Groundwater and Surface Water Monitoring for Pesticides and Nitrate in the Judith River Basin, Central Montana

Christian Schmidt and Rick Mulder
Hydrologists
Montana Department of Agriculture
Helena, Montana

March 2010

Table of Contents

ANALYTICAL RESULTS

DISCUSSION

Figures

Tables

Appendices

Cover photo: Farmstead northwest of Moccasin, MT; photo credit C. Schmidt, MDA

Introduction

Pesticides refer to any synthetic or biological substance used to destroy, mitigate or repel unwanted pests. They include the full range of herbicides, insecticides, fungicides and rodenticides used in the environment. Pesticides have a wide spectrum of solubility, leaching potential and half-lives under different temperature and moisture regimes. The inherent characteristics of each respective chemical mark them as mobile or immobile in the environment and groundwater and surface waters may be susceptible to pesticide contamination in certain circumstances reflective of timing, method and rate of application. Concerns include the susceptibility of drinking water and ecological impacts from contamination.

In 1989, the Montana Agricultural Chemical Groundwater Protection Act was passed (MCA Title 80, Chapter 15, Sections 80-15-101 through 80-15-414). Section 80-15-103 states that it is the policy of the state to: protect groundwater and the environment from impairment or degradation due to the use of agricultural chemicals including all pesticides and nitrogen fertilizers, allow for the proper and correct use of agricultural chemicals, provide for the management of agricultural chemicals to prevent, minimize, and mitigate their presence in groundwater, and provide for education and training of agricultural chemical applicators and the general public on groundwater protection, agricultural chemical use, and the use of alternative agricultural chemicals. Under this Act, it is the directive of the Ground-Water Protection Program of the Technical Services Bureau of the Montana Department of Agriculture (MDA) to monitor the occurrence and concentration of agricultural chemicals in the waters of the State of Montana.

During the summer of 2009, the Ground-Water Protection Program (GWPP) conducted a monitoring project in the Judith River Basin in central Montana (Figure 1). The study was performed in order to determine potential impacts to groundwater and surface water from the use of pesticides and contributions from nitrogen sources (i.e. fertilizer, manure, septic effluent). Sampling efforts were focused on wells and springs in shallow, unconfined Quaternary/Tertiary gravel aquifers. These unconfined aquifers are vulnerable to contamination by agricultural chemicals given the dominant cropping systems and the hydrogeologic characteristics of the basin.

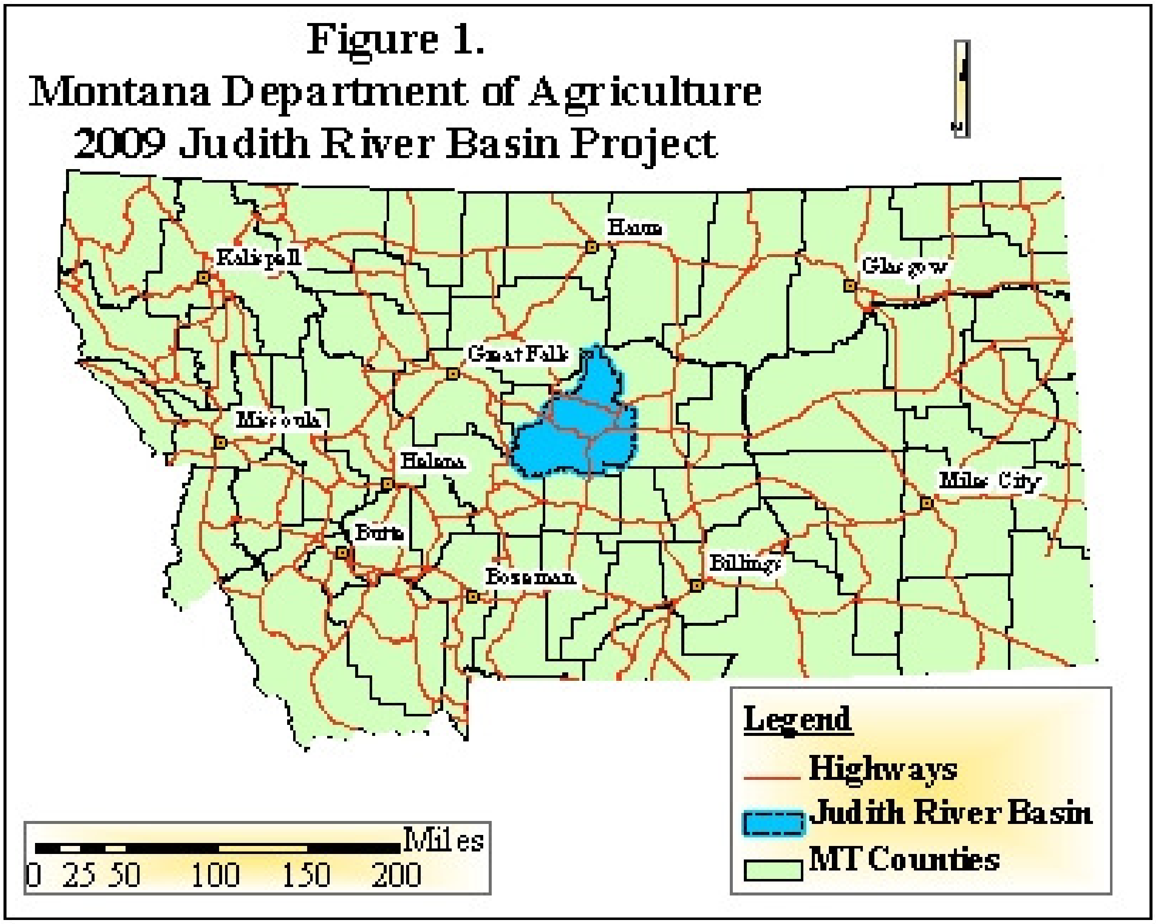


Figure 1.
Montana Department of Agriculture
2009 Judith River Basin Project

Geology of the Judith River Basin

The Judith River Basin is a large structural and physiographic basin in central Montana that is part of the unglaciated section of the Missouri Plateau of the Great Plains (Fenneman, 1931). It is partly enclosed by the Highwood, Little Belt, Big Snowy, Judith, North Moccasin and South Moccasin Mountains and encompasses an area of 2762 mi^2. Total area in the basin is divided between Judith Basin County (1284 mi^2) and Fergus County (1478 mi^2). Away from the mountains and foothills, the basin is dominated by northeast sloping level terraces. Terraces are dissected by steep-sided stream valleys whose relief becomes more dramatic moving north and westward in the basin. Stream valleys may vary in depth from a few feet at the head of small coulees to several hundred feet at the stream mouths (Zimmerman, 1966). The basin drains northward with myriad coulees and small tributaries entering the Judith River which joins the Missouri River at the northern terminus of the basin.

In the basin, terrace gravel deposits are covered by a thin loamy soil (~1.5 ft deep). Soils tend to be thicker on geologically younger surfaces suggesting that soil is weathered from flood plain deposits of sand and silt (Feltis, 1973; Zimmerman, 1966). Older terrace formations exhibit stonier soils due to a greater degree of erosion than on the younger deposits. The terrace gravel deposits range in depth from 0 to 100 feet but generally do not exceed 50 feet deep (Zimmerman, 1966). Terrace[1] and alluvial[2] deposits dominate surficial geology and cover 47% (1298.3 mi^2) of the total basin area (Figure 2). This estimate is based on the most current surficial geology maps produced by the Montana Bureau of Mines and Geology (MBMG) (Porter and Wilde, 1993; Porter and Wilde, 2001; Porter et al, 1999; Vuke et al, 2002) and the United States Geological Survey (USGS) (Reynolds and Brandt, 2007).

The exact method of deposition of these gravels has not been determined conclusively though Zimmerman (1966) theorized that:

> *"pluvial conditions during glacial advances probably produced the torrential streams necessary to erode and transport the gravel…and periodic changes in the erosional base level, due to disruptions in the course of the Missouri River by glacial ice, caused the alternating deposition by streams in this region"*

Zimmerman (1966) was unable to discern whether the gravel terraces were the remnants of a broader surface that covered much of the basin or were intact former valleys between bedrock hills that had since weathered away although Feltis (1973) and Alden (1932) regarded them as ancient alluvial deposits. Porter and Wilde (1993) observed that several periods of pedimentation and down-slope alluvial deposition occurred along the mountain flanks in central MT. Units described as braid plains include thin veneers of pediment gravel and several layers of thicker gravels deposited in broad alluvial fans now being incised by modern streams. Most authors regard these broad, coalescing alluvial fan deposits to be both Quaternary and Tertiary in age due to the lack of a single, defining period of deposition and the difficulty associated with aging geologically recent deposits.

Recharge of the shallow gravel aquifers is limited to precipitation and induced recharge from irrigation though the latter comprises a very small percentage of total cropland in the basin. The few substantial irrigation networks are located in quaternary alluvial deposits west of Hobson and along the main stem of the Judith River. Limited irrigation networks may be found along tributaries of the Judith River such as Ross Fork Creek, Cottonwood Creek, Wolf Creek, Sage Creek and Antelope Creek. Irrigated terrace deposits are found on small acreages near Stanford and on ~1600 acres northeast of Ackley Lake. Recharge is dominated by precipitation in the shallow gravel aquifers. Well yields are limited by recharge from precipitation except where augmented by irrigation water.

The saturated thickness of the terrace gravels is not substantial and decreases towards the edges of the benches as the gravels thin and spring/seep discharges further draw down the water table (Zimmerman, 1966). Adequate groundwater supply for domestic and stock use is more likely in the middle of extensive terrace deposits. Alluvium deposits along

---

[1] Terrace gravel deposits included: terrace gravel (Qt), pediment gravel (Qp), older pediment gravel (QTp), older gravel (Qog, QTg), alluvium of braid plains (Qab, QTab), alluvium of alluvial terrace deposit (Qat, QTat, Tat), and alluvium, older, undivided (Qao)

[2] Alluvial deposits included: alluvium of modern channels and flood plains (Qal), and alluvium (Qa)

the stream channels are more reliable aquifers than the terrace gravels and receive more recharge via high flow events and terrace spring and stream discharges.

Due to the extensive agricultural land use in the basin, the shallow, unconfined aquifers in terrace deposits and alluvium are vulnerable to contamination from agricultural chemicals (Figure 2). Total cropland as a percentage of county area is 24.3% (677,327 ac) in Fergus County and 15.0% (306,553 ac) in Judith Basin County (US Department of Agriculture). Total harvested acres in Fergus and Judith Basin Counties are dominated by small grains and hay production. In 2007, 163,300 ac (44.7%) of the 365,100 total harvested acres in the county were wheat (winter, summer) (US Department of Agriculture). All small grains accounted for 53.6% of harvested acres. All hay accounted for 46.0% (168,000 ac) of total harvested acres of which alfalfa hay comprised 81.0% (136,000 ac).

Similar distributions were observed in Judith Basin County for 2007 where small grain production comprised 65.9% of 155,600 total harvested acres of which wheat (summer, winter) accounted for 50.5% (78,600 ac) of total harvested acres. As in Fergus County, hay production was significant and accounted for 32.1% (50,000 ac) of all harvested acres of which alfalfa hay comprised 68.0% (34,000 ac). In 2007, pea and lentil production accounted for just 0.4% and 2.0% of total harvested acres in Fergus and Judith Basin Counties respectively (US Department of Agriculture). It is important to note that these statistics are not directly comparable to the Judith River Basin which contains 68.6% of Judith Basin County and 34.0% of Fergus County. Crop distribution on the terrace gravel deposits within the basin is likely skewed in favor of small grain production and for wheat in particular.

The geology, thin soil mantle, rapid infiltration and low relative saturated thickness of the terrace gravels render groundwater susceptible to contamination from surface application of pesticides and fertilizers. Due to the sensitivity of these aquifers, MDA sampling efforts were focused in identified Quaternary/Tertiary deposits.

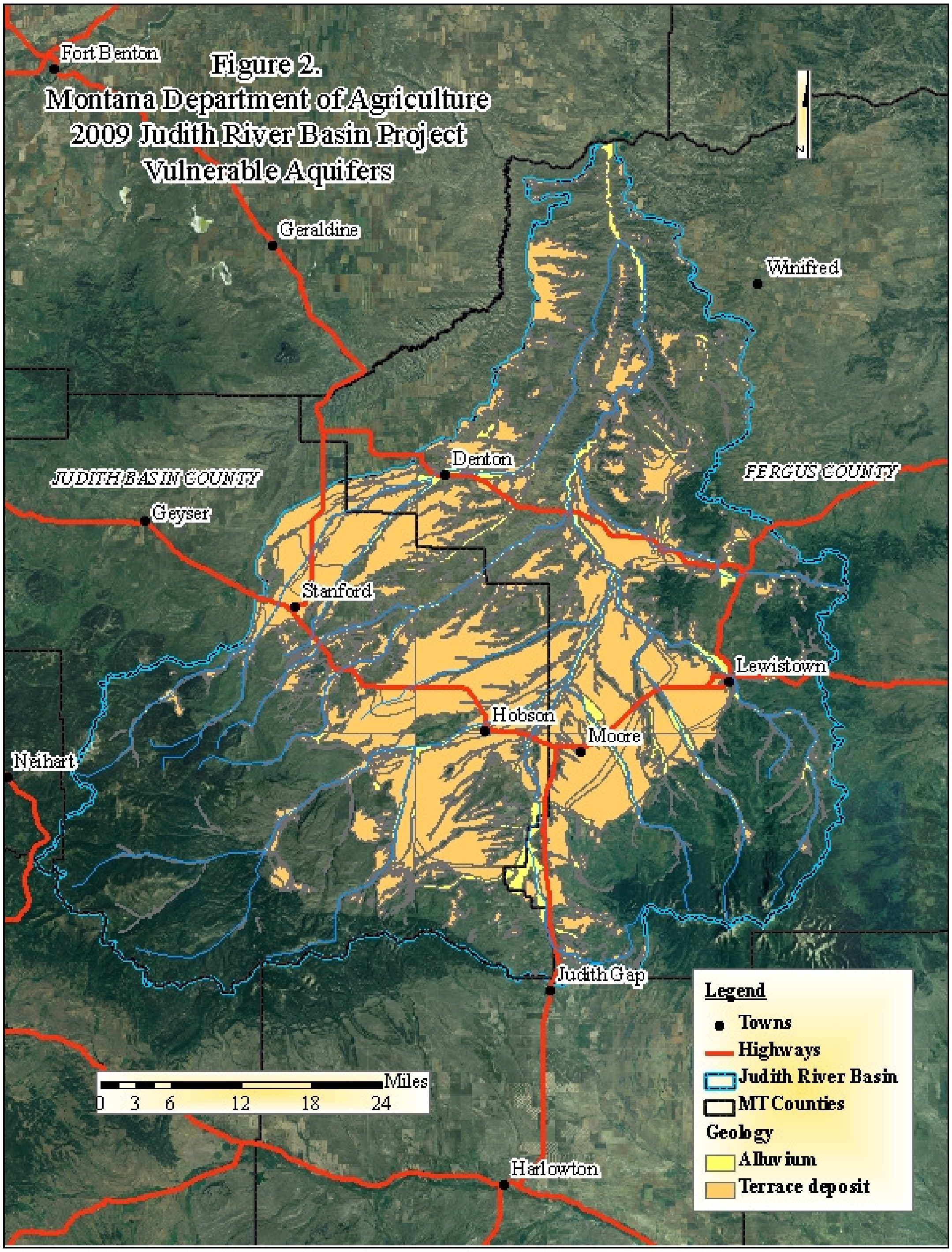


Figure 2.
Montana Department of Agriculture
2009 Judith River Basin Project
Vulnerable Aquifers

Meteorologic and Hydrologic Characteristics

A National Oceanic and Atmospheric Administration (NOAA) weather station is located at the Montana State University Extension Moccasin Experiment Station 5.3 miles northwest of Hobson, MT. The 40-year (1968-2008) precipitation mean at the Ag

Research Center (COOP ID #245761) was 15.81 inches with more than half falling during the main growing season (May-August). Mean annual rainfall at the same location from 1909 to 1970 was 14.94 inches (Feltis, 1977). From 1968-2008 temperatures averaged 43.4°F with mean highs of 96.2°F and lows of -25.6°F. Annual precipitation decreases north of the agricultural research center towards the mouth of the Judith River and increases with decreasing distance to the mountains that border the basin to the west, southwest and southeast. The basin receives approximately 14-18 inches of precipitation per year in the main agriculture areas while higher elevations in the mountains may receive upwards of 45 inches per year.

The climate has been described as a modified continental type where the surrounding mountains are large enough to influence local weather to a greater degree then the main chain of the Northern Rockies. Annual precipitation is greater than in most agricultural regions in north-central and eastern Montana.

A data logger to record groundwater elevation was installed in Permanent Monitoring Well (PMW) M-1 on 3/18/09 and data was downloaded from the recorder on 12/28/09. Over the period of record the gain in groundwater elevation was 1.9 feet with the most significant rise occurring May 4-5 (Figure 3). Changes in water level were not as sensitive to precipitation events during the growing season as they were to recharge from rain/snow events in April and late October (Figures 3 & 4).

Figure 3. PMW M-1 Static water level 3-18-09 to 12-28-09

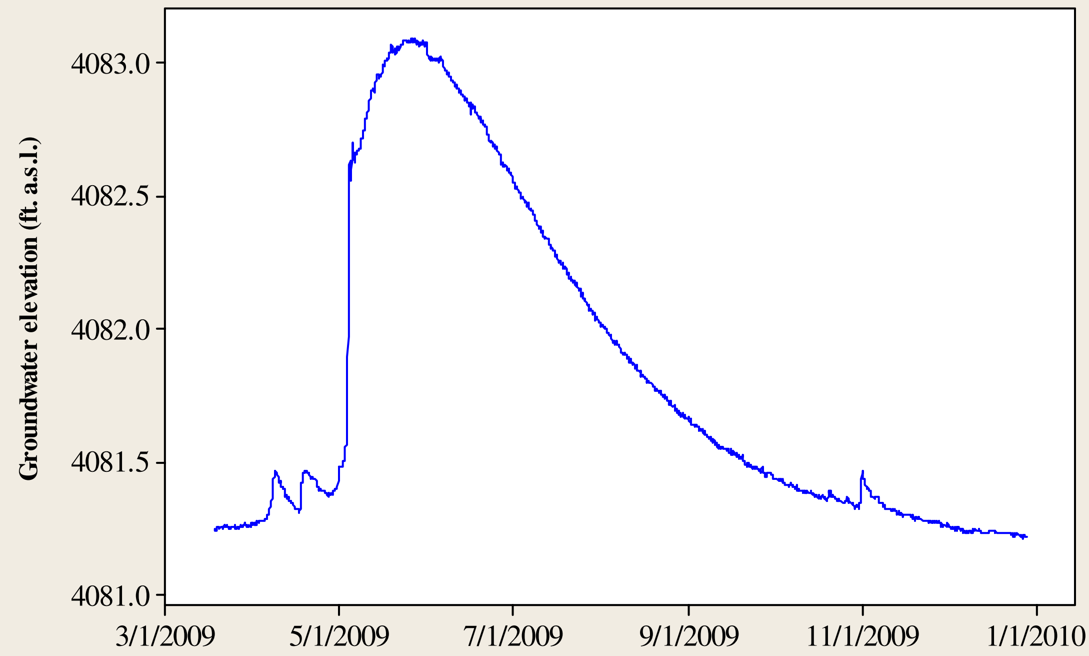
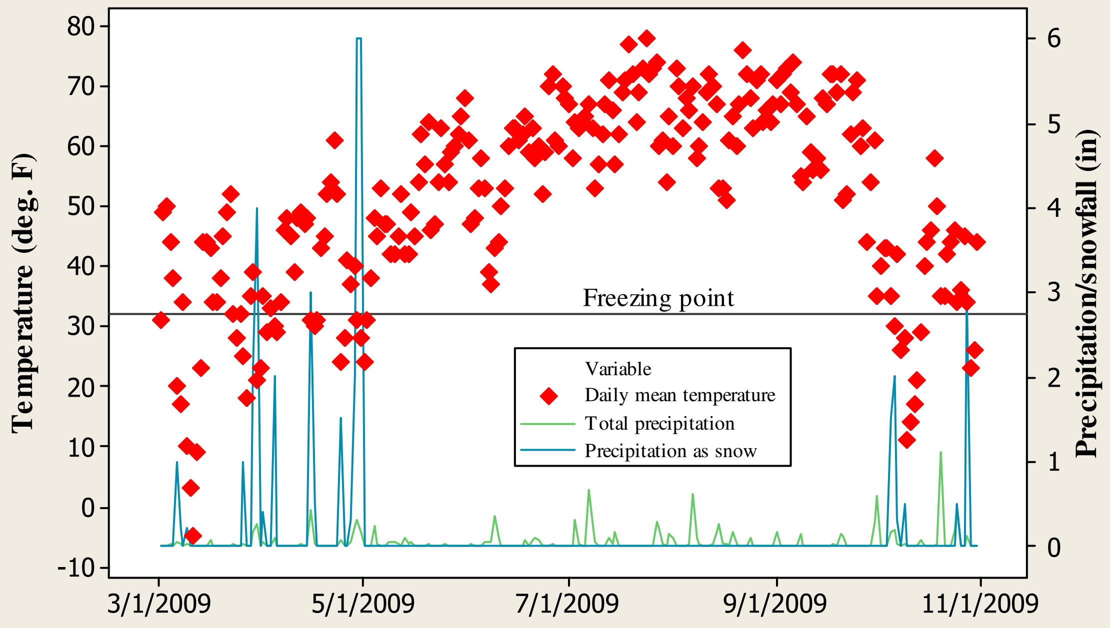
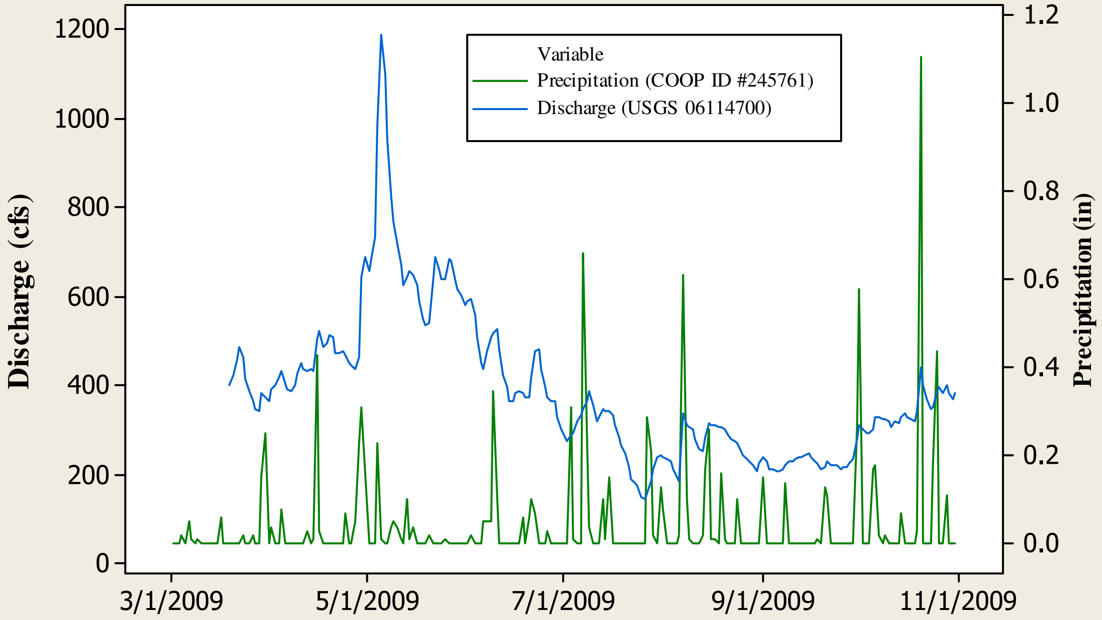


Figure 4. Climate data from MSU Central Ag Research Center, Moccasin, MT



In Figure 5, precipitation at the Ag Research Center in Moccasin and discharge at USGS gauging station 061147000 near the mouth of the Judith River is presented. Judith River discharge displayed short lag times between precipitation events and increases in flow. In the notably short record at USGS 0614700 (2001-2009) peak discharge occurs on average around June 14th (mean cfs = 950). In 2009, peak discharge occurred 40 days earlier on May 5th (1,190 cfs).

Figure 5. Precipitation at Moccasin, MT and Judith River discharge



Previous Work

In 1955, a cooperative program of groundwater investigations between the MBMG and the USGS was begun. The Judith River Basin and some areas outside the basin were included as one of 8 different cooperative investigations in the state. These investigations documented and analyzed available water resources in the project area. No pesticide analyses were completed although samples were tested for nitrate-N (NO_3^-N). The USGS examined geology and groundwater resources in the western and southern parts of the basin (Zimmerman, 1966). The MBMG completed similar studies in the northern (Feltis, 1977) and eastern (Feltis, 1973) parts of the Judith River Basin. These geological studies mapped formations and discussed hydrogeologic properties and water quality for human and stock use. All three reports discussed the terrace gravel and alluvium deposits and collected a limited number of water samples from these aquifers. Feltis (1977) collected a large number of surface water samples within the basin. Nearly all collected samples were analyzed for NO_3^-N.

The MDA maintains one PMW in the Judith River Basin. Currently consisting of 44 wells, the PMW network was established by the MDA to monitor agricultural chemicals in groundwater in Montana. Well M-1 is located approximately 4 miles northwest of the town of Moccasin and was drilled in a terrace gravel deposit (Figure 6). It has been continuously monitored by MDA since 1994. Samples collected from M-1 during the 2009 field season are included in this report.

The MBMG also manages the Ground-Water Information Center (GWIC) which includes the periodic monitoring of 900 wells located throughout the state of Montana. A query of the GWIC database found 11 NO_3^-N observations for wells that met MDA project parameters. This dataset includes 2 samples collected from PMW M-1[3].

In addition, MSU Extension Water Quality (MSUEWQ) offered a private well testing program as part of the Well Educated Program in Fergus County. The Well Educated Program educates private well owners about how to test and understand their water quality and also provides a centralized database for private well data. A collaborative testing and education project between MSUEWQ, Fergus County Extension, and the Fergus Conservation District was carried out in 2008 and 2009. During the program, 45 private wells in Fergus County were sampled. Five of the wells met MDA project parameters and are included along with other historic nitrate-N data from the MBMG and the USGS in Appendix A.

---

[3] MBMG recognizes MDA PMW M-1 as MOS-1.

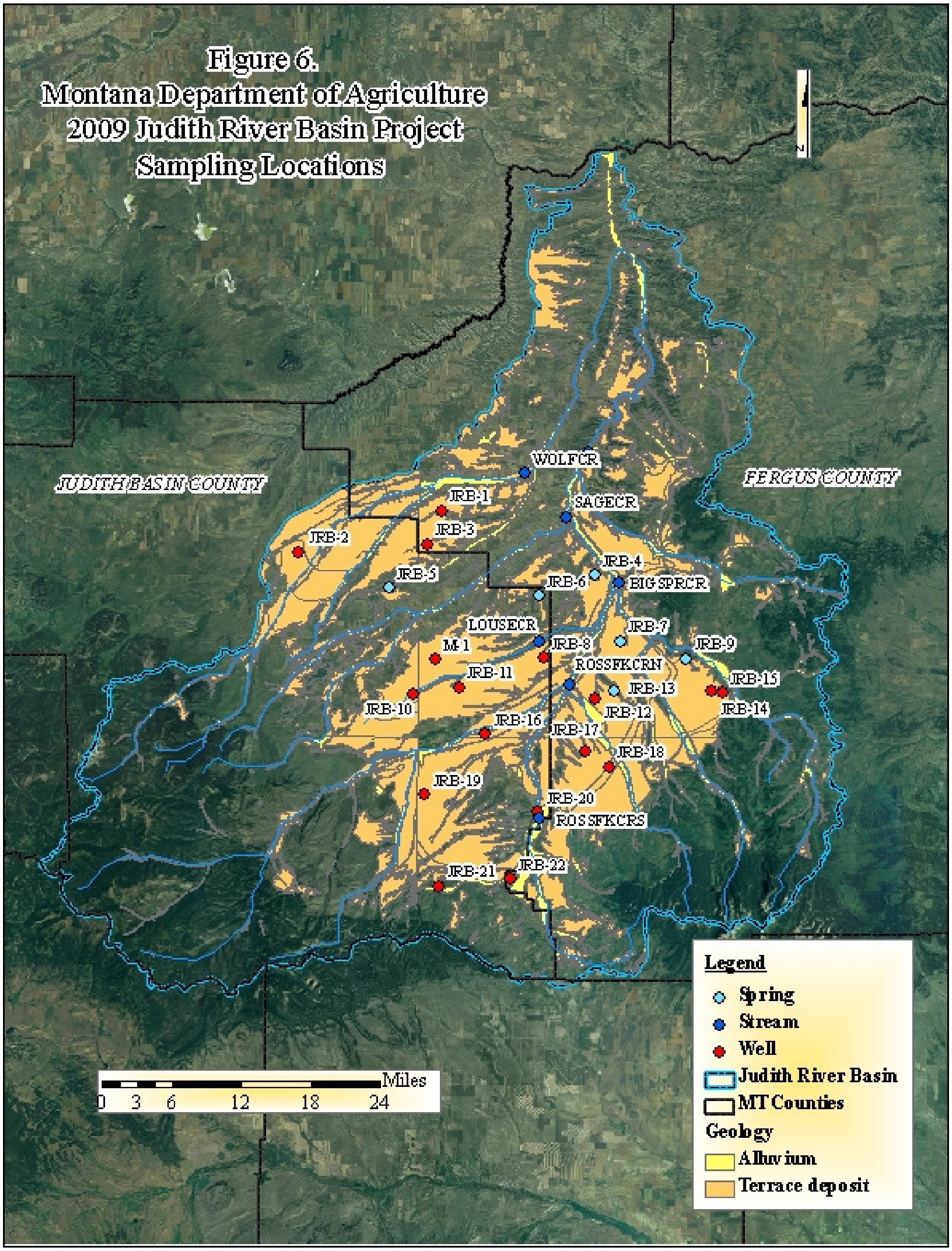


Figure 6.
Montana Department of Agriculture
2009 Judith River Basin Project
Sampling Locations

Mapping Resources

Utilizing the index-overlay method, ArcGIS was used to produce maps of wells and springs that met project parameters. To identify vulnerable gravel aquifers, 100k digital data coverages for Belt, Big Snowy Mountains, Lewistown and Winifred were obtained from the MBMG and the 100k digital data coverage for White Sulphur Springs from the USGS were used to map the extent of Quaternary/Tertiary surficial geology. A GWIC wells shapefile produced by MBMG was used to identify all wells ≤ 50 feet total depth and/or screened in identified terrace and alluvial deposits within the boundaries of the Judith River Basin. GWIC was also used to research existing water-quality and hydrograph data for all wells meeting project parameters.

In addition, MDA utilized Montana Department of Natural Resources and Conservation (DNRC) data. The DNRC produced a digital coverage of water rights points of diversion (WRDiv). All groundwater source types identified as groundwater, springs, or unnamed tributaries along with additional filters[4], were identified as potential sampling sites. Cadastral coverages for the Judith Basin were used to identify landowners in order to verify sample points and obtain permission.

MDA Water Sampling

In June and September 2009, the MDA collected groundwater samples from 17 wells and 6 springs (n=45) (Figure 6). In sampled wells, the mean depth of well screens below the ground surface was 19 feet and mean total depth was 33 feet (Table 1). Sampling locations were chosen to optimize geographic distribution in vulnerable aquifers across the basin.

All wells were sampled after purging at least three well casing volumes or until field parameters (temperature, pH, specific conductivity, and dissolved oxygen) had stabilized if the water level or well depth was unknown. MDA utilized standard operating procedures (SOPs) for groundwater and surface water collection, discharge measurements, and transportation[5]. Recorded water quality parameters for all samples may be found in Appendix C.

As part of the investigation, dual isotope analyses of $\delta^{18}O_{NO3}/\delta^{15}N_{NO3}$ were utilized for nitrogen source identification at selected sites where $NO_3^{-}N$ concentrations were found in excess of the human health standard (HHS) ($\geq$10 mg L^{-1}). The use of dual isotope testing has several benefits including better source resolution as oxygen isotopic separation of some sources is greater than with nitrogen isotopes, the signatures of some N sources cannot be determined using N isotopes alone, and, in denitrifying environments, N and O isotopes vary systematically (Kendall and McDonnell, 1998).

---

[4] Means of diversion: dam, developed spring, dike, ditch, flowing, headgate, instream, livestock direct from source, pipeline, pit, pump, or spring box

[5] Static water level measurement (GWPP-01), well purging (GWPP-02), water quality parameter measurement (GWPP-03), discharge measurements (GWPP-05), surface water sample collection (GWPP-06), sample transportation (GWPP-08), and sample custody and security (GWPP-09)

Sampling sites included in the isotope analyses include: JRB-1, -3, -5, -8, -10, -11, -13, -17, -18, -19, M-1 and MW-5[6] (n=12). Theses sites were chosen based on nitrate-N detections from the June 2009 sampling and in their spatial distribution in the project area.

Table 1. Groundwater Site Information

Site ID	Well or Spring	Water use	Total Depth (ft bgs)	Screened Interval (ft bgs)	Water Level (ft bgs)
JRB-1	W	D	7	Dug (no screen)	5
JRB-2	W	D	60	Open bottom	20
JRB-3	W	D	21	Open bottom	20
JRB-4	SP	D	-	-	-
JRB-5	SP	D	-	-	-
JRB-6	SP	S	-	-	-
JRB-7	SP	S	-	-	-
JRB-8	W	I	25	Open bottom	20
JRB-9	SP	S	-	-	-
JRB-10	W	D	45	29-32	24
JRB-11	W	D	52	30-36	14
JRB-12	W	D	22	Dug (no screen)	2
JRB-13	SP	D	-	-	-
JRB-14	W	M	45	35-45	38
JRB-15	W	M	30	15-30	25.3
JRB-16	W	D	36	UNK	7
JRB-17	W	D	39	UNK	34.5
JRB-18	W	S	40	Dug (no screen)	3
JRB-19	W	D	16	Dug (no screen)	8
JRB-20	W	D	11	Dug (no screen)	9
JRB-21	W	D	39	15-36	10
JRB-22	W	D	55	40-55	17
M-1	W	M	18.8	8.8-18.8	7.8
MW-5	W	M	45	25-44.5	31.5

bgs = below ground surface; D = domestic; I = irrigation; M = monitoring; S = stockwater; SP = spring; INK=unknown; W = well

---

[6] MW-5 is a monitoring well located approximately 125 feet southeast of JRB-15.

A range of surface water sites were selected to compliment groundwater sampling efforts. Sites were chosen to gather water quality data from small tributaries to the Judith River where spring discharges constituted a significant proportion of flow and from larger surface waters including the Judith River and Big Spring Creek. The MDA collected surface water samples (*n*=16) from 7 locations in the summer of 2009 (Figure 6). Streams sampled included: the Judith River, Louse Creek, Sage Creek, Wolf Creek, Big Spring Creek, and Ross Fork Creek at two different locations (Table 2).

Table 2. Surface Water Site Information

Site ID	Location description	Date	Discharge (cfs)
BIGSPRCR	Big Spring Creek 0.75 miles upstream of mouth	6/16/2009	*NM - HF*
		9/14/2009	103.88
JUDITHR	Judith River at terminus of Bally Dome Road	5/28/2009	655
		6/29/2009	303
		8/31/2009	236
		9/28/2009	224
LOUSECR	Louse Creek at Kolin Road	6/15/2009	2.7
		9/15/2009	*NM*
ROSSFKCRN	Ross Fork Creek at Echo Lane	6/16/2009	4.65
		9/15/2009	0.70
ROSSFKCRS	Ross Fork Creek at Tognetti Road	6/16/2009	20.00
		9/14/2009	6.66
SAGECR	Sage Creek at MT 81	6/15/2009	*NM*
		9/15/2009	*NM*
WOLFCR	Wolf Creek at Bally Dome Road	6/15/2009	*NM*
		9/15/2009	*NM*

All discharge data collected by MDA hydrologists except for Judith River (USGS gage station 06114700); cfs = cubic feet per second; NM = not measured; HF = high flow

Streams were sampled using both vertical and horizontal integration techniques. Stream flow data for the Judith River was obtained from the USGS gauging station (06114700) located near the mouth of the Judith River west of Winifred, MT. Discharge measurements for all other surface water sampling sites were obtained when conditions allowed. Due to high flow conditions, discharge was not measured for Big Spring Creek in June, 2009. Due to low flow, discharge could not be accurately measured at Louse Creek in September and for Sage Creek and Wolf Creek for either sampling event.

Both surface water and groundwater samples were collected in 900-mL amber glass jars, put on ice, and transported to the MDA Analytical Laboratory at Montana State University in Bozeman per MDA SOPs. The samples were analyzed using the Universal Method, an analytical method developed by the MDA Analytical Bureau for the detection of pesticides in water. The Universal Method analyzes for 95 pesticides and degradates. The MDA lab also performed all nitrate-N/nitrite-N analyses. A list of analytes and their respective limits of quantification for the Universal Method is included in Appendix B. Samples were collected during the fall sample collection for agricultural chemical analyses. Isotope samples were sent to the Environmental Isotope Laboratory at the University of Waterloo in Waterloo, Ontario, Canada.

Analytical Results

Groundwater samples - pesticides

Groundwater samples were collected June 14-15 and September 15-16, 2009. All sites were sampled during both events with the exception of a spring site (JRB-6) which was not flowing when visited in September. There were a total of 199 detections of 33 different pesticide analytes observed in 45 groundwater samples (Table 3). Three sampling sites had no detections for either sampling event (JRB-2, -21, -22). The weighted mean of detections in samples collected from wells in terrace deposits (*n*=14) and alluvium (*n*=3) were 5.46 and 0.33 pesticide detections per sample respectively. The three sites in alluvium were located in the southern part of the basin along Ross Fork Creek and near the margins of the Little Belt Mountains. Collectively, in groundwater wells with detections, the mean was 5.50 pesticide detections per sample. All springs (*n*=6) had pesticide detections and samples averaged 3.75 detections per sample. Most significantly, no single pesticide detection exceeded the HHS for drinking water.

Common groundwater detections included (*n*=23 sites): atrazine (7), chlorsulfuron (18), deethyl atrazine (DEA) (8), metsulfuron methyl (13), and triasulfuron (8). Of the 199 total pesticide detections, sulfonylurea (SU) herbicides accounted for 41.7% (83 detections) with chlorsulfuron and metsulfuron methyl being detected most frequently. Where detected, metsulfuron methyl was observed with chlorsulfuron 92.3% of the time. Remaining analytes were observed in groundwater at 1 to 5 different locations. Atrazine and a degradate, DEA, were observed at all three non-agricultural sites and DEA was observed at 7 of the 8 sites where atrazine was detected. Springs accounted for 2 of the 7 sites where both analytes were found.

All but three groundwater sites were determined to be under the direct influence of agricultural practices. In examining data from the non-agricultural sites (JRB-14, -15, and -16), bromacil and prometon were found at all three sites. This group also accounted for the only detections of diuron, sulfometuron methyl and tebuthiuron. The aforementioned chemicals are all soil sterilants and/or herbicides used for non-cropland weed control.

Table 3. Groundwater Pesticide Results, Judith River Basin, 2009

Site ID	Date	2,4-D	Aminopyralid	Atrazine	Bromacil	Carbaryl	Chlorpyrifos	Chlorsulfuron	Clopyralid	Deethyl deisopropyl atrazine	Deethyl atrazine	Deisopropyl atrazine	Difenoconazole
JRB-1	6/15/2009	0.026	ND	ND	ND	ND	ND	0.033	ND	ND	ND	ND	ND
	9/14/2009	ND	ND	ND	ND	ND	ND	0.032	ND	ND	ND	ND	ND
JRB-2	6/16/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	9/14/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
JRB-3	6/16/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	9/14/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
JRB-4	6/16/2009	ND	ND	ND	ND	ND	ND	0.036	ND	ND	ND	ND	ND
	9/14/2009	ND	ND	ND	ND	ND	ND	0.033	ND	ND	ND	ND	ND
JRB-5	6/16/2009	ND	ND	ND	ND	ND	ND	Q	0.062	ND	ND	ND	ND
	9/14/2009	ND	ND	ND	ND	ND	ND	Q	Q	ND	ND	ND	ND
JRB-6	6/15/2009	ND	ND	ND	ND	ND	ND	Q	ND	ND	ND	ND	ND
JRB-7	6/15/2009	ND	ND	ND	ND	ND	ND	0.013	ND	ND	ND	ND	ND
	9/14/2009	ND	ND	ND	Q	ND	ND	0.015	ND	ND	ND	ND	ND
JRB-8	6/15/2009	ND	ND	ND	ND	ND	0.059	ND	0.052	ND	ND	ND	0.024
	9/15/2009	ND	ND	ND	ND	ND	ND	0.045	ND	ND	ND	ND	ND
JRB-9	6/15/2009	ND	ND	0.0037	ND	ND	ND	0.011	ND	ND	0.0034	ND	ND
	9/15/2009	ND	ND	0.0043	ND	ND	ND	0.01	ND	ND	0.0044	ND	ND
JRB-10	6/15/2009	ND	ND	ND	ND	ND	ND	0.044	ND	ND	ND	ND	ND
	9/14/2009	ND	ND	ND	ND	ND	ND	0.075	ND	ND	ND	ND	ND
JRB-11	6/15/2009	0.032	ND	0.017	ND	ND	ND	0.038	ND	ND	0.0057	ND	ND
	9/14/2009	0.012	ND	0.015	ND	ND	ND	0.033	ND	ND	0.0064	ND	ND
JRB-12	6/15/2009	ND	ND	ND	ND	ND	ND	0.0087	ND	ND	ND	ND	ND
	9/14/2009	ND	ND	ND	ND	ND	ND	0.0058	ND	ND	ND	ND	ND
JRB-13	6/16/2009	ND	ND	0.0026	ND	ND	ND	Q	ND	ND	0.0024	ND	ND
	9/14/2009	ND	ND	Q	ND	ND	ND	Q	ND	ND	0.0025	ND	ND
JRB-14	6/15/2009	ND	Q	0.0048	0.014	ND	ND	0.055	Q	ND	0.0031	ND	ND
	9/15/2009	ND	ND	0.0054	0.012	ND	ND	0.052	ND	ND	0.0034	ND	ND
JRB-15	6/15/2009	Q	ND	0.29	30	ND	ND	ND	0.12	Q	0.38	2.2	ND
	9/15/2009	Q	ND	0.25	27	0.052	ND	Q	0.03	Q	0.3	1.9	ND
JRB-16	6/15/2009	ND	ND	Q	Q	ND	ND	0.015	ND	ND	0.003	ND	ND
	9/15/2009	ND	ND	0.0038	ND	ND	ND	0.13	ND	ND	0.0099	ND	ND
JRB-17	6/15/2009	ND	ND	ND	ND	ND	ND	0.028	ND	ND	Q	ND	ND
	9/14/2009	ND	ND	ND	ND	ND	ND	0.028	ND	ND	Q	ND	ND
JRB-18	6/15/2009	ND	ND	ND	ND	ND	0.042	0.042	0.039	ND	ND	ND	Q
	9/14/2009	ND	ND	ND	ND	ND	ND	0.022	0.026	ND	ND	ND	ND
JRB-19	6/15/2009	ND	ND	Q	ND	ND	ND	0.039	ND	ND	Q	ND	ND
	9/14/2009	ND	ND	Q	ND	ND	ND	0.016	ND	ND	Q	ND	ND
JRB-20	6/16/2009	ND	ND	ND	ND	ND	ND	0.025	ND	ND	ND	ND	ND
	9/14/2009	ND	ND	ND	ND	ND	ND	0.038	ND	ND	ND	ND	ND
JRB-21	6/15/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	9/14/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
JRB-22	6/15/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	9/14/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M-1	6/16/2009	ND	Q	ND	ND	ND	ND	0.03	ND	ND	ND	ND	ND
	9/15/2009	ND	ND	ND	ND	ND	ND	0.056	ND	ND	ND	ND	ND
Type		H	H	H	H	I	I	H	H	H	H	H	F
Sites with detections		3	2	7	4	1	2	19	5	1	8	1	2
Max detection		0.032	Q	0.55	31	0.052	0.059	0.13	0.12	Q	0.38	2.2	0.024
HHS		70	none	3*	90	700	20	1750	3500	3*	3*	3*	none

HHS=Human Health Standard; µg/L = micrograms per liter (1 µg/L = 1 part per billion); ND = not detected; Q = analyte detected below analytical method limit of quantification (see Appendix B for limits of quantification); H=herbicide; I=insecticide; F=fungicide

Table 3. (cont.) Groundwater Pesticide Results, Judith River Basin, 2009

Site ID	Date	Diuron	Flucarbazone	Flucarbazone sulfonamide	Hexazinone	Hydroxyatrazine	Imazamethabenz methyl ester	Imazamethabenz methyl acid metabolite	Imazapic	Imazapyr	MCPP	Metsulfuron methyl	Picloram
JRB-1	6/15/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND	**0.014**	ND	ND
	9/14/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
JRB-2	6/16/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	9/14/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
JRB-3	6/16/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	**Q**	**0.17**
	9/14/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	**0.038**	ND
JRB-4	6/16/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	**0.036**	ND
	9/14/2009	ND	**0.0079**	ND	ND	ND	ND	ND	ND	ND	ND	**0.036**	ND
JRB-5	6/16/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	9/14/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
JRB-6	6/15/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
JRB-7	6/15/2009	ND	ND	ND	ND	ND	**Q**	**Q**	ND	ND	ND	**0.033**	ND
	9/14/2009	ND	ND	ND	ND	ND	**0.0011**	**Q**	ND	ND	ND	**0.051**	ND
JRB-8	6/15/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	9/15/2009	ND	ND	ND	ND	ND	ND	ND	ND	**Q**	ND	**Q**	ND
JRB-9	6/15/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	9/15/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
JRB-10	6/15/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	9/14/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	**Q**	ND
JRB-11	6/15/2009	ND	ND	ND	**0.0068**	ND	ND	ND	ND	ND	ND	**Q**	ND
	9/14/2009	ND	ND	ND	**0.0073**	ND	ND	ND	ND	ND	ND	**Q**	ND
JRB-12	6/15/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	9/14/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
JRB-13	6/16/2009	ND	**0.013**	ND	ND	ND	ND	ND	ND	ND	ND	**Q**	ND
	9/14/2009	ND	**0.014**	ND	ND	ND	ND	ND	ND	ND	ND	**Q**	ND
JRB-14	6/15/2009	**0.26**	ND	ND	**Q**	ND	ND	ND	ND	ND	ND	**Q**	**Q**
	9/15/2009	**0.16**	ND	ND	**Q**	ND	ND	ND	ND	ND	ND	**0.042**	**0.24**
JRB-15	6/15/2009	**0.16**	ND	ND	ND	**0.13**	ND	**Q**	ND	**1.2**	ND	ND	**Q**
	9/15/2009	**0.051**	ND	ND	ND	**0.12**	ND	ND	ND	**0.57**	ND	**0.035**	ND
JRB-16	6/15/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	9/15/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	**0.071**	ND
JRB-17	6/15/2009	ND	ND	ND	ND	ND	ND	ND	**0.073**	ND	ND	**Q**	ND
	9/14/2009	ND	ND	ND	ND	ND	ND	ND	**0.071**	ND	ND	**Q**	**Q**
JRB-18	6/15/2009	ND	**0.045**	**Q**	ND	ND	ND	ND	ND	ND	ND	**0.035**	ND
	9/14/2009	ND	**0.026**	ND	ND	ND	**Q**	ND	ND	ND	ND	**0.026**	ND
JRB-19	6/15/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	**Q**	ND
	9/14/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
JRB-20	6/16/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	9/14/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
JRB-21	6/15/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	9/14/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
JRB-22	6/15/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	9/14/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
M-1	6/16/2009	ND	**0.026**	ND	ND	ND	**0.002**	**0.022**	ND	ND	ND	ND	ND
	9/15/2009	ND	**0.021**	ND	ND	ND	**0.001**	**0.007**	ND	ND	ND	ND	ND
Type		**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**
Sites with detections		**2**	**4**	**1**	**2**	**1**	**3**	**3**	**1**	**2**	**1**	**13**	**4**
Max detection		**0.26**	**0.045**	**Q**	**0.0073**	**0.13**	**0.0011**	**Q**	**0.073**	**1.2**	**0.014**	**0.071**	**0.24**
HHS		**10**	**none**	**none**	**400**	**70**	**400**	**400**	**none**	**21,000**	**7**	**1,750**	**500,000**

HHS=Human Health Standard; µg/L = micrograms per liter (1 µg/L = 1 part per billion); ND = not detected; Q = analyte detected below analytical method limit of quantification (see Appendix B for limits of quantification); H=herbicide; I=insecticide; F=fungicide

Table 3. (cont.) Groundwater Pesticide Results, Judith River Basin, 2009

Site ID	Date	Prometon	Prosulfuron	Simazine	Sulfometuron methyl	Sulfosulfuron	Tebuthiuron	Triallate	Triasulfuron	Triclopyr
JRB-1	6/15/2009	ND	ND	ND	ND	ND	ND	ND	**0.036**	ND
	9/14/2009	ND	ND	ND	ND	ND	ND	ND	**0.038**	ND
JRB-2	6/16/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND
	9/14/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND
JRB-3	6/16/2009	ND	ND	**0.0027**	ND	**Q**	ND	**1.1**	**Q**	ND
	9/14/2009	ND	ND	**Q**	ND	ND	ND	**Q**	**Q**	ND
JRB-4	6/16/2009	**0.03**	ND	ND	ND	ND	ND	ND	**Q**	ND
	9/14/2009	**0.031**	ND	ND	ND	ND	ND	ND	ND	ND
JRB-5	6/16/2009	ND	ND	ND	ND	ND	ND	ND	**0.048**	**Q**
	9/14/2009	ND	ND	ND	ND	ND	ND	ND	**0.078**	ND
JRB-6	6/15/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND
JRB-7	6/15/2009	ND	**Q**	ND	ND	ND	ND	ND	ND	ND
	9/14/2009	ND	**Q**	ND	ND	ND	ND	ND	ND	ND
JRB-8	6/15/2009	ND	ND	ND	ND	ND	ND	**Q**	ND	ND
	9/15/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND
JRB-9	6/15/2009	ND	ND	**Q**	ND	ND	ND	ND	ND	ND
	9/15/2009	ND	ND	**Q**	ND	ND	ND	ND	ND	ND
JRB-10	6/15/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND
	9/14/2009	ND	ND	ND	ND	ND	ND	ND	**Q**	ND
JRB-11	6/15/2009	ND	ND	**Q**	ND	ND	ND	ND	ND	ND
	9/14/2009	ND	ND	**Q**	ND	ND	ND	ND	ND	ND
JRB-12	6/15/2009	ND	ND	ND	ND	ND	ND	ND	**Q**	ND
	9/14/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND
JRB-13	6/16/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND
	9/14/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND
JRB-14	6/15/2009	**0.054**	ND	**0.0026**	**0.088**	ND	**0.015**	ND	**Q**	ND
	9/15/2009	**0.044**	ND	**Q**	**0.081**	ND	**0.012**	ND	**Q**	ND
JRB-15	6/15/2009	**0.029**	ND	**0.51**	ND	ND	ND	ND	ND	ND
	9/15/2009	**0.024**	ND	**0.36**	ND	ND	ND	ND	ND	ND
JRB-16	6/15/2009	**Q**	ND	ND	ND	ND	ND	ND	ND	ND
	9/15/2009	**Q**	ND	ND	ND	ND	ND	ND	ND	ND
JRB-17	6/15/2009	**0.0067**	ND	ND	ND	ND	ND	ND	ND	ND
	9/14/2009	**0.0076**	ND	ND	ND	ND	ND	ND	ND	ND
JRB-18	6/15/2009	ND	**0.028**	ND	ND	ND	ND	**Q**	**Q**	ND
	9/14/2009	ND	ND	ND	ND	ND	ND	ND	**Q**	ND
JRB-19	6/15/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND
	9/14/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND
JRB-20	6/16/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND
	9/14/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND
JRB-21	6/15/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND
	9/14/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND
JRB-22	6/15/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND
	9/14/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND
M-1	6/16/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND
	9/15/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND
Type		**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**
Sites with detections		**5**	**2**	**5**	**1**	**1**	**1**	**3**	**8**	**1**
Max detection		**0.083**	**0.028**	**0.66**	**0.088**	**Q**	**0.015**	**1.1**	**0.078**	**Q**
HHS		**100**	**none**	**4**	**1750**	**none**	**500**	**5**	**70**	**350**

HHS=Human Health Standard; µg/L = micrograms per liter (1 µg/L = 1 part per billion); ND = not detected; Q = analyte detected below analytical method limit of quantification (see Appendix B for limits of quantification); H=herbicide; I=insecticide; F=fungicide

Groundwater samples – nitrate-N

Assuming that non-detects (ND) = 0, the weighted mean across all groundwater samples was 13.36 mg L^{-1} NO_3^-N. Detections ranged from ND to 38 mg L^{-1} NO_3^-N. The weighted mean for springs and wells was 12.06 mg L^{-1} and 13.77 mg L^{-1} NO_3^-N respectively. Groundwater in terrace gravels (*n*=20) had a weighted mean of 15.32 mg L^{-1} while alluvium groundwater (*n*=3) was 0.28 mg L^{-1} NO_3^-N.

In reviewing the results, the most at-risk water supplies were wells in agricultural areas completed in the terrace gravel deposits. These sources had a weighted mean of 19.60 mg L^{-1} NO_3^-N and 9 of 11 sites exceeded the HHS for drinking water (10 mg L^{-1}). Including springs, terrace gravel concentrations of NO_3^-N exceeded the HHS at 75% of sites. Of the 15 sites where the HHS was exceeded for NO_3^-N, 9 are used for domestic supply, 3 for stock, 2 are unused and 1 is used for irrigation. Nitrite-N (NO_2^-N) was not detected in groundwater.

Table 4. Groundwater Nitrate/Nitrite Results, Judith River Basin, 2009

Site ID	Date	Nitrate-N (mg L^{-1})	Drinking Water Standard (mg L^{-1})	Nitrite-N (mg L^{-1})	Drinking Water Standard (mg L^{-1})
JRB-1	*6/15/2009*	21	10	ND	1
	9/14/2009	21	10	-	1
JRB-2	*6/16/2009*	3.5	10	ND	1
	9/14/2009	3.5	10	-	1
JRB-3	*6/16/2009*	22	10	ND	1
	9/14/2009	22	10	-	1
JRB-4	*6/16/2009*	10	10	ND	1
	9/14/2009	13	10	-	1
JRB-5	*6/16/2009*	22	10	ND	1
	9/14/2009	23	10	-	1
JRB-6	*6/15/2009*	ND	10	ND	1
JRB-7	*6/15/2009*	7.7	10	ND	1
	9/14/2009	10	10	-	1
JRB-8	*6/15/2009*	35	10	ND	1
	9/15/2009	38	10	-	1
JRB-9	*6/15/2009*	13	10	ND	1
	9/15/2009	13	10	-	1
JRB-10	*6/15/2009*	20	10	ND	1
	9/14/2009	19	10	-	1
JRB-11	*6/15/2009*	23	10	ND	1
	9/14/2009	22	10	-	1
JRB-12	*6/15/2009*	7.1	10	ND	1
	9/14/2009	7.2	10	-	1
JRB-13	*6/16/2009*	17	10	ND	1
	9/14/2009	16	10	-	1
JRB-14	*6/15/2009*	13	10	ND	1
	9/15/2009	13	10	-	1
JRB-15	*6/15/2009*	1	10	ND	1
	9/15/2009	ND	10	-	1

Only June samples were only analyzed for nitrite-N; mg L^{-1} = milligrams per liter (1 mg L^{-1} = 1 part per million); ND = not detected above analytical method detection limit of 1 mg L-1

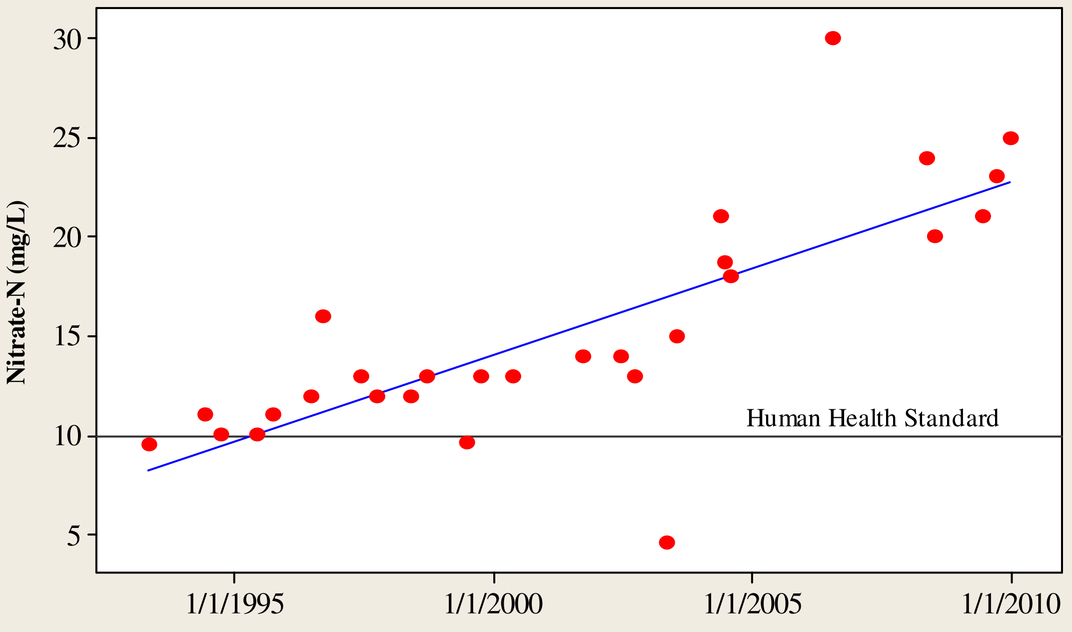
Table 4. (cont.) Groundwater Nitrate/Nitrite Results, Judith River Basin, 2009

Site ID	Date	Nitrate-N (mg L^{-1})	Drinking Water Standard	Nitrite-N (mg L^{-1})	Drinking Water Standard
			(mg L^{-1})		(mg L^{-1})
JRB-16	*6/15/2009*	5.3	10	ND	1
	9/15/2009	4.8	10	-	1
JRB-17	*6/15/2009*	20	10	ND	1
	9/14/2009	18	10	-	1
JRB-18	*6/15/2009*	28	10	ND	1
	9/14/2009	18	10	-	1
JRB-19	*6/15/2009*	18	10	ND	1
	9/14/2009	21	10	-	1
JRB-20	*6/16/2009*	1.7	10	ND	1
	9/14/2009	ND	10	-	1
JRB-21	*6/15/2009*	ND	10	ND	1
	9/14/2009	ND	10	-	1
JRB-22	*6/15/2009*	ND	10	ND	1
	9/14/2009	ND	10	-	1
M-1	*6/16/2009*	21	10	ND	1
	9/15/2009	23	10	-	1

Only June samples were only analyzed for nitrite-N; mg L^{-1} = milligrams per liter (1 mg L^{-1} = 1 part per million); ND = not detected above analytical method detection limit of 1 mg L-1

In Figure 7, temporal trend data for NO_3^{-}N at M-1, including 2009 data, shows an increasing trend in concentration. PMW M-1 is completed in terrace gravels and the water level is less than 10 feet below the land surface.

Figure 7. Nitrate-N results from M-1 (1994-2009)



Note: Surrounding parcel has been under management by the same owner since 1991.

Groundwater samples – $\delta^{15}N_{NO3}$ and $\delta^{18}O_{NO3}$ isotopes

In order to determine the source of NO_3^-N in groundwater, 12 sites where NO_3^-N exceeded the human health standard (10 mg L^{-1}) were analyzed for oxygen and nitrogen isotope ratios. Values for $\delta^{15}N$ ranged from $3.305^{o}/_{oo}$ to $11.17^{o}/_{oo}$ with a mean of $6.14^{o}/_{oo}$[7] (Table 5). Oxygen isotopes of NO_3^-N had a range of $-2.95^{o}/_{oo}$ to $4.14^{o}/_{oo}$ $\delta^{18}O$ with a mean of $0.349^{o}/_{oo.}$

Table 5. Results of Isotope Analyses,
Judith River Basin Project 2009

Site ID	$\delta^{15}N_{NO3}$		$\delta^{18}O_{NO3}$	
	Result	**Repeat**	**Result**	**Repeat**
	AIR		**VSMOW**	
JRB-1	3.58	3.03	-1.79	-1.67
JRB-3	4.28		-2.95	
JRB-5	4.71		-2.85	
JRB-8	12.1	11.64	4.14	
JRB-10	4.63		-1.3	0.01
JRB-11	7.32		3.27	
JRB-13	5.5	4.84	-1.92	-1.9
JRB-17	4.42	4.59	-1.61	
JRB-18	8.83	8.6	-0.62	
JRB-19	6.32	5.92	-0.94	-0.43
M-1	5.53		-2.48	
MW-5	7.26		3.8	3.97

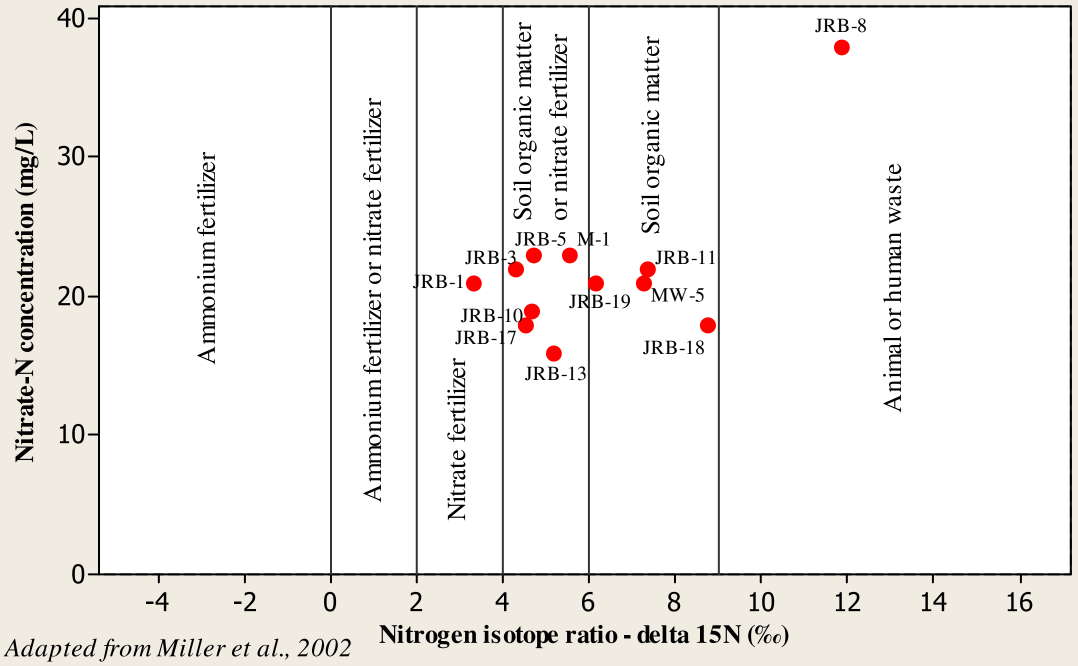
Samples collected September and October 2009; MW-5 is a monitoring well (TD=45 feet; screen interval 25-45 feet) 125 ft SE of JRB-15

Nitrate-N concentrations from the September sampling event and $\delta^{15}N$ values are displayed in Figure 8. Reviewing both sampling events, the highest concentrations observed were in JRB-8 and JRB-18 both ~100 year old, hand-dug (25-40 ft deep) wells located near current or historic small livestock operations. Nitrogen isotope signatures identify the sources as nitrate-N fertilizer, soil organic matter, or animal or human waste products in Figure 8.

---

[7] It is acceptable to average the values where repeat analyses were performed.

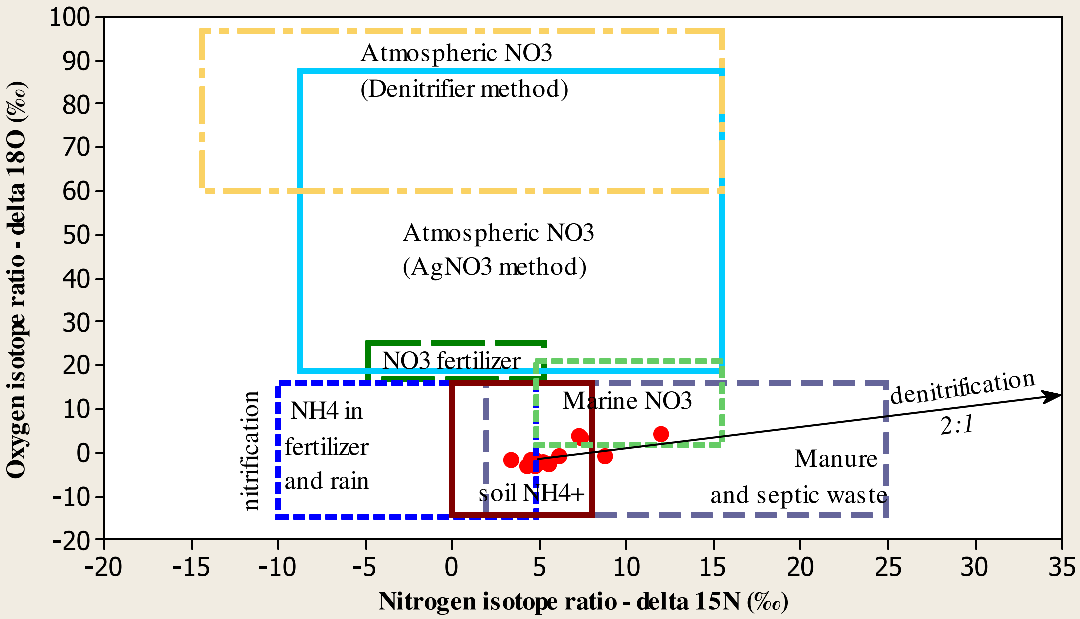
Figure 8. Nitrogen isotope results, Judith River Basin, 2009



Adapted from Miller et al., 2002

In Figure 9, the O and N isotope ratios are plotted in reference to established ranges of different N sources. With source separation increased by the O isotope results, data points fall in the range of NH_4^+ in fertilizer and rain, soil NH_4^+, and manure/septic waste.

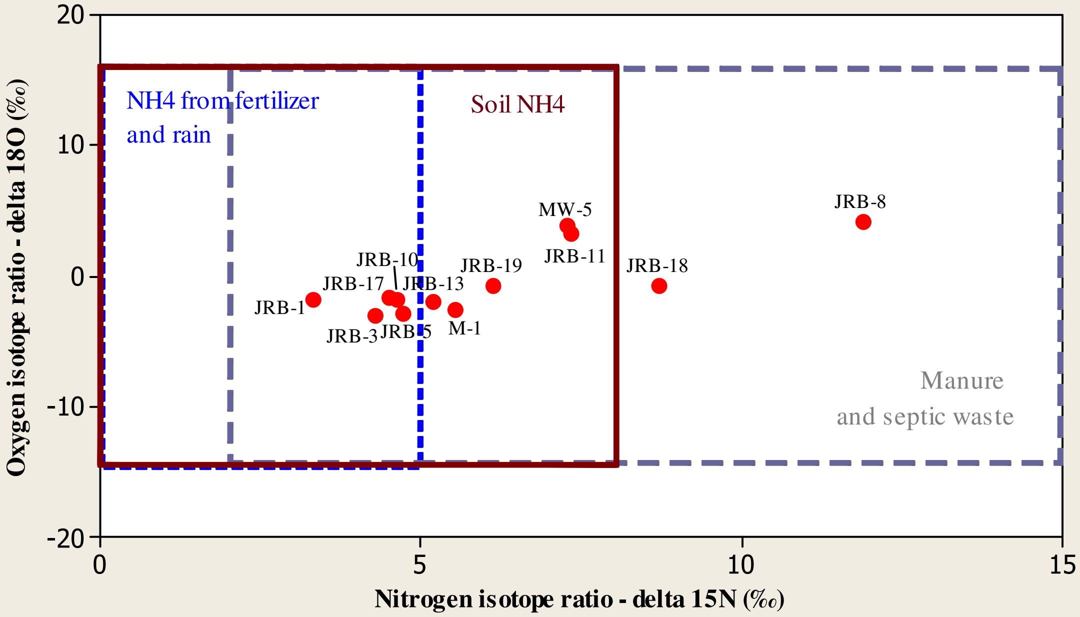
Figure 9. Dual isotope results from Judith River Basin, 2009



Adapted from Kendall et al., 2007

The tight clustering of data points in Figure 10 suggests that soil NH_4^+ is the likely source of NO_3^-N in groundwater. JRB-8 and JRB-18 are the only points that fall outside of this range and are the probable result of mixing of soil NH_4^+ and manure/septic waste.

Figure 10. Dual isotope results - site identification, Judith River Basin, 2009



Adapted from Kendall et al., 2007

Surface water samples - pesticides

A total of 18 different pesticide analytes were observed in surface water samples (n=16) (Table 6). At the 7 different locations, frequent detections included 2,4-D (7), chlorsulfuron (6), MCPA (6), metsulfuron methyl (4) and tebuthiuron (4). Results included MCPA and NOA 407854, a pinoxaden metabolite, which were not observed in groundwater. The weighted mean was 4.07 detections per sample. SUs comprised 30.6% of the 62 total detections in surface waters. SUs triasulfuron and metsulfuron methyl were always detected with chlorsulfuron in the samples.

Table 6. Surface Water Pesticide Results, Judith River Basin, 2009

Site ID	Date	2,4-D	Atrazine	Bromacil	Carbofuran	Chlorsulfuron	Clopyralid	Diuron	Hydroxyatrazine	Imazamethabenz methyl ester
BIGSPRCR	*6/16/2009*	**0.01**	ND	ND	ND	ND	ND	ND	ND	ND
	9/14/2009	**Q**	ND	ND	ND	ND	ND	ND	ND	ND
JUDITHR	*5/28/2009*	**Q**	ND	ND	ND	ND	ND	ND	ND	ND
	6/29/2009	**0.011**	ND	**0.043**	ND	**Q**	ND	**0.053**	ND	ND
	8/31/2009	**Q**	ND	ND	ND	ND	ND	ND	ND	ND
	9/28/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND
LOUSECR	*6/15/2009*	**Q**	ND	ND	**Q**	**0.077**	ND	ND	ND	ND
	9/15/2009	ND	ND	ND	ND	**0.071**	ND	ND	ND	ND
ROSSFKCRN	*6/16/2009*	**0.016**	ND	ND	ND	**0.022**	ND	ND	ND	ND
	9/14/2009	**Q**	ND	ND	ND	**0.024**	ND	ND	ND	ND
ROSSFKCRS	*6/16/2009*	**0.14**	ND	ND	ND	**0.011**	ND	ND	ND	ND
	9/15/2009	ND	ND	ND	ND	**0.011**	ND	ND	ND	ND
SAGECR	*6/15/2009*	**0.66**	ND	ND	ND	**0.015**	ND	ND	ND	ND
	9/15/2009	ND	ND	ND	ND	**Q**	ND	ND	ND	ND
WOLFCR	*6/15/2009*	**0.11**	**0.0027**	ND	ND	**0.024**	ND	ND	ND	ND
	9/15/2009	ND	**0.0053**	ND	ND	**0.035**	**0.048**	ND	**Q**	**Q**
Type		**H**	**H**	**H**	**I/N**	**H**	**H**	**H**	**H**	**H**
Sites with detections		**7**	**1**	**1**	**1**	**6**	**1**	**1**	**1**	**1**
Max detection		**0.66**	**0.0053**	**0.043**	**Q**	**0.077**	**0.048**	**0.053**	**Q**	**Q**
HHS		**70**	**3***	**90**	**40**	**1750**	**3500**	**10**	**0.13**	**400**

HHS=Human Health Standard; µg/L = micrograms per liter (1 µg/L = 1 part per billion); ND = not detected;
Q = analyte *detected below analytical method limit of quantification (see Appendix B for limits of quantification);*
H=herbicide; I=insecticide; N=nematicide

Table 6. (cont.) Surface Water Pesticide Results, Judith River Basin, 2009

Site ID	Date	Imazamethabenz methyl acid metabolite	Imazapic	MCPA	MCPP	Metsulfuron methyl	NOA 407854	Prometon	Tebuthiuron	Triasulfuron
BIGSPRCR	*6/16/2009*	ND	ND	**Q**	ND	ND	ND	ND	**Q**	ND
	9/14/2009	ND	ND	ND	ND	ND	ND	ND	**Q**	ND
JUDITHR	*5/28/2009*	ND	ND	ND	**Q**	ND	ND	**Q**	ND	ND
	6/29/2009	ND	ND	**Q**	ND	ND	ND	ND	**Q**	ND
	8/31/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND
	9/28/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND
LOUSECR	*6/15/2009*	ND	ND	**0.0031**	ND	ND	ND	ND	ND	ND
	9/15/2009	ND	ND	ND	ND	**Q**	ND	ND	ND	ND
ROSSFKCRN	*6/16/2009*	ND	ND	**Q**	ND	ND	ND	ND	**0.0015**	ND
	9/14/2009	ND	ND	ND	ND	**Q**	**Q**	**Q**	**Q**	**Q**
ROSSFKCRS	*6/16/2009*	ND	**Q**	**0.0041**	ND	ND	ND	ND	ND	ND
	9/15/2009	ND	ND	ND	ND	ND	**Q**	ND	ND	ND
SAGECR	*6/15/2009*	**Q**	ND	ND	ND	**0.071**	ND	ND	ND	ND
	9/15/2009	ND	ND	ND	ND	ND	ND	ND	ND	ND
WOLFCR	*6/15/2009*	**Q**	ND	**0.0026**	ND	**0.09**	ND	**Q**	**0.0047**	**Q**
	9/15/2009	**Q**	ND	ND	ND	**0.055**	ND	**Q**	**0.0026**	**Q**
Type		**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**
Sites with detections		**2**	**1**	**6**	**1**	**4**	**2**	**3**	**4**	**2**
Max detection		**Q**	**Q**	**0.0041**	**Q**	**0.09**	**Q**	**Q**	**0.0047**	**Q**
HHS		**400**	**none**	**4**	**7**	**1,750**	**2,000**	**100**	**500**	**70**

HHS=Human Health Standard; µg/L = micrograms per liter (1 µg/L = 1 part per billion); ND = not detected;
Q = analyte detected below analytical method limit of quantification (see Appendix B for limits of quantification);
H=herbicide; I=insecticide; N=nematicide

With respect to aquatic life benchmarks, surface water detections of agricultural chemicals did not exceed or approach thresholds set forth by the US EPA (Table 7).

Table 7. US EPA aquatic life benchmarks for pesticides detected in 2009 in surface water in the Judith River Basin (µg/L)

Pesticide compound	Acute Fish	Chronic Fish	Acute invertebrates	Chronic invertebrates	Acute non-vascular plants	Acute Vascular plants
2,4-D	1,000	—	7,500	—	932	—
Atrazine	2,650	65	360	60	1	37
Bromacil	18,000	3,000	60,500	8,200	6.8	45
Carbofuran	44	5.7	1.115	0.75	—	—
Chlorsulfuron	—	—	—	—	—	—
Clopyralid	984,000	—	56,500	—	—	—
Diuron	355	26	80	160	2.4	—
Hydroxyatrazine	>1,500	—	>2,050	—	>10,000	—
Imazamethabenz methyl ester	—	—	—	—	—	—
Imazamethabenz methyl acid met.	—	—	—	—	—	—
Imazapic	—	—	—	—	—	—
MCPA	—	—	—	—	300	170
MCPP	—	—	>45,500	50,800	—	—
Metsulfuron methyl	—	—	—	—	—	—
NOA 407854	>51,500	>960	>50,500	5,800	>100,000	10,000
Prometon	6,000	9,500	12,850	3,500	98	624
Tebuthiuron	53,000	9,300	148,500	21,800	50	135
Triasulfuron	>50,000	68,600	>50,000	105,000	—	—

Surface water samples – nitrate-N

Assuming that non-detects (ND) = 0, the weighted mean was 1.88 mg L^{-1} $NO_3^{-}N$ in surface waters. However, $NO_3^{-}N$ was not detected at 5 of the 7 surface water sites having only been observed at Louse Creek (LOUSECR) and at the Ross Fork Creek site at the Tognetti Road bridge (RSSFKCRN). At these sites, $NO_3^{-}N$ concentrations increased between the June and September sampling events. Nitrite-N ($NO_2^{-}N$) was not detected in surface water.

Table 8. Surface Water Nitrate/Nitrite Results, Judith River Basin, 2009

Site ID	Date	Nitrate-N	Drinking Water Standard	Nitrite-N	Drinking Water Standard
		(mg L^{-1})	(mg L^{-1})	(mg L^{-1})	(mg L^{-1})
BIGSPRCR	6/16/2009	ND	10	ND	1
	9/14/2009	ND	10	-	1
JUDTHR	5/28/2009	ND	10	ND	1
	6/29/2009	ND	10	-	1
	8/31/2009	ND	10	-	1
	9/28/2009	ND	10	-	1
LOUSECR	6/15/2009	8.1	10	ND	1
	9/15/2009	12	10	-	1
ROSSFKCRN	6/16/2009	3.7	10	ND	1
	9/14/2009	6.2	10	-	1
ROSSFKCRS	6/15/2009	ND	10	ND	1
	9/15/2009	ND	10	-	1
SAGECR	6/15/2009	ND	10	ND	1
	9/15/2009	ND	10	-	1
WOLFCR	6/16/2009	ND	10	ND	1
	9/14/2009	ND	10	-	1

Only June samples were only analyzed for nitrite-N; mg L^{-1} = milligrams per liter (1 mg L^{-1} = 1 part per million); ND = not detected above analytical method detection limit of 1 mg L-1

Uses of Pesticides Detected in Water Samples

The Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) established the authority of the Environmental Protection Agency (EPA) over the distribution, sales, and uses of all pesticides. Under FIFRA, all pesticides (herbicides, insecticides, fungicides, and rodenticides) must be labeled for specific uses. The use of any pesticide outside of those specified on the label is against federal and state law. However, not all pesticides are labeled for a single use and most pesticides, including all of the pesticides detected during this project, are labeled for multiple uses.

In the Judith River Basin, all but 4 of the 33 pesticides detected were herbicides. Sulfonylurea (SU) herbicides and degradates include chlorsulfuron, metsulfuron methyl, flucarbazone, flucarbazone sulfonamide, prosulfuron, sulfosulfuron, sulfometuron methyl and triasulfuron. Theses herbicides were first synthesized in 1975. With the exception of sulfometuron methyl, these highly potent, low application rate herbicides are used broadly on wheat, barley and other small grains. Chlorsulfuron, metsulfuron methyl and sulfometuron methyl have fallow and noncropland uses as well. Other herbicides used in small grains include imazamethabenz methyl ester, MCPA, MCPP, and triallate.

Atrazine was widely used in agriculture before it became a restricted-use herbicide in 1993. In Montana, it is currently registered for use in corn and soybeans and in wheat (fallow) and wheat (stubble) applications. Atrazine and its degradates have proven to be very persistent in the environment and are commonly detected in surface water and groundwater in Montana and across the United States.

Soil sterilants are herbicides used in rights-of-way, industrial sites, parking lots and other places where long-term weed control is desired. Herbicides in this category include bromacil, diuron, prometon, tebuthiuron, and triclopyr. At lower application rates diuron, tebuthiuron, and triclopyr have some noncropland uses as well. Noncropland herbicides encompass a wide variety of chemicals including clopyralid, imazapic, imazapyr, MCPA, picloram and simazine. Many noncropland herbicides detected in the project area may also be used in rangeland, pasture and alfalfa such as aminopyralid, MCPA, tebuthiuron and triclopyr. Simazine also has some orchard applications.

The insecticides carbofuran, chlorpyrifos and carbaryl have myriad uses. The registration for carbofuran has been canceled and as of 12/31/09, it may no longer be applied. It had been registered for use in small grains, alfalfa and sunflowers. Chlorpyrifos and carbaryl have numerous uses in agriculture, forestry and residential applications.

Difenoconazole is a fungicide that is often used as a seed treatment in small grains and as a foliar application in pome fruits, vegetables, sugar beets and potatoes. It can also be used in irrigation delivery systems as a water treatment. It was the only fungicide detected in the study.

Discussion

Atrazine and sulfonylurea herbicide detections

The two most frequent detections in groundwater and surface water were of the sulfonylurea herbicides and the triazine herbicide atrazine and its degradates. Atrazine is a selective, systemic herbicide which inhibits photosynthesis. Synthesized in 1958, atrazine saw widespread use in the agricultural and residential sectors until its use was restricted in 1993. It is still one of the most frequently used herbicides in the United States utilized predominantly for weed control in corn and soybeans. In Montana, atrazine is also labeled for post-harvest applications for wheat (stubble) and as a soil treatment in wheat (fallow). It also has a few noncropland applications. In products registered for use in the state, atrazine comprises from 42.6% to 88.5% active ingredient in emusifiable concentrates and water dispersible granules. Recommended application rates for wheat-fallow-wheat are 0.5-1.1 lbs/ac to 2.5 lbs/ac per year depending on the product.

Atrazine is a moderately persistent environmental contaminant with a high leaching risk. It has a typical half-life of 80 days in the sediment/water interface (PPDB, 2009, 2010). Aqueous photolysis is moderately fast (half-life of 2.6 d.) which suggests that the detections of the atrazine parent in Wolf Creek was from a within season application. The parent compound was observed at 7 sites in the basin. Detections included 4 agricultural sites where atrazine was detected in 2 shallow wells and 2 springs. Atrazine has several degradates including hydroxyatrazine (HA), deethyl atrazine (DEA), deethyl deisospropyl atrazine (DEIA) and deisopropyl atrazine (DIA). HA is the most common degradate of atrazine but it has a greater tendency to sorb to soil particles and it not as commonly detected in groundwater as the other degradates. DEA is the most common degradate detected and is more mobile in soils than the parent compound (Barbesh and Resek, 1996). The HHS of 3 ppb[8] was not exceeded in the course of the study.

The sulfonylurea (SU) herbicides are characterized by their low application rate and high toxicity. First synthesized in the 1970s, chlorsulfuron was the first SU made available to producers in 1981. SUs are moderately persistent with a high leaching risk. In the Judith River Basin, 7 different SUs and 1 SU degradate were detected comprising 41.7% of all groundwater detections. The most common SUs detected were chlorsulfuron (soil (aerobic) half-life of 36 d.), metsulfuron methyl (10 d.), and triasulfuron (19 d.) (PPDB, 2009, 2010). Multiple SU detections were verified at 11 of the 23 groundwater sites and at 1 of the 7 surface water sites (Wolf Creek). At JRB-18 and JRB-14, 4 different SUs were verified. The high number of detections indicates widespread use of the sulfonylurea herbicides for weed control in small grains production.

It is important to recognize that the high potency and low application rates of SUs likely allowed older, less potent, higher-rate herbicides to be abandoned thereby decreasing the cumulative herbicide load. However, other herbicides used in small grains such as imazamethabenz, MCPA and triallate had relatively few detections suggesting an overreliance on the SU herbicides and raising concerns about future resistance issues. The frequent detection of multiple SUs in groundwater may be attributed to the prevalence of products registered for use in MT that have multiple SU active ingredients. This includes combinations of chlorsulfuron/metsulfuron-methyl, chlorsulfuron/ sulfometuron-methyl, and metsulfuron-methyl/sulfometuron-methyl. This may partially explain why metsulfuron methyl, where detected, was observed with chlorsulfuron 92.3% of the time. Frequent detections of herbicides with short half-lives and low application rates also provide evidence of the relative vulnerability of the targeted aquifers to contamination.

The noticeable lack of detections of herbicides used for long-term weed control and soil sterilants outside of suburban/urban areas suggests a lack of broad use of such chemicals.

---

[8] Detections of atrazine, DEA, DEIA, and DIA are additive.

This stands in contrast to sampling conducted in other parts of the state such as the Bitterroot Valley where the occurrence and distribution of such chemicals were more widespread.

Nitrate-N in groundwater

Agricultural wells in terrace gravel deposits are most at-risk to NO_3^-N HHS exceedances. In this study, these sites had a weighted mean of 19.60 mg L^{-1} NO_3^-N and 9 of 11 sites exceeded the HHS for drinking water (10 mg L^{-1}). However, there is a historic precedence for elevated NO_3^-N in the basin. Groundwater characterization studies completed by the MBMG and the USGS in the late-1960s and 1970s observed NO_3^-N concentrations in terrace gravels and alluvium ranging from ND to 27.12 mg L^{-1} with a mean of 7.60 mg L^{-1} (n=17) (Zimmerman, 1966, Feltis, 1973, Feltis, 1977) (Appendix A). Data collected by the MBMG since 1976 to the present in the same deposits had a range of ND to 35.7 mg L^{-1} and a mean of 9.92 mg L^{-1} (n=11). A sample collected by the MSU Well-educated program in 2009 from a shallow domestic well completed in a terrace gravel deposit had a NO_3^-N concentration of 50.7 mg L^{-1}; the highest concentration collected by the MDA in 2009 was 38 mg L^{-1}. These limited datasets are too small to be compared statistically, but elevated groundwater nitrates have been documented in the terrace gravels since 1963.

Analysis of $\delta^{15}N_{NO3}$ and $\delta^{18}O_{NO3}$ isotopes revealed the probable source of nitrates as soil NH_4^+. There were 2 sites which exhibited mixed signatures of soil NH_4^+ and manure/septic sources. Both of these sites were ~100-year-old, hand-dug wells (25-40 ft total depth), located in terrace deposits with existing or historic small livestock operations. In groundwater studies using the dual isotope method, denitrification is of concern. Denitrification is the conversion of NO_3^-N to N_2 gas in groundwater and results in altered O and N isotopic signatures. Indicators of denitrification include low dissolved oxygen and low NO_3^-N concentrations as NO_3^-N is converted to N_2 gas. Neither of these indicators was observed in the samples. In coarse-grained soils with rapid infiltration and a shallow water table, denitrification is much less likely than in fine grained soils. In shallow, transmissive aquifers such as the terrace gravel aquifers in the Judith Basin, denitrification is not significant due to low organic carbon, oxic water and shallow water tables (Gilham and Cherry, 1978, Gormly and Spaulding, 1979, Starr and Gilham, 1993).

Mineralization of soil organic nitrogen (SON) to NO_3^-N occurs where soil is regularly tilled. Tillage increases oxygen in the soil profile and facilitates decomposition of organic matter releasing N as NO_3^-N. It is worth noting that the effect of conservation tillage on NO_3^-N loading is not well understood. SON isotopic signatures commonly have $\delta^{18}O$ around $0^o/_{oo}$ and $+3^o/_{oo}$ to $+8^o/_{oo}$ $\delta^{15}N$ (Kendall and McDonnell, 1998). In dryland systems, where excess fertilizer is applied, studies have found that much of the fertilizer N is converted into soil or plant organic N before being re-released and leached through the profile as nitrate-N.

The USGS completed a groundwater characterization study on the Ft. Peck Indian Reservation in northeastern Montana (Nimick and Thamke, 1998). The surficial geology and agricultural practices in the Flaxville gravels on the reservation are very similar to those in the Judith Basin. As in the basin, elevated $NO_3^{-}N$ concentrations were observed in the shallow, unconfined gravel aquifers of the Flaxville gravel formation. Analysis of $\delta^{15}N_{NO3}$ and $\delta^{18}O_{NO3}$ isotopes determined that N fertilizer was not a direct source of $NO_3^{-}N$ in groundwater. The authors theorized that fertilizer applications likely increased N storage in organic matter which released N as nitrate during decomposition of roots and stubble during the fallow period. Dual isotope testing also found that domestic wells in close proximity to livestock operations were affected by $NO_3^{-}N$ loading from manure and/or septic waste. However, the authors noted that given the small density of livestock operations in relation to cropped acres in the region, $NO_3^{-}N$ from manure was a much smaller N source than crop-fallow agriculture.

Nitrogen contributions from mineralization of plant biomass and soil N are the likely source of $NO_3^{-}N$ in groundwater in the Judith Basin. At the Ag Research Center in Moccasin, soil organic nitrogen (SON) is typically 0.15% or 3000 lb N/ac SON in the upper 6 inches (C. Jones[9], pers. comm. 2010). If 1-2% of this N reservoir mineralizes to $NO_3^{-}N$ every year it would release 30-60 lb N/ac. If dryland small grains fertilization rates are 40-80 lb N/ac in the Judith Basin, the $NO_3^{-}N$ contributions from SON and fertilizer are approximately equal. If most fertilizer in the Judith Basin is applied in spring, a higher percentage of fertilizer N is liable to be removed by the crop whereas mineralization is occurring year round. The most significant leaching of $NO_3^{-}N$ is likely occurring from fall to mid-spring when there is no plant water uptake, and therefore relatively little of the deeper soil nitrate is directly from fertilizer N (C. Jones, pers. comm. 2010).

From the 2007 Census of Agriculture, 16.75% and 9.65% of total cropland in Fergus and Judith Basin Counties respectively were summer fallow (US Department of Agriculture). In Fergus County, 11.62% of total cropland was enrolled in federal programs. In Judith Basin County the figure was slightly lower at 10.12% of total cropland. Since 1966, both counties have shown significant decreases in acreages in summer fallow with accompanying increases in continuous cropping acreages for non-irrigated wheat production (US Department of Agriculture). This is a more efficient use of water and fertilizers, but plant uptake is not able to utilize nitrate-N availability in the profile resulting in significant losses of $NO_3^{-}N$ to groundwater during the non-growing season.

Nitrate-N in surface water

MDA surface water sampling efforts resulted in few $NO_3^{-}N$ detections; the analyte was only detected at Louse Creek and in Ross Fork Creek at the Tognetti Road bridge. In both instances, concentrations increased between the June and September sampling events. These results are in contrast to Feltis, 1977 (Appendix A). Feltis, 1977 sampled numerous streams in the above-average water year of 1970 including Wolf Creek, Sage Creek, Big Spring Creek, Ross Fork Creek and the Judith River. Nitrate-N was detected from 0.09 mg L^{-1} in the Middle Fork, Judith River to 8.36 mg L^{-1} in Sage Creek. The

---

[9] Dr. Clain Jones, Montana State University-Extension, Soil Fertility Specialist

range and number of detections suggests that $NO_3^{-}N$ surface water concentrations from 1970 in the basin were higher and more widespread than in the present day.

It is difficult to hypothesize why there is such a marked difference. One possibility could be changes in N loading to surface waters from manure and septic sources. However, cow/calf pairs in both Fergus and Judith Basin County are quite similar compared with populations in the 1960s and 1970s (US Department of Agriculture). In Fergus County, cow/calf pairs were 86,400 in 1960, 115,000 in 1970 and 108,500 in 2009. In Judith Basin County, cow/calf pairs were 46,300 in 1960, 64,000 in 1970 and 65,400 in 2009. Population in both counties has also decreased from 17,103 in 1960 to an estimated 13,209 in 2008 (Population Division US Census Bureau). The decrease in human population may have led to a decreases in N loading from septic tanks and/or drain fields, but given the proportion of people to cattle, this would be a relatively small source of N to aquifer recharge and stream baseflow and would be more important at the micro-scale such as the spatial relationship between a septic system and a wellhead.

Although difficult to assess, implementation of Best Management Practices (BMPs) in the basin since the 1960s map be partially responsible for decreases in surface water $NO_3^{-}N$ concentrations. BMPs include excluding cattle from stream drainages, manure management strategies and stream buffers to minimize direct loading of manure and urea to surface waters.

Summary

In 2009, the MDA detected 33 different pesticides and degradates in the Judith River Basin in central Montana. Detections reflected the cropping systems and agricultural practices of the region with sulfonylurea herbicides comprising 41.7% of all detections and 8 of the 33 different analytes detected. Most importantly, none of the pesticide detections exceeded established HHS for drinking water. Elevated $NO_3^{-}N$ has been observed in terrace gravel aquifers since 1963 (Zimmerman, 1966) and wells in agricultural areas completed in the terrace gravel deposits had a weighted mean of 19.60 mg L^{-1} $NO_3^{-}N$ in the MDA study. Analyses of $\delta^{15}N_{NO3}$ and $\delta^{18}O_{NO3}$ isotopes suggest that soil NH_4^+ is the dominant source of $NO_3^{-}N$ in groundwater. Fertilizer increases production of biomass and N is stored in plant tissue and soil before being released as $NO_3^{-}N$ following mineralization during the fallow period and/or non-growing season. This is the likely process resulting in N loading to the shallow aquifers.

An excellent comparison site is the Greenfields (aka Fairfield) Bench in north-central Montana. The Bench has nearly identical aquifer characteristics as the gravel aquifers in the Judith Basin. It is a topographically isolated bench of Cretaceous age overlain by Quaternary gravel deposits 3–40 feet thick and underlain by bedrock with a thin soil mantle (1-1.5 ft). The ~83,000 acres of the Bench are almost entirely irrigated. It has been estimated that 70% of aquifer recharge is derived from irrigation, canal leakage, and ponded tailwater (Osbourne, 1983). MDA has sampled groundwater extensively across the Bench since 1998 and has documented numerous pesticide detections and elevated $NO_3^{-}N$ concentrations with an overall median of 5 mg L^{-1} $NO_3^{-}N$ (*n*=171). Irrigated small grains production utilizes significantly higher volumes of fertilizer and herbicides than dryland agriculture. However, the dilution effects of induced recharge from irrigation practices results in lower concentrations of contaminants in the shallow, unconfined aquifer. Nitrate-N concentrations were found to increase with conversion to more efficient irrigation delivery systems on the Greenfields Bench.

As on the Greenfields Bench, the Quaternary/Tertiary gravel aquifers in the Judith River Basin are vulnerable to contamination. These aquifers are unconfined, with a thin soil mantle (~1-1.5 ft) which has a high infiltration rate and relatively low clay and organic matter content. Combined with a shallow depth to groundwater, low land surface slope on the terraces and recharge almost entirely dependent upon snowmelt and precipitation, these aquifers are vulnerable to at or near-surface applications of agricultural chemicals. The shallow depth to bedrock (<50 feet) in most parts of the basin restricts aquifer storage capacity increasing the sensitivity of the aquifers to contamination.

Elevated NO_3^{-}N concentrations in the Quaternary/Tertiary gravel aquifers are a significant issue in the Judith River Basin. Concentrations will continue to remain high, in many cases in excess of the HHS, as long as dryland small grains production remains the dominant form of agriculture in the basin. Of concern is the distribution of groundwater resources that are impacted by high nitrates. Strictly examining well data, in the GWIC database there are 526 wells $\leq$50 feet deep located in Quaternary/Tertiary gravel deposits in the Judith River Basin. From the DNRC WRDiv data, another 546 wells meet these criteria[10]. An unknown number of these 1000+ wells are likely to have been abandoned, destroyed or are not used for human consumption. However, even assuming a gross attrition rate of this compilation, there are likely at least several hundred wells used for human consumption in excess of the HHS for NO_3^{-}N in the Judith River Basin given the detection frequency of elevated NO_3^{-}N in groundwater as documented by the MDA. Springs were not considered for this compilation, but would have added a few hundred additional records.

There are several long-term strategies that would reduce nitrate-N loading to the shallow aquifers. In the Judith Basin, agriculture replaced a short-grass prairie ecosystem. Native prairie vegetation was a thick, multi-layered perennial cover which maintained a highly efficient nutrient cycle. Mimicking a prairie ecosystem, perennial forage and pasture systems would decrease N fertilizer use and N loading to the aquifer. The planting of deep-rooted crops such as alfalfa would also better utilize N stored in the soil and decrease losses to groundwater through most of its life cycle. Alfalfa utilizes available N before converting N_2 from the atmosphere. Other agricultural practices that would decrease N loading such as continuous cropping and reduction in summer fallowing are already being practiced on a large scale in the watershed. Less fertilizer-intense crops such as peas and lentils would also make a positive impact if such crops replaced wheat production at a significant scale. As agriculture is likely the main contributor of N to groundwater, changes in cropping practices and strategies will have the greatest long-term impact to water quality in the basin. Given the spatial and temporal scales necessary

---

[10] WRDiv $\leq$50 feet well records within 250 feet of GWIC $\leq$50 feet well records were omitted to avoid duplication (n=143).

to observe changes in water quality, it is advisable that landowners get their wells tested and appropriate water treatment systems installed should HHS exceedances be observed.

Literature Cited

Alden, W.C., 1932, Physiography and glacial geology of eastern Montana and adjacent areas: United States Geological Survey Prof. Paper 174., 133p., 51pl.

Barbash J.E. and Resek, E.A., 1996, Pesticides in Groundwater: Distribution, Trends, and Governing Factors: Ann Arbor Press, Inc., Chelsea, MI, 588 p.

Feltis, R.D., 1973, Geology and Water Resources of Eastern Part of Judith Basin, Montana: Bulletin 101, State of Montana Bureau of Mines and Geology. Montana College of Mineral Science and Technology, Butte, MT, 51 pp.

Feltis, R.D., 1977, Geology and Water Resources of Northern Part of Judith Basin, Montana: Bulletin 101, State of Montana Bureau of Mines and Geology. Montana College of Mineral Science and Technology, Butte, MT, 65 pp.

Fennema, N.M., 1931, Physiography of Western United States: New York, McGraw-Hill Book Co., 534 p.

Gillham, R.W. and Cherry, J.A., 1978, Field evidence of denitrification in shallow groundwater flow systems: Water Pollution Research Journal of Canada, v. 13, p. 53-71.

Gormly, J.R. and Spalding, R.F., 1979, Sources and concentrations of nitrate-nitrogen in groundwater of the central Platte region, Nebraska: Ground Water, v. 17, p. 291-301.

Kendall, C. and McDonnell, J.J., 1998, Isotope Tracers in Catchment Hydrology: Elsevier Science B.V., Amsterdam, 839 pp.

Kendall C., Elliott E.M., and Wankel S.D., 2007, Tracing anthropogenic inputs of nitrogen to Ecosystems; In Stable Isotopes in Ecology and Environmental Science, 2nd edn, Lajtha K, Michener RH (eds): Blackwell Scientific Publications, Oxford, 375–449.

Miller, K.J., Rise, D.S. and McDonald C., 2002, Ground-water and surface-water quality, herbicide transport, and irrigation practices, Greenfields Bench Aquifer, Teton County, Montana: MBMG Open-File Report 463.

Nimick, D.A. and Thamke, J.N., 1998, Extent, magnitude, and sources of nitrate in the Flaxville and underlying aquifers, Fort Peck Indian Reservation, northeastern Montana: U.S. Geological Survey Water-Resources Investigations Report 98-4079, 45 p.

Osborne, T.J., Noble, R.A., Zaluski, M.H., and Schmidt F.A., 1983, Evaluation of the ground-water contribution to Muddy Creek from the Greenfields Irrigation District: Montana Bureau of Mines and Geology Open-File Report 113, 141 p.

PPDB, 2009, 2010, The Pesticide Properties Database (PPDB) developed by the Agriculture & Environment Research Unit (AERU), University of Hertfordshire, funded by UK national sources and the EU-funded FOOTPRINT project (FP6-SSP-022704).

Porter, K.W. and Wilde, E.M., 1993, Preliminary geologic map of the Lewistown 30' x 60' quadrangle, revised 1999, Montana Bureau of Mines and Geology: Open-File Report 308, 22 p., 1 sheet(s), 1:100,000.

Porter, K.W. and Wilde, E.M., 2001, Geology of the Winifred 30' x 60' quadrangle, eastern Montana, Montana Bureau of Mines and Geology: Open-File Report 437, 13 p., 1 sheet(s), 1:100,000.

Porter, K.W., Wilde, E.M., and Vuke, S.M., 1999, The preliminary geologic map of the Big Snowy Mountains 30' x 60' quadrangle, Montana, revised 1999, Montana Bureau of Mines and Geology: Open-File Report 341, 16 p., 1 sheet(s), 1:100,000.

Population Division US Census Bureau (www.census.gov)

Reynolds, M.W. and Brandt, T.R., 2007, Preliminary geologic map of the White Sulphur Springs 30' x 60' quadrangle, Montana: U.S. Geological Survey Open-File Report 2006-1329, scale 1:100,000.

Starr, R.C. and Gillham, R.W., 1993, Denitrification and organic carbon availability in two aquifers: Ground Water, v. 31, p. 934-947.

US Department of Agriculture, National Agricultural Statistics Service (NASS). http://www.nass.usda.gov/Statistics_by_State/Montana/index.asp

Vuke, S.M., Berg, R.B., Colton, R.B., and O'Brien, H.E., 2002, Geologic map of the Belt 30' x 60' quadrangle, central Montana, Montana Bureau of Mines and Geology: Open-File Report 450, 18 p., 2 sheet(s), 1:100,000.

Zimmerman, E.A. 1966. Geology and Ground-Water Resources of Western and Southern Parts of Judith Basin, Montana. Bulletin 50-A. State of Montana Bureau of Mines and Geology. Montana College of Mineral Science and Technology, Butte, MT. 33 pp.

Appendix A

Historic Nitrate-N Data

Historic groundwater nitrate-N data in the Judith River Basin that met MDA project parameters

Collection date	Data Source	Site location (Town/Range)	Source	Well total depth	Nitrate as Nitrogen (mg L^{-1})	Dissolved solids (mg L^{-1})	Specific conductance (uS cm^{-1})	pH	Temperature (deg. C)
4/13/1959	USGS, 1966	14N16E15CB	well	50	0.00	375	-	-	-
10/2/1963	USGS, 1966	13N12E18AC	spring	-	0.16	504	780	-	7.8
10/2/1963	USGS, 1966	18N12E2CB	well	32.6	16.79	1596	2000	-	-
11/8/1963	USGS, 1966	17N12E10AD1	well	9.2	2.87	486	900	-	8.9
11/12/1963	USGS, 1966	14N11E6CB	spring	-	0.05	136	-	-	6.7
11/18/1963	USGS, 1966	15N12E12DA	well	9.9	1.56	826	1100	-	8.9
-	USGS, 1966	18N12E3DC	well	23	9.04	2985	-	-	-
9/13/1966	MBMG, 1973	17N20E19AC	spring	-	0.02	111	128	5.3	7.8
4/26/1968	MBMG, 1973	18N1924DA	spring	-	2.49	258	440	-	7.8
6/18/1968	MBMG, 1973	15N1830CBB	well	48	27.12	642	-	-	8.9
6/18/1968	MBMG, 1973	17N1823ADB	well	50	10.17	392	-	-	-
4/29/1971	MBMG, 1977	18N13E36AAA	spring	-	20.79	423	688	8.1	8
5/27/1971	MBMG, 1977	16N13E12DDD	spring	-	0.00	1790	2160	8.2	7
5/27/1971	MBMG, 1977	16N13E35BCD	spring	-	0.11	2780	3420	8	7
5/27/1971	MBMG, 1977	18N14E14CAB	drain	-	4.52	5590	5650	8.2	6.5
5/27/1971	MBMG, 1977	18N14E15DBB	drain	-	16.72	3750	4170	8.2	6
-	MBMG, 1977	17N13E14ABB2	well	30	16.72	475	-	-	-
9/22/1976	MBMG GWIC	21N15E26BCDC	well	20	15.81	1864	2730	7.7	10.5
4/6/1978	MBMG GWIC	17N15E6BCAB	well	20	4.40	1504	2419	7.96	5
9/25/1979	MBMG GWIC	17N15E7AAAB	well	18	8.00	68098	40095	7.46	12
1/23/1980	MBMG GWIC	17N15E7BAAC	well	23	2.20	1034	7028	8.35	12.2
6/7/1983	MBMG GWIC	14N19E23CDCD	well	35	0.02	2848	4571	8.15	-
6/7/1983	MBMG GWIC	14N19E23CDCD	well	25	0.78	891	1235	6.83	11
5/6/1993	MBMG GWIC	15N14E4BBCC	well	20	9.52	483	1025	7.2	-
6/15/2004	MBMG GWIC	15N14E4BBCC	well	20	18.70	487	820	7.82	7.7
9/8/2004	MBMG GWIC	14N16E15BBCB	well	42	0.05	39	60	9.48	12.3
7/13/2000	MBMG GWIC	14N16E15BBCB	well	39	13.90	288	546	7.67	9.8
6/20/2007	MBMG GWIC	14N16E15BBCB	well	39	35.70	277	651	8.27	8.4
10/27/2008	MSU Ext., 2008-09	22N16E34AD	well	<50	4.61	-	-	-	-
4/6/2009	MSU Ext., 2008-09	14N17E2CB	well	<50	0.88	-	-	-	-
6/15/2009	MSU Ext., 2008-09	18N15E30CCC	well	26	50.70	-	-	-	-
9/28/2009	MSU Ext., 2008-09	15N18E16AB	well	<50	1.40	-	-	-	-
11/16/2009	MSU Ext., 2008-09	13N16E31ACA	well	<50	2.69	-	-	-	-

This groundwater result is outside the Judith Basin to the northwest, but was sampled in Quaternary/Tertiary gravels.

4/29/1971	MBMG, 1977	18N13E05BAD	spring	-	20.34	917	1350	8.5	8.5

Historic surface water nitrate-N data in the Judith River Basin that met MDA project parameters

Collection date	Data source	Site location (Town/Range)	Surface water ID	Discharge (cfs)	Nitrate as Nitrogen (mg L^{-1})	Dissolved solids (mg L^{-1})	Specific conductance (uS cm^{-1})	pH	Temperature (deg. C)
11/12/1963	USGS-1966	16N11E35BD	Wolf Creek	NM	0.11	240	-	-	4.4
11/13/1963	USGS-1966	13N11E35BD	Judith River, Middle Fork	NM	0.09	140	-	-	-
6/22/1970	MBMG-1977	16N17E27BB	Big Spring Creek	248	1.02	432	632	8.1	19.5
6/22/1970	MBMG-1977	16N17E28AA	Cottonwood Creek	284	0.61	225	374	8.1	8
6/23/1970	MBMG-1977	21N17E30DB	Judith River	1150	0.50	414	615	7.6	24.5
6/23/1970	MBMG-1977	18N16E31DD	Sage Creek	13	0.90	1530	1860	8.2	26
6/23/1970	MBMG-1977	18N16E21CD	Warm Spring Creek	144	0.45	672	875	8.1	20.5
6/23/1970	MBMG-1977	19N16E19CB	Wolf Creek	109	0.50	668	965	8.1	26
6/24/1970	MBMG-1977	13N12E17BA	Judith River	411	0.27	152	255	8.2	12
6/24/1970	MBMG-1977	14N15E11BC	Ross Fork Creek	41	1.31	554	820	8.2	22
6/24/1970	MBMG-1977	15N12E12CD	Sage Creek	12	2.49	552	800	7.9	18.5
6/24/1970	MBMG-1977	16N11E26DA	Wolf Creek	169	0.23	170	287	7.9	13.5
8/26/1970	MBMG-1977	16N17E27BB	Big Spring Creek	145	3.62	395	538	7.9	15
8/26/1970	MBMG-1977	16N17E28AA	Cottonwood Creek	13	6.10	415	796	8	18.5
8/26/1970	MBMG-1977	18N16E31DD	Sage Creek	0.5	4.07	2410	2690	7.9	26
8/26/1970	MBMG-1977	18N16E21CD	Warm Spring Creek	132	3.16	648	824	8	21.5
8/27/1970	MBMG-1977	21N17E30DB	Judith River	320	2.06	530	774	8	18.5
8/27/1970	MBMG-1977	19N16E19CB	Wolf Creek	0.19	4.07	2100	2380	8	23.5
8/28/1970	MBMG-1977	13N12E17BA	Judith River	22	1.08	284	440	8	14.5
8/28/1970	MBMG-1977	14N15E11BC	Ross Fork Creek	6	4.52	672	896	8.1	20
8/28/1970	MBMG-1977	15N12E12CD	Sage Creek	2.4	8.36	538	638	7.7	13.5
8/28/1970	MBMG-1977	16N11E26DA	Wolf Creek	10	1.70	282	689	8	11.5
5/27/1971	MBMG-1977	18N14E13DD	Wolf Creek	<1 est	3.39	1850	2320	8.2	17
These surface water results are outside the Judith Basin to the northwest, but flow through Quaternary/Tertiary gravel deposits.									
6/23/1970	MBMG-1977	19N14E02AC	Coffee Creek	2.5	10.62	4450	4700	8.3	27
6/24/1970	MBMG-1977	19N12E11CD	Arrow Creek	71	0.61	944	1410	7.9	19
8/27/1970	MBMG-1977	19N12E11CD	Arrow Creek	0.95	2.26	1820	1890	8.1	26.5

Appendix B

Universal Method Analyte List and Limits of Quantification (LOQ)

2009 MDA Universal Method Analytes and the Limits of Quantification (LOQ)

Analyte Name	LOQ	Units	Analyte Name	LOQ	Units
2,4-D	0.0045	ug/L (ppb)	Hexazinone	0.0059	ug/L (ppb)
2,4-DB	0.091	ug/L (ppb)	Hydroxy atrazine	0.0064	ug/L (ppb)
2,4-DP	0.011	ug/L (ppb)	Imazalil	0.01	ug/L (ppb)
3-OH Carbofuran	0.01	ug/L (ppb)	Imazamethabenz methyl acid met.	0.0052	ug/L (ppb)
Acetochlor	0.14	ug/L (ppb)	Imazamethabenz methyl ester	0.001	ug/L (ppb)
Acetochlor ESA	0.01	ug/L (ppb)	Imazamox	0.012	ug/L (ppb)
Acetochlor OA	0.0042	ug/L (ppb)	Imazapic	0.011	ug/L (ppb)
Alachlor	0.11	ug/L (ppb)	Imazapyr	0.011	ug/L (ppb)
Alachlor ESA	0.011	ug/L (ppb)	Imazethapyr	0.01	ug/L (ppb)
Alachlor OA	0.0034	ug/L (ppb)	Imidacloprid	0.0018	ug/L (ppb)
Aldicarb	0.0028	ug/L (ppb)	Linuron	0.011	ug/L (ppb)
Aldicarb sulfone	0.0011	ug/L (ppb)	Malathion	0.028	ug/L (ppb)
Aldicarb sulfoxide	0.056	ug/L (ppb)	MCPA	0.0023	ug/L (ppb)
Aminopyralid	0.053	ug/L (ppb)	MCPP	0.0022	ug/L (ppb)
Atrazine	0.0022	ug/L (ppb)	Metalaxyl	0.012	ug/L (ppb)
Azinphos methyl	0.037	ug/L (ppb)	Methomyl	0.0016	ug/L (ppb)
Azinphos methyl oxon	0.031	ug/L (ppb)	Metolachlor	0.012	ug/L (ppb)
Azoxystrobin	0.0011	ug/L (ppb)	Metolachlor ESA	0.0025	ug/L (ppb)
Bentazon	0.0011	ug/L (ppb)	Metolachlor OA	0.021	ug/L (ppb)
Bromacil	0.0074	ug/L (ppb)	Metsulfuron methyl	0.026	ug/L (ppb)
Carbaryl	0.04	ug/L (ppb)	Nicosulfuron	0.011	ug/L (ppb)
Carbofuran	0.0052	ug/L (ppb)	Nitrate as Nitrogen	1.0	mg/L (ppb)
Chlorpyrifos	0.031	ug/L (ppb)	Nitrite as Nitrogen	0.1	ug/L (ppb)
Chlorsulfuron	0.0056	ug/L (ppb)	NOA 407854	0.0052	ug/L (ppb)
Clodinafop-propargyl-acid metabolite	0.013	ug/L (ppb)	NOA 447204	0.01	mg/L (ppm)
Clopyralid	0.022	ug/L (ppb)	Picloram	0.14	mg/L (ppm)
Cyproconazole	0.0051	ug/L (ppb)	Prometon	0.0051	ug/L (ppb)
Deethyl atrazine	0.0017	ug/L (ppb)	Propachlor	0.0028	ug/L (ppb)
Deisopropyl atrazine	0.01	ug/L (ppb)	Propachlor OA	0.0094	ug/L (ppb)
Diazinon	0.01	ug/L (ppb)	Propiconazole	0.01	ug/L (ppb)
Dicamba	0.051	ug/L (ppb)	Prosulfuron	0.005	ug/L (ppb)
Difenoconazole	0.02	ug/L (ppb)	Simazine	0.0026	ug/L (ppb)
Dimethenamid	0.01	ug/L (ppb)	Sulfometuron methyl	0.01	ug/L (ppb)
Dimethenamid OA	0.0038	ug/L (ppb)	Sulfosulfuron	0.0054	ug/L (ppb)
Dimethoate	0.0011	ug/L (ppb)	Tebuconazole	0.01	ug/L (ppb)
Disulfoton	0.13	ug/L (ppb)	Tebuthiuron	0.0011	ug/L (ppb)
Disulfoton sulfone	0.014	ug/L (ppb)	Terbacil	0.0051	ug/L (ppb)
Disulfoton sulfoxide	0.064	ug/L (ppb)	Terbufos	0.17	ug/L (ppb)
Diuron	0.01	ug/L (ppb)	Tetraconazole	0.0062	ug/L (ppb)
Epoxyconazole	0.028	ug/L (ppb)	Thifensulfuron	0.026	ug/L (ppb)
Ethion	0.39	ug/L (ppb)	Tralkoxydim	0.0051	ug/L (ppb)
Ethofumesate	0.025	ug/L (ppb)	Tralkoxydim acid	0.005	ug/L (ppb)
Ethoprop	0.012	ug/L (ppb)	Triadimefon	0.0057	ug/L (ppb)
Fenamiphos	0.0011	ug/L (ppb)	Triadimenol	0.026	ug/L (ppb)
Fenbuconazole	0.0053	ug/L (ppb)	Triallate	0.039	ug/L (ppb)
Flufenacet OA	0.0053	ug/L (ppb)	Triasulfuron	0.026	ug/L (ppb)
Flumetsulam	0.063	ug/L (ppb)	Triclopyr	0.011	ug/L (ppb)
Glutaric Acid	0.0074	ug/L (ppb)	Triticonazole	0.032	ug/L (ppb)
Halosulfuron methyl	0.01	ug/L (ppb)			

Appendix C

MDA Sample Water Quality Parameters

MDA Groundwater Quality Parameters, Judith River Basin, 2009

Site ID	Collection Date	Temperature (°C)	Field pH	Field specific conductance (uS cm^{-1})	Field dissolved oxygen (mg L^{-1})	Field dissolved oxygen (%)
JRB-1	6/15/2009	8.65	8.04	570	8.42	72.2
	9/14/2009	12.44	7.59	877	8.31	77.9
JRB-2	6/16/2009	8.79	7.71	554	12.52	107.9
	9/14/2009	9.08	7.90	600	13.8	119.8
JRB-3	6/16/2009	9.02	7.74	889	8.97	77.9
	9/14/2009	13.82	7.69	988	8.46	81.7
JRB-4	6/15/2009	9.09	7.73	673	11.92	102.7
	9/14/2009	13.28	7.63	809	10.14	97
JRB-5	6/16/2009	7.38	7.99	690	12.81	106.7
	9/14/2009	9.22	7.97	746	12.29	107
JRB-6	6/15/2009	7.79	7.41	4572	2.97	25.3
JRB-7	6/15/2009	12	7.91	894	3.78	35
	9/14/2009	14.9	8.40	1319	2.76	27
JRB-8	6/15/2009	8.2	7.64	1066	11.01	93.6
	9/15/2009	10.12	7.82	1107	11.34	102.7
JRB-9	6/15/2009	9.9	8.37	501	5.72	51
	9/15/2009	9.1	7.80	368.4	3.59	31.2
JRB-10	6/15/2009	8.65	8.04	570	12.3	105.1
	9/14/2009	10.36	7.78	613	11.34	102.5
JRB-11	6/15/2009	8.78	7.92	597	11.69	101.3
	9/14/2009	8.55	7.66	642	12.41	106.4
JRB-12	6/15/2009	8.5	8.35	535	5.42	45.6
	9/14/2009	9.9	8.10	396.7	4.02	35.6
JRB-13	6/16/2009	8	8.00	393.3	6.09	51.7
	9/14/2009	9.8	7.90	372.6	3.96	34.8
JRB-14	6/15/2009	9.4	7.71	539	6.51	56.9
	9/15/2009	9.2	7.60	393.6	3.34	29
JRB-15	6/15/2009	9.9	7.41	1368	0.85	7.5
	9/15/2009	9.8	7.80	881	0.56	4.9
JRB-16	6/15/2009	9.1	7.14	758	7.5	65.1
	9/15/2009	12.3	7.20	575	2.16	20.2
JRB-17	6/15/2009	8.4	7.91	584	5.09	43.4
	9/14/2009	8.7	8.70	416.2	5.15	43.9
JRB-18	6/15/2009	8.3	7.98	833	7.63	64.3
	9/14/2009	7.9	8.00	428.5	4.86	41
JRB-19	6/15/2009	10	7.82	577	5.07	45
	9/14/2009	12.1	8.20	429.9	2.92	26.9
JRB-20	6/16/2009	8.7	8.00	571	2.85	24.4
	9/14/2009	11.2	7.80	620	2.08	19
JRB-21	6/15/2009	7.2	10.25	620	0.79	6.5
	9/14/2009	10.2	7.90	535	2.2	20.9
JRB-22	6/15/2009	7.8	8.05	1318	2.39	21.6
	9/14/2009	14.4	7.80	970	1.17	11.4
M-1	6/16/2009	6.25	7.93	685	11.41	92.4
	9/15/2009	9.49	7.91	824	10.36	91.1

MDA Surface Water Quality Parameters, Judith River Basin, 2009

Site ID	Collection Date	Temperature (°C)	Field pH	Field specific conductance (uS cm^{-1})	Field dissolved oxygen (mg L^{-1})	Field dissolved oxygen (%)
BIGSPRCR	6/16/2009	13.4	8.61	591	7.13	68.2
	9/14/2009	17.4	7.70	428.6	3.16	32.8
JUDITHR	5/28/2009	18.49	8.39	600	11.02	117.9
	6/29/2009	20.05	8.37	637	10.53	116
	8/31/2009	21.01	8.38	661	11.1	124.8
	9/28/2009	14.0	8.35	734	11.47	111.6
LOUSECR	6/15/2009	18.36	8.34	751	9.6	102.4
	9/15/2009	11.09	8.09	795	10.86	99.1
ROSSFKCRN	6/16/2009	16.7	7.80	838	6.57	67.6
	9/14/2009	16.4	7.80	543	3.97	40.6
ROSSFKCRS	6/16/2009	21.0	8.70	996	6.1	68.2
	9/15/2009	16.8	7.80	847	3.21	33.2
SAGECR	6/15/2009	19.26	8.17	3880	10.26	112.6
	9/15/2009	13.13	7.94	5409	11.12	107.8
WOLFCR	6/15/2009	19.15	8.28	6594	14.49	160.2
	9/15/2009	13.34	7.77	5626	8.37	81.2