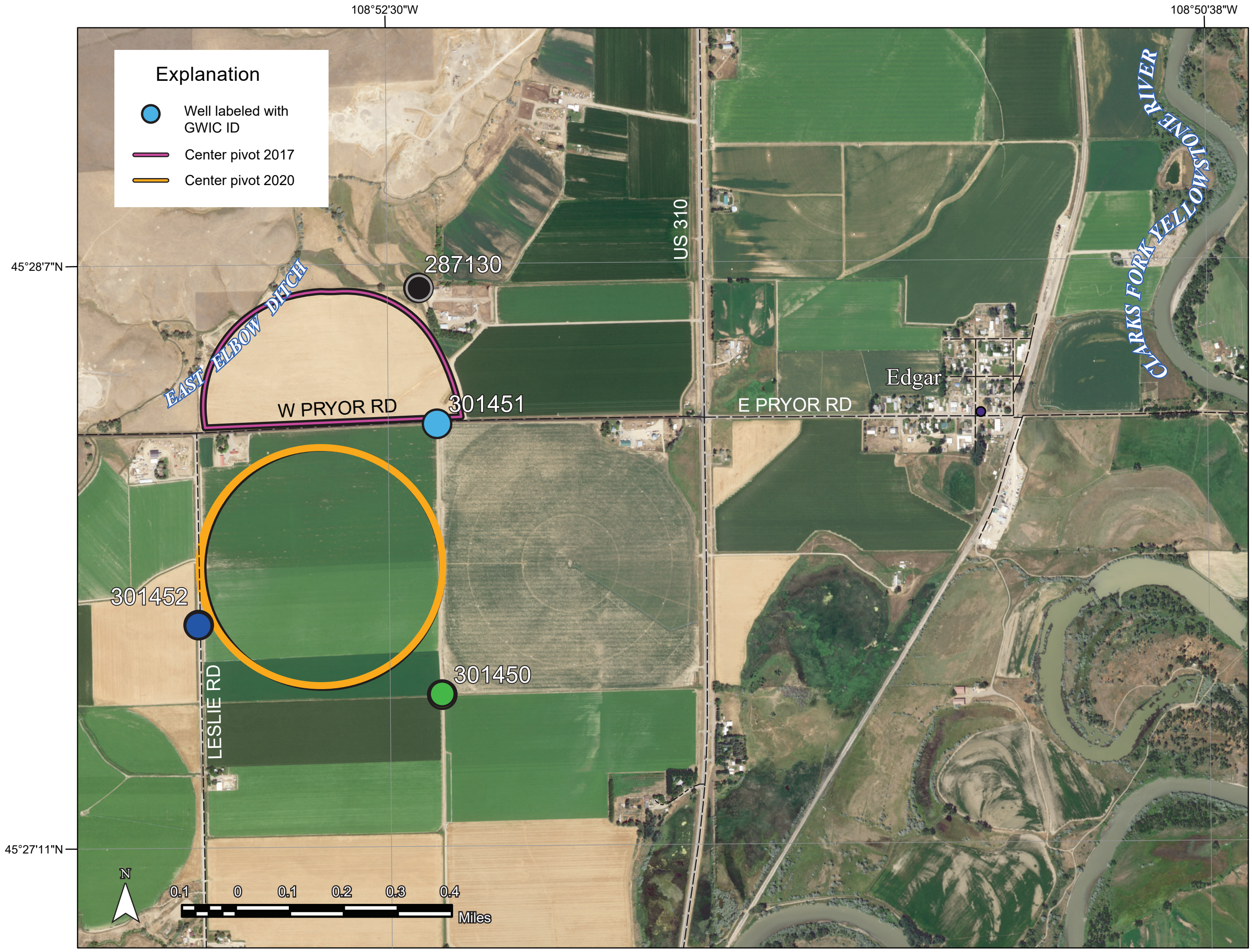

Figure 4. Edgar site location map. Groundwater flow direction is towards the Clarks Fork River.

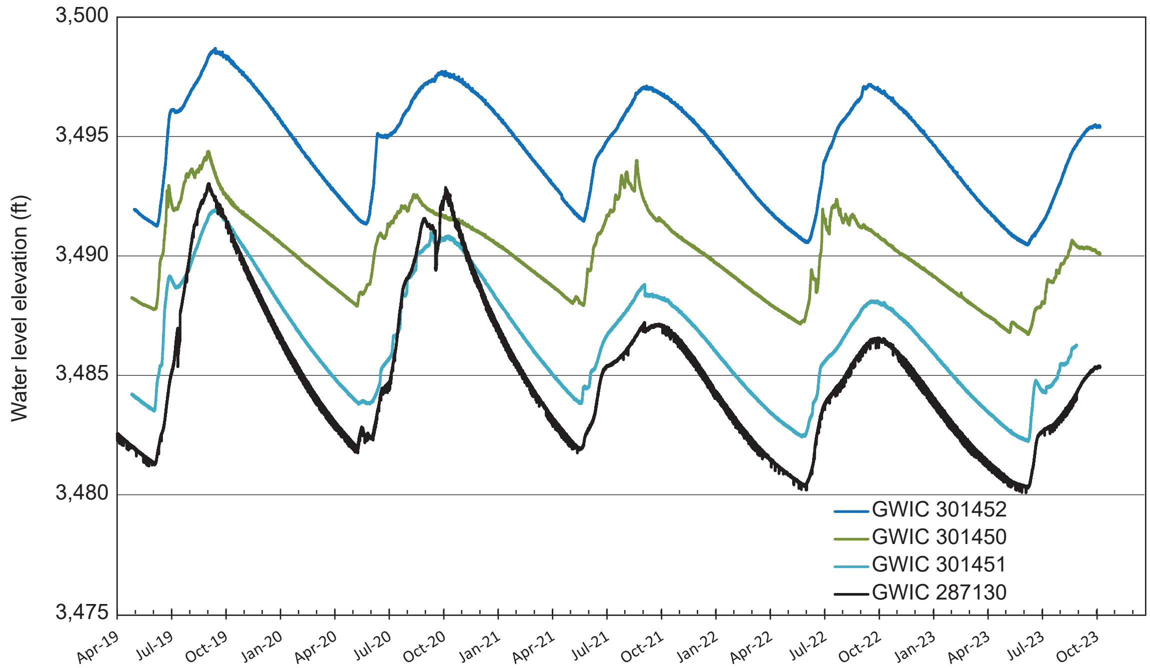

Figure 5. Groundwater levels show a yearly irrigation response and some have a declining trend.

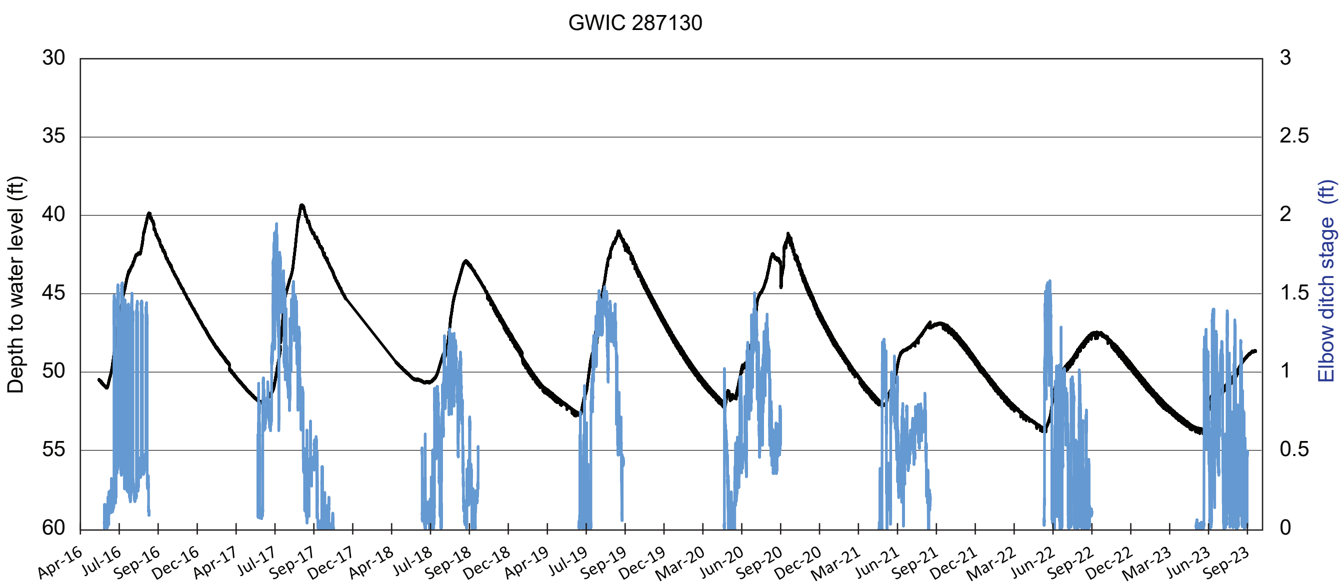

Figure 6. The groundwater near East Elbow Ditch responds annually to the presence of water in the ditch. The recharge to the aquifer appears to depend on the stage in the ditch. The fuller the ditch, the more recharge to the aquifer.

ROCKVALE SITE

Monitoring wells were installed near farm fields about 1 mile south of Rockvale, Montana (fig. 7) to assess the impact of conversion from flood to center pivot irrigation and to determine the thickness of the underlying alluvial aquifer; thicker alluvial material can potentially store more groundwater. The well depths ranged from 25.5 to 61.5 feet deep, and the depth generally increased from west to east towards the Clarks Fork of the Yellowstone River.

Groundwater at the site flows northeast towards the river, and groundwater levels were measured in most wells beginning 1 year before and 3 years after the pivot installation (fig. 7). Groundwater levels show distinct seasonal patterns that reflect irrigation timing (fig. 8). The amount of seasonal fluctuation seems to depend on proximity to recharge/discharge sources such as flood-irrigated fields, leaking irrigation canals, or constructed, underground drain systems. Figure 8 compares 4 years of water levels measured in four monitoring wells. The two wells downgradient from the pivot (307748 and 307749) show the water levels dropped in response to the conversion from flood to pivot irrigation in 2021 (fig. 8). The seasonal water-level peaks were lower in years with pivot irrigation, but the seasonal lows were mostly consistent. The two wells upgradient of conversions (313444 and 307747) show consistent water-level patterns year to year, unaffected by the conversion (fig. 8). Precipitation events are a minor component of recharge; the dominant recharge source is upgradient irrigation (fig. 9).

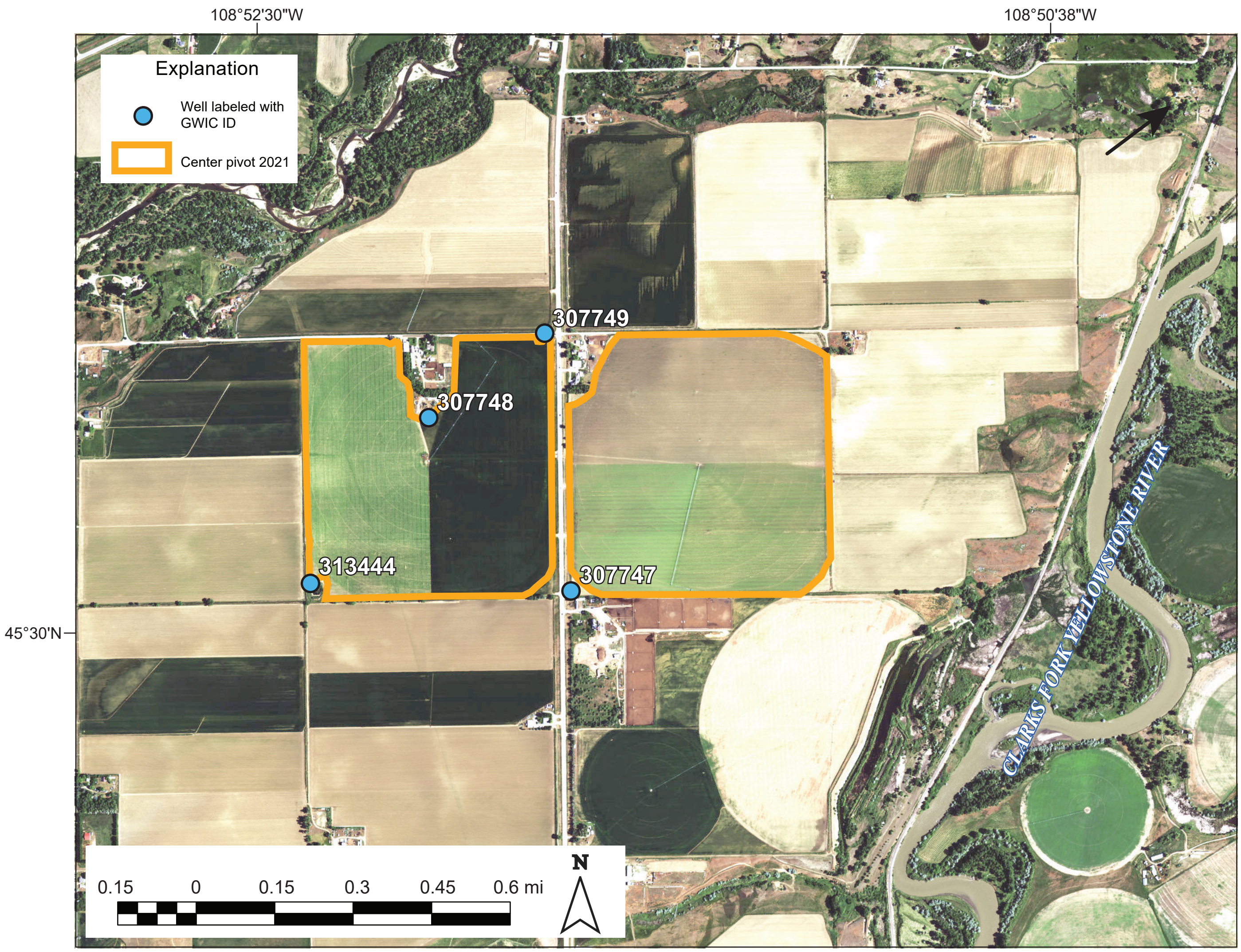

Figure 7. South of Rockvale, pivots were installed in 2021, The groundwater flow direction is towards the Clarks Fork River.

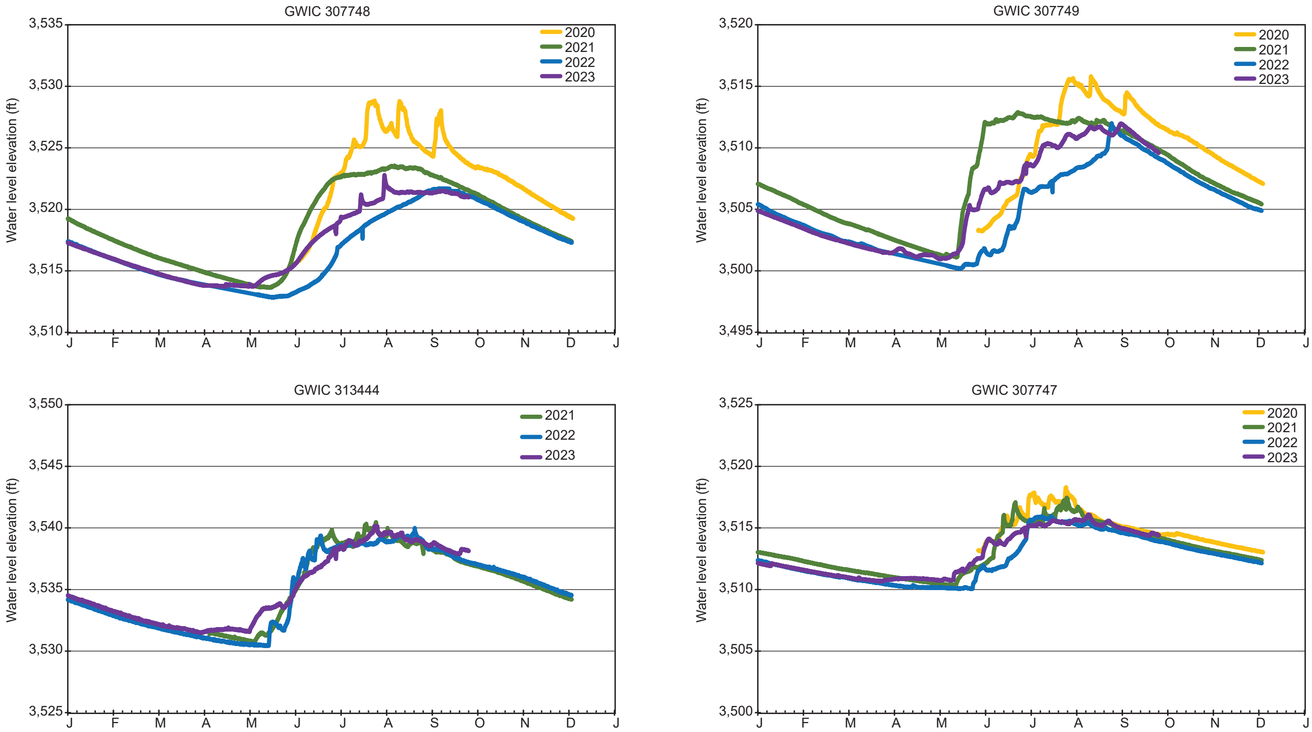

Figure 8. Water-level data over 4 years shows a decreasing water-level trend in wells downgradient from pivot irrigation.

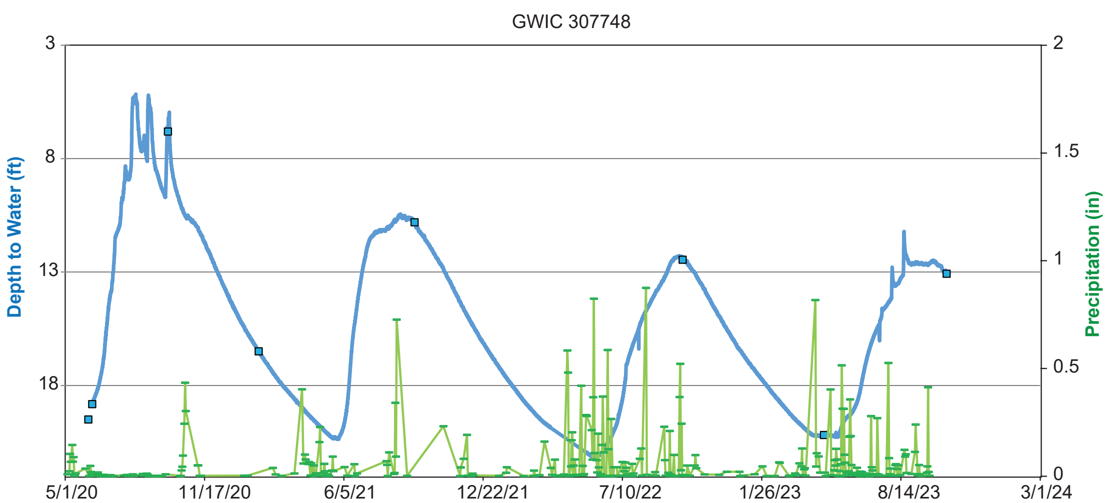

Figure 9. The yearly water-level pattern shows only slight responses to precipitation and that irrigation is the dominant recharge source. The decreasing seasonal, high-water level shows a response to changing irrigation practices.

Soil moisture was estimated using a Browns tool for a range of depths up to 3 feet below flood- and pivot-irrigated fields. The soil moisture was estimated by a feel technique developed by Texas A&M AgriLife Research (https://sanangelo.tamu.edu/extension/agronomy/agronomy-publications/how-to-estimate-soil-moisture-by-feel). The soil moisture of the flood-irrigated field was measured at 3 feet from the outflow of the irrigation pipe and halfway down the field. Generally, the soil moisture under the flood field was categorized as “at field capacity” to a depth of at least 3 feet. Soil below the pivot-irrigated field was measured along the length of the pivot arm and varied from “at field capacity” near the surface to “50 percent or less” of field capacity at depth (fig. 10).

Figure 10. The Browns tool can collect soil moisture up to 3 feet deep.

CONCLUSIONS

Over the course of the study, groundwater levels were measured in surficial alluvial aquifers beneath three different irrigated fields experiencing conversion from flood to pivot irrigation, and near irrigation ditches that conveyed varying amounts of water each year as measured by stage. The results indicate that the aquifer recharge in these settings is sensitive to changes in irrigation practices and the stage of water in the ditches.

The shallow alluvial system at the Dover Road site responded to the crop-specific irrigation practices. Different crops have different water needs and excess applied irrigation water can recharge the aquifer. Water levels under fields cultivated with sugar beets, which can require more water than the other crops in the field rotation, showed greater seasonal fluctuations.

At the Edgar site, the groundwater-level changes reflect the water stage in upgradient East Elbow Ditch and removal of flood irrigation in upgradient fields. In years when the ditch stage is kept full throughout the irrigation season, the aquifer has maximum time for recharge. However, in recent years, when the stage has been low or dry for part of the season, groundwater levels were lower, indicating less recharge. At this location, ditch leakage and upgradient flood irrigation appears to be the main aquifer recharge source.

South of Rockvale, the alluvial aquifer thickens towards the Clarks Fork of the Yellowstone River, which allows more aquifer storage. The wells downgradient from the pivot show the water levels dropped in response to the conversion from flood irrigation to pivot irrigation. Wells upgradient of conversions show similar water-level patterns year to year, unaffected by the conversion.

RECOMMENDATIONS

When selecting fields for pivot irrigation, irrigators should consider the local hydrogeology. The location of nearby water-supply wells (e.g., domestic or stock), groundwater flow direction, and recharge sources should be identified, as groundwater supply could be reduced in sensitive areas.

Ditch managers should consider running water in ditches early in the season, while water is abundant, and as late into the season as possible, given limitations of water rights and stream stage. Ditch leakage can be a constant source of recharge to the aquifer and, if permitted to run from early spring into late fall, recharge from ditch loss could result in higher overall groundwater levels.

Irrigators should consider keeping fields that are in important recharge areas in flood irrigation. Flood irrigation provides irrigation water in excess of plant demand; the excess water percolates past the root zone to recharge the aquifer. In areas where the aquifer is sensitive to changes in recharge, new pivot installations should be located away from valley margins, where the aquifer is thin, and where recharge sources are limited, to minimize the risk of lowering the water table.

ACKNOWLEDGMENTS

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