Report of Investigation 10

Hydrogeology of the West Billings Area: Impacts of Land-Use Changes on Water Resources

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Executive Summary

Hydrogeological investigations sponsored by the Yellowstone Conservation District (YCD) between October 1998 and June 2001 consisted of

- Compiling previously existing and newly collected data into a geographic information system (GIS) data base
- Measuring ground-water elevations and surface-water flows
- Collecting ground-water and surface-water samples for water-quality analyses
- Collecting ground-water samples for stable-isotope and radioisotope analyses
- Performing aquifer property tests
- Mapping and interpreting the data

This investigation evaluated potential impacts of urban and suburban development of the West Billings area. Land use in the region is transforming from primarily flood-irrigated agriculture to residential subdivisions. Most of the project area is outside city limits, and ground water from a relatively shallow alluvial aquifer is the primary or sole source of potable water.

Ground-Water Hydrogeology

In the West Billings area five, terraces, or benches, rise above the modern Yellowstone River flood plain. The terraces are designated in sequence with terrace 1 being the lowest and youngest and terrace 5 being the highest and oldest. An aquifer develops where ground water saturates the coarse-grained sand and gravel underlying the modern flood plain and terraces. Distinct aquifers have been identified underlying terraces 2, 3, and 4. Ground water under the modern flood plain and terrace 1 appears to be a single hydrologic unit; ground water is not present in terrace 5. The aquifers are separated by hydrologic discontinuities at the terrace scarp. There is little or no flow across terrace scarps. Ground water in the terraces is primarily discharged through baseflow to numerous small, surface drainages.

Very low–permeability shale of the Colorado Group forms the base of alluvial aquifers in this part of the Yellowstone River valley. The aquifers are overlain by fine-grained alluvial and slope-wash deposits that range from 0 to 100 feet thick. These fine-grained deposits are thickest along the edge of the valley and in tongues protruding into the valley along Canyon Creek, Hogan's Slough, and under the city of Laurel.

Surface-Water Hydrology

Agriculture in the area is supported by flood-irrigation water supplied via several canals from the Yellowstone River. The most significant of these include Italian Ditch, Big Ditch, High Ditch, Cove Ditch, Canyon Creek Ditch, and the Billings Bench Water Association (BBWA) Canal. All of the ditches except the BBWA terminate within the project area; the BBWA ditch extends out to agricultural lands east of Billings.

The project area is drained by numerous small perennial streams—most of which are artificial drains or highly modified natural streams. The most significant of these are Canyon Creek, Hogan's Slough, Danford Drain, and the City-County Drain. During the non-irrigated season (October–April), these streams are fed primarily by ground-water baseflow. During the growing season, flows in these streams increase substantially and consist almost entirely of discharges from irrigation ditch overflows and irrigation returns. All streams and drains in the area discharge to either the Yellowstone River or its tributary, the Clarks Fork of the Yellowstone.

Ground-Water Recharge

Ground-water level fluctuations are qualitative indicators of aquifer recharge. Ground-water levels measured at 80 wells in the project area demonstrated that the largest fluctuations (and thus the greatest recharge) occurred near flood-irrigated fields or near irrigation ditches. Ground-water fluctuations of as much as 14 feet were observed in irrigated areas. Ground-water levels in urban or large residential subdivision areas fluctuate by less than a foot and drop during the growing season.

A hydrologic balance of a 30,600-acre area between Laurel and Billings indicates that 66 percent of the water input is from agricultural irrigation and 29 percent from precipitation. Eighty percent of the water is lost by evapotranspiration. Stable isotope analyses of water (deuterium and oxygen-18) shows that 84 percent of the ground-water recharge is derived from high-altitude, snow-melt waters (the Yellowstone River). The difference between the water input and ground-water recharge values suggests that precipitation is more likely to be lost by evapotranspiration and runoff before infiltrating than is flood irrigation water.

Tritium-helium-3 analyses indicates ground water ages ranging from 0.9 to 32 years old. The sample age appears to be a function of distance to the upgradient margin of the aquifer and the saturated thickness of the fine-grained sediment layer.

Ground-Water Quality

Ground water in the alluvial aquifer system ranges from a relatively fresh water dominated by bicarbonate anions to a highly mineralized water dominated by sulfate anions. Both water types have relatively even proportions of calcium, magnesium, and sodium. The distribution of dissolved constituents seems strongly influenced by the fine-grained cover thickness. Where the fine-grained cover is thin, irrigation recharge can infiltrate rapidly, while the water quality remains relatively unchanged from river water. Where the fine-grained cover is thick, water infiltrates slowly, and dissolved constituents concentrate in the recharge water through evapotranspiration and soil-mineral dissolution. Leaks through major irrigation supply canals also have significant influence on water quality. In several locations the dissolved-constituents concentrations were significantly lower downgradient of ditches in areas of otherwise mineralized water.

Ground-water nitrate concentrations in the project area ranged from below detection (<0.1 mg/L) to 20 mg/L, with an average concentration of 3 mg/L. Approximately 5 percent of the 130 samples reviewed exceeded the human health limit of 10 mg/L. Nitrate contribution from septic drain fields presently account for 10 to 20 percent of the total regional nitrate load to ground water. However, septic drain fields may cause more serious local impacts to ground water. Most nitrate in the ground water is likely from chemical fertilizers, manure, or soil organic matter.

Surface-Water Impacts

Evaluation of stream, irrigation ditch, and Yellowstone River flows and water quality in 1999 indicated that irrigation in the project area contributed 4–15 percent of the summer dissolved load and 1–4 percent of the summer suspended load in the river. Thermal inputs from irrigation appear to have increased the temperature of the Yellowstone River by less than 1ºC. Discharges from minor streams provide 10–20 percent of the nitrate in the Yellowstone River at Billings.

During irrigation season, minor streams in the area essentially become irrigation return conveyances. Excess flows from irrigation apparently caused significant erosion in Canyon Creek. However, baseflow to these streams is provided by ground water, which is stored irrigation water. Consequently, these streams would not exist, except as ephemeral stormwater drains without irrigation in the valley.

Ground-Water Impacts

The primary impact from development of the area is in the reduction of ground-water recharge. Reduced recharge will result in lower ground-water levels and decreased well yields. Some developed locations have demonstrated a 5-foot ground-water level decline in the past 20 years. However, adequate historical data are lacking for most of the project area, making trend-assessment difficult. Data from this investigation also indicate that recharge rates and water quality are linked. This link suggests that declining recharge rates also may result in overall water-quality deterioration.

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Introduction

Urbanization is rapidly spreading in the Yellowstone River valley between Billings and Laurel in Yellowstone County, Montana (plate 1), as more land is being converted from irrigated cropland to residential lots. Residential properties built in these newly developed areas are beyond municipal water and sewer services. For much of the project area, the sole source of potable water is a shallow, alluvial aquifer system. The primary method of household wastewater disposal in these areas is through septic drain fields, which have been shown to impact shallow ground water (Robertson and others, 1991).

Development also has the potential to adversely impact the aquifer system through changing recharge sources and quantities. The alluvial aquifer system is and has been an artificially recharged system since the advent of agricultural irrigation in the 1890s. Prior to irrigation, the Billings area was primarily a treeless alkali flat (Stevens and Redman, 2000). If the alluvial aquifer system existed before irrigation, the saturated portion likely was considerably thinner and was less extensive areally.

The Yellowstone alluvial aquifer system provides baseflow to Canyon Creek and other tributaries to the Yellowstone River. Consequently, deteriorating ground-water quality can impact these streams and the river. During irrigation season, these streams receive irrigation-return water and excess ditch water. These discharges drastically increase the flows carried by these small streams and can provide dissolved- and suspended-solid loading and thermal inputs to the Yellowstone River. The Montana Department of Environmental Quality has listed Canyon Creek and the Yellowstone River as water bodies in need of Total Maximum Daily Load (TMDL) assessment.

Purpose and Scope of Research

This project was conducted to evaluate the potential impacts of land-use changes and non-point source pollution impacts to the Yellowstone River alluvial aquifer system and the surface-water system in the West Billings area. This project was conducted between October 1998 and June 2001 and consisted of

- Compiling previously existing and newly collected data into a geographic information system (GIS) data base
- Measuring ground-water elevations and surface-water flows
- Collecting ground-water and surface-water samples for water-quality analyses
- Collecting ground-water samples for environmental isotope analyses
- Performing aquifer parameter tests

Previous Investigations

The alluvial aquifer in West Billings has been evaluated by several previous investigators. Hall and Hunt (1929) evaluated ground-water resources by individual townships in Yellowstone and Treasure Counties and described the stratigraphy and general hydrologic controls on water resources in the region. Irrigation was observed to control water levels and quality in the alluvial and terrace aquifers. Most wells in the alluvial/terrace aquifers were for stockwater and were considered unsuitable for domestic use. Gosling and Pashley (1973) constructed a hydrogeologic map of the alluvial aquifer in the Yellowstone River valley near Billings. Hutchinson (1983) compared aquifer hydrology and changes in water level and quality in the Yellowstone alluvial aquifer from 1968 to 1978. Both of these previous documents mapped the alluvial aquifer as one continuous aquifer. Lopez (2000) mapped the surficial geology in the Billings area and identified discontinuities between successive terraces.

Methods of Data Collection

Data collection for this project included database compilation, ground-water and surface-water measurements, and sampling for water-quality, stable isotopes, and tritium-noble gas analyses. The ground-water level and water quality data are available on-line at The Montana Ground-Water Information Center (GWIC at www.mbmggwic.mtech.edu). All field and laboratory data collected for this project are presented in MBMG Open-File Report 436 (Olson and Reiten, 2001). All wells used in this report are identified by a GWIC ID number.

The hydrogeology of the West Billings alluvial aquifer system was characterized using GIS coverages of geologic and geographic data, and measured ground-water elevation data from the project-monitoring network (plate 1). Compiled data sources include the MBMG's Ground-Water Information Center data base, MBMG geologic mapping (Lopez, 2000), Yellowstone County, and the Natural Resource Information System. Changes in land-use patterns were evaluated using aerial photographs from 1966 and 1999.

Between January 1999 and October 2000, water-level measurements were obtained from 80 wells on a monthly basis (plate 1). Fifty-three of the measured wells were private wells previously inventoried by MBMG as part of a ground-water characterization program for Yellowstone and Treasure Counties. Twenty-five wells were dedicated monitoring wells installed by MBMG. Two wells were installed by the Montana Department of Agriculture as part of their pesticide-monitoring network. Twenty of the MBMG monitor wells, both Department of Agriculture wells, and three private wells were equipped with analog or digital water-level recorders. Ground-water elevations are based on measuring point elevations estimated from USGS 1:24,000 quadrangle maps. The accuracy of the measuring-point elevations in most locations is approximately +/- 5 feet.

Aquifer hydraulic properties were evaluated by performing 24–48-hour pumping tests at four test sites. The test sites consisted of a six-inch-diameter pumping well and 3 or 4 two-inch-diameter observation wells. Water-level data were measured using pressure transducers and digital data recorders. Additional aquifer property data were obtained by evaluating pumping tests by others and by evaluating reported specific-capacity information.

The surface-water system of the West Billings area was characterized by monitoring stream stage, flows and field-water quality (pH, temperature, SC) at as many as 44 locations across the project area (plate 1). Surface-water monitoring was performed on a monthly to bi-weekly basis. Stream flows were measured using a wading rod and current velocity meter. A continuous data logger was installed at the mouth of Canyon Creek during the summer of 1999. The data logger recorded stream stage and water temperature, specific conductance, turbidity, and dissolved oxygen on a 2–4-hour basis.

Ground-water samples for common-ion and trace constituent analyses were collected from 22 wells and 9 surface-water stations in the project area (plate 2). Selected wells were additionally sampled semiannually for common ions and quarterly for nitrate. Ground-water samples were collected from wells that had been purged of approximately three well volumes. Field measurements of pH, temperature and specific conductance were made using electronic probes. The samples were contained and preserved in accordance with standard laboratory protocols. Common-ion and trace-metal analyses were performed by the MBMG analytical laboratory. Analyses of quarterly nitrate samples were performed by Energy Laboratories in Billings.

Stable-isotope analyses were performed on selected samples to better delineate the source(s) of ground-water recharge and source(s) of the dissolved constituents. The analyses included evaluation of water isotopes (deuterium and oxygen-18) and dissolved carbon-13 (of bicarbonate), sulfur-34 (of sulfate), nitrogen-15 (of nitrate) and oxygen-18 (of nitrate). Stable isotope analyses were performed by the University of Waterloo, Ontario.

Isotope contents are expressed in terms of the difference between the measured ratio of isotopes (i.e., sampled $^{18}O/^{16}O$) to a standard reference ratio of the isotopes (i.e. reference $^{18}O/^{16}O$) and are expressed in a delta notation (δ) in parts per thousand (permill). The formula for this expression (using ^{18}O as an example) is as follows:

$$\delta^{18}O \text{ sample} = \frac{^{18}O/^{16}O \text{ sample} - ^{18}O/^{16}O \text{ VSMOW}}{^{18}O/^{16}O \text{ VSMOW}}$$

The standard reference ratios (Coplen and others, 2000) for the isotopes used in this investigation are as follows:

Hydrogen (δ^2H):	VSMOW (Vienna Standard Mean Ocean Water)
Oxygen ($\delta^{18}O$):	VSMOW
Carbon ($\delta^{13}C$):	PDB (Pee Dee Belemnite)

Sulfur ($\delta^{34}S$): CDT (Canon Diablo Troilite)

Nitrogen ($\delta^{15}O$): AIR (atmospheric air)

Samples for tritium and dissolved noble gases were collected to age-date ground water (using the $^{3}H/^{3}He$ method) to quantify ground-water recharge and flow rates. The tritium samples were collected from purged wells and placed unpreserved in 1-liter bottles. Dissolved noble gas samples were collected in ¼-inch copper tubes attached to a specialized bailer to avoid contamination from air bubbles or contact with the atmosphere. The copper tubes were crimped at both ends with metal pinch clamps to seal the sample. Sample analyses and age calculations were performed by the University of Utah.

Project Setting

Land Use and Land-Use Changes

The West Billings project area is located in south-central Montana in Yellowstone County and includes a portion of the city of Billings and all of the City of Laurel. The project area covers approximately 79,000 acres (122 square miles) within the Yellowstone River valley from Division Street in Billings to approximately the western border of Yellowstone County (plate 1). Fifty-three percent of the land area is used for flood-irrigated crops and pastures. Based on agricultural census data (U.S. Department of Commerce, 1997), the primary irrigated crops are hay (53 percent of the irrigated acreage) and sugar beets (17 percent of the irrigated acreage).

Over the past several decades, there has been extensive conversion of formerly flood irrigated rural lands in the project area to residential subdivisions. The subdivision developments in the area are occurring in a patchwork manner (figure 1). This form of development is progressively isolating and decreasing the size of the remaining fields; in many cases the smaller fields are no longer practical to flood irrigate.

Figure 1. Subdivision development in the West Billings area has broken up the flood-irrigated lands into a patchwork of smaller, isolated fields.

The population of the project area in 1990 was approximately 67,000, of which approximately 11,000 people lived in rural areas (1990 census block data). Between 1990 and 2000 the population of West Billings grew by approximately 26 percent (Yellowstone County Board of Planning, 2001); this rate is twice that of Billings. Review of aerial photographs from 1966 and 1999 demonstrate a net loss of 18,000 acres, or approximately 23 percent of irrigated lands (figure 2). Most of the land-use change occurred immediately west of the city.

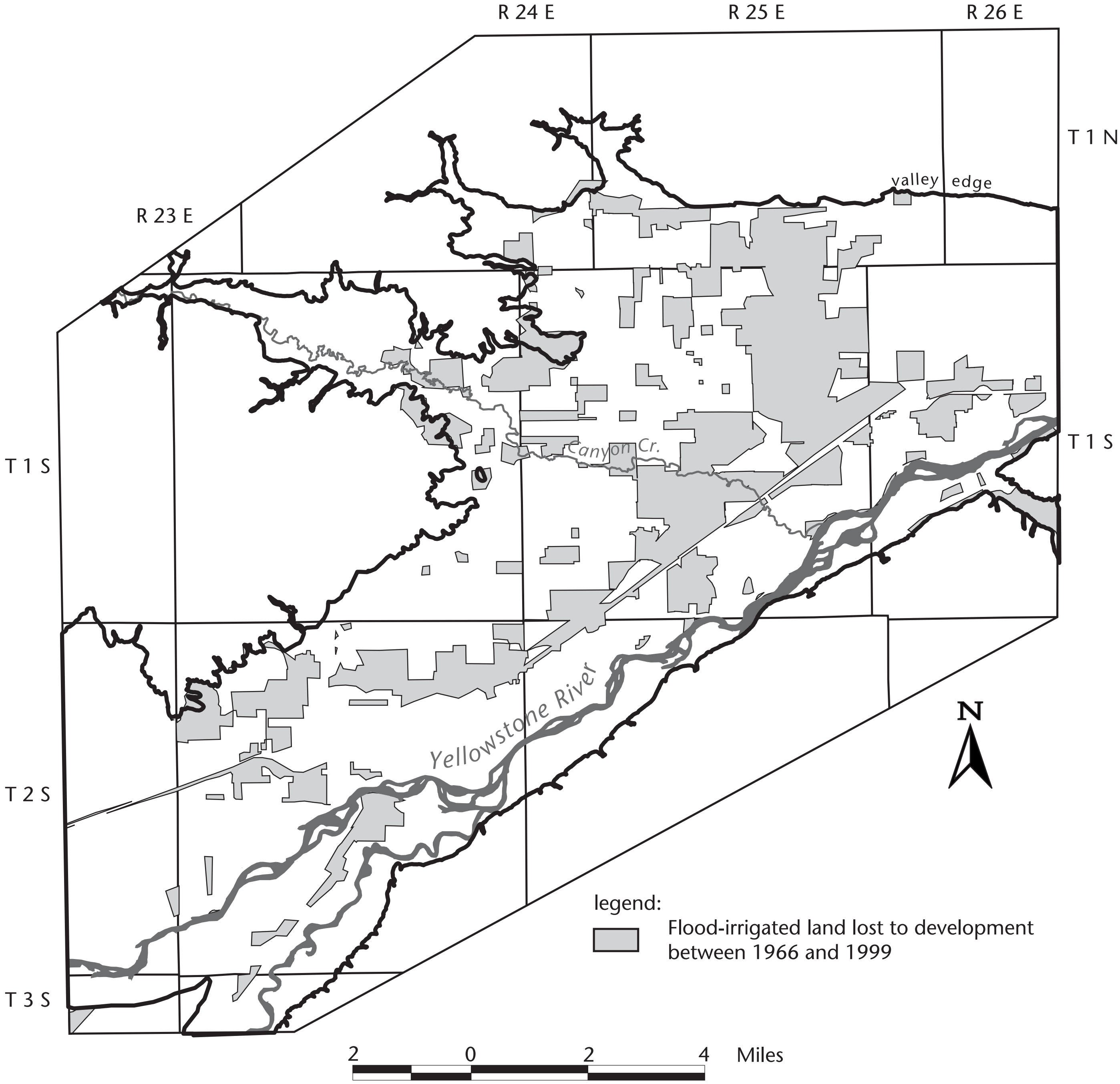

Figure 2. Between 1966 and 1999, approximately 18,000 acres of formerly flood-irrigated lands were converted to rural-residential or gravel-mining uses.

Climate

The West Billings area has a semi-arid climate with a 30-year average annual precipitation of 15 inches (NOAA climatic data for the City of Billings (www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?mtbill). During 1999 and 2000, the area experienced drought with precipitation totals 20–30 percent below normal, respectively. Monthly precipitation accumulation and departures from normal are shown in figure 3. Fifty percent of the precipitation in 1999–2000 occurred as light showers or snowfall (<0.25 inches). Only 15 percent of the precipitation occurred in events with greater than 0.5 inches.

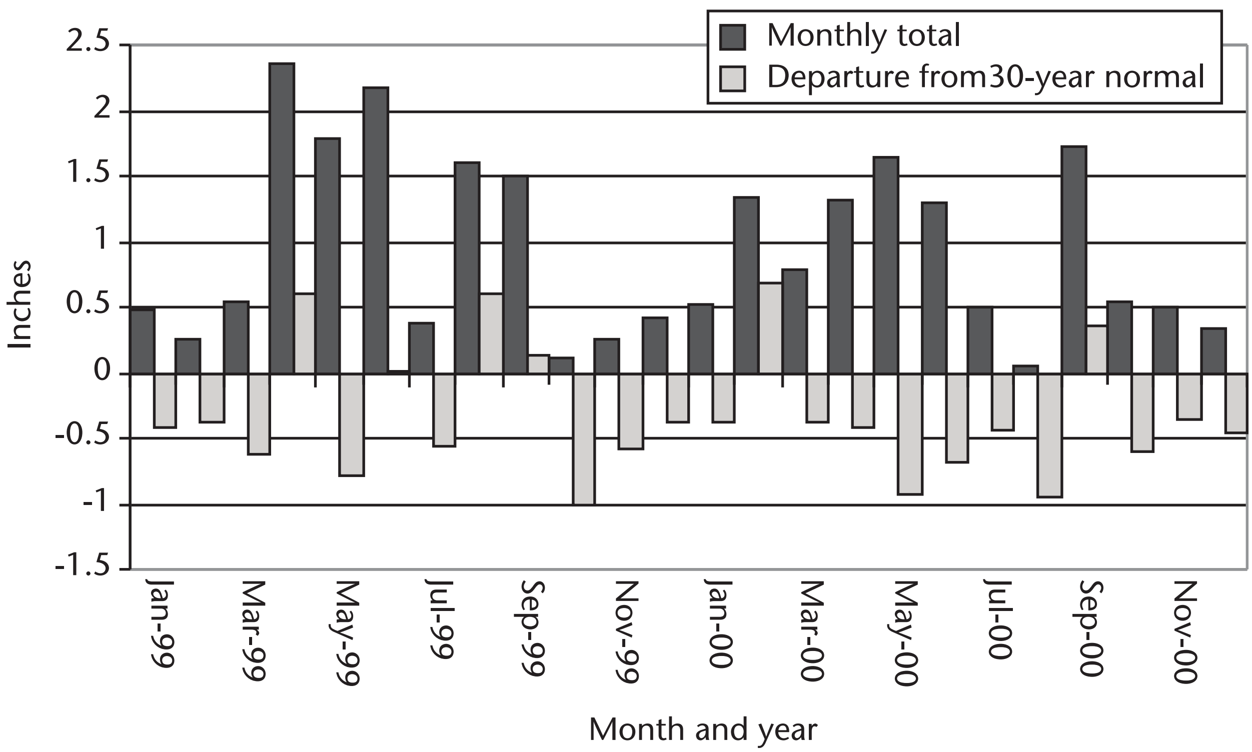

Figure 3. Monthly precipitation totals were below the 30-year average nearly every month during 1999 and 2000.

Agriculture in the valley is supported primarily by flood irrigation from irrigation canals that divert water out of the Yellowstone River. The region is designated by the NRCS as a highly consumptive water-use area for agriculture (Soil Conservation Service, 1995). Estimated water consumption for grasses and typical crops of the area ranges approximately 20 to 30 inches per year, which is about twice the rate of precipitation. Most of the water consumption (and so most irrigation) occurs June through August.

Ground-Water System

Stratigraphic Components

The Yellowstone alluvial valley in the West Billings area is underlain by a relatively shallow, thin, unconfined to semi-confined aquifer system. Stratigraphic components of this system include the shale base underlying the aquifer, terrace alluvial gravel aquifers, and a fine-grained sediment cap.

In the project area, the Yellowstone River has cut its valley 200–300 feet into late Cretaceous shale formations of the Colorado Group. The Colorado Group is exposed south of the valley and underlies the alluvial deposits of the valley (Lopez, 2000). The approximately 2,000-foot-thick shale sequence is typically a poor source of ground water, with low yields and poor water quality. The shale bedrock surface has been scoured by past erosion of the Yellowstone River. Deeper channel cuts and terrace-cut benches are evident in the bedrock topography (plate 1). The shale at the base of the aquifer is typically weathered to a dense clay that is relatively impermeable and does not provide significant recharge to or discharge from the alluvial aquifer system. The valley is bounded on the north by a 300-foot-high cliff formed by the Eagle Sandstone and the Telegraph Creek Formation. These formations are Cretaceous, interbedded sandstone and shale that dip gently northward and are not present under the valley in the project area (Lopez, 2000).

In the West Billings area, the ancestral Yellowstone River deposited gravel on five, distinct Holocene to Pleistocene terrace levels. The youngest and lowest terrace (terrace 1) is approximately 10 feet above the modern river. This terrace is found only in small isolated areas adjacent to the modern flood plain. Terrace 2 is approximately 20–40 feet above the modern river and is found in a 1–2-mile-wide band north of the river flood plain. Terrace 3 (50–90 feet above the river level) is the most areally extensive surface. Terrace 4 (200–300 feet above river level) is found only in a small area north of Laurel. Terrace 5 is the oldest and highest Yellowstone River surface (400–500 feet above the river level) and occurs on high, isolated erosional remnants. Terrace 5 is not known to be water bearing. The map and cross sections on plate 1 show the distribution and relations between terraces 1 through 4.

Ground water occurs in relatively thin (0–30-feet-thick) alluvial gravel deposits that underlie four of the terrace surfaces within the valley. The average saturated thickness of the terrace gravel aquifers is 15 feet. The gravel deposits of terraces 2, 3, and 4 are discontinuous, separated by the terrace scarps, and form distinct hydrogeologic units (plate 1). Terrace 1 and the modern alluvium are separated by a low escarpment (less than 10 feet) and appear to be in hydraulic communication. The discontinuities between the other terraces are demonstrated by the following conditions at the base of terrace scarps:

1) the presence of shale outcrops,
2) the presence of fine-grained colluvial deposits,
3) the absence, or significant thinning, of the gravels that underlie the terraces,
4) the absence or thinning of ground-water saturated thickness, or
5) discharge of ground water to springs and seeps along the terrace scarps.

The discontinuity likely has been enhanced in some locations by gravel removal during open-pit mining along the tops of the terrace scarps in several locations. Saturated thickness of the alluvial gravels ranges from 0 to more than 30 feet (plate 1). The thicker saturated gravels under portions of terraces 2 and 3 appear to be buried channels. The thinnest saturated zones occur along terrace scarps and along the modern river channel. In areas where the aquifer is thin, ground-water supplies may be inadequate for domestic supply. Well yields are likely to increase with saturated thickness.

The terrace gravels are overlain by from 0 to more than 100 feet of silty clay or clayey sand. This fine-grained sediment cap is usually thickest along the northwest valley margins. However, tongues of fine-grained sediment up to 50 feet thick protrude into the valley along Canyon Creek, Hogan’s Slough, and near Laurel (plate 2). Throughout most of the project area, ground water is semi-confined (figure 4) with static ground-water levels occurring at approximately similar or slightly higher elevations in the fine-grained layer than in the underlying gravel. Because of the lower permeability of the silty clays nearly all of the horizontal ground-water flow occurs in the sand and gravel. In areas of semi-confined ground water, water-level fluctuations do not change the saturated thickness of the aquifer. Ground-water flow in the saturated fine-grained materials is anticipated to be primarily vertical at the same rate as the recharge from the surface.

Colluvium consists of slope wash and alluvial fan sediment deposited along the valley margins. This sediment typically is composed of silt and silty-clay overlying layers of sandstone or siltstone rubble in a fine-grained matrix. The colluvial sediment can be as thick as 100 feet and grade laterally into the fine-grained cover. Although some wells are completed in colluvial deposits, it is generally poor aquifer material.

Aquifer Properties

Evaluation of three aquifer-pumping tests conducted by MBMG and a review of tests conducted by others indicate a hydraulic conductivity range of 20–600 feet/day for the sand and gravel aquifers

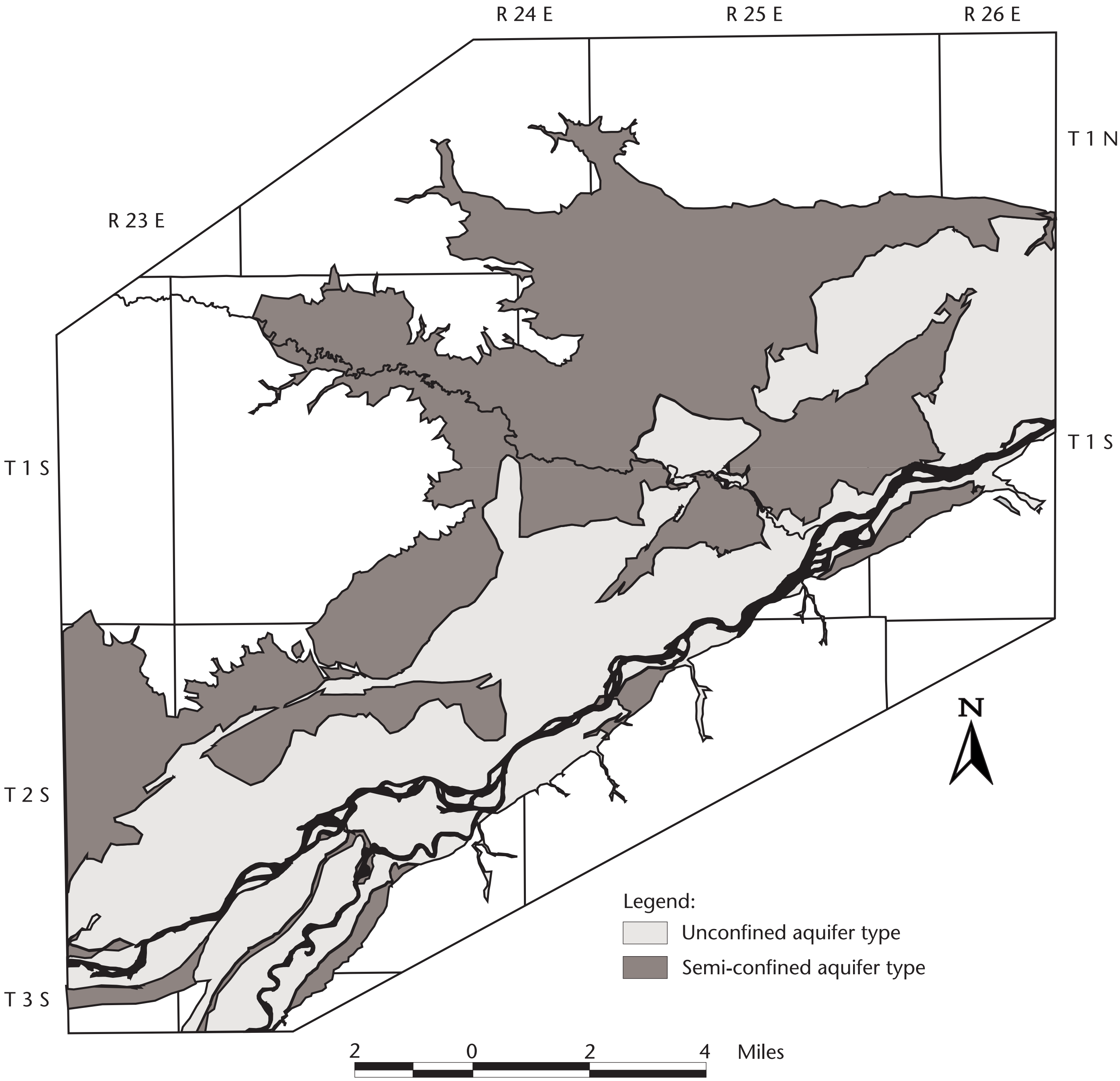

Figure 4. For most of the project area the fine-grained sediment layer acts to semi-confine the ground water.

(plate 1). This is within the expected range for sand and gravel (Todd, 1980). Additionally, hydraulic conductivity values were estimated from reported specific-capacity data for a much larger number of wells in the area. These data indicate a range of hydraulic conductivity of 20–400 feet per day and an average of 90 feet per day (plate 1). Based on specific-capacity data, there are no significant differences in hydraulic conductivity between gravel aquifers underlying terraces 1, 2, and 3. There were insufficient data to evaluate the hydraulic conductivity of the gravel underlying terrace 4.

Ground-Water Flow

Ground-water flow is generally east to southeast under a hydraulic gradient typically ranging between 0.002 ft/ft and 0.006 ft/ft (plate 1). Steeper gradients (greater than 0.01 ft/ft) are encountered in the lower permeability colluvial deposits. Evaluation of ground-water elevations in January 2000 and August 2000 indicates that gradient patterns do not change significantly between summer and winter months. Gradient magnitudes generally decrease by less than 10 percent during the winter.

The average ground-water velocity and flow can be calculated by the following formulas:

Velocity = K x I/n,

where K = Hydraulic conductivity (90 ft/day; plate 1)

I = Hydraulic gradient (see above)

n = effective porosity (0.2 for sand and gravel and 0.1 for colluvium)

Using the above velocity formula and available aquifer property data (plate 1), ground-water flow velocities will likely range from 1 to 3 ft/day in the terrace gravels.

Hydraulic discontinuities at the terrace scarps are evident in 10- to 50-foot changes in ground-water level across these boundaries. The terrace scarps are interpreted as no-flow boundaries based on the observed hydraulic and stratigraphic discontinuities. In reality, some flow occurs as seeps discharging along the toes of the scarps and drains into drainage ditches or irrigation canals. Ground-water discharges from the terrace gravels to several small artificial or human-modified drainages. These drainages are the primary discharge areas for ground water underlying terraces 2, 3, and 4.

Surface-Water System

Surface water in the project area consists of the Yellowstone and Clarks Fork of the Yellowstone Rivers (Clarks Fork), and numerous minor streams (including Canyon Creek) and irrigation supply canals. Flow and water-quality data for the Yellowstone and Clarks Fork were obtained from USGS monitor stations at Billings (for the Yellowstone River) and Edgar (for the Clarks Fork River). Data for the minor streams and irrigation supply canals were collected as part of this project.

Rivers

The Yellowstone River is the primary surface-water body in the project area. Its flow in 1999–2000 ranged from a low of 2,500 cubic feet per second (cfs) during the winter months to a spring high of 24,500 cfs (Shields and others, 2000). Rain and snowmelt in the higher altitudes of Yellowstone National Park contribute most of the flow May through July. The remainder of the year the flow is primarily from ground water discharging from the river drainage basin upstream from Billings (Gosling and Pashley, 1973). The Yellowstone River supplies Billings and Laurel with municipal and industrial water and supplies area agriculture with irrigation water via several large water-supply canals.

The only major tributary in the project area is the Clarks Fork, which enters the project area southeast of Laurel. The Clarks Fork contributes approximately 18 percent of the total flow of the Yellowstone River. The Clarks Fork contributes about 30–50 percent of the suspended sediment (Shields and others, 2000) to the Yellowstone River.

Minor Streams

The project area is drained by several small perennial streams; most of which are artificial drains or highly modified natural streams. The most significant of these are Canyon Creek, Hogan's Slough, Danford Drain, and the City-County Drain (figure 5). Canyon Creek originates approximately 10 miles northwest of the project area but enters the valley with a flow of less than 0.5 cfs. Canyon Creek drains approximately 8,400 acres within the project area. It is incised 15–25 feet below the terrace surfaces it crosses. The only tributary to Canyon Creek in the project area is a minor (<0.5 cfs) drainage that enters near 48th Street (feature 1, figure 5). The stream baseflow gains 0.1 cfs/mile in the upper colluvial segment of the stream and gains approximately 0.3 cfs/mile once the stream crosses

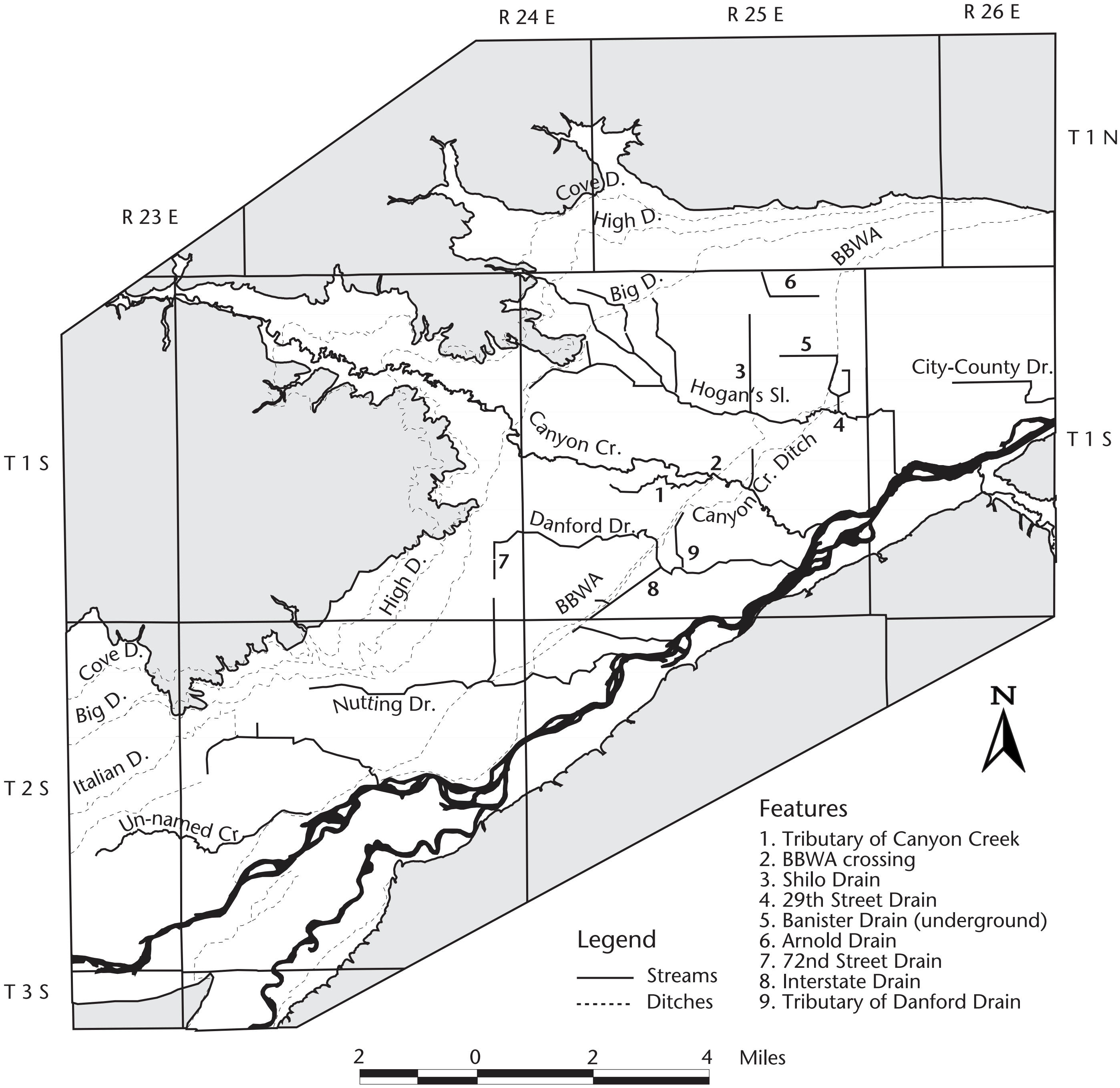

Figure 5. The area is drained by numerous small streams into the Yellowstone and Clarks Fork of the Yellowstone rivers.

the alluvial terraces (figure 6). The winter baseflow discharging into the Yellowstone River is 3–5 cfs. During irrigation season, Canyon Creek receives overflow discharges from five of the major ditches. These discharges cascade water down into the stream along flume crossings. Figure 7 shows a photograph of the flume at the BBWA crossing (location at feature 2, figure 5). Canyon Creek also receives return flows from several smaller ditches draining fields. As a result of these discharges, the flow in Canyon Creek increases to between 100 and 200 cfs.

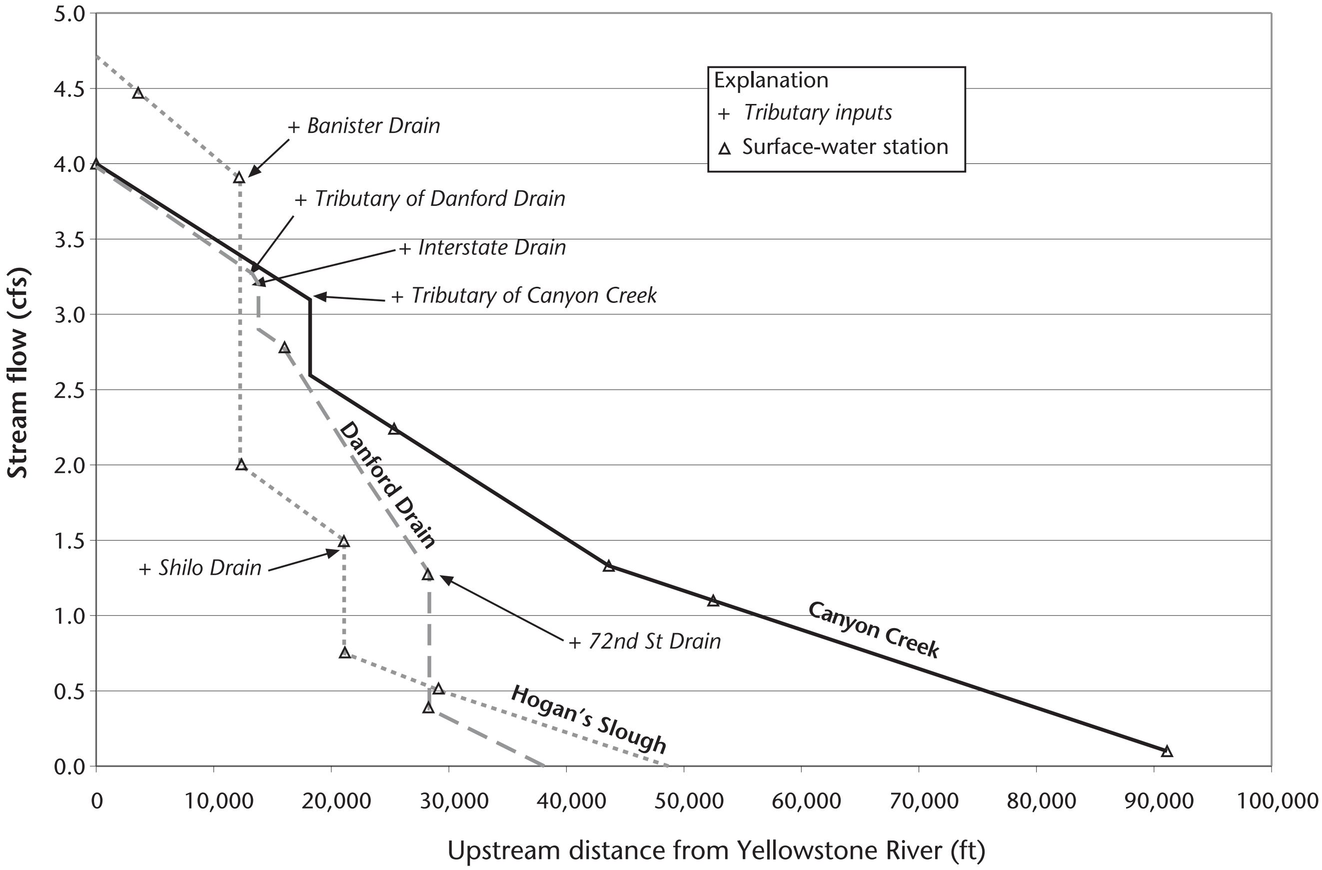

Figure 6. April 1999 stream flow profiles for selected streams.

Figure 7. The BBWC cascades water into Canyon Creek at its flume crossing.

Although the perennial portion of Hogan's Slough begins in the project area, it is connected to a relatively large drainage basin to the north. This basin has ephemeral drainage that has historically produced large flash floods down Hogan's Slough (Yellowstone Planning Board, personal communication). Within the project area, Hogan's Slough drains approximately 11,600 acres and has several tributaries. During non-irrigation season, Hogan's Slough receives approximately 25 percent of its flow from the Shilo Drain and half its total flow from a culvert at its 29th Street crossing (features 3 and 4, figure 5). This culvert connects with the Banister and Arnold drains (features 5 and 6, figure 5). Baseflow gains are similar to those observed for Canyon Creek, and its total winter discharge into the Yellowstone is 4–6 cfs. During the irrigation season, Hogan's Slough receives return flows from a number of smaller ditches and receives the terminal discharge from Canyon Creek Ditch through the 29th Street Culvert. Summer flows in Hogan's Slough are 80–100 cfs.

Danford Drain begins approximately 3 miles northeast of Laurel and drains approximately 5,000 acres in the project area. The Danford Drain receives significant flow inputs from three tributary drains (figures 5, 6). Peak baseflows (14 cfs) occur in early fall after the ditches have been deactivated. The flows drop steadily during the winter and reach a minimum flow of 3 cfs in March or April. During the summer, the drain receives irrigation return flows from minor ditches and has a flow of 20–30 cfs.

The City-County Drain emerges from a large culvert south of Billings. The drain is fed by the city storm sewer network and includes many former springs and streams now mostly piped underground. During the winter months baseflows to this drain are approximately 3–5 cfs. During the summer months, the drain receives terminal discharges from Big Ditch and Cove Ditch and flows increase to approximately 50 cfs.

Irrigation Supply Canals

Water for irrigation is supplied to the project area by several large water-supply canals. The most significant of these are Italian Ditch, Big Ditch, High Ditch, Cove Ditch, Canyon Creek Ditch, and the Billings Bench Water Canal (BBWA, figure 5). Intakes for all the ditches except the BBWA and Canyon Creek Ditch are west of the project area. Canyon Creek Ditch originates southwest of Laurel and the BBWA originates southeast of Laurel. Measured ditch flows ranged from 200 to 600 cfs on the BBWA to 30 to 100 cfs on Cove Ditch. All of the ditches except the BBWA terminate within the project area. The BBWA ditch extends out to agricultural lands east of Billings. Flows leaving the project area through the BBWA ranged from 200 to 400 cfs.

Evaluation of Ground-Water Recharge

Ground-water recharge to the alluvial aquifer system was assessed by conducting an area hydrologic balance and by evaluating ground-water level fluctuations, chloride balance, and stable isotopes.

Ground-Water Fluctuation

General Patterns

The magnitude and timing of ground-water level fluctuations in the alluvial aquifer system are controlled by recharge and discharge rates. Ground-water levels rise when recharge is occurring faster than the ground-water discharge rate. Conversely, ground-water levels drop when recharge is less than the ground-water discharge rate.

Ground-water levels fluctuate seasonally in the project area by as much as 14 feet. The maximum fluctuations occur in and near flood-irrigated fields. The typical hydrograph of irrigated locations (plate 1) demonstrates a rapid water level rise starting with the irrigation season in late April. This water level rise is in response to the infiltration of excess flood-irrigation water and irrigation ditch leaks. Water levels reach their peak in early August to late September and then fall steadily until the next irrigation season.

This pattern differs markedly from hydrographs of non-irrigated locations (plate 1). For non-irrigated areas, ground-water levels fall during the growing season and typically reach a minimum in July or August. The falling summer water levels indicate that evapotransiration and ground-water withdrawal exceed recharge from precipitation and lawn watering in these areas. Lawn watering in urban and rural setting appears insufficient to support ground-water levels during the summer months. Water levels begin to recover in September or October and remain relatively static until the next growing season. Total seasonal fluctuation in the non-irrigated area is usually only 1–2 feet.

Storage Changes

Fluctuations in aquifer storage occur through seasonal inequalities between aquifer recharge and aquifer discharge. This can be expressed in the following formulas:

Volume of recharge minus volume discharged = volume change in storage

Volume change in storage = specific yield (Sy) x change in the water level (dh)

Sy = 0.05 for the areas of semi-confined ground water and 0.15 for the areas of unconfined ground water.

However, for the full year, recharge will approximately equal discharge and the overall storage change is zero. Assuming no recharge occurs during the non-irrigation season, recharge can be approximated by the following formula:

Recharge (in inches/year) = (Sy x dh/dt x 12 months / year) x 12 inches/foot

where dt = the length of the discharge period (dropping water levels) in months

Calculated recharge rates by this method (table 1) demonstrate that recharge is influenced by land use (irrigated vs. non-irrigated) and by the thickness of the fine-grained cover. Based on average values the annual ground-water recharge volume for the project area is roughly 35,100 acre-feet per year.

Table 1. Recharge rates estimated from ground-water storage changes.

Well Group	Annual recharge (inches per year)		
		Fine-grained cover	
	All wells in group	<20 feet thick	>20 feet thick
All wells	5.4(n=64)	5.8(n=36)	4.5(n=28)
Irrigated areas not near major ditches	7.3(n=26)	10.0(n=13)	4.7(n=13)
Non-irrigated areas not near major ditches	2.9(n=23)	3.2(n=16)	1.2(n=6)
Wells within 200 feet of major ditches	6.5(n=16)	6.6(n=7)	5.7(n=9)

Where:
Recharge = Sy*dh/dt *12 months *12 inches/foot
Sy = specific yield
dh = total seasonal water level decline
dt = time in months for decline
(n = 64) refers to the number of samples in the group

Ground-Water Level Responses near Irrigation Ditches

Wells near major irrigation ditches experience a rapid water level rise immediately after the ditches are activated in mid-April (plate 1). This ground-water level rise demonstrates that the ditches are leaking into the ground water. The ground-water levels rise until they reach equilibrium with the ditch water level sometime in July or August. For the remainder of the irrigation season, ditch and ground-water levels are similar and leakage from the ditches are likely minimal.

Ground-water levels in nine wells near major irrigation ditches were evaluated to estimate the recharge contribution from ditch leakage. The selected wells were near the upgradient margin of an aquifer where flood irrigation contributions are less significant. The water level rise was evaluated by a method developed by Theis in 1938 (presented in Lohman, 1979) for a line-source discharge:

$s = Q \times X \times D(u) / (2 \times T)$

where

Q = ditch loss per linear foot of ditch (ft^3/day/ft)

s = change in the ground-water level (ft)

X = distance to ditch (ft)

T = transmissivity (assumed to be 1000–3000 ft^2/day)

$u = X^2 \times S / (4 \times T \times t)$

S = storage coefficient (assumed to be 0.1)

t = time since recharge began

D(u) is a drain function (Lohman, 1979)

Using this method, ditch leakage was estimated to be approximately 4 cubic feet/day/foot of ditch (or 0.5 acre-feet/day/mile). A summary of the calculated values is shown in table 2.

Table 2. Estimated recharge from ditch leakage.

GWIC ID and well name	Location	Ditch	Estimated leakage cfd/ft	afd/mL
160920, Yellowstone Baptist College	01S-25E-14-C	BBWC	5.0-8.0	0.6-1.0
93316, Yellowstone Boys Ranch	01S-25E-19-BBAB	Big	1.0-2.0	0.1-0.2
162747, Flohr Gary	01S-25E-22-CDCD	Canyon	2.5-4.5	0.3-0.5
93417, Zoo Montana	01S-25E-22-DADA	Canyon	4.0-6.5	0.5-0.8
144832, Zoo Montana	01S-25E-22-DBAB	BBWC	6.0-7.5	0.7-0.9
705285, Schlaeppi Neil	01S-25E-6-AABB	High	0.6-1.2	0.1-0.2
10615, Evergreen Park	01N-25E-36-DDBB	BBWC	3.0-3.5	0.4-0.4
171260, Ditchfalls-2	02S-24E-4-CDAA	Big	3.5-5.0	0.4-0.6
171261, Golfeast	02S-24E-7-DAAA	Big	3.0-5.5	0.4-0.7
Average			**3.0-5.0**	**0.4-0.6**

Where:
cfd/ft= cubic foot per day per linear foot of ditch
afd/mi= acre-foot per day per linear mile of ditch

Most of the major ditches cross the terraces where the fine-grained cover is relatively thick and the floor of these ditches is primarily silty clay. When the ditches are initially activated, flow through the ditch floor is by gravity drainage through the silty clay. Gravity drainage can be approximated by multiplying the saturated hydraulic conductivity (typically about 0.2 ft/d for silt; Todd, 1980) and the canal width (10–30 feet for the major ditchs). The ditch leakage then would be 2–6 cubic feet/day/foot of ditch, which is consistent with the estimated ranges in table 2. East of Hogan's Slough the BBWA canal crosses terrace 3 where the fine-grained cover is thin. The canal is cement lined through most of this area. Based on the water-level response in well 10615 the leakage rate through the cement appears to be similar to that of the silty-clay bottom.

There are approximately 80 miles of major irrigation ditches (20–30 feet wide) and 110 miles of minor canals (2–5 feet wide). By scaling the leakage rate with canal width and assuming that almost all of the ditch infiltration occurs during the first half of the irrigation season, approximately 5,000 acre-feet/year of water likely leak through the canal bottoms. Comparison of this value with the total recharge estimated by storage changes (35,100 acre-feet) indicates that ditch leakage represents roughly 14 percent of the total recharge for the area.

Hydrologic Balance

A water balance was constructed by measuring the primary ditch and drainage flows in and out of a subregion (figure 8) during 1999. The water balance subregion (WBSR) comprises all of the Danford Drain, Canyon Creek, and Hogan's Slough ground-water drainage basins. The WBSR was selected such that the number of streams and ditches could be reduced to a manageable number, yet provide a microcosm of the full project area. The hydraulic fluxes calculated for the WBSR was used to estimate chemical mass balances where appropriate. The subset region includes 30,600 acres, of which 3,000 acres are for residential use and 26,200 acres are irrigated. The water balance area has a rural population of roughly 8,000. Eighty-three percent of the population in the WBSR live in rural subdivisions (2000 Census Block Data, http://www.nris.state.mt.us/nsdi/tgr2000/helpstatepfire.html).

The hydrologic balance developed for the WBSR is shown in table 3. All ground water from the three terrace units present in the WBSR is assumed to discharge as baseflow into area streams. Baseflow was measured directly during the non-irrigation season. Combined gains from irrigation and ditch infiltration were estimated by subtracting the measured ditch inflows with the surface-water outflows (less the baseflow contribution). Household consumptive ground-water use was estimated by multiplying the area population by 78 gallons/person/day (USGS water use data for Yellowstone County, 1995; http://water.usgs.gov/watuse/spread95/mtco95.txt). Septic water return was estimated by multiplying the population by 50 gallons per person per day (Woessner and others, 1996). Lawn irrigation was estimated at 20 inches over the residential landscaped areas (Beard, 1982;

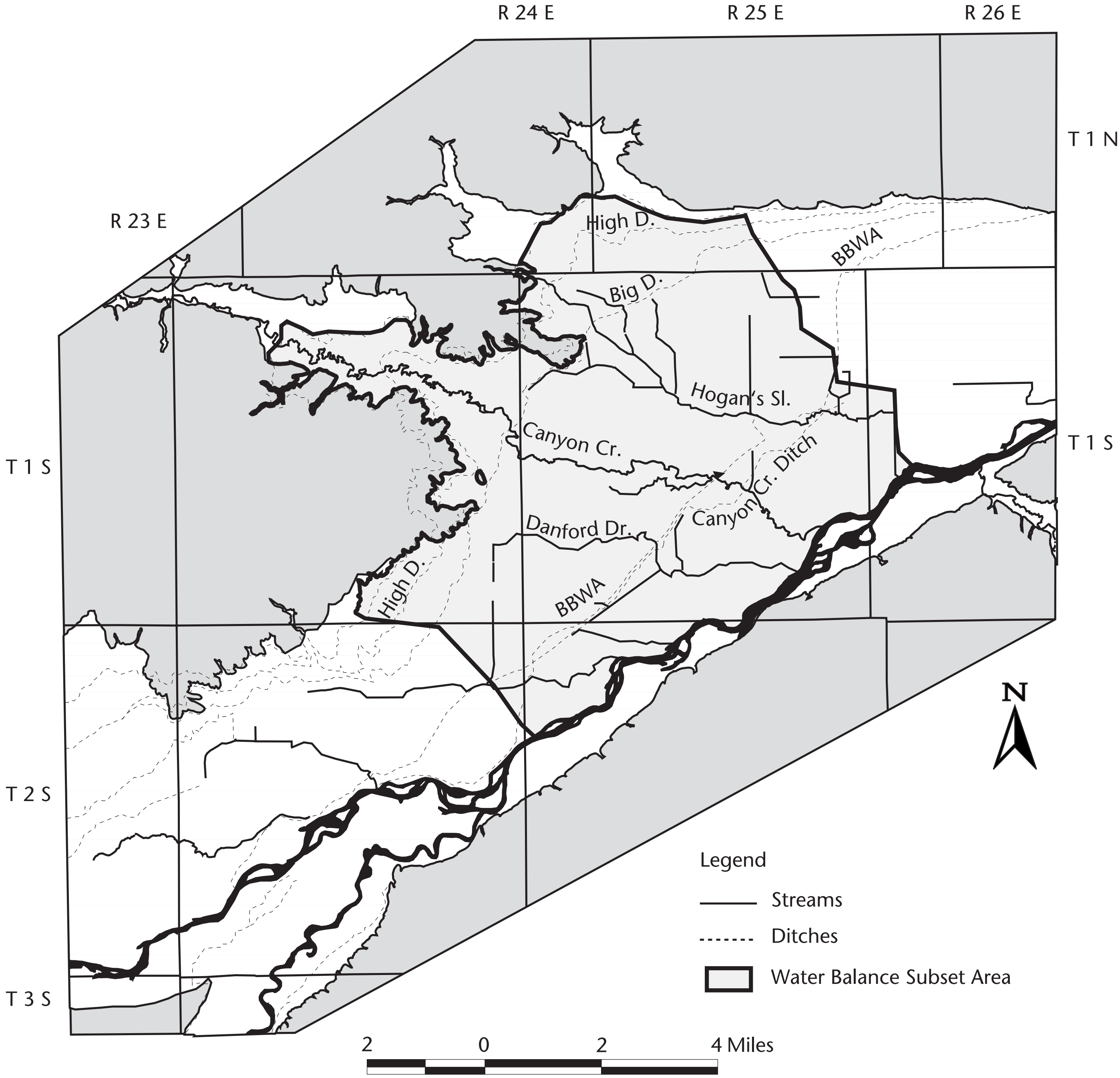

Figure 8. WBSR hydrologic balance.

Soil Conservation Service, 1995; Mahler, 1999). The remaining surplus water (83,080 acre-feet or 80 percent) was assumed lost through evapotranspiration. Because of the relatively flat terrain, storm-water runoff was assumed to be a negligible component of the water balance. This assumption was particularly true during 1999 because of the general lack of major storm events. Ground-water recharge (total input minus evapotranspiration divided by total area) averaged 8.2 inches per year. The areal recharge rate is likely to vary significantly, depending on land use and soil infiltration.

The hydrologic balance indicates that irrigation water accounts for 65 percent of the area water input; however, the actual percentage contribution to ground-water recharge is higher because most rain (50 percent of Billings 1999 total) occurred in minor events (0.25 inch or less) that are readily

Table 3. WBSR hydrologic balance

Item	Water quantity	
Surface-water balance	Acre-feet/year	
Ditches inflow	255,000	
BBWC outflow	-102,000	
Return and overflow	-83,500	
Flood irrigation and ditch leakage	**69,500**	
Area water balance		
Input		
Flood irrigation and ditch leakage	69,500	
Lawn irrigation (GW)	5,000	
Septic returns	450	
Precipitation	30,100	
Total input	**105,050**	
Output		
Ground-water discharge	16,400	
Household use (GW)	700	
Lawn irrigation withdrawal (GW)	5,000	
Evapotranspiration (ET)	82,950	
Total output	**105,050**	
		Inches/Year
Average recharge (total input minus ET)	22,100	8.73

evapotranspirated. On the other extreme, large summer thunderstorms drop rain at rates too fast to infiltrate, generating mostly runoff. In flood irrigation, soaking is relatively uniform and deep, so more of the applied water infiltrates.

Septic returns account for 0.4 percent of the hydrologic input; however, septic water is discharged below the root zone and is generally not subject to losses by evapotranspiration. If all 448 acre-feet of septic return water is assumed to infiltrate to the ground water, it would account for 2 percent of the aquifer recharge regionally. Residential lawn watering accounted for 5 percent of the area water input. Most subdivision residents use ground water for lawn watering. Considering that most applied water is lost through evapotranspiration, lawn watering in subdivisions is actually a large net hydrologic loss.

Chloride and Evapotranspiration

Chloride is a non-reactive ion that is readily flushed through the hydrologic system and is not significantly removed by plant uptake or evaporation, so it becomes concentrated through evapotranspiration (ET) losses. If the primary source of chloride is from the recharge water (irrigation water), the percentage ET loss can be calculated as follows:

$E = (1 - [Cl_r / Cl_{gw}]) \times 100$ percent (from Clark and Fritz, 1997)

where

E = percent ET loss

Cl_{gw} = ground-water chloride concentration

Cl_r = recharge chloride concentrations (5 mg/L)

The total annual ground-water discharge of chloride from the WBSR was calculated from average ground-water concentrations (19.8 mg/L) and total stream baseflows (15,181 acre-feet/year) to be 440 tons. Nearly all of this chloride (380 tons) can be accounted for by the 68,500 acre-feet per year of applied irrigation water with an average chloride concentration of 4 mg/L (Shields and others, 2000). Other potential sources of chloride in the project area (septic systems, road salts, fertilizer, and manure) appear to be minor contributors; therefore, chloride can be used as an indicator of ET loss.

Table 4. Chloride concentrations and evapotranspiration losses

Group	Average chloride concentration (mg/l)	Estimated ET loss
All wells	19.8(n=54)	80%
Fine-grained cover thickness		
less than 5 feet	12.7(n=18)	69%
Between 5-20 feet	20.4(n=18)	80%
Greater than 20 feet	23.8(n=18)	83%

Where:
(n=18) refers to the number of wells in the group
ET loss= The percentage of water removed from the original application by evapotranspiration

Chloride data provided in table 4 indicate that on average ET losses are between 70 and 83 percent. These losses appear to be influenced by the thickness of the fine-grained cover. Where the cover is thin, the soils are more permeable and irrigation water infiltrates rapidly. However, where the fine-grained cover is thick, soils are less permeable; water stays within the root zone for longer periods and is subject to greater ET losses, which concentrates the chloride.

Deuterium-Oxygen-18

Isotopic analyses of deuterium (^2H) and oxygen-18 (^{18}O) were used to delineate sources of ground-water recharge. Values of δ^2H and $\delta^{18}O$ in precipitation are influenced by meteorological processes and particularly by the temperature, elevation, and latitude of the rain or snowfall event (Clark and Fritz, 1997) [1]. Precipitation occurring over warmer climates, low elevations, and low latitudes has lower (more depleted) δ^2H and $\delta^{18}O$ values than precipitation occurring over colder climates, higher elevations, and higher latitudes. This isotopic trend is significant to this investigation because irrigation water is composed primarily of high-altitude snowmelt from the Yellowstone River (containing lower values of δ^2H and $\delta^{18}O$), whereas the local precipitation is primarily composed of late spring and early summer showers and thunderstorms (containing higher values of δ^2H and $\delta^{18}O$). Therefore, the δ^2H and $\delta^{18}O$ of ground water should reflect the relative contributions of each recharge source.

The isotope composition of Yellowstone River irrigation water (sampled at Livingston; Coplen and Kendall, 2000) indicates an irrigation-season range (April–October) for $\delta^{18}O$ of -18.1 to -16.4 permill and -130.5 to -143.8 permill for δ^2H. This indication agrees with data from a West Billings irrigation water sample (from the BBWA canal) that had a $\delta^{18}O$ of -16.99 permill and a δ^2H of -133.2 permill (table 5).

Isotope ranges for the Billings area precipitation were estimated Billings area composite samples (table 5) from isotope-temperature relationships and reported weighted precipitation averages from recording stations in southern Canada (from the Canadian Network of Isotopes in Precipitation, http://sciborg.uwaterloo.ca/~twdedwar/cnip/cniphome.html). These data suggested a typical $\delta^{18}O$ range of -6.6 to -15 permill and a δ^2H range of -61 to -135 permill for the growing season (April–October). The weighted average for precipitation was -11.4 permill for $\delta^{18}O$ and -103.5 permill for δ^2H.

Analyses of 15 ground-water samples from throughout the study area indicated a $\delta^{18}O$ range of -15.5 to -17.39 permill and a δ^2H range of -126.4 to -135.6 permill (table 5). These values are within or slightly higher than the range for irrigation water and are much lower than for local precipitation (figure 9). The relative proportion of irrigation and local precipitation contributions to ground water can be calculated by the following mixing formula:

$$\text{Irrigation fraction} = (\delta^{18}O_{\text{ground water}} - \delta^{18}O_{\text{precipitation}})/(\delta^{18}O_{\text{irrigation}} - \delta^{18}O_{\text{precipitation}})$$

[1] Isotopic ratios of deuterium ($^2H/H$), oxygen-18 ($^{18}O/^{16}O$) and all other stable isotopes discussed in this report are expressed as delta (δ) values in terms of parts per thousand (permill) departure from a standard reference ratio (see Methods of Data Collection for further details).

Table 5. Summary of stable isotope data

GWIC ID	Location (TRS)	Sample Date	$\delta^{18}O$ (water)	$\delta^{2}H$ (water)	$\delta^{15}N$ (NO_3)	$\delta^{18}O$ (NO_3)	$\delta^{13}C$ (HCO_3)	δ34S (SO_4)
92840	01S-25E-1-CBBB	09/28/99	-16.35	-126.60	18	-	-14.23	-13.37
93058	01S 25E 25 BCBC	09/21/99	-17.26	-132.20	19.5	-	-13.11	-16.38
93305	01S-25E-18-DDDC	09/29/99	-17.09	-132.20	14.1	-	-13.57	-10.11
94118	01S-26E-16-ABCB	7/31/00	-16.55	-	15.1	0.68	-	-
151382	01S-25E-4-DDDC	09/29/99	-	-	20.6	-	-	-
154210	01S-25E-26-AADD	09/29/99	-	-	8	-	-	-
158589	01S-25E-33 ACDA	07/31/00	-16.43	-	-	-	-	-
158941	01N-25E-30-BBCA	07/31/00	-16.58	-	-	-	-	-
171243	01S-25E 15 ACCC	09/29/99	-16.93	-131.10	23.7	-	-11.78	-14.66
171243	01S-25E 15 ACCC	7/31/00	-	-	24	**	-	-
171246	01S-25E-10-AABC	7/31/00	-	-	23	6.4	-	-
171250	01S-25E-21-DDAD	09/21/99	-17.29	-132.60	6.7	-	-14.89	-11.56
171250	01S-25E-21-DDAD	7/31/00	-	-	15.3	0.43	-	-
171251	01S 25E 21 DAAA	09/21/99	-16.69	-131.60	-	-	-13.45	-14.369
171252	01S 25E 21 DAAA	09/21/99	-16.43	-130.10	-	-	-12.24	-13.17
171257	01S 26E 19 BBBD	09/22/99	-17.32	-134.10	9.4	-	-13.62	-9.289
171257	01S 26E 19 BBBD	7/31/00	-	-	9.4	-1.10	-	-
171258	01S 25E 25 BCBC	09/22/99	-17.39	-135.60	-	-	-13.67	-10.58
171261	02S 24E 7 DAAA	09/30/99	-15.50	-126.40	18.8	-	-15.26	-24.24
171261	02S 24E 7 DAAA	7/31/00			18.8	**	-	-
171264	01S 23E 13 BBAB	10/06/99	-16.93	-129.70	16.8	-	-14.09	-11.69
172389	02S-24E-13-AABB	9/27/99	-16.99	-133.20	-	-	-8.02	-2.59
March precipitation composite		3/2002	-21.97	-176.01	-	-	-	-
April precipitation composite		4/2002	-17.21	-125.67	-	-	-	-
May precipitation composite		5/2002	-11.06	-93.64	-	-	-	-
June precipitation composite		6/2002	-7.42	-	-	-	-	-
July precipitation composite		7/2002	-7.11	-76.94	-	-	-	-

Note: ** sample interferences

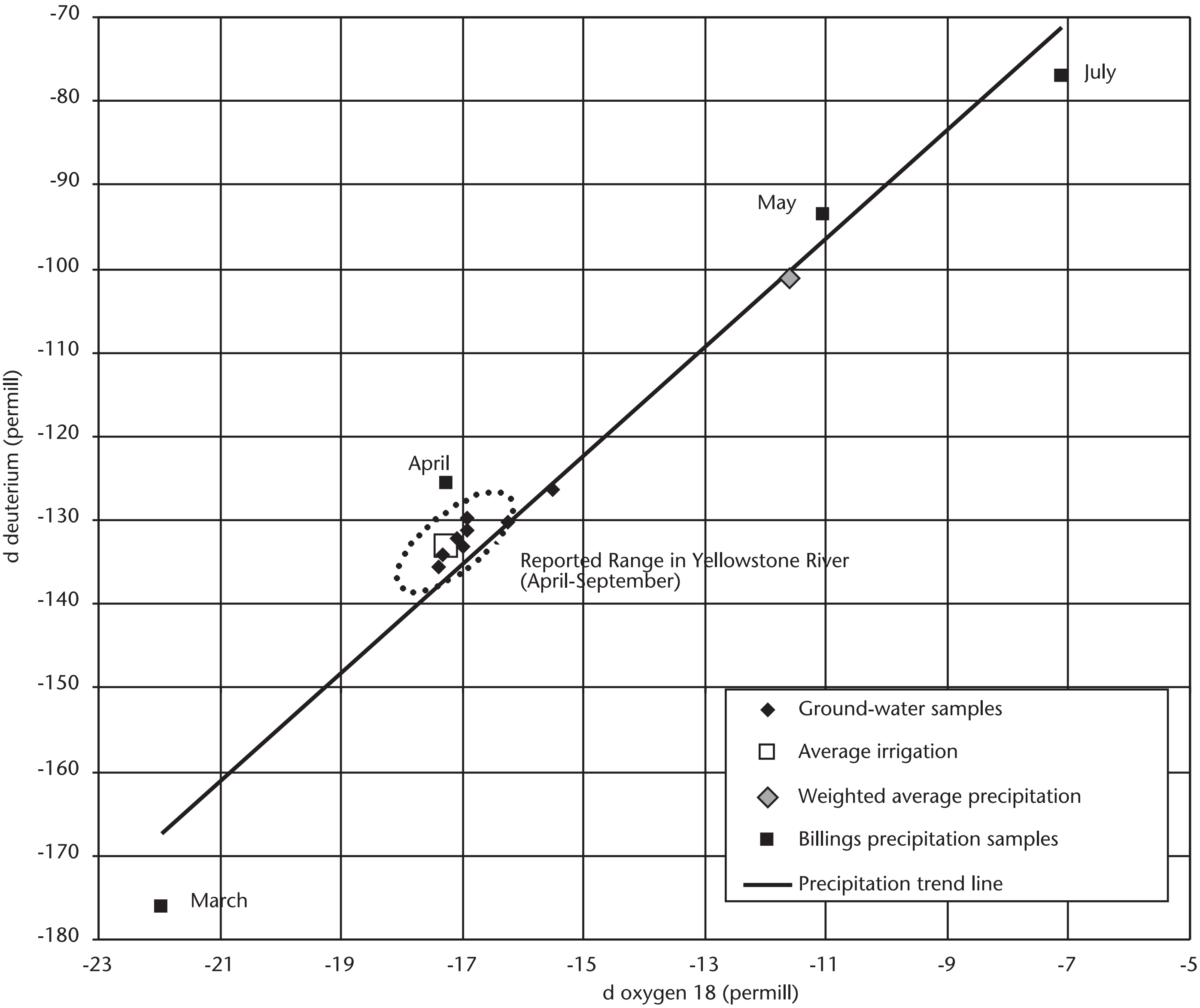

Figure 9. δ^2H and $\delta^{18}O$ values in ground water are similar to those in the irrigation water (Yellowstone River) and dissimilar to those in local precipitation.

using the following average values

$\delta^{18}O_{\text{ground water}}$ = -16.6 permill

$\delta^{18}O_{\text{precipitation}}$ = -11.4 permill

$\delta^{18}O_{\text{irrigation}}$ = -17.6 permill

Using this formula, the proportion of irrigation water (or other snowmelt-derived water) averaged 84 percent. The water balance data indicated that 66 percent of the water input was from irrigation. To achieve the estimated 84 percent irrigation water in ground water, 90 percent of the precipitation water would need to be lost through evapotranspiration or runoff, an assumption that is realistic. Most of the precipitation (50 percent) in 1999 through 2000 occurred as light showers (<0.25 inches), and that water is readily evaporated. But, much water from high-intensity thunderstorms is lost to surface runoff rather than infiltration. Flood-irrigation water is applied relatively uniformly and soaks in deeply. Consequently, a much larger proportion of irrigation water infiltrates than does precipitation.

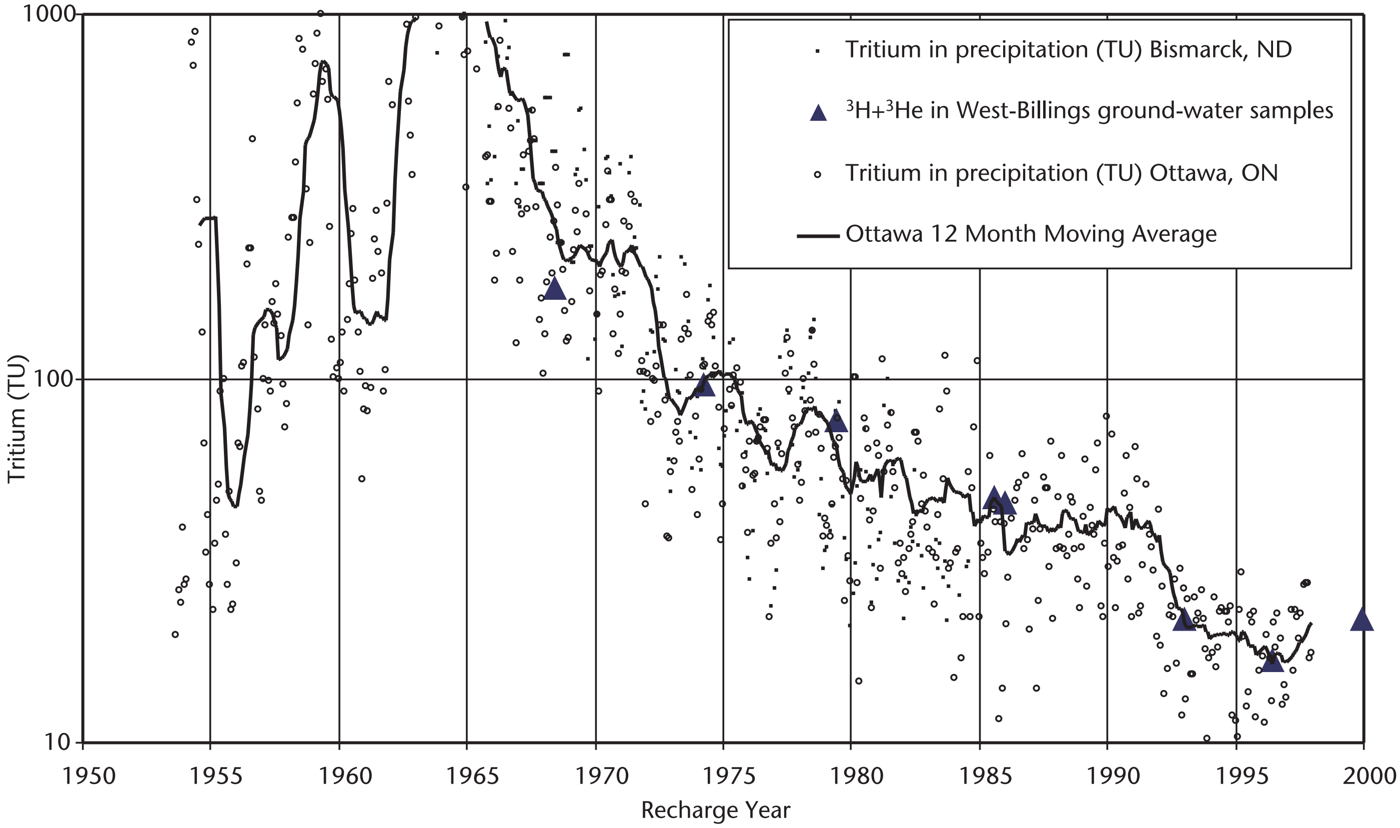

Figure 10. The recombined ^3H + ^3He concentrations match reasonably well with the historical tritium precipitation input.

Ground-Water Age

Tritium (^3H) is a radioactive isotope of hydrogen that decays with a half-life of 12.43 years to helium-3 (^3He). The “age” of a water sample (the time since the sample was last in contact with the atmosphere) is determined by the ratio of parent (^3H) to daughter (^3He) atoms. Although ^3H occurs naturally in the atmosphere, that natural production was overwhelmed by ^3H output from nuclear weapons testing in the 1960s. Historical ^3H concentrations in precipitation (Global Network of Isotopes in Precipitation; (http://isohis.iaea.org/) are shown in figure 10 from two stations at similar latitude as Billings, which are Bismarck, North Dakota (the closest station), and Ottawa, Ontario (the most complete record).

Table 6. Summary of tritium-helium-3 data

Sample Name and GWIC ID	Tritium TU	Tritium Error +/-	Tritigenic Helium-3 TU	Tritium plus Helium-3 TU	ground-water age years
Slough-1 (1712430	24.31	1.22	52.60	76.91	20.7
Thomas (171248)	13.71	0.69	3.43	17.14	4.0
Giesick-O (93058)	30.52	1.53	150.84	181.36	32.0
Bond (171253)	21.60	2.10	1.07	22.67	0.9
Armstrong (171257)	14.83	0.74	7.65	22.48	7.5
Apostolic (92840)	20.80	1.04	25.25	46.05	14.3
Gable (154210)	21.08	1.05	27.33	48.41	14.9
Saunders-1 (171251)	22.79	1.14	74.11	96.90	26.0
Eldergrove (93305)	29.20	1.50	**	**	**

Notes: ** Sample stripped of gas

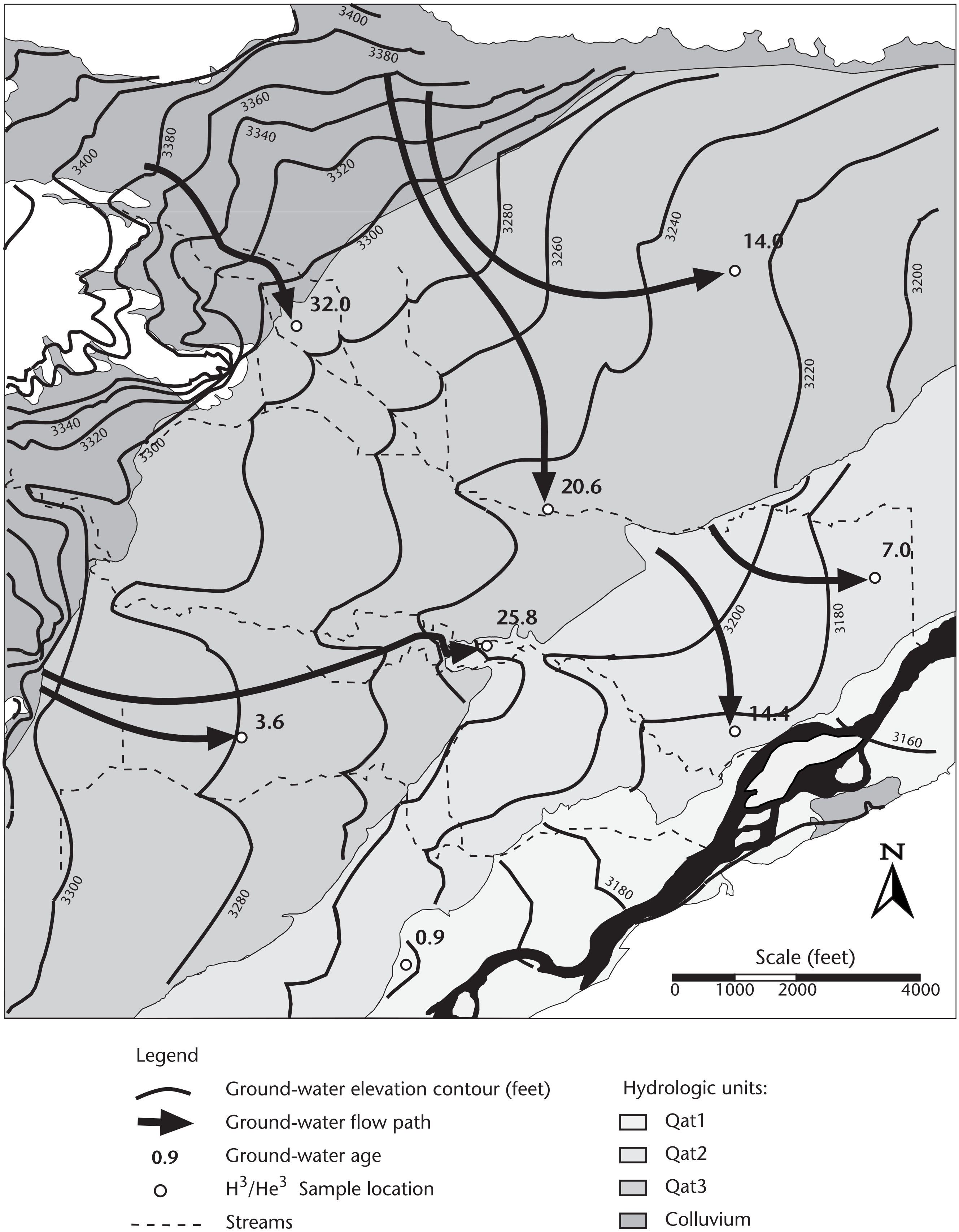

Figure 11. The distribution of ground-water age near Canyon Creek and Hogan's Slough.

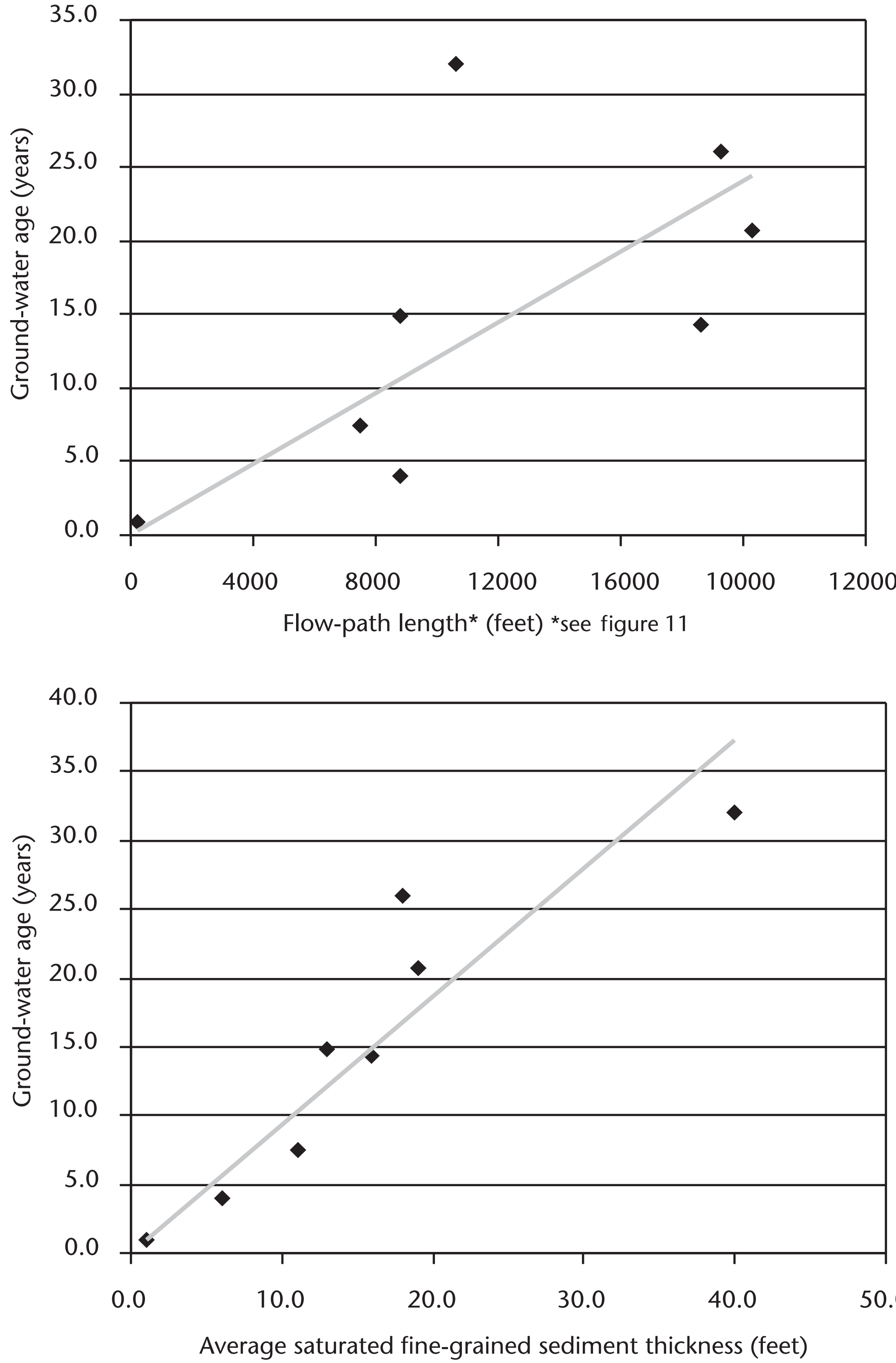

Figure 12. Ground-water ages are proportional to flow path length and the average, saturated, fine-grained sediment thickness.

Tritium concentrations in the sampled ground water ranged from 15 to 31 tritium units (TU, table 6), which is consistent with modern water (less than 50 years old). Ground-water ages calculated from $^3H/^3He$ range from 0.9 to 32 years (figure 11). Reported ground-water sample ages and recombined tritium content (tritium plus the tritium-derived helium) match reasonably well with the measured historical tritium content in precipitation (figure 10).

The age of a ground-water sample is a composite of ground water from the farthest part of the flow path and recharge along the flow path. In general, the oldest ages were found at the end of longer ground-water flow paths (figures 11 and 12). A notable exception to this is the sample from well 93058, which appears to be much older than accounted for by flow path length (figure 12). However, recharge water in this area must infiltrate 35 feet of saturated fine-grained sediment, so the water likely ages considerably before it reaches the sand and gravel aquifer. The thickness of the saturated fine-grained sediment also appears to be an influence on ground-water ages for the other samples and is demonstrated by the linear correlation of ground-water age and the average thickness of saturated fine-grained sediment (figure 12).

Evaluation of Ground-Water Quality

Ground water in the alluvial aquifer system ranges from a relatively fresh bicarbonate-dominated water to a highly mineralized sulfate-dominated water (plate 2). For both types of water, the relative proportions of calcium, magnesium, and sodium are nearly equal (in terms of meq/L). The bicarbonate-dominated waters typically have dissolved constituents (sum of major ions) concentrations of less than 1,000 mg/L, whereas the sulfate-dominated waters have a dissolved constituents concentrations of 1,000 mg/L to more than 5,000 mg/L.

Water-quality data shown on plate 2 indicate that ground water for most of the project area is generally acceptable for domestic use (dissolved-constituents concentrations of less than 2,000 mg/L). However, ground water along the valley margins, near Laurel, and along much of Hogan's Slough has dissolved-constituents concentrations greater than 3,000 mg/L and is undesirable as a domestic water source.

The distribution of dissolved constituents and ground-water age appears to be related to the fine-grained cover thickness (plate 2). Where the fine-grained cover is thin, irrigation recharge can infiltrate rapidly and the water quality is similar to that of irrigation water. Where the fine-grained cover is thick, water infiltrates slowly and dissolved constituents accumulate in the recharge water through evapotranspiration and soil-mineral dissolution.

Bicarbonate and ^{13}C

Bicarbonate (HCO_3) is the dominant anion in ground water having dissolved-constituents (sum of major ions) concentrations generally less than 1,000 mg/L, but its predominance decreases at higher concentrations. The bicarbonate concentration in irrigation water is between 90 and 140 mg/L (Yellowstone River water, May–September 2000; Shields and others, 2000). Bicarbonate concentrations in ground water range from 300 to 500 mg/L and the water is saturated or supersaturated with respect to calcite (calcium carbonate) in all of the ground-water samples collected (calculated from Lindsay, 1979).

Potential sources of bicarbonate include dissolved and dissociated atmospheric carbon dioxide, soil reactions (mineral and gas phase), dissolution of mineral carbonates in sedimentary rocks, and oxidized organic matter. Bicarbonate from each of the above sources is expected to have a distinctive fractionation of ^{13}C. Anticipated ranges (Clark and Fritz, 1997) are listed below:

- Atmospheric CO_2 has a $\delta^{13}C$ of -8 permill.
- Soil mineral and gas reactions on infiltrating water impart a $\delta^{13}C$ signature that is soil pH dependent. Soils having a pH of near 7.5 (typical of the West Billings area; Meshnick and others, 1972) should have a $\delta^{13}C$ of -16 to -17 permill.
- Dissolved carbonate from marine sedimentary rocks (such as calcareous shale) will have a $\delta^{13}C$ of near 0 permill.
- Organic matter oxidized to bicarbonate will have a $\delta^{13}C$ of near -25 permill.

A sample of West Billings area irrigation water had a δ13C of -8, which is consistent with atmospheric carbon dioxide. The range of δ13C in the 11 ground-water samples was -11.8 to -15.3 permill (table 5), which is slightly higher than the δ13C anticipated from soils. These data suggest the bicarbonate in ground water is primarily from soil reaction sources, with some inputs from atmospheric carbon dioxide and/or dissolved sedimentary carbonate.

Sulfate and ^{34}S

Sulfate (SO_4) is the primary anion in ground water, having dissolved-constituents concentrations greater than 1,000 mg/L. In fact, sulfate can comprise up to 63 percent of the total dissolved-constituents mass. Sulfate concentrations in irrigation water range from 10 to 70 mg/L, with an average of 30 mg/L (Yellowstone River at Billings May–September 2000; Shields and others, 2000). Sulfate in ground water ranges from 100 mg/L to 4,000 mg/L (average of 850 mg/L).

Potential sources of sulfate in the region include atmospheric sulfur, dissolution of evaporates, and oxidized pyrite dissolved from soils. Anticipated $\delta^{34}S$ ranges in potential sulfate sources are listed below (Clark and Fritz, 1997):

- Atmospheric sulfate has $\delta^{34}S$ values ranging from 0 to -5 permill.
- Marine limestone and evaporates have $\delta^{34}S$ of roughly +20 permill.
- Pyrite has $\delta^{34}S$ of 0 to -20 permil.

In a sample of irrigation water (from the BBWA), the $\delta^{34}S$ was 3 permill, which indicates the sulfate is primarily from precipitation. However, the $\delta^{34}S$ values in the ground-water samples were much lower (-9 to -18 permill, table 5) and are within the expected range for oxidized pyrite. Ground water with high sulfate concentrations occurs in areas with thick, fine-grained sediment covers. Much of the fine-grained soils were washed down from the surrounding silty-clayey soils derived from the Colorado Group. Marine organic-rich shale of the Colorado Group contains 1–3 percent sulfur, which is primarily pyrite (iron sulfide; Dean and Arthur, 1989). In the soils, the pyrite is oxidized and reacts with soil carbonates to form gypsum (Lindsay, 1979). Gypsum formed in this manner differs from marine or evaporite gypsum in that the sulfate is isotopically similar to or slightly depleted from the original sulfide.

The results from the ground-water sampling show that $\delta^{34}S$ decreases with increasing sulfate concentrations (figure 13). In general, sulfate concentrations decrease and $\delta^{34}S$ increases along the flow path, which indicates that the highly mineralized water (containing mostly pyrite-derived sulfate) is being diluted by relatively unaltered irrigation water (containing mostly atmospheric sulfate).

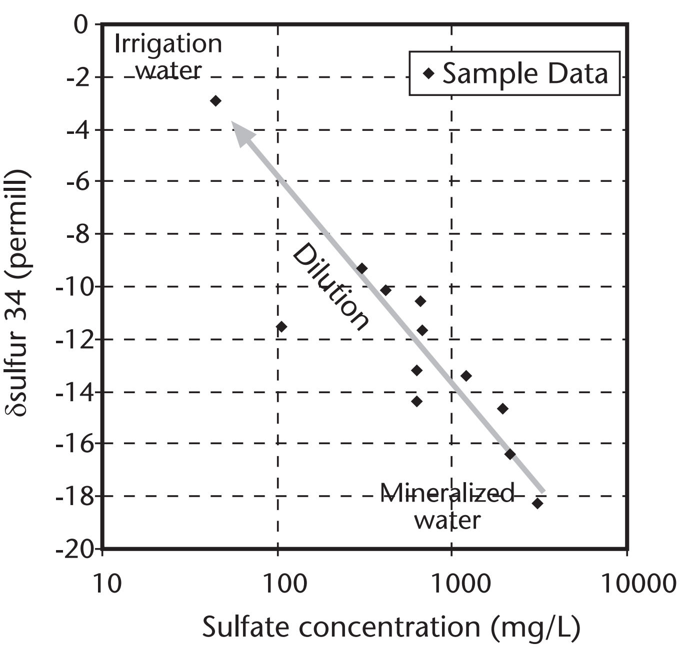

Figure 13. Sampled ground-water $\delta^{34}S$ increases with sulfate concentrations. This occurrence demonstrates mixing between relatively unaltered irrigation water containing atmospheric sulfate with $\delta^{34}S$ of -3 permill) and water containing sulfate from pyrite dissolution ($\delta^{34}S$ of -18 permill).

Nitrate and ^{15}N and ^{18}O

Ground-water nitrate (NO^3) concentrations ranged from below detection (<0.1 mg/L) to 20 mg/L, with an average concentration of 3.3 mg/L. Approximately 5 percent of the 130 samples reviewed exceeded the recommended human health limit of 10 mg/L. However, 18 percent of the samples had nitrate concentrations approaching that limit (between 5 and 10 mg/L).

Nitrate concentrations monitored on a quarterly basis at nine wells displayed seasonal variations as high as an order of magnitude (plate 2). In five of the wells, the nitrate concentration was highest in the early spring (March), and in three wells, the nitrate concentration was highest in the fall (September). One well had no nitrate concentrations above detection. However, more sampling by the Yellowstone Conservation District in 1989–1990 in the Duck Creek Road area indicated a pattern with spikes occurring in the late fall and early spring (MBMG unpublished data on file, 1991).

Evaluation of nitrate concentrations by land use and fine-grained soil cover (plate 2) indicates wide ranges of nitrate concentrations beneath irrigated and urban/residential land uses. However, on average the nitrate concentrations on irrigated lands were slightly higher than for the residential/urban lands. Additionally, for both land-use categories, nitrate concentrations were on average lower in areas where the fine-grained cover is thick.

Potential sources of nitrate in the West Billings area are residential septic systems, soil organic matter, agricultural fertilizers, and animal manure. Nitrate impacts from septic systems will depend on soil characteristics, system design and efficiency, and housing density. Nitrate impacts from the other sources are largely controlled by plant uptake, agricultural practices, and soil characteristics.

Relative contributions of these sources to ground water were evaluated using nitrate concentrations and water fluxes. Based on the average nitrate concentrations (3.3 mg/L) and the total ground-water outflow, 68 tons of nitrate is added to ground water in the WBSR each year. Based on various investigations (Robertson, and others, 1991; Woessner and others, 1996; Walker and others, 1973), 10–20 mg/L of nitrate from septic effluent is assumed to infiltrate to the ground water. Using the above effluent concentration and the total septic water flux, septic systems may contribute 7–14 tons per year (or 10–20 percent of the total) of nitrate in the WBSR. The remaining 54–61 tons of nitrate per year probably is from soil organic matter, agricultural fertilizers, and animal manure.

Organic matter in soils includes residual plant materials and manure, roots, and humus. Additionally, the shale formations in the Colorado Group can be carbonaceous, so soils formed from the shale also may contain organic matter. Nitrate from soil organic matter can be an important source of nitrate in ground water (Fogg and others, 1998; Nimick and Thamke, 1998; Kendy, 2001). However, there are presently insufficient data to evaluate the significance of this source.

Of the annually applied sources of nitrogen, chemical fertilizers in agricultural areas appear to be the most significant. Roughly 100–200 pounds per acre (as nitrogen) of chemical fertilizer is applied over agricultural areas in the West Billings area (Lichthard and Jacobsen, 1991; Meshnick and others, 1972; Kendy, 2001). Nearly all of the chemical fertilizer is consumed by plants. Fertilizer also is applied on lawns and gardens but typically at considerably lower rates. Typical lawn and garden applications in rural subdivisions are approximately 5 pounds/acre/year (Hantzche and Finnemore, 1992). Animal manure also is used as an agricultural fertilizer and soil amendment; however, it accounts for a small portion of the total agricultural nitrogen applications in the Yellowstone River valley area. There are no large concentrated animal feed lots in the West Billings area.

Nitrogen-15 (^{15}N) and oxygen-18 (^{18}O) of nitrate can provide a diagnostic tool to identify nitrate sources. Twelve wells sampled and analyzed for ^{15}N, and six wells were later sampled for $\delta^{15}N$ and $\delta^{18}O$ (of nitrate). However, because of analytical problems, $\delta^{15}N$ and $\delta^{18}O$ values were reported for only four samples. Anticipated ranges in $\delta^{15}N$ and $\delta^{18}O$ for likely sources of nitrate are as follows:

- Urea- and ammonia-based fertilizers have a $\delta^{15}N$ value of -4 to +2 permill (Spalding and others, 1982),
- Soil humus has a $*^{15}N$ value of +4 to +9 permill (Boyce and others, 1976), and
- Geologic nitrogen (organic-rich marine shale) has a $\delta^{15}N$ of +3 to +9 permill.
- Septic waste or animal manure have a $\delta^{15}N$ of +9 to +22 permill (Komor and Anderson, 1993).
- Nitrate formed from ammonia oxidation (all of the above sources) should have a $\delta^{18}O$ of -10 to +10 permill (Clark and Fritz, 1997).

The samples exhibited a $\delta^{15}N$ range of +6.7 to +23.7 permill and a $\delta^{18}O$ of -1.1 to 6.4 permill (table 5). The $\delta^{18}O$ values are consistent with all of the listed probable sources of the areas. Three of the samples were in the $\delta^{15}N$ range of soil or geologic nitrogen and nine of the samples were in the range

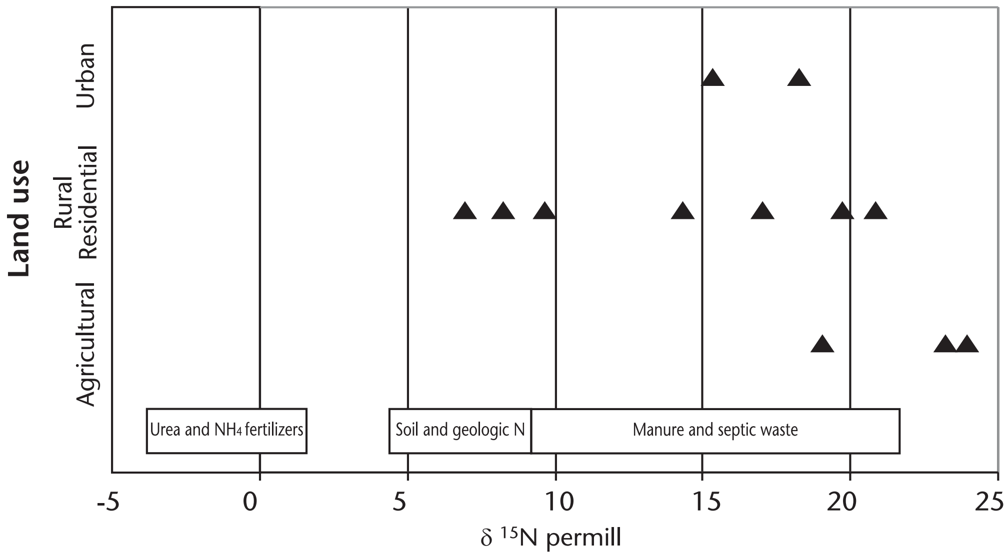

Figure 14. Most samples had $\delta^{15}N$ values between 14 and 24 permill (in the range for manure and septic waste. There did not appear to be an obvious pattern with land use.

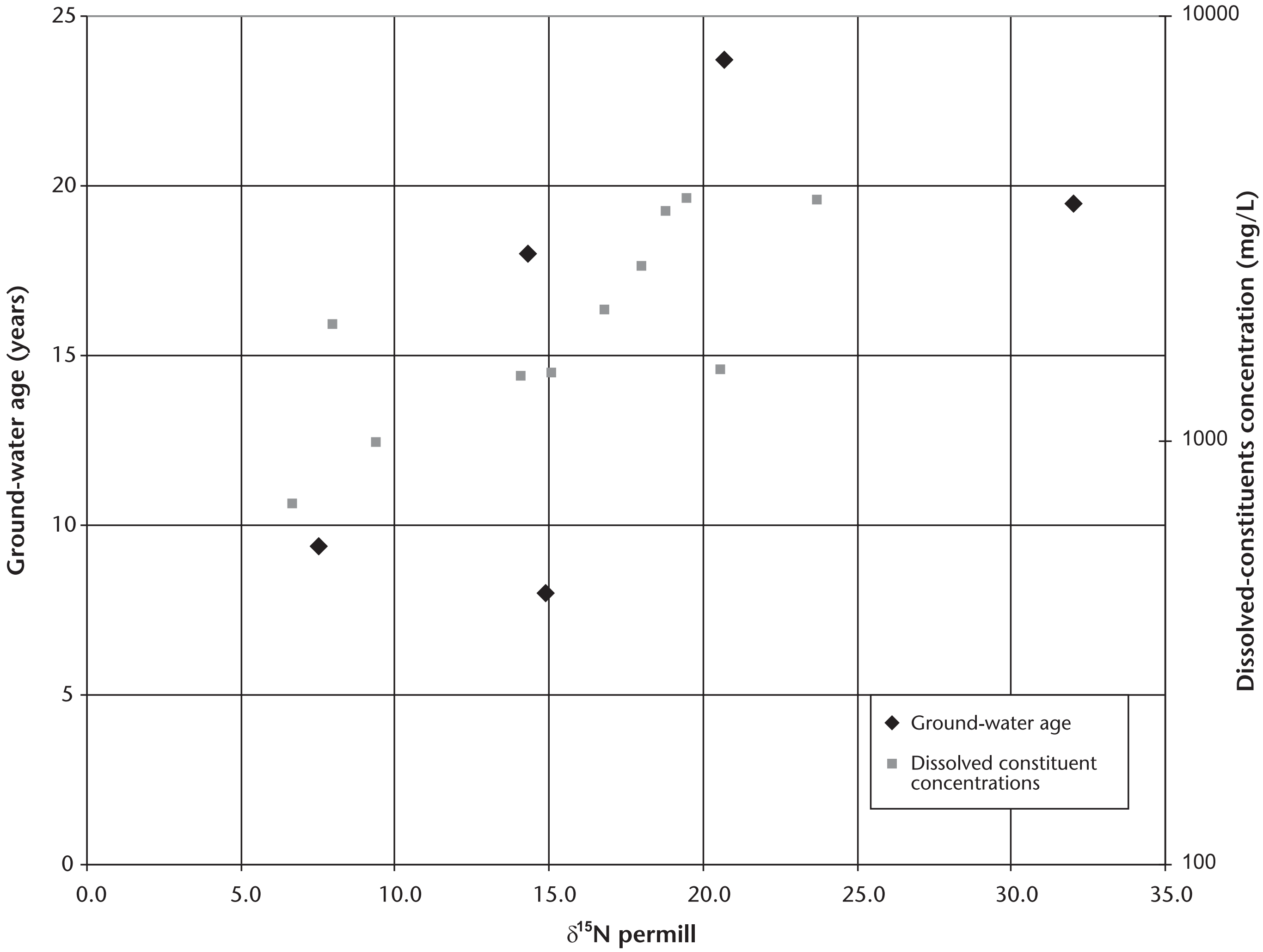

Figure 15. $\delta^{15}N$ values exhibit correlation with ground-water age, specific conductance and with $\delta^{18}O$.

of septic waste or animal manure (figure 14). None of the samples had a $\delta^{15}N$ in the range of fertilizers.

These data appear to conflict with the earlier discussion of nitrate sources. Even more puzzling is that $\delta^{15}N$ or $\delta^{18}O$ values do not correlate with land use or proximity to septic systems (figure 14). However, $\delta^{15}N$ does appear to increase with ground-water age and specific conductance (figure 15). The higher $\delta^{15}N$ in the older ground water could indicate that manure application was more common in the past, or some process (such as denitrification) has increased $\delta^{15}N$ over time. Denitrification (the biochemical reduction of nitrate to nitrogen gas) has been documented to increase $\delta^{15}N$ and $\delta^{18}O$ in the residual nitrate. A plot of $\delta^{15}N$ and $\delta^{18}O$ demonstrates a linear relationship (figure 16) that could indicate that $\delta^{15}N$ and $\delta^{18}O$ have been increased.

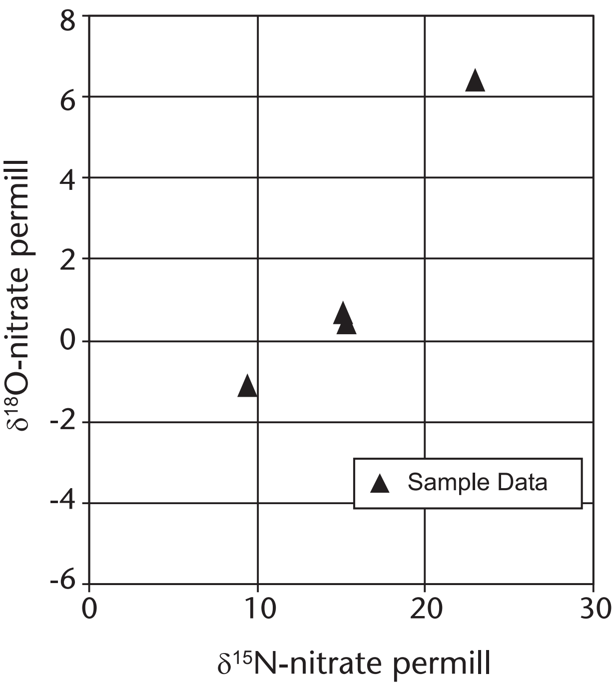

Figure 16. There appears to be a relationship between $\delta^{15}N$ and $\delta^{18}O$-nitrate. This could be the result of denititrification.

Evaluation of Surface-Water Quality

Yellowstone River

The Yellowstone River at Billings is calcium-bicarbonate water with a relatively low concentration of dissolved constituents (from 70 to 200 mg/L; Shields and others, 2000). For most of the year, the river is relatively clear (total sediment of 1–30 mg/L). However, during spring melt (May and June), sediment concentrations increase to 50–1,000 mg/L. The water temperature in the river ranges from 0.5°C in January to 23°C in September.

The impacts of irrigation on the Yellowstone River were evaluated by comparing Yellowstone River water quality at Billings (USGS monitoring station), with stream outflows and water quality between Laurel and Billings (14.5 river miles). The influences from the Clarks Fork were evaluated with flow and water-quality data from the USGS monitoring station at Edgar.

These data (summarized in table 7) indicate that the Clarks Forks River accounted for approximately 20 percent of the dissolved load, 40–50 percent of the suspended load, 20–40 percent of the nitrate concentration and increased the water temperature by approximately 4°C. Irrigation return flows from the Laurel-to-Billings reach accounted for 4–15 percent of the dissolved load, 10–20 percent of the nitrate concentration and 0–4 percent of the suspended load. Temperature impacts from irrigation are negligible.

Canyon Creek

As it enters the Yellowstone River valley north of Laurel, Canyon Creek is alkaline and highly mineralized. The dissolved-constituents concentration is more than 5,000 mg/L, and it is primarily a sodium-sulfate water. During the winter months, ground-water baseflow discharging from the terrace gravels mixes and dilutes the initial stream water. By the time the creek reaches the Yellowstone River, it is essentially an average of the ground-water quality from the terrace gravels it crosses. At its confluence with the Yellowstone River, the creek has a dissolved-constituents concentration of 2,100 mg/L.

During the irrigation season, the creek becomes a conveyance for irrigation-return water and ditch overflows. Consequently, water quality in the creek becomes similar to that of the Yellowstone River. However, due to evaporation and soil interactions, the irrigation-return water contains approximately 300–400 mg/L more dissolved constituents and 10–70 mg/L more suspended

Table 7. Water-quality impacts to the Yellowstone River from surface-water discharges, Laurel to Billings.

	Yellowstone River *1	Clarks Fork Yellowstone *2			Minor streams *3		
A) Flow							
Month	Flow (cfs)	Flow (cfs)	Contribution to total		Flow (cfs)	Contribution to total	
March	2500	346	14%		20	0.8%	
June	41600	8080	19%		310	0.7%	
August	6820	1070	16%		355	5.2%	
B) Dissolved Constituents							
Month	Dissolved constituents (mg/l)	Dissolved constituents (mg/l)	Contribution to total *4	Concentration contribution *5	Dissolved constituents *6 (mg/l)	Contribution to total	Concentration addition mg/l
March	232	409	25%	57	1175	4%	9.4
June	66	69	20%	13	317	4%	2.4
August	162	239	23%	37	455	15%	23.7
C) Nitrate							
Month	NO_3 (mg/l-N)	NO_3 (mg/l-N)	Contribution to total *4	Concentration contribution *5	NO_3 (mg/l-N)	Contribution to total	Concentration addition (mg/l-N)
March	0.22	0.52	33%	0.07	3.45	13%	0.03
June	0.16	0.13	16%	0.03	1.05	5%	0.01
August	0.15	0.49	51%	0.08	0.59	20%	0.03
D) Temperature							
Month	Temperature (°C)	Temperature (°C)	Contribution to total *4	Temperature contribution (°C)*5	Temperature (°C)*6	Contribution to total	Temperature addition (°C)
March	5.5	8	20%	1.1	5.6	1%	0.04
June	14	19	26%	3.7	5.7	0%	0.04
August	18.5	22	19%	3.5	5	1%	0.26
E) Total Suspended Sediment							
Month	TSS (mg/l)	TSS (mg/l)	Contribution to Total	Concentration Contribution	TSS (mg/l) *6	Contribution to total	Concentration addition (mg/l)
March	12	24	28%	3	<10	0	0
June	290	612	41%	119	189	0.5%	1.4
August	50	162	51%	25	36	3.7%	1.9

Notes:

River segment Laurel to Billings (14.6 river miles)
*1 Yellowstone River at Billings USGS 1999, station 06214500
*2 Clarks Fork Yellowstone River USGS 1999, station 06208500
*3 Weighted average of West-Billings stream data 1999
*4 Contribution to total = 100% * % flow of contributer * concentration of contributer / concentration total
*5 Concentration contribution= %contribution of total * total concentration
*6 Weighted average of minor stream concentrations (or Temperature) minus intake concentrations

sediment than the river. In 1999, irrigation-return water in Canyon Creek was approximately 2°C warmer than the river.

It is difficult to assess what the flows and quality of Canyon Creek would be in the absence of irrigation. The creek is profoundly influenced by irrigation during the irrigation season and non-irrigation season. During irrigation season, essentially all the flows in the creek are irrigation-return water or ditch overflows. During the non-irrigation season, the creek is all ground-water baseflow, which is stored irrigation water.

Surface-water sample analyses have indicated that the only constituent above an aquatic-life standards is selenium (5 μg/L chronic and 20 μg/L acute standard; DEQ, 2000). Selenium on Canyon Creek during the winter months ranges from 17 μg/L near its confluence with the Yellowstone River to 76 μg/L where it enters the valley north of Laurel. During the irrigation season selenium concentrations in Canyon Creek range from less than 1 μg/L near the confluence with the Yellowstone River to 5 μg/L where it enters the valley. Phosphate concentrations were less than detection for all samples. Nitrate concentrations in the minor streams ranged from 2 to 5 mg/L during the winter months to 0.5 mg/L during irrigation season.

Impacts from Land-Use Changes

Ground Water

The primary impact on ground water that results from the shift from agricultural to residential land use is the recharge loss. Data supplied in this report strongly demonstrate that almost all of the recharge is derived from infiltration of flood irrigation. Development of the West Billings area is shifting the recharge sources from primarily flood irrigation to septic returns and precipitation. Most lawn irrigation relies on ground water, so with evapotranspiration losses, this is a net removal of ground water rather than a recharge source.

The recharge sources in the residential areas lack the quantity and the quality to support the aquifer system in its present condition. Historical data on ground-water levels and quality are sparse. Limited analyses by Gosling and Pashley (1973) and Hutchinson (1983) do not show any detectable changes in water level or water quality during the period of 1968–1978. Comparison with the period of 1978 to 2000 indicates areas of significant ground water–level decline (greater than five feet; figure 17). The areas of ground-water decline do seem to correspond with development. However, because these comparisons look at single-event water levels and use different well sets, they should be considered with caution.

Ground-water quality also will be affected by land-use change. Although nitrate loading rates per acre for subdivisions are only slightly higher than those of agricultural lands, decreasing recharge rates will diminish the aquifer's capacity to disperse and dilute nitrate concentrations. As a result, nitrate concentrations are anticipated to increase if recharge rates decrease. Dissolved-constituents concentrations also are anticipated to increase. Much of the dissolved-solids concentrations are derived from soil interactions. Rapid infiltration from flood irrigation presently acts to dilute the mineralized load from the thick, fine-grained cover soils.

Lawn irrigation also may contribute to higher dissolved-constituents concentrations. Applied ground water for subdivision lawn watering contains more dissolved constituents than ditch-irrigation water. The dissolved-constituents content is further concentrated by evapotranspiration at the surface.

Surface Water

Impacts to ground-water quality due to land-use change will be manifested in surface-water quality during the winter months when streams are primarily ground-water baseflow. The most likely impacts include lower flow rates, higher nitrate concentrations, and a higher dissolved-constituents concentration. During the summer months, the water quality of Canyon Creek will remain relatively unchanged as long as the ditches are active and discharge overflows into the creek. Mitigation of the ditch overflows would benefit Canyon Creek by minimizing erosion and turbidity.

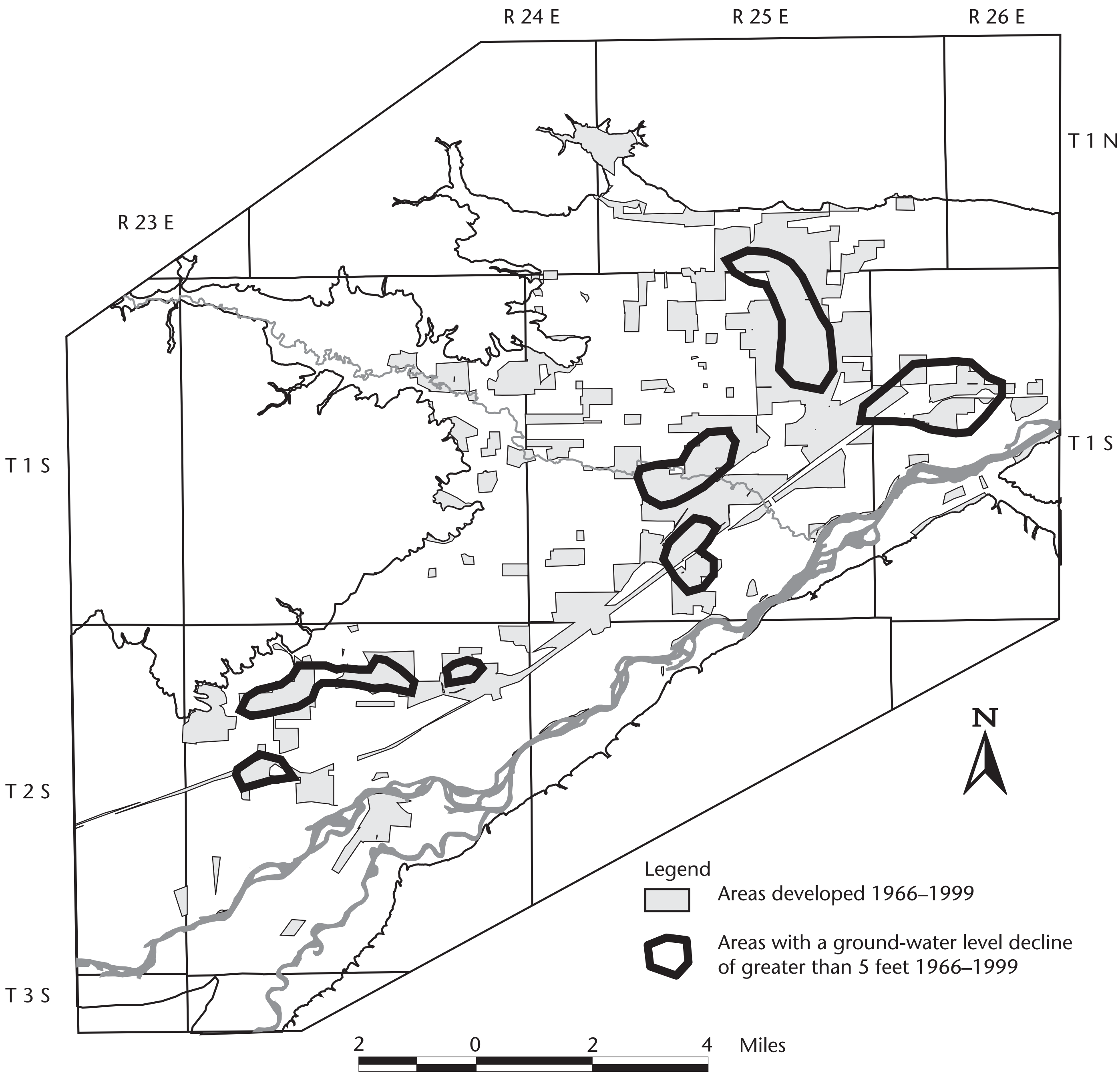

Figure 17. Comparison of August 2000 ground-water elevations with those measured in 1968 and 1978 demonstrate a ground-water level decline of greater than 5 feet in the areas developed since 1966. Most of the decline has occurred in the past 22 years.

Impacts to the Yellowstone River due to development would likely be minimal. Water-quality degradation in the minor streams would be offset by smaller flows. Therefore, the mass loading of dissolved constituents or nitrate would be expected to be the same or less.

Acknowledgements

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