Reducing groundwater nitrate in the Judith River Watershed: a participatory approach to achieve effective management for improved water quality

Stephanie A. Ewing[1], W. Adam Sigler[1,2], Douglas Jackson-Smith[3], Clain Jones[1], Gary S. Weissmann[4]*

*[*stephanie.ewing@usgs.gov](mailto:stephanie.ewing@usgs.gov); [1]Montana State University Dept of Land Resources & Environmental Sciences; [2]MSU Extension Water Quality Program ; [3]University of Utah Dept of Sociology; [4]University of New Mexico Dept of Earth & Planetary Sciences*

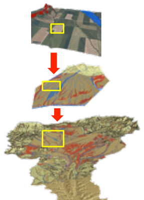
Introduction

Rising levels of nitrate in groundwater threaten human health and downstream ecosystems. In the Judith River Watershed, Montana, groundwater nitrate concentrations frequently exceed 10 mg L^{-1}, and may be increasing due to agricultural practices on thin soils overlying shallow, unconfined aquifers with short groundwater residence times. Previous extension and research activities in the watershed have provided key data and established working relationships with local stakeholders, but adoption rates of water quality best management practices (BMPs) have been low. With this project, we undertake a participatory approach that engages agricultural producers and stakeholders to:

(1) Better understand the sources of nitrate in groundwater and surface water;
(2) Identify effective management strategies for reducing nitrate leaching; and
(3) Engage the local community for increased adoption of effective practices.

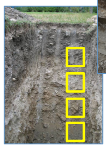
Approach

Research Advisory Council meeting, October 2011



- Active participation of growers and stakeholders in research (above)
- Plot scale study of management effects (Fig 3)
- Groundwater dynamics using landform scale modeling (ModFlow with GMS interface) and targeted well testing (Fig 4)
- Nitrate source attribution using tracers of origin & pathway (Fig 5)
- Farmer survey of 300 growers (Fig 6)
- Strategic soil sampling and monitoring for nitrate and water distribution with depth (Fig 7)
- Watershed scale implications using periodic nested sampling of surface waters and modeling

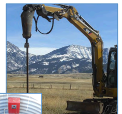
Methods



Soil sampling

Soil water sampling

Groundwater monitoring in existing wells



Groundwater sampling in driven point wells

Producer Research Advisory Group meeting, March 2012

Surface water sampling

Nitrate source attribution

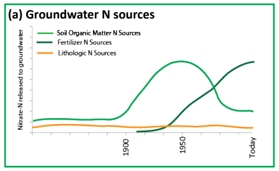
Candidate sources:

1. sedimentary rocks
2. soil organic matter
3. fertilizer

Hypothesis: Soil organic matter and fertilizer are the dominant sources of nitrate in groundwater and surface water.

Nitrogen Isotope Ratios ($\delta^{15}N$) will be used to discern among sources/pathways

- Air: 0‰
- Ammonium Fertilizer: -5 to +5‰
- Soil Organic Matter: +2 to +8‰
- Sedimentary Rock: +2 to 9‰
- Manure: +10 to +22‰



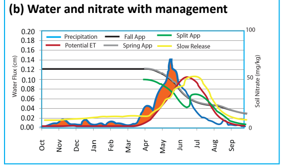


***Fig. 5** (a) Hypothesized trends in groundwater N sources with time; (b) seasonal water and nitrate trends: left axis reflects measured rainfall and estimated evapotranspiration (ET), right axis reflects estimated fertilizer nitrate release for four management practices*

Judith River Watershed: agricultural land management over shallow, unconfined aquifers

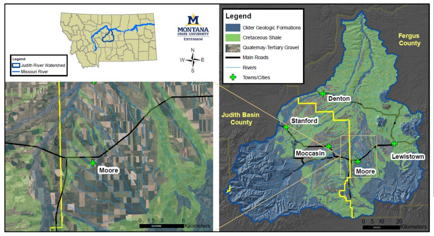


***Fig. 1 (a)** Judith River Watershed **(right)** with geologic units, topography, and aerial photography of the QT gravels showing dominant agricultural use; **(left)** alluvial fill near Moore.*

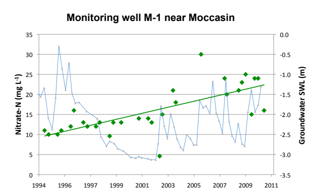


***Fig. 1 (b)** Rising nitrate-N concentrations (green symbols) in a monitoring well near Moccasin are largely independent of water level (blue line).*

A case study of human modification of the nitrogen cycle

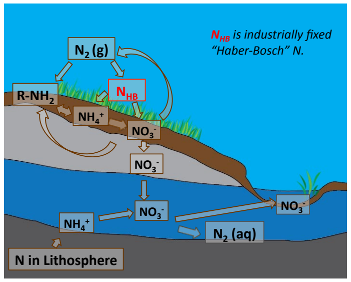
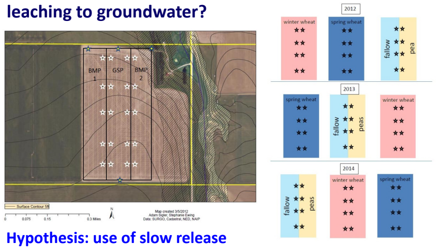


***Fig. 2** Globally, human alteration of the N cycle for food production adds at least 15 Tg N y^{-1} to groundwater (Puckett et al., 2011). Due to probable soil and groundwater residence times, the effect of this influx on downstream water quality will not be recognized for decades (Canfield et al., 2010).*

What farming practices are effective at reducing nitrate leaching to groundwater?



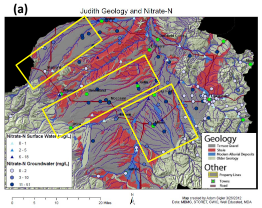
Hypothesis: use of slow release N and split N application will increase N use efficiency

***Fig. 3** Treatments will test management practices likely to reduce nitrate leaching and be adopted by growers*

Hypothesis: peas in rotation will take up water and require little or no N fertilization

Landforms and groundwater nitrate: Mountain front stream connection

Hypothesis: Shallow aquifers lacking mountain front stream connection will have higher nitrate concentrations due to recharge dominated by dispersed infiltration through soils.



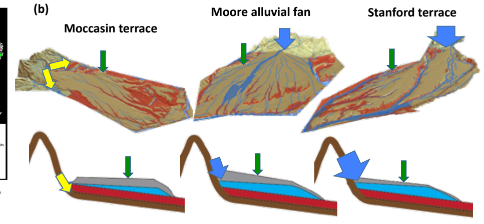


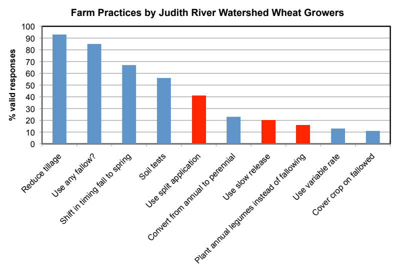
***Fig. 4 (a)** Location of landforms selected for study with associated nitrate-N concentrations in surface water and groundwater; **(b)** conceptual model of landform influence on shallow aquifers in the JRW.*

dispersed recharge to landform surface

flow that bypasses landform (to surface water or deep confined aquifer)

mountain front stream recharge to shallow aquifer

Preliminary survey results: Dryland wheat production in the Judith



Profile of Respondents

Manage any cropland	**69%**
Raise commodity	
Beef	**83%**
Sheep/goats	9%
Horses	23%
Other livestock	3%
Winter wheat	43%
Spring wheat	28%
Any wheat	**47%**
Other grains	28%
Forages	**78%**
Commodity providing most income last year	
Beef	57%
Cereals	25%
Hay	10%
Other	8%

***Fig. 6** Survey results for an adjusted sample size of 242 JRW growers and a response rate of 58.7%*

References

Bohlke, J. K. 2002. Groundwater recharge and agricultural contamination. Hydrogeology Journal. 10:153-179.
Canfield, D.E., Glazer, A.N., Falkowski, P.G. (2010), The evolution and future of the nitrogen cycle. *Science* 330, 192-196.
Holloway, J.M., R.A. Dahlgren. 2002. Nitrogen in rock: Occurances and biogeochemical implications. Global Biogeochemical Cycles. 16:4:1118.
MDA (2010), Montana Department of Agriculture (C. Schmidt and R. Mulder), Groundwater and Surface Water Monitoring for Pesticides and Nitrate in the Judith Basin, Central Montana.
Puckett, L.J., Tesoriero, A.J. and Dubrovsky N.M. (2011), Nitrogen contamination of surficial aquifers – a growing legacy. *Env. Sci. Tech* 45, 839-844.

Acknowledgements

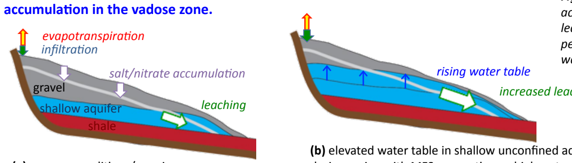
Judith Project Advisory Council
Judith Project Producer Research Advisory Group
Christine Miller (MS student, MSU)
Ann Armstrong (PhD student, USU)

Funding

USDA/NIFA NIWQP
Montana State University College of Agriculture/MAES

Unsaturated zone thickness: characteristic salt (nitrate) distribution

Hypothesis: Landform positions with greater depth to perched aquifer exhibit less frequent nitrate delivery to groundwater and greater nitrate accumulation in the vadose zone.



(a) average conditions/growing season

(b) elevated water table in shallow unconfined aquifer during spring with MFS connection or high water year

***Fig. 7** Salt accumulation and leaching with periodic rise in water table*

Expected outcomes

1. **Nitrate sources**: Lithologic sources << soil organic matter and fertilizer
2. **Landform hydrologic connection**: MFS recharge aquifers have better mixing, shorter residence times, water levels driven by mountain snowmelt timing and lower nitrate
3. **Landform geometry**: A thicker unsaturated zone leads to less nitrate delivery to groundwater
4. **Landfrom age**: Soil texture and structure will influence solute leaching/accumulation rates; cement gravels (opal and other pedogenic salts) result in perched vulnerable aquifers
5. **Fertilizer timing**: Slow release & split application → reduced nitrate leaching
6. **Crop rotation**: Peas rather than fallowing → reduced nitrate leaching