

US EPA ARCHIVE DOCUMENT

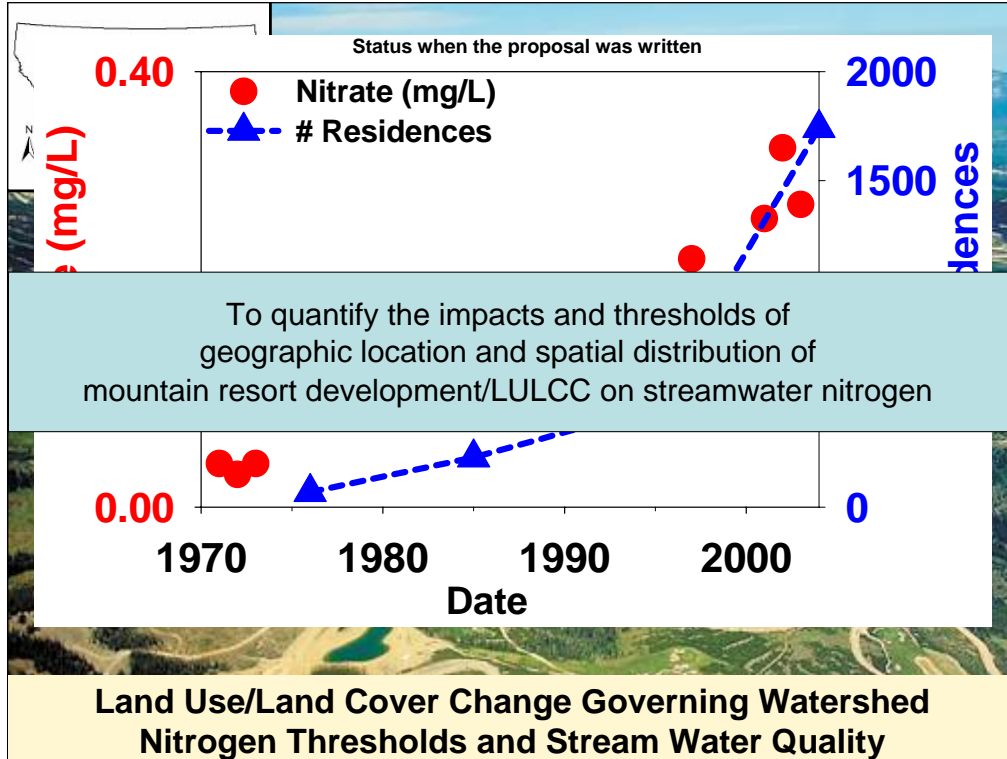
## Land Use/Land Cover Change Thresholds Governing Watershed Stream Water Quality



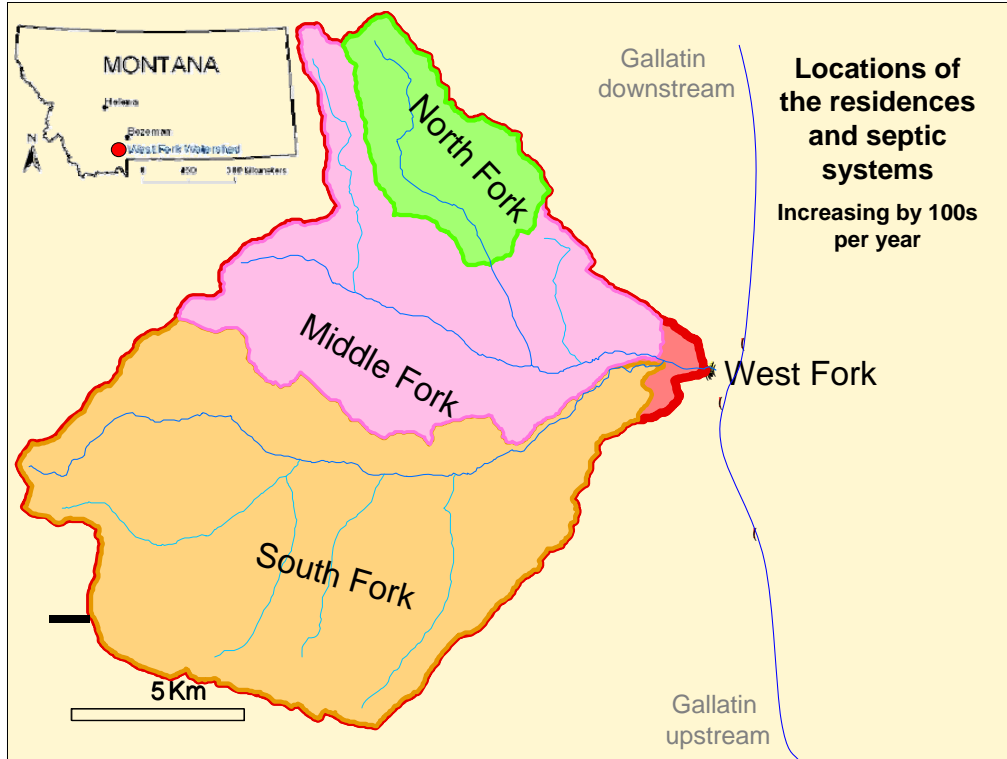
### Research Team

**Brian McGlynn, PI**  
**Kristin Gardner, PhD student and co-PI**

**Duncan Patten, co-PI**  
**Jamie Shanley, collaborator - USGS**  
**Natalie Campos, MS**  
**Rebecca McNamara, MS**  
**Rick Lawrence, collaborator Remote Sensing**



The study site is the Big Sky watershed, which is the west fork of the Gallatin River in southwest Montana. The watershed measures 200 square kilometers. Until the mid-1970s, the land was undeveloped. A dramatic shift in background nitrate concentration coincided with the building of a number of houses.



There is significant clustering of houses (and their corresponding septic systems) to the left of the red area and in the lower left-hand corner of the Middle Fork. Several ski resorts, four golf courses, and approximately 2,000 houses have been built in the latter area. Thousands more houses (3,000 to 5,000) are slated to be built in the coming years.

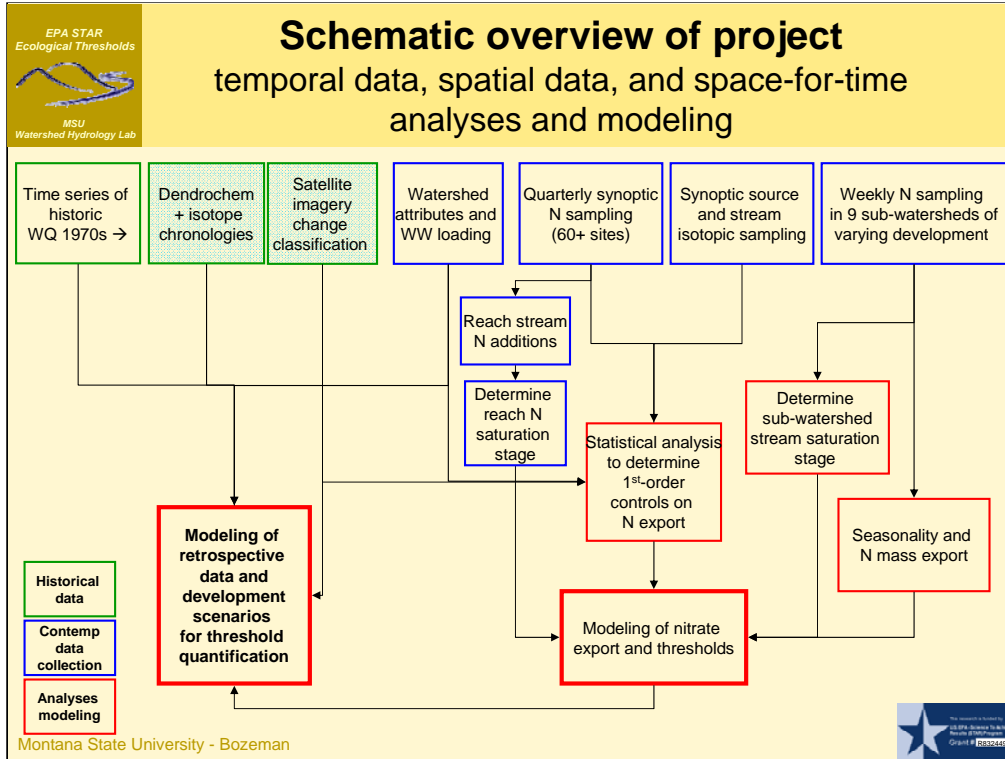
## What is the ecological significance of the particular thresholds you are investigating?

- ◆ Water quality – stream nutrient status
  - Increased nitrate levels in surface waters lead to:
    - ◆ compromised aquatic macroinvertebrate community composition,
    - ◆ algal blooms, and eutrophication.
    - ◆ such changes in the base of the food chain carry forward further alteration of the trophic structure of the stream ecosystem
  - Downstream impacts – nutrient loading
  - World renowned trout fishery
  - Aesthetic values
  - Recreation

# Objectives

1. Assess the spatial variability of nitrogen status across the West Fork drainage sub-watersheds.
2. Determine the relationship between LULC and watershed characteristics (e.g. soils, vegetation, geology, riparian features, topography, topology, and hydrological flow paths) and stream  $\text{NO}_3^-$  concentration.
3. Combine LULC, watershed characteristics, and both historic and contemporary streamwater N concentrations to assess and model contemporary and historical nitrogen thresholds and saturation status in a mountainous watershed.

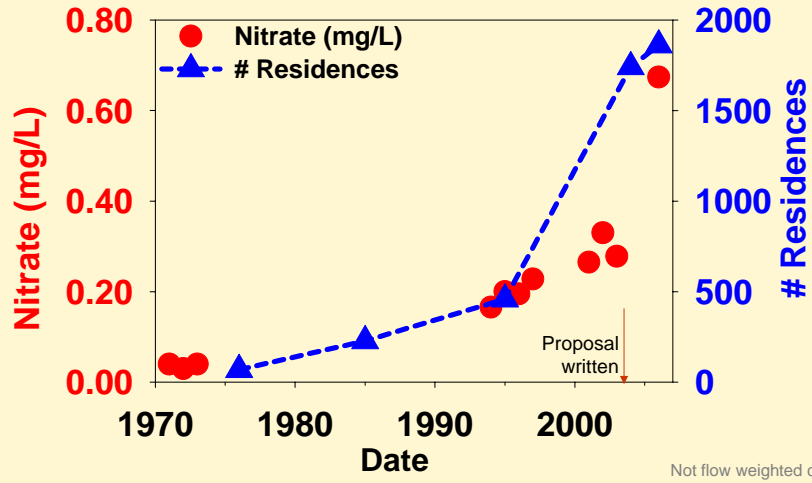
**Examine water quality time series and snapshots to determine whether nitrogen thresholds have been crossed, and if so, determine the spatial and temporal dynamics of land use/land cover which drove the ecosystem to cross these thresholds.**



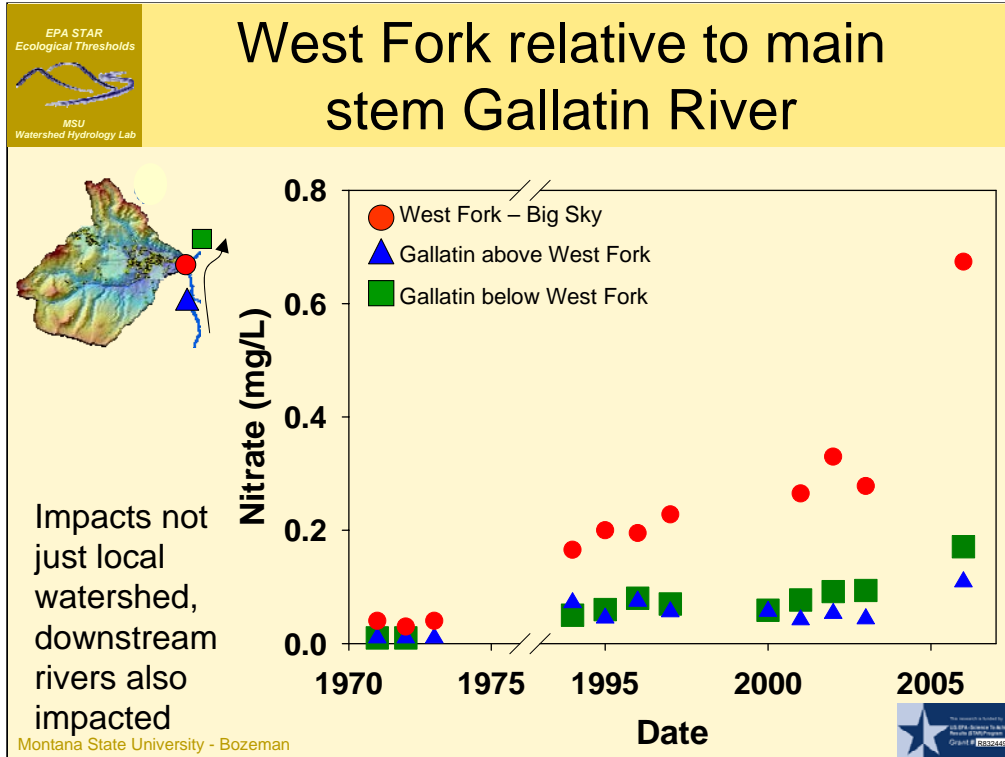
# Outlook

Average annual concentrations ~2x higher today than in 2003

Next 3-5 years number of houses could more than double...  
potentially 5000+ residences

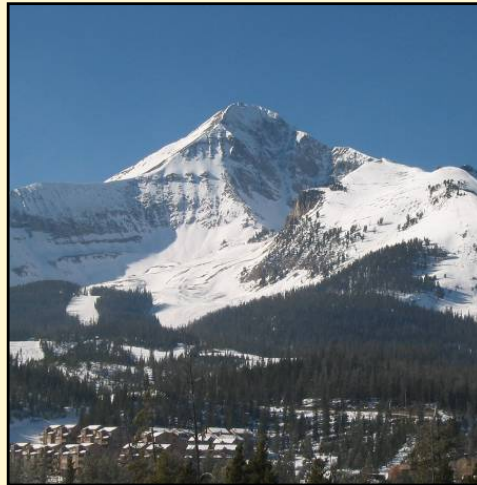






# Hydrology

- ◆ Precipitation:  
500 mm/yr in lower elevations to 1300+ mm/yr in higher elevations.
- ◆ Snowmelt dominated system:  
Peak flows in late May/June.
- ◆ West Fork Watershed ~207 km<sup>2</sup>





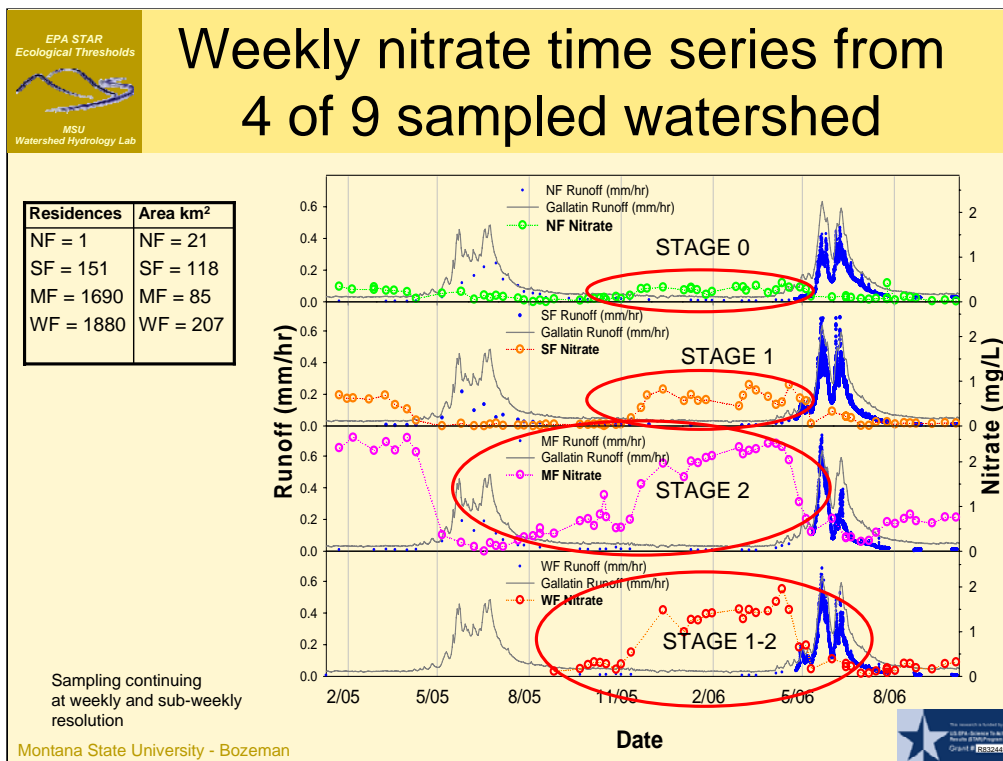
# N saturation

Documented shifts in states in stream ecosystems (Aber et al., 1989)

Stage	Characteristics
State 0	Very low/immeasurable $\text{NO}_3^-$ concentrations during most of the year. Measurable concentrations during snowmelt.
Stage 1	Seasonal pattern typical of Stage 0 watershed is amplified. Delay in onset of N limitation.
Stage 2	Episodic $\text{NO}_3^-$ concentrations as high as Stage 1. Elevated baseflow $\text{NO}_3^-$ concentrations resulting in dampening of seasonal pattern.
Stage 3	Watershed net source of $\text{NO}_3^-$ resulting in extremely high $\text{NO}_3^-$ concentrations. Lack of any coherent seasonal pattern in $\text{NO}_3^-$ .

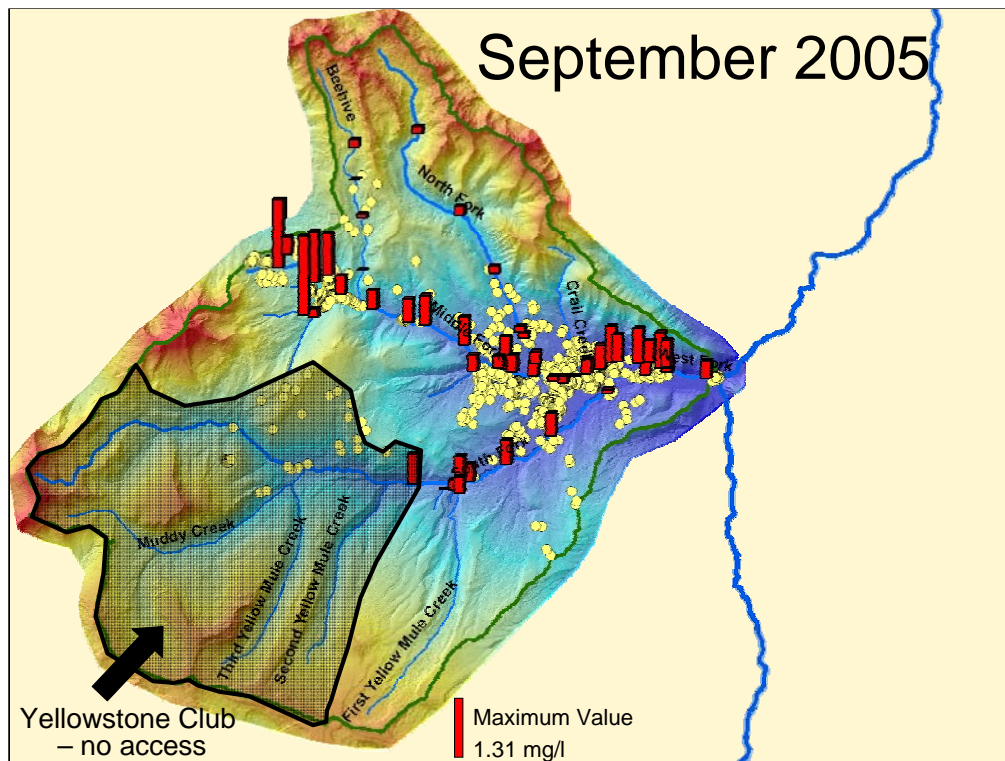
***We propose that localized nitrogen inputs can result in heterogeneous nitrogen saturation (flowpath saturation) across the watershed and result in temporal patterns and export dynamics similar to observation from atmospheric deposition of N***





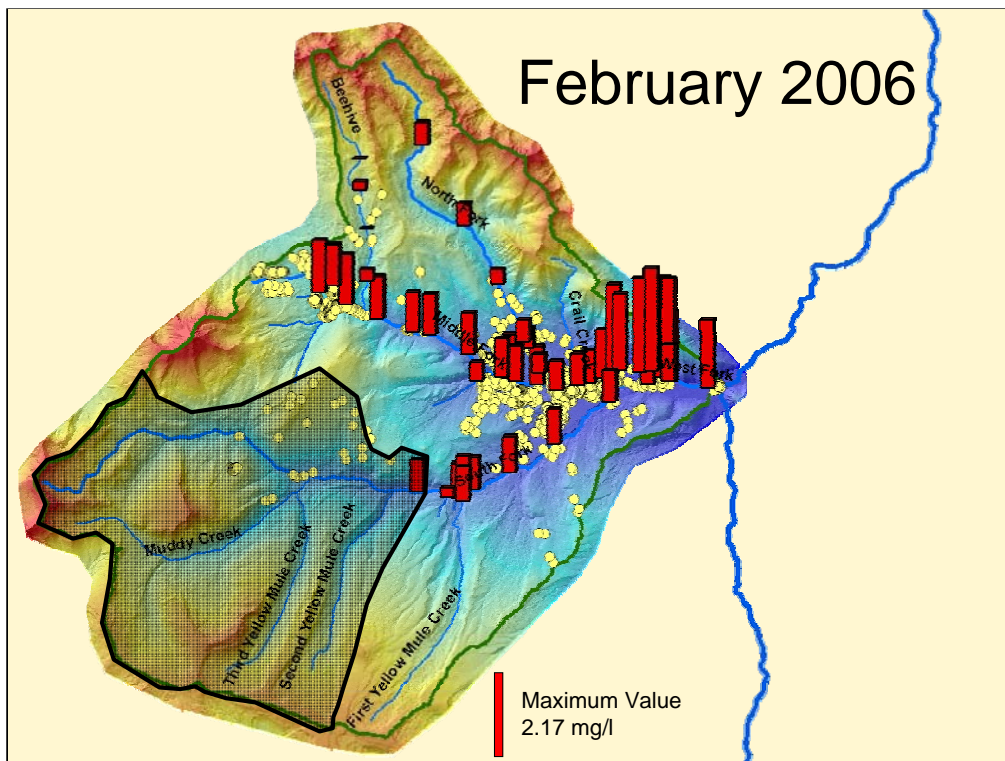
The first graph represents the North Fork (less developed), the second the South Fork (150 houses, development has occurred during the past 5 to 7 years), and the third the Middle Fork. The last graph represents all three watersheds combined. The building of 2,000 houses in 200 square kilometers has had a major effect on these watersheds.

The peak time of the year for exporting nitrate is in the winter. The summer export is a function of development.

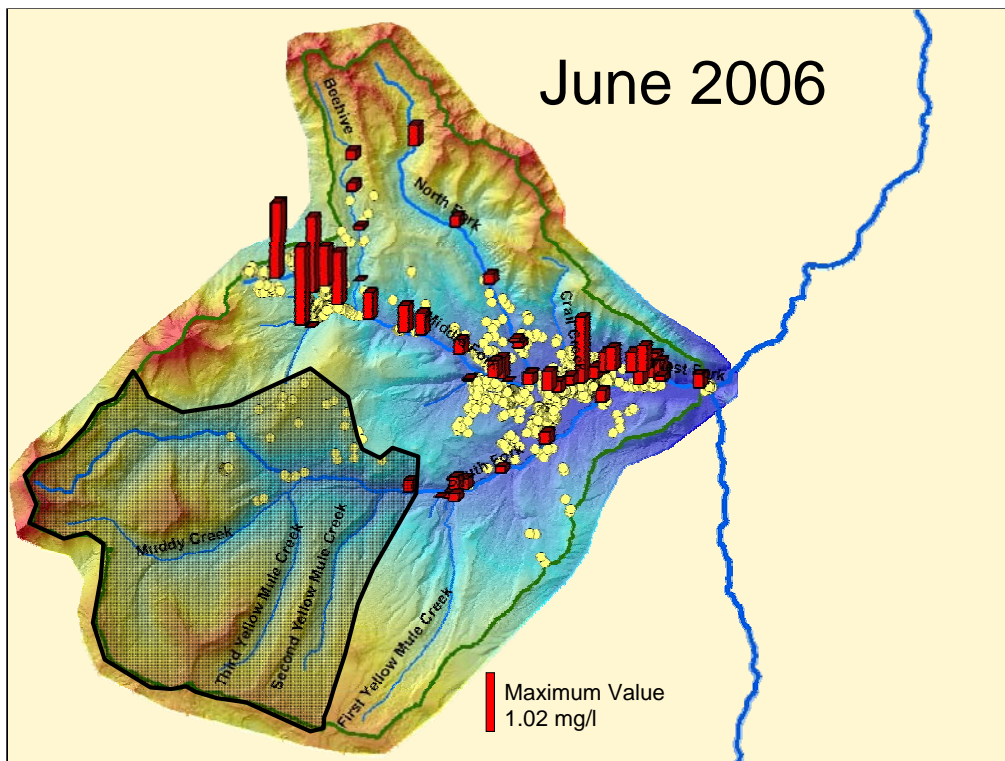


How much do development details matter? Is the number of houses the most important factor, or are other related factors—such as where the houses are located—important?

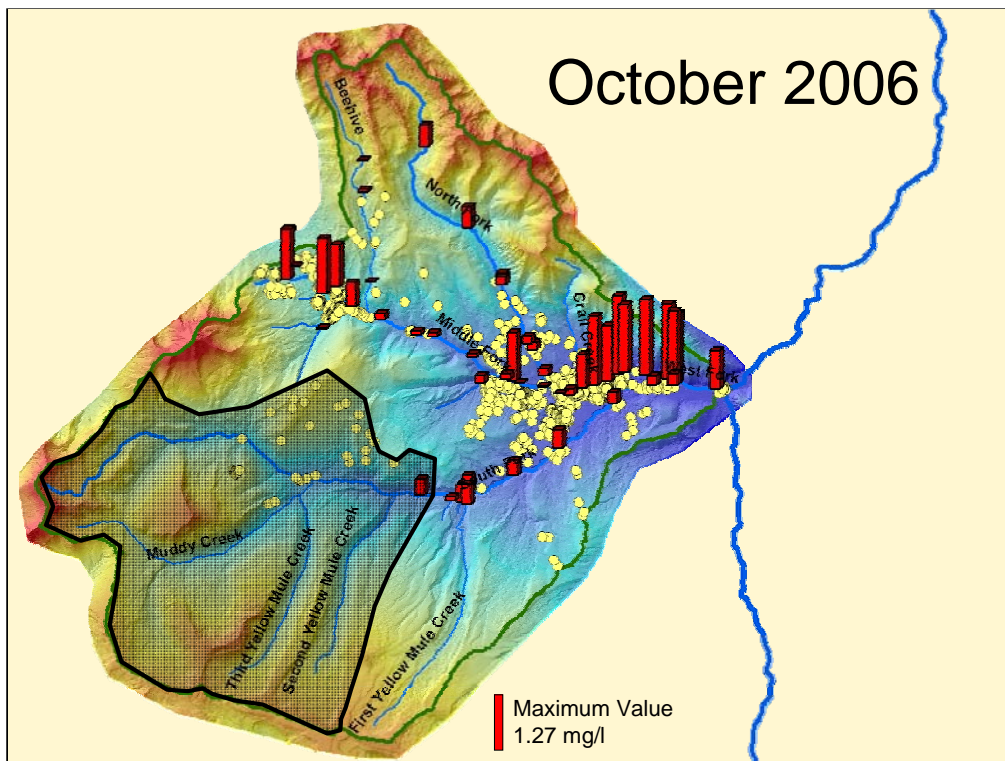
Yellow represents the septic system locations. The red bars represent the nitrate concentrations.



This graph shows that nitrate levels across the board are elevated in the winter.

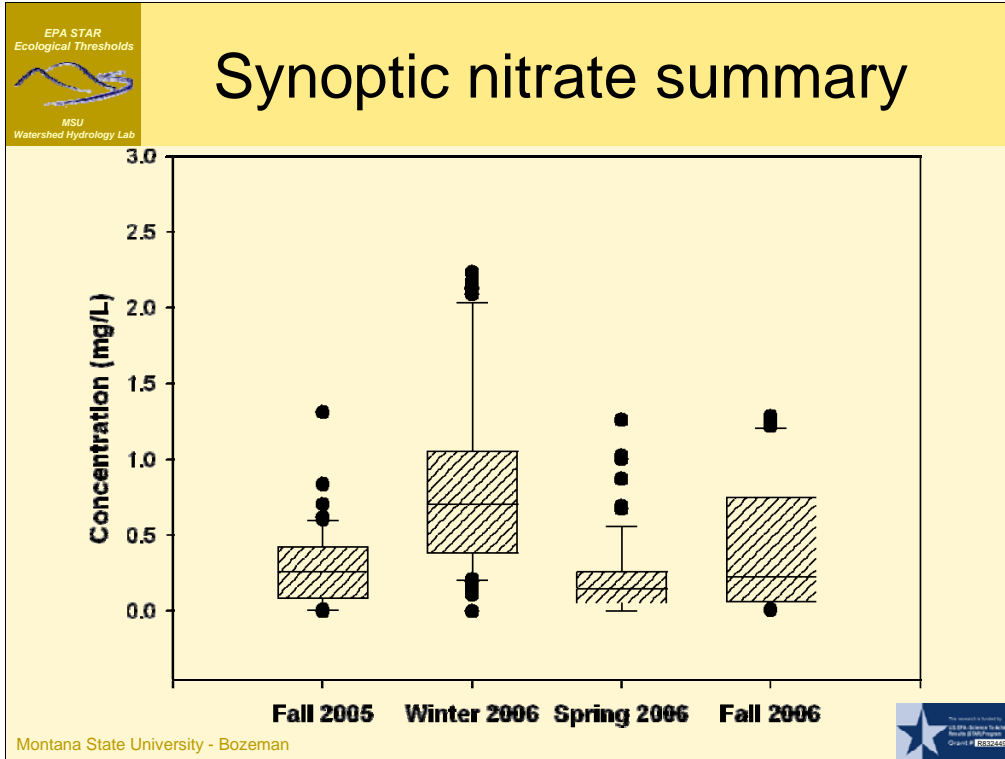


The nitrate levels then return to levels similar to those seen in September 2005.

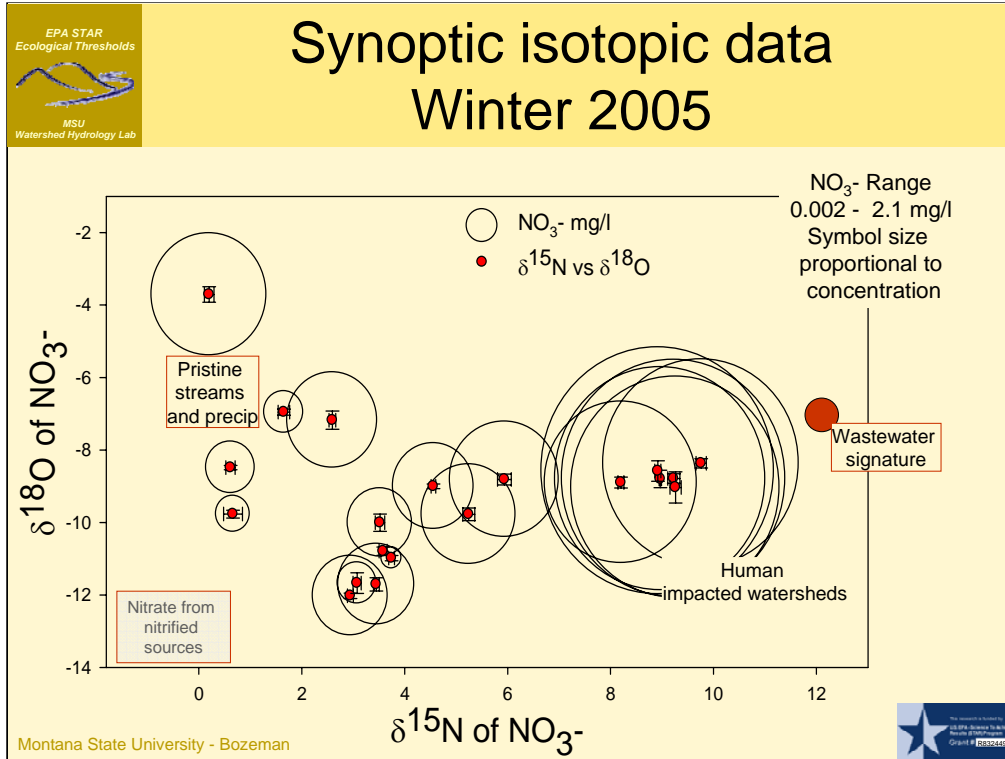


Researchers often treat water quality as a static variable. These data show that water quality changes with the seasons.





This is another representation of the nitrate levels by season.



The streams that fall in the region near the wastewater <sup>15</sup>N signal also have the highest concentrations of nitrate.





## Preliminary regression results for seasonal synoptic sampling

- ◆ This is a first step – exploratory analysis!
- ◆ Based on >55 locations at 5 points in time
- ◆ Multiple stepwise linear regression
  - Variables included:
    - ◆ slope, stream order, watershed size, watershed elevation, riparian buffering potential, # septic systems, weighted septic systems (TT, Dist, Grad.), wastewater input, forest cover, geology, and aspect.

EPA STAR  
Ecological Thresholds

MSU  
Watershed Hydrology Lab

## Seasonal Controls on Streamwater Nitrate

Spring 2006	Late Fall 2006
<ul style="list-style-type: none"><li>◆ Elevation</li><li>◆ #Septics weighted by travel time</li><li>◆ Stream Order</li><li>◆ Riparian/Hillslope Ratio</li></ul>	<ul style="list-style-type: none"><li>◆ #Septics weighted by travel time</li><li>◆ Wastewater Input</li><li>◆ Elevation</li></ul>
	

Montana State University - Bozeman

The University of Montana  
The Montana State University  
Bozeman, Montana 59717-3100  
Phone: (406) 243-2444  
Fax: (406) 243-2445

These are the explanatory variables, listed in order of importance.

EPA STAR  
Ecological Thresholds

MSU  
Watershed Hydrology Lab

## Seasonal Controls on Streamwater Nitrate

Early Fall 2005	Winter 2006
<ul style="list-style-type: none"><li>◆ Stream Order</li><li>◆ Riparian/Hillslope Ratio</li><li>◆ #Septics weighted by travel time</li><li>◆ Wastewater Input</li></ul>	<ul style="list-style-type: none"><li>◆ #Septics</li><li>◆ Wastewater Input</li><li>◆ Elevation</li></ul>
 <p>Montana State University - Bozeman</p>	

These are the explanatory variables, listed in order of importance.




## Seasonal Controls on Streamwater Nitrate

Season	Explanatory Variables	Adj R <sup>2</sup>
Early Fall	Stream Order, Riparian/Hillslope Ratio, #Septics weighted by travel time, and Wastewater Input	0.22
Winter	# Septics, Wastewater Input, and Elevation	0.92
Late Spring	Elevation, #Septics weighted by travel time, Stream Order, and Riparian Hillslope Ratio	0.57
Late Fall	#Septics weighted by travel time, Wastewater Input, and Elevation	0.69

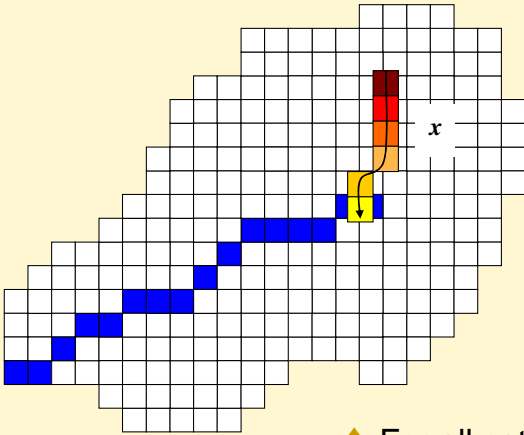
Montana State University - Bozeman





**Integration of flowpath lengths and gradients  
- terrain analysis -**

## Travel Time estimation

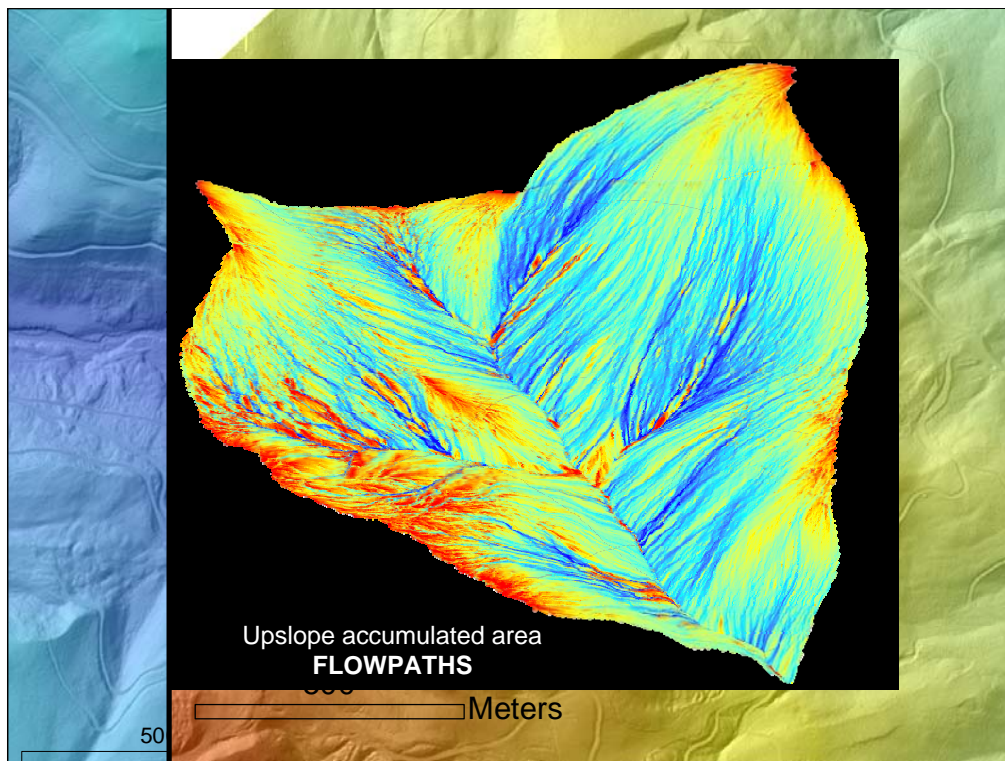


◆ For all catchment grid cells:

- Flowpath distance to stream network
- divided by the flowpath gradient

Montana State University - Bozeman Schematic courtesy of Kevin McGuire

The blue squares represent the stream, and the red squares represent the wastewater input. The time it takes for the nitrogen to reach the stream and the distance traveled both affect the impact that the nitrogen has on water quality.



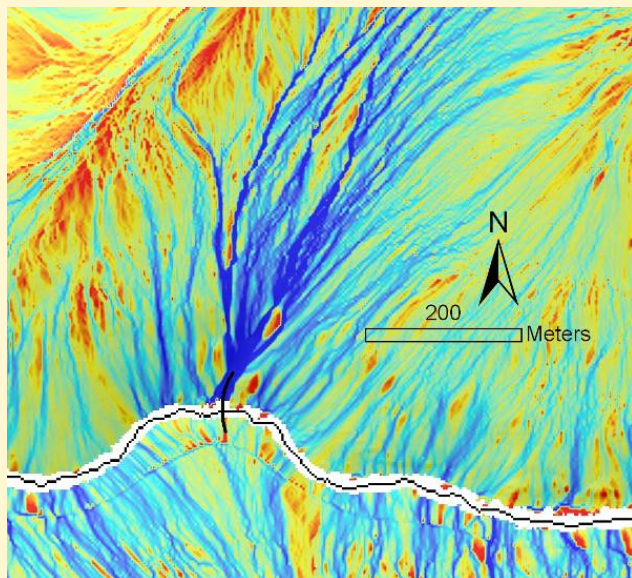
Topography is used as a surrogate for hydrology.

These maps are used to determine upslope accumulated area and flowpath. Flowpath is particularly important. The researchers start at the septic system and determine where the flow meets the stream channel, the amount of water along the flowpath, the distance traveled, and the gradient.





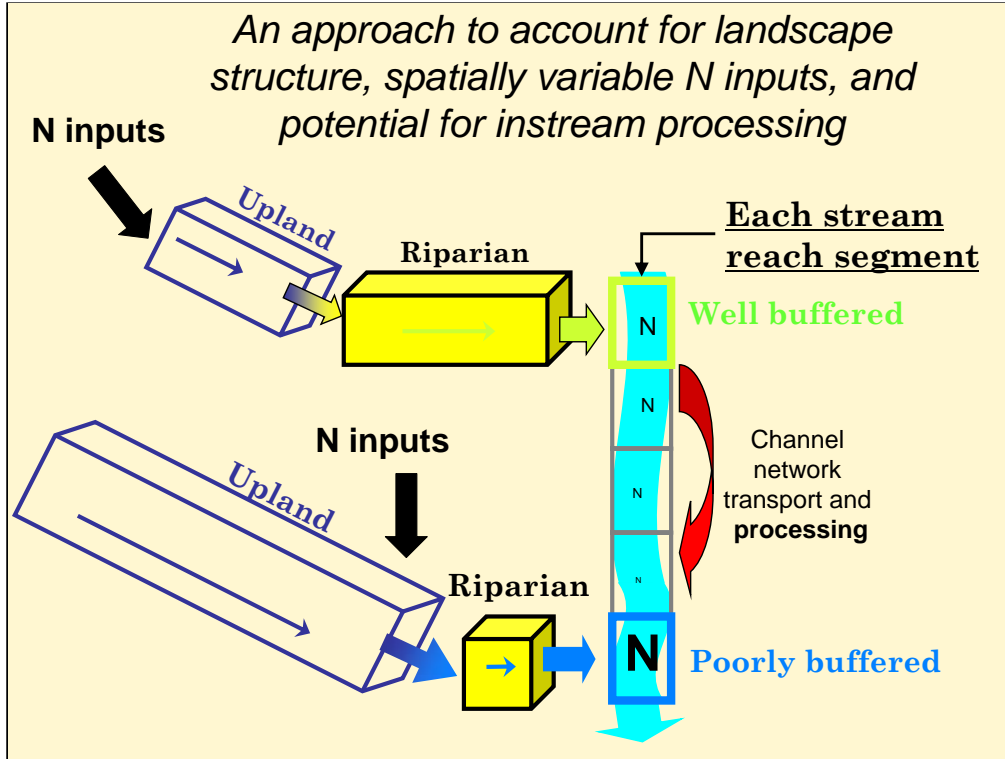
## Mapping of riparian area and buffering potential along the stream network



Montana State University - Bozeman

- ◆ Threshold elevation above stream following flowpaths to the stream
- ◆ Can be applied to large catchments that cannot be mapped in person
- ◆ When combined with upland flowpaths provide distributed measures of riparian buffering potential





An approach to account for landscape structure, spatially variable N inputs, and potential for instream processing

$$NE_m = \left( \sum_{i=1}^n LULC_i * E_i + (S_i * s) + (W_i * w) \right) (TWF * RBI) + \left( NE_{m-1} \right) \exp^{-\frac{K_L X}{Q^{0.5}}}$$

Stream reach N                      Upland N Loading                      Downslope conditions                      Instream processing

**NE** is the watershed nitrogen export at sample point m.

**LULC<sub>i</sub>** is the land use/ land cover in grid cell *i*

**E<sub>i</sub>** Export coefficient for **LULC<sub>i</sub>**

**S** is the number of septic systems in the grid cell *i*, **s** is the septic N load.

**W** is a wastewater coefficient (1 if distributed on land) and **w** is the wastewater N load

**TWF<sub>i</sub>** is a topographic weighting factor of grid cell *i* and is a scaled combination of the TT index (**TTI**) and Topographical index (**TI**).

**RBI** is a riparian buffer index (a function of upgradient slope, riparian width)

**NE<sub>m-1</sub>** is the NO<sub>3</sub>- concentration of the upstream sampling point that will decay exponentially as a function of distance (*X*) and the uptake rate, (*K<sub>L</sub>*) and is a function of stream size (specifically stream discharge *Q*<sup>0.5</sup>)



## Any surprising results or "lessons learned" related to your work to date?

- ◆ Clarity of wastewater signal in isotopic measurements
- ◆ Stage 2 watershed N behavior in 85 km<sup>2</sup> basin and ~ stage 2 in 200 km<sup>2</sup> basin
- ◆ Magnitude of concentrations despite significant dilution in system
- ◆ Seasonality of explanatory variables – incorporating biological component into modeling approach even more important than anticipated
  - Spatial concentration pattern shift from Winter to Summer to Fall
  - Upland and instream immobilization
- ◆ Rapidity of development – number houses doubling in next 3-5 years

Spin-off ideas or possible collaborations: More process based research to fill in science gaps





## How might your results be used to better manage for resilient ecosystems and to avoid threshold exceedances or regime shifts.

- ◆ Quantify the impact of spatial location of LULCC and wastewater loading driving the ecosystem to leak increased N to the stream
- ◆ Integrate analysis of spatial and temporal thresholds
- ◆ Identify first-order controls on temporal (seasonal) and spatial patterns of N export
- ◆ Inform TMDL process – seasonality, thresholds, N saturation status of watersheds and streams, integrate stream and watershed analysis and relative roles in processing wastewater N
- ◆ **Generate loading sensitivity planning tools and guide monitoring programs to detect early signs of regime shift and minimize impacts of LULC change**



## Have you received any inquiries about your work from others in the scientific community, or from resource managers, or the private sector?

### Stream ecologists –

- Stream N saturation,
- Aquatic-terrestrial linkages and network behavior
- N vs P limitation in impacted streams and changes with season
- Seasonality of N assimilation in uplands and streams
- Aquatic macro invertebrate impacts

### Process watershed hydrology and biogeochemistry –

- Follow up proposals investigate areas of poor understanding relative to hydrological and biogeochemical processes and seasonality in uplands (flushing and residence time) and streams (uptake as a function of concentration perturbation)

### Remote Sensing –

- New applications and analysis techniques for integration of ALSM, Quickbird, and Landsat for contemporary and retrospective analysis

### Resource/Community Managers –

- Montana DEQ – TMDL development and water resource assessment
- Blue water task force – grassroots water quality group instrumental in our work
- Big Sky community – actively involved from data collection to small funding the Bluewater Task Force with resort tax

This initial work has led to a great number of follow-up research possibilities and potential collaborations from the local to international level

Montana State University - Bozeman





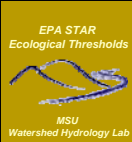
## Summary of work in progress

### Integrated approach

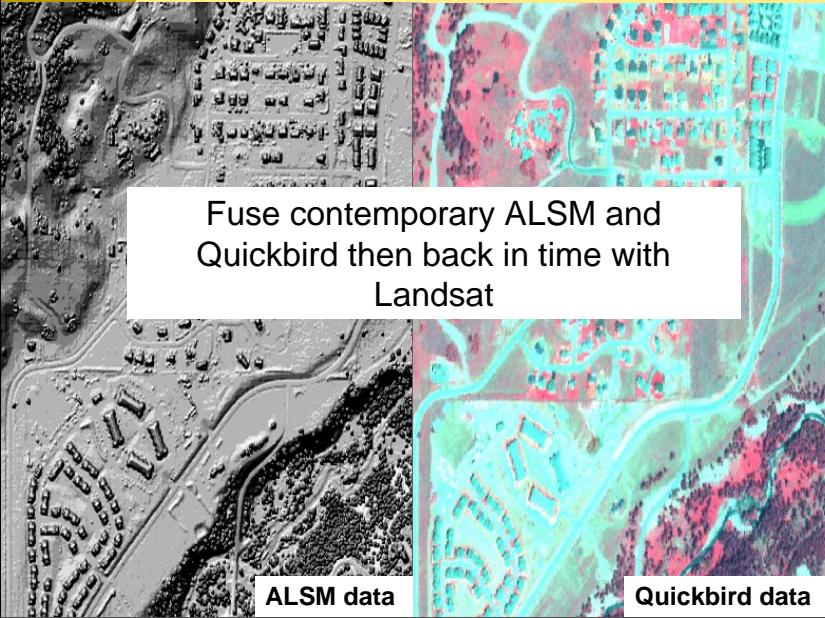
retrospective and future scenario water quality modeling

Documenting the range of land use/land cover and hydrologic impacts beyond which ecological resilience of nitrogen cycling in the West Fork subwatersheds is compromised.

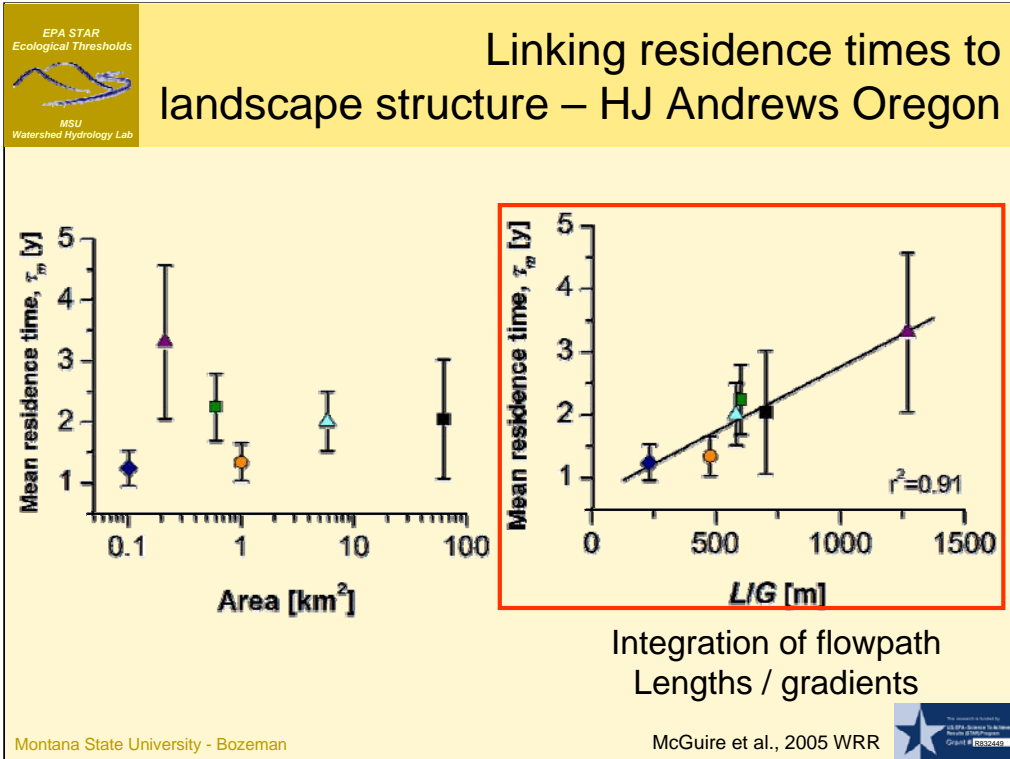




# Remote sensing - LULC







The slide features a yellow background with the title "Discussion" in bold black text at the top center. In the top left corner, there is a logo for "EPA STAR Ecological Thresholds" with a blue wave graphic and "MSU Watershed Hydrology Lab" text below it. In the bottom left corner, it says "Montana State University - Bozeman". In the bottom right corner, there is a blue star logo with the text "The National Science Foundation" and "Grant # 0532449".

A participant asked if there is a watershed management group in the area. If so, are they working on a watershed plan? Dr. McGlynn responded that the Blue Water Task Force is the watershed group for the area. The group currently is not developing a plan, but it is monitoring the water. Dr. McGlynn pointed out that much of the data he presented are new.

Another participant commented that the researchers should be able to predict the amount of nitrate coming from the septic systems based on the population in the area. Dr. McGlynn explained that he and his colleagues do not yet have a full year of data on distribution, nutrient loading from septic systems, the amount of wastewater treatment plants are receiving and producing, and the nitrate concentration of the water used on golf courses. These data will allow for further analysis.