Montana Bureau of Mines and Geology
Information Pamphlet 14
2023

GROUNDWATER/SURFACE-WATER STUDY IN THE UPPER JEFFERSON VALLEY, MONTANA

Modeling the Effects of Changing Irrigation Practices and Increased Residential Development on Low Streamflows

Andrew Bobst, Ali Gebril, and Jenna Dohman

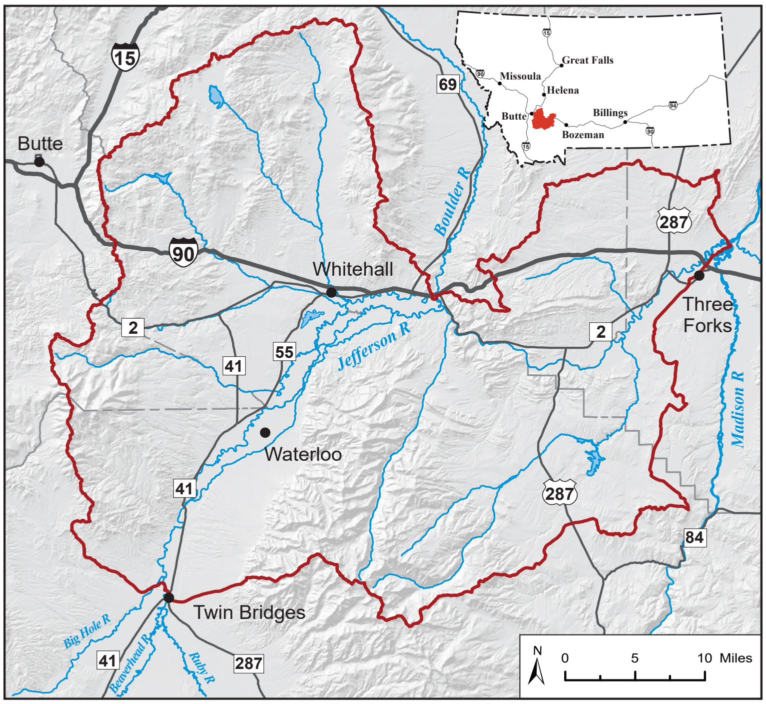


Figure 1. The Upper Jefferson Watershed in southwest Montana.

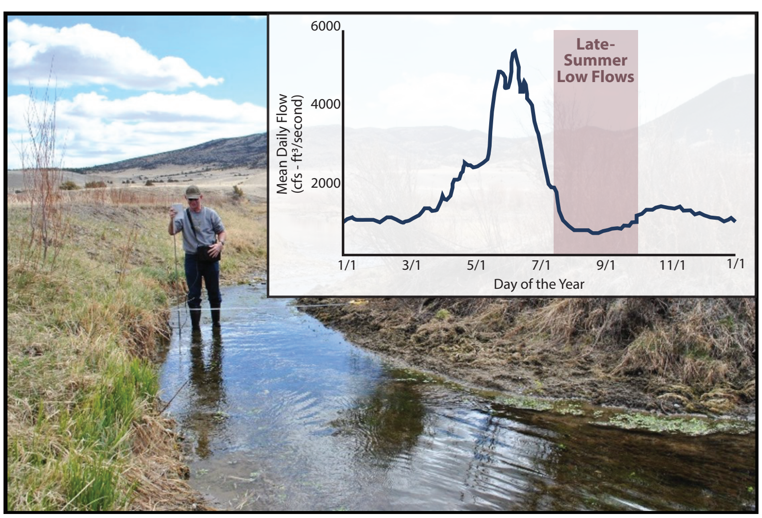


Figure 2. Surface-water monitoring was conducted at 53 locations. Average stream flows on the Jefferson River near Twin Bridges, Montana (USGS gage 06026500) are shown over the period of record 1940–2019. High flows occur in the spring and early summer due to snowmelt and spring rains. Irrigation diversions, evaporation, and plant water use contribute to low flows in the late summer. Photo credit: John Wheaton, MBMG.

INVESTIGATING LOW STREAMFLOWS IN THE UPPER JEFFERSON RIVER

During the late summer, low flows and elevated water temperatures often result in fishing closures on the Jefferson River. The Montana Department of Fish, Wildlife and Parks designated this fishery as "chronically dewatered," meaning that virtually every year, water levels in the Jefferson River are below what is adequate for fish habitat. Agriculture in the Upper Jefferson Valley also relies on sufficient streamflow and groundwater availability. Groundwater discharge to streams typically occurs year-round, and is often the only source of water to streams during the late-summer low-flow season. As such, having adequate groundwater recharge and storage to sustain river flows during late summer is critical for agriculture and healthy fisheries. Local communities have grown concerned about how current and future land-use practices may affect flow in the Jefferson River.

To address these questions, the Montana Bureau of Mines and Geology Ground Water Investigation Program (GWIP) developed site-specific groundwater models focused on how changing irrigation management activities (such as lining canals or installing pivot systems) and increasing residential development would affect surface flows in the Jefferson River. These models require an understanding of (1) the distribution of hydrogeologic units (the geologic units where groundwater flows) and (2) the groundwater budget (an estimation of the inflows and outflows of the groundwater system). Model simulations were developed based on stakeholder input. Simulations focused on late-summer streamflows, which are characterized by low surface-water flows, high groundwater consumption rates, and high rates of evaporation and plant water use (fig. 2). This pamphlet highlights these findings; for more detail, refer to the "Additional Information" section.

HYDROGEOLOGIC SETTING

The geologic units in the Upper Jefferson Valley were grouped into four hydrogeologic units (fig. 3). Each unit constitutes an aquifer, but they have different properties; for example, sediments such as sand and gravel are more permeable, allowing water to move easily between grains, resulting in higher well yields. Based on these different properties, these aquifers are distinct, but groundwater still flows between them.

Unit	Description	Well Yields
Alluvium	Unconsolidated gravel and sand with some silt and clay	50–100 gpm*
Bench Sediments	Unconsolidated to semi-consolidated sand and gravel with some mudstones	10–50 gpm
Renova Formation	Semi-consolidated mudstones with some sand lenses	10–15 gpm
Bedrock	Consolidated bedrock; water moves through fractures	<10 gpm

*gpm, gallons per minute

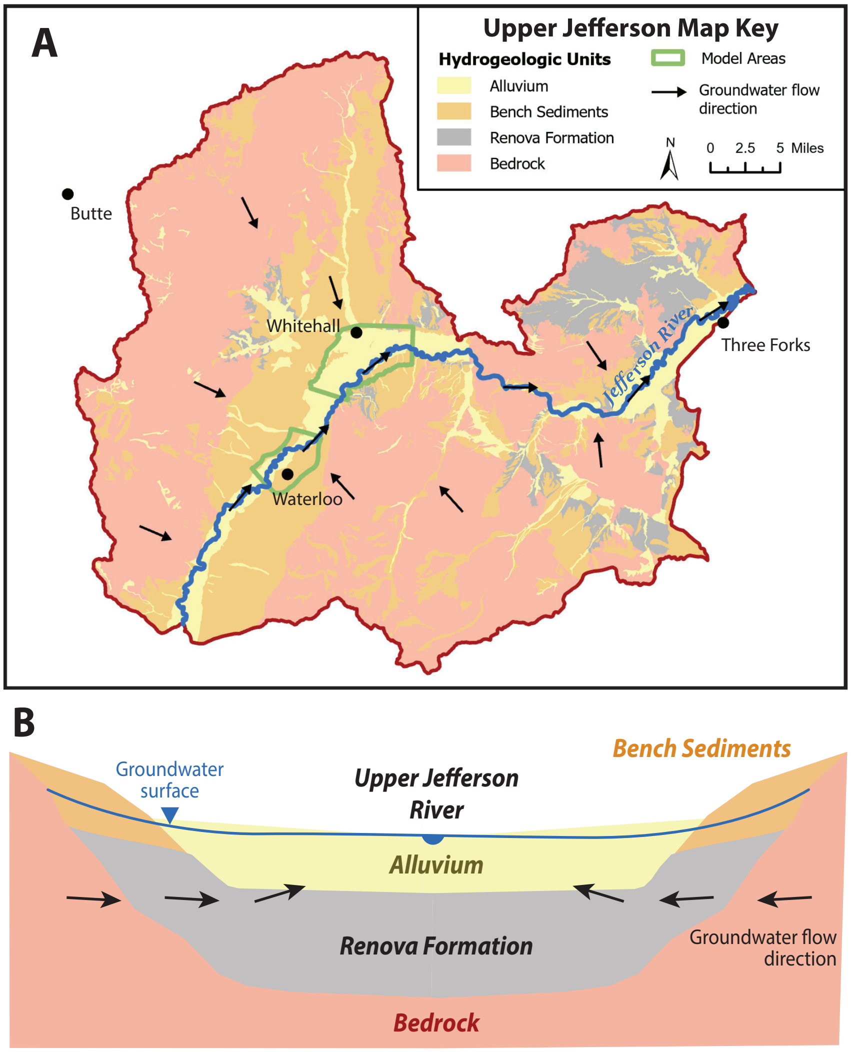


Figure 3. (A) Surficial hydrogeologic units in the Upper Jefferson Valley, shown in map view. Groundwater flows through the aquifer system from the mountainous areas toward the Jefferson River. Note that both model areas are located in regions with alluvium and bench sediments, the two most productive units. (B) Idealized cross-section showing how these hydrogeologic units overlie one another.

GROUNDWATER BUDGET COMPONENTS

Groundwater budgets are used to aid in understanding the components of groundwater recharge and discharge, and their relative importance. The components of a groundwater budget are described below (fig. 4). Groundwater budgets were developed for the Waterloo and Whitehall model areas.

Groundwater Recharge

Groundwater Inflow
Water that flows through the subsurface into the study area

Irrigation Recharge
Excess precipitation or irrigation water that is not used by crops and infiltrates to groundwater

Surface-Water Recharge
Water that flows to groundwater from surface water (e.g., infiltration)

Canal Leakage
Water that infiltrates from unlined canals to the subsurface

Groundwater Discharge

Groundwater Outflow
Water that flows through the subsurface out of the study area

Well Withdrawals
Groundwater pumped from wells

Discharge to Surface Water
Water that flows to surface water from groundwater (e.g., springs)

Riparian Evapotranspiration
Evaporation and water use by plants

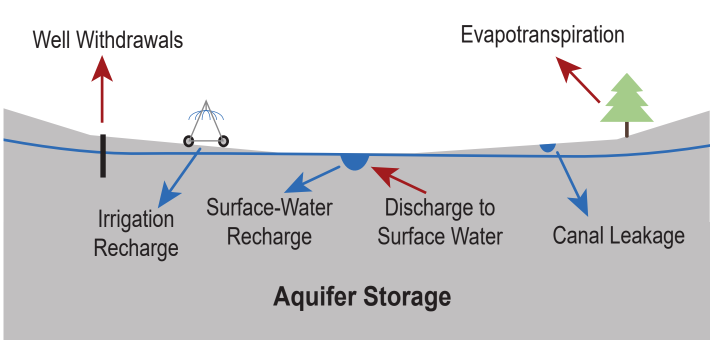


Figure 4. Groundwater recharge pathways → send water into the aquifer and increase aquifer storage. Groundwater discharge pathways → send water out of the aquifer, decreasing aquifer storage.

CHANGING IRRIGATION PRACTICES

In Waterloo (fig. 3), stakeholders were curious about how different irrigation practices may affect flows in the Jefferson River. The groundwater flow model simulates how lining irrigation canals, switching from flood to center-pivot irrigation, and employing split-season irrigation would affect late-summer streamflows in the Jefferson River (fig. 5). Split-season irrigation is a technique that uses flood irrigation rates when irrigation water is plentiful, and uses center-pivot irrigation rates when water is scarce.

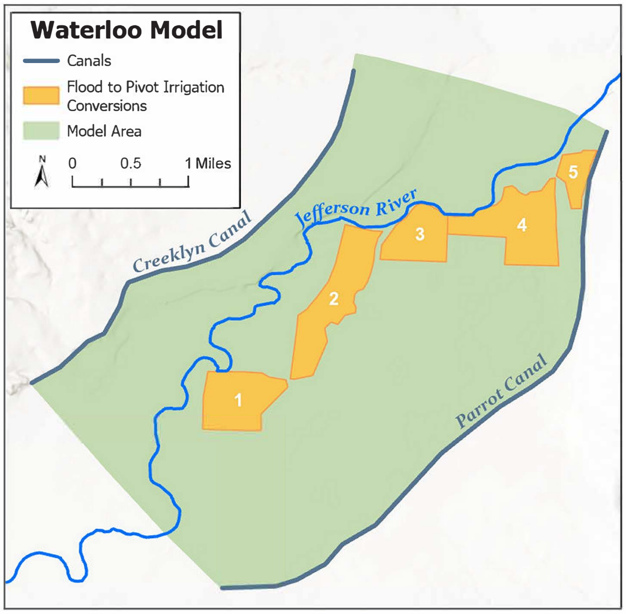


Figure 5. The effects of lining the Parrot and Creeklyn Canals and changing irrigation practices were modeled. Photo credits at right: Ginette Abdo, MBMG, lined canal in Lower Beaverhead; Kirk Waren, MBMG, flood irrigation in Stevensville, MT.

Lined Irrigation Canals

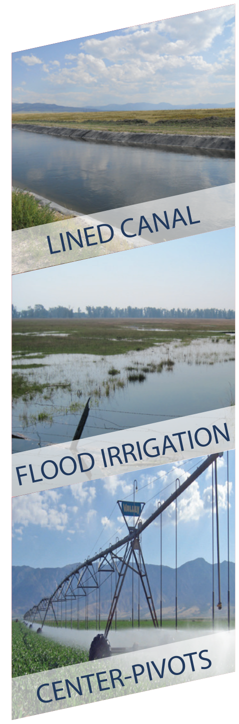
Lining Parrot and Creeklyn Canals reduced simulated late-summer flows in the Jefferson River by about 17 cubic feet per second, or cfs (2.4%). This indicates that water from these canals recharges groundwater that later discharges into the river.

Flood vs. Center-Pivot Irrigation

Converting five flood-irrigated fields (fig. 5) to center-pivots reduced simulated late-summer flows in the Jefferson River by 13 cfs (1.8%). This demonstrates that more recharge occurs from flood irrigation than from center-pivots.

Split-Season Irrigation

Simulated split-season irrigation was more effective when applied to fields further from the river. The increased distance from the river resulted in excess applied irrigation water discharging to the river during late summer.



INCREASED RESIDENTIAL DEVELOPMENT

In Whitehall (fig. 3), stakeholders were concerned about residential development. The groundwater flow model simulates how late-summer streamflows in the Jefferson River would be affected by groundwater pumping from different aquifers, changes in housing density, and converting irrigated vs. non-irrigated areas to housing developments (fig. 6).

Shallow vs. Deep Wells

Simulations of the same number of wells in the shallow alluvium compared to wells in the deeper Renova Formation showed late-summer streamflow depletion was nearly identical. This suggests that measurable increases to late-summer flows would not be gained by installing deeper wells.

Housing Density

Simulated reductions in late-summer streamflow were directly proportional to the total pumping rate from all wells. This demonstrates that it is the total amount of groundwater pumped from wells, not the number of wells that water is pumped from, that affects discharge to streams.

Irrigated vs. Non-Irrigated Development

Development in irrigated areas reduced simulated late-summer streamflows 12x more than development in non-irrigated areas. In addition to adding groundwater pumping, development in irrigated areas reduced irrigation recharge to the aquifer.

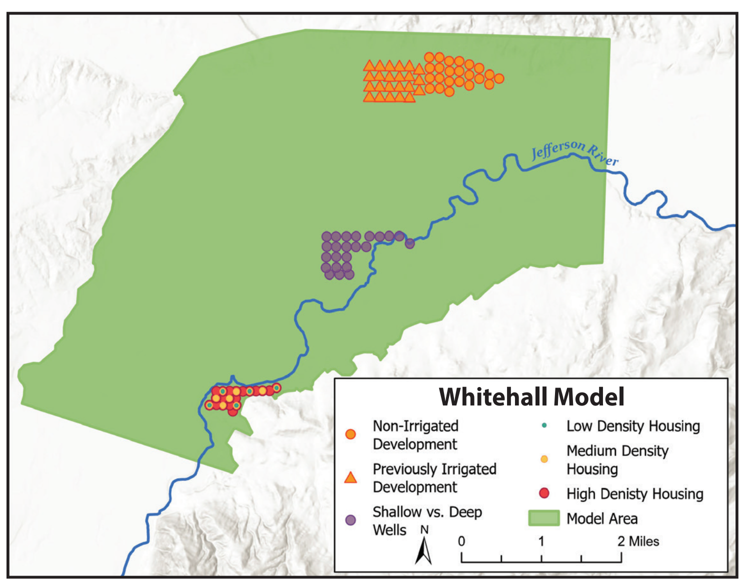


Figure 6. Multiple scenarios simulating residential development were modeled, focusing on well depth, housing density, and development of irrigated and non-irrigated lands.

IRRIGATION RECHARGE IS KEY FOR MAINTAINING LATE-SUMMER STREAMFLOWS IN THE UPPER JEFFERSON RIVER

◊ **Flood-irrigated fields and unlined canals provide substantial groundwater recharge.**
Converting irrigated lands to almost any other use, or lining canals, will decrease groundwater recharge, seasonal groundwater storage, and late-summer streamflows.

◊ **Split-season irrigation may be useful for increasing or maintaining late-summer streamflows.**
The application of excess water early in the irrigation season, while water is abundant, and using more efficient irrigation methods when water is scarce, can help maintain late-summer flows. The site-specific setting of each field, its soil types, and effects on ranch operations should be evaluated before applying these techniques.

◊ **Adding wells through residential development has less of an effect on streamflows than changing irrigation practices.**
However, if development occurs on previously irrigated fields, the reduction in groundwater recharge is likely to have a larger effect on streamflows.

ADDITIONAL INFORMATION

For more information on the research, models, and interpretations conducted by GWIP in the Upper Jefferson Valley, refer to the following reports:

Bobst, A., and Gebril, A., 2021, Hydrogeologic investigation of the Upper Jefferson Valley–Montana: Interpretive report: MBMG Report of Investigation 28, 130 p.

Gebril, A., and Bobst, A., 2021, Hydraulic investigation of the Upper Jefferson River Valley: Waterloo modeling report: MBMG Report of Investigation 29, 101 p.

Gebril, A., and Bobst, A., 2020, Hydraulic investigation of the Upper Jefferson River Valley: Whitehall modeling report: MBMG Report of Investigation 27, 93 p.

Bobst, A., and Gebril, A., 2020, Upper Jefferson aquifer tests: MBMG Open-File Report 727, 52 p.

FIGURE REFERENCES

Center Pivot, United States Geologic Survey, available at https://www.usgs.gov/media/images/center-pivot-irrigation-system-arizona-usa [Accessed Sept 2022].

Photo credit: Ali Gebril, MBMG, Jefferson River.

The **Ground Water Investigation Program (GWIP)** encompasses site-specific studies of groundwater resource concerns that support statewide and local decisions regarding water. The Montana Legislature established GWIP in 2009, with a design that allows local communities or other stakeholders to nominate projects for study. The interagency Ground Water Assessment Steering Committee ranks and prioritizes project nominations every 3 years. MBMG hydrogeologists bring data-driven scientific analyses that address important questions to Montana’s citizens, business communities, and agricultural and industrial/commercial stakeholders.

MBMG publications can be found on our website:
mbmg.mtech.edu