Green County: Groundwater 101

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UW Extension
University of Wisconsin-Extension

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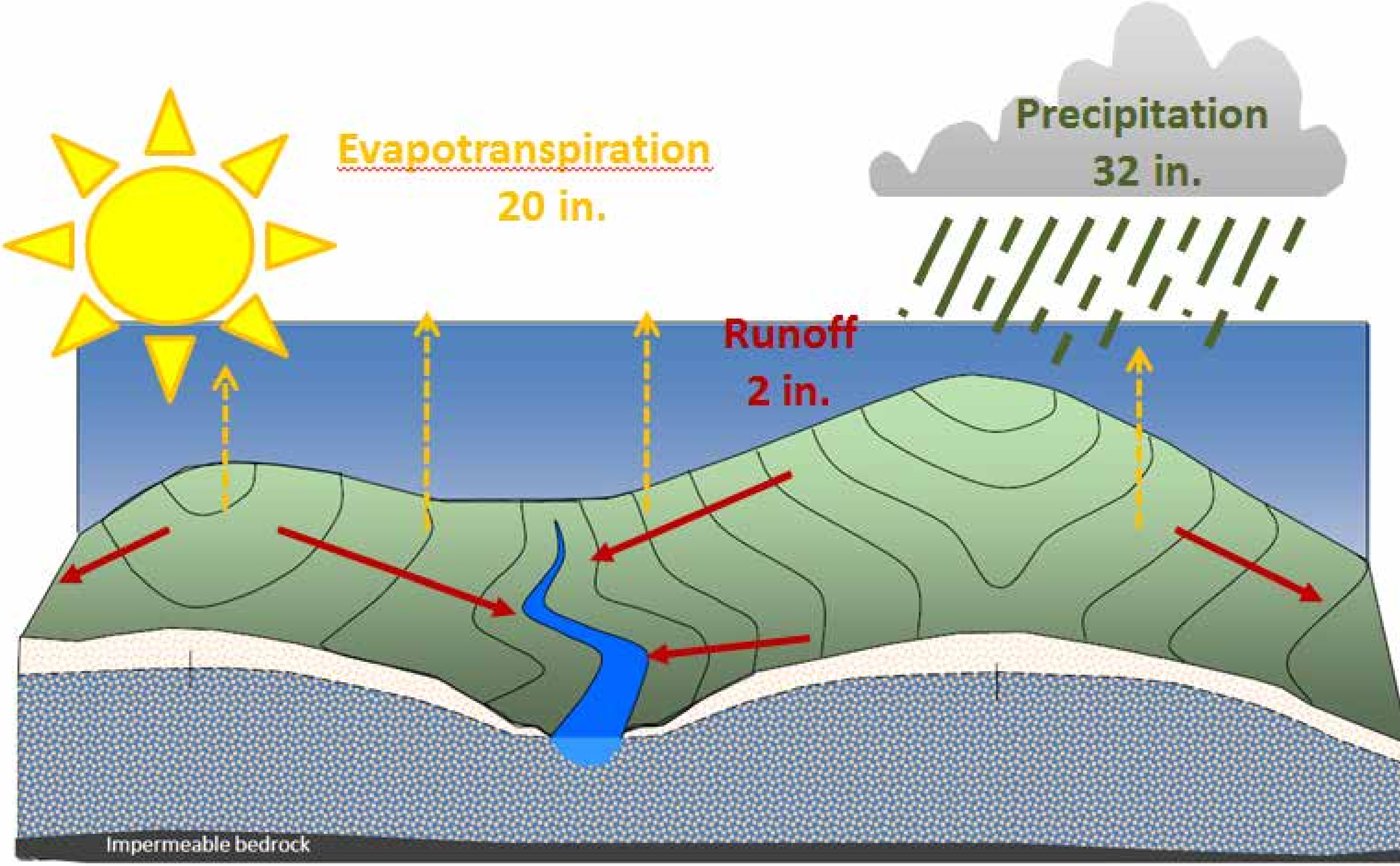
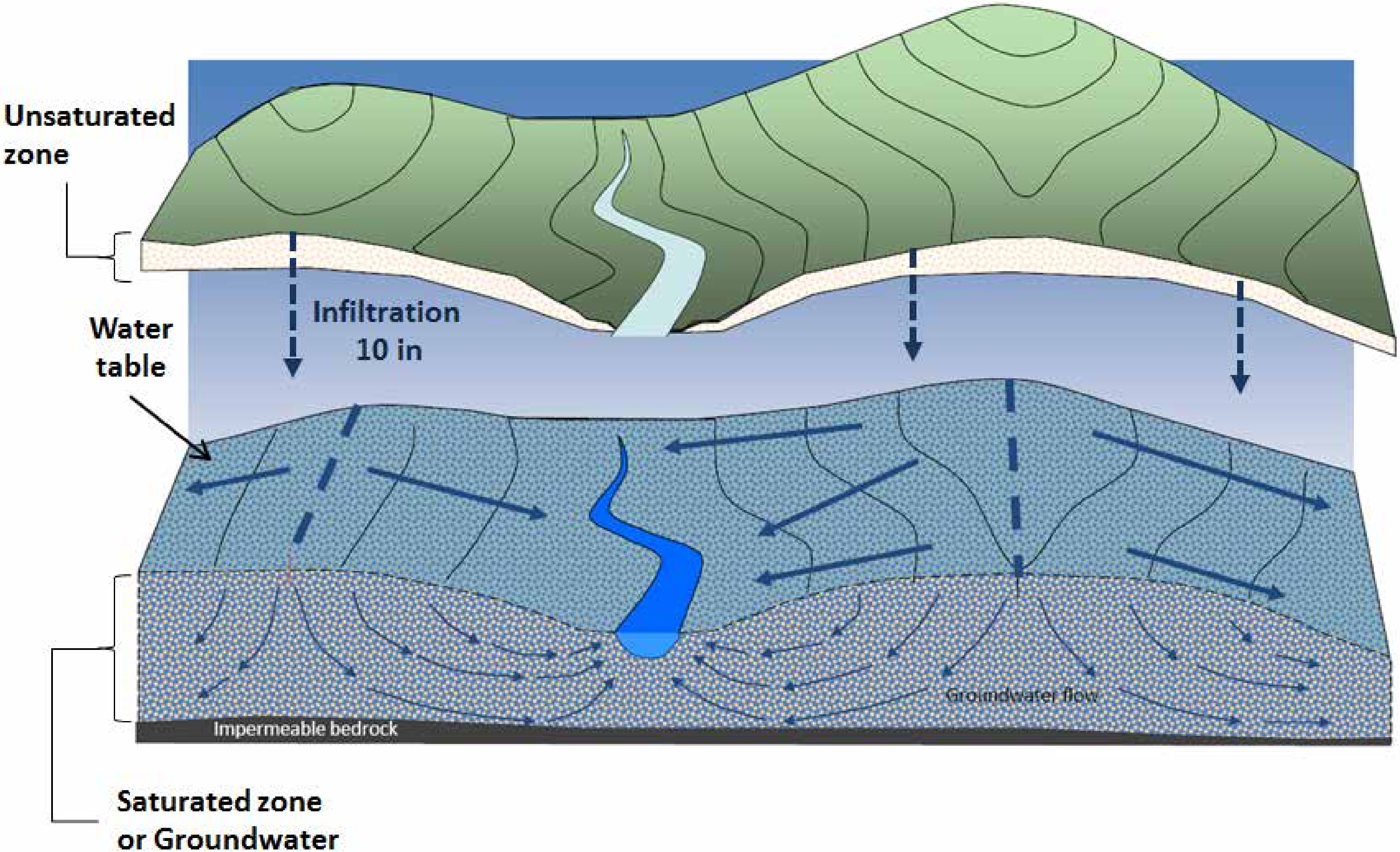
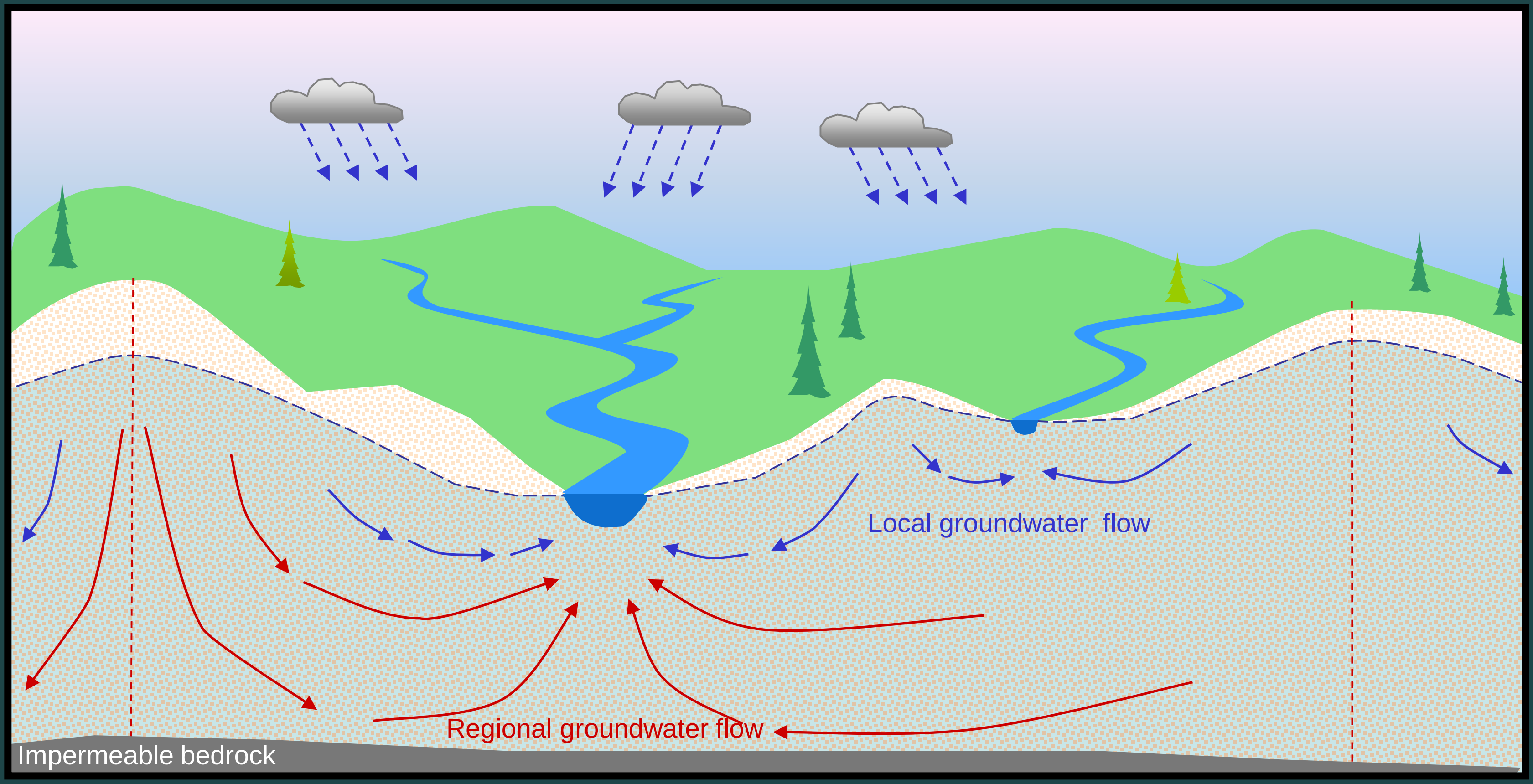
Overview

- Introduction to groundwater
  - Water cycle, aquifers, watersheds
- Groundwater Quantity
- Groundwater Quality
  - Bacteria
  - Nitrate
- Nitrate and Groundwater
- Question/Answer


Evapotranspiration
20 in.
Precipitation
32 in.
Runoff
2 in.
Impermeable bedrock


Unsaturated zone
Infiltration 10 in
Water table
Groundwater flow
Impermeable bedrock
Saturated zone or Groundwater

What happens when we have more rain?



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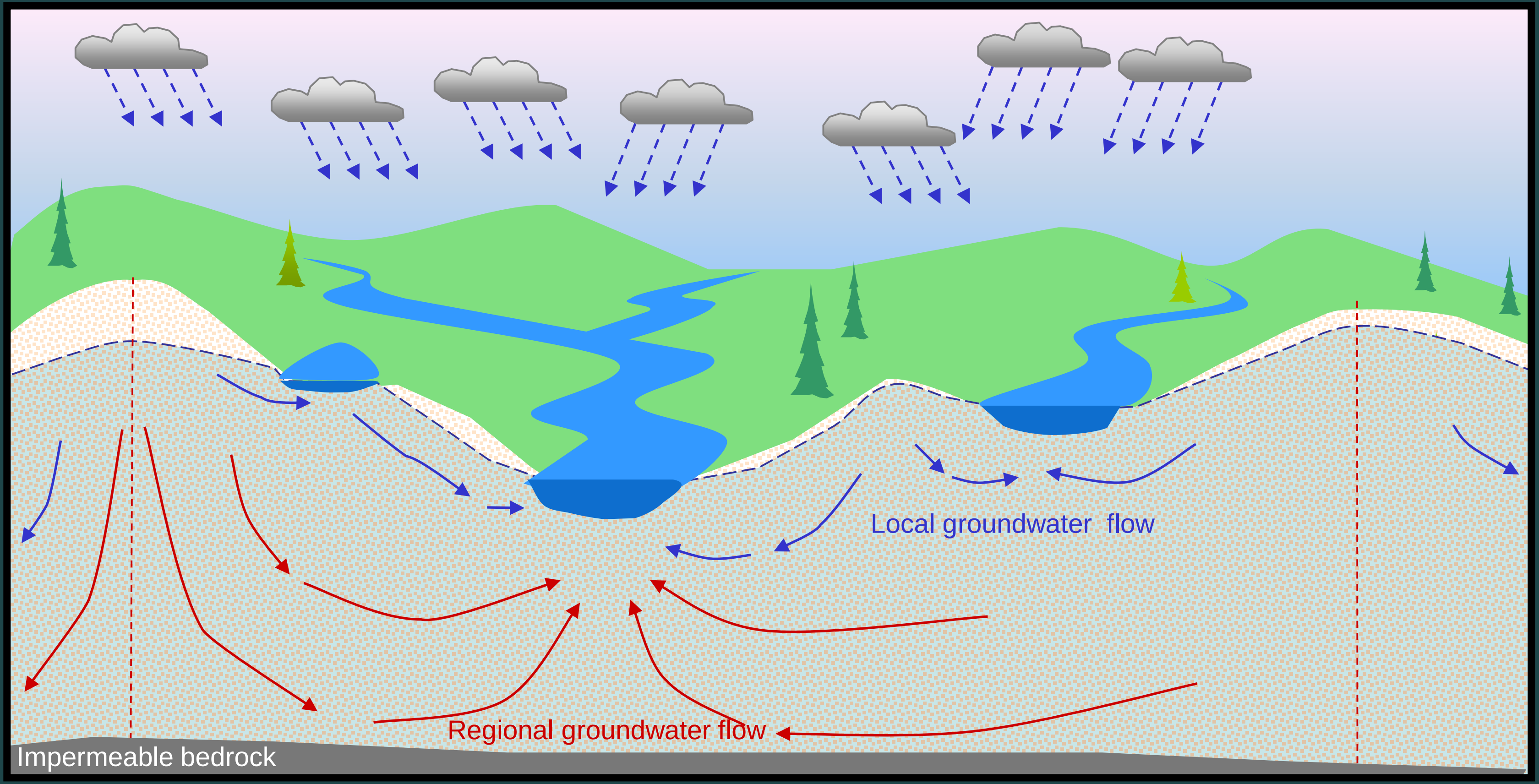
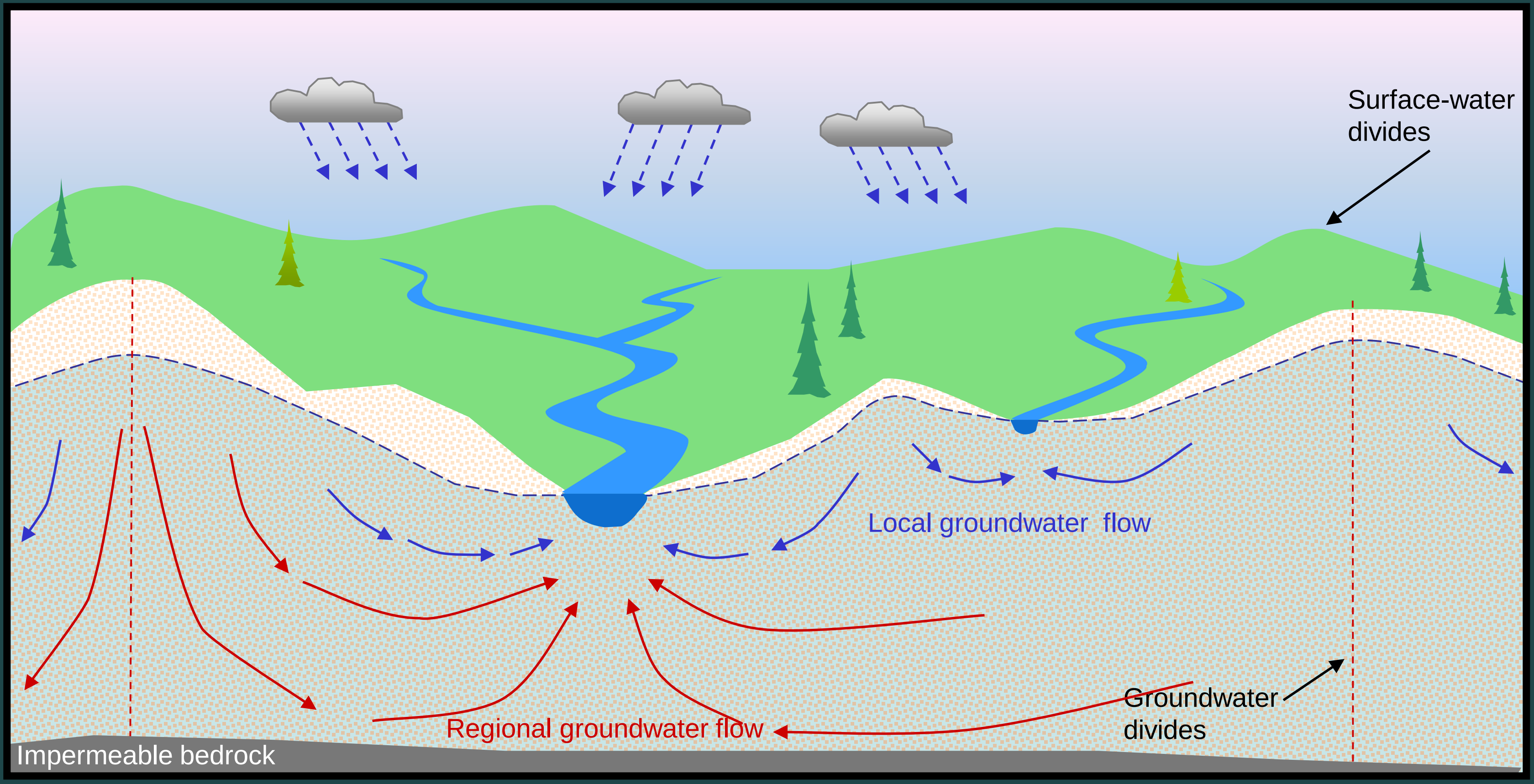
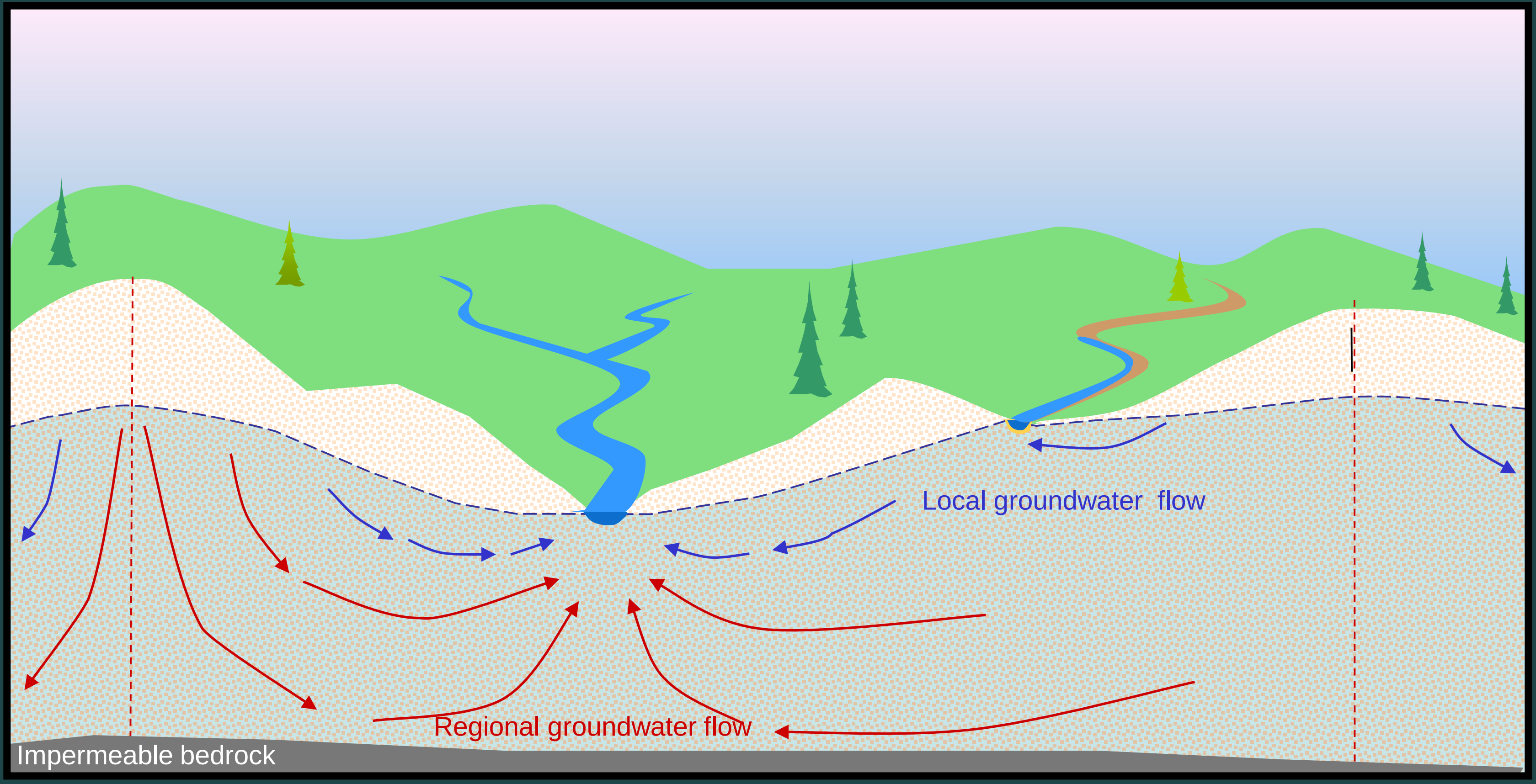


- More infiltration
- Groundwater levels rise
- More water in rivers, lakes and streams

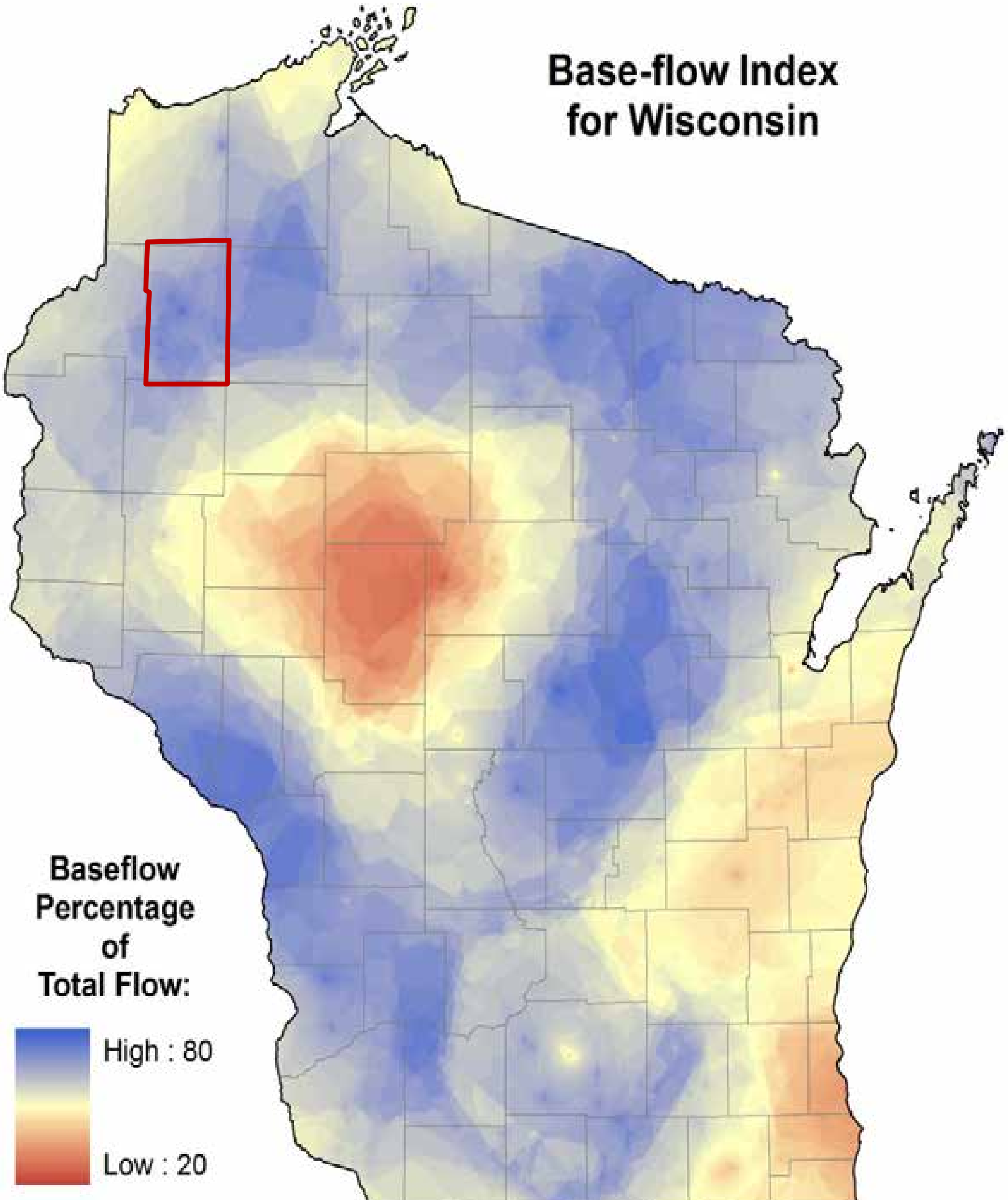
What happens when we have less rain?

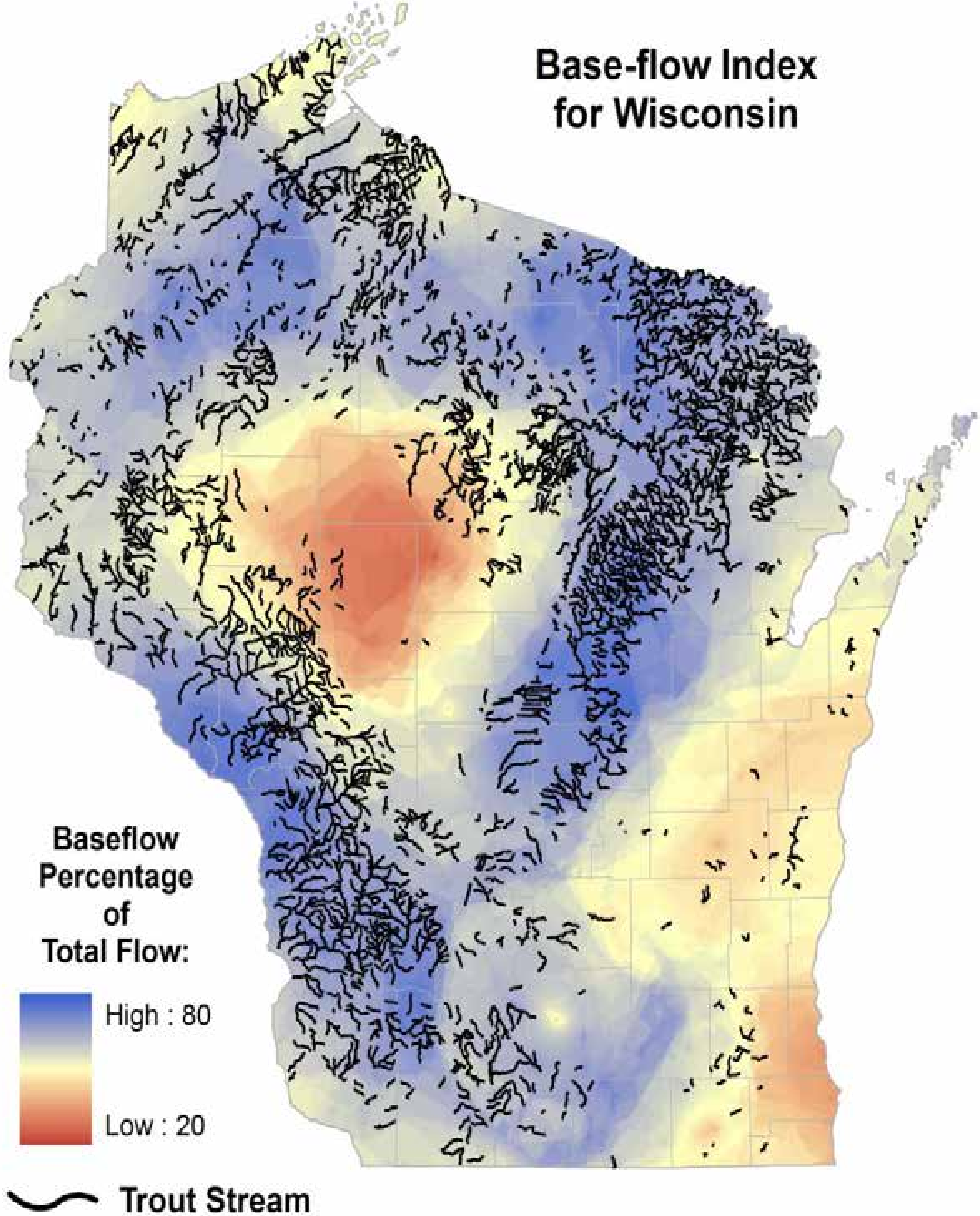


What happens when we have less rain?



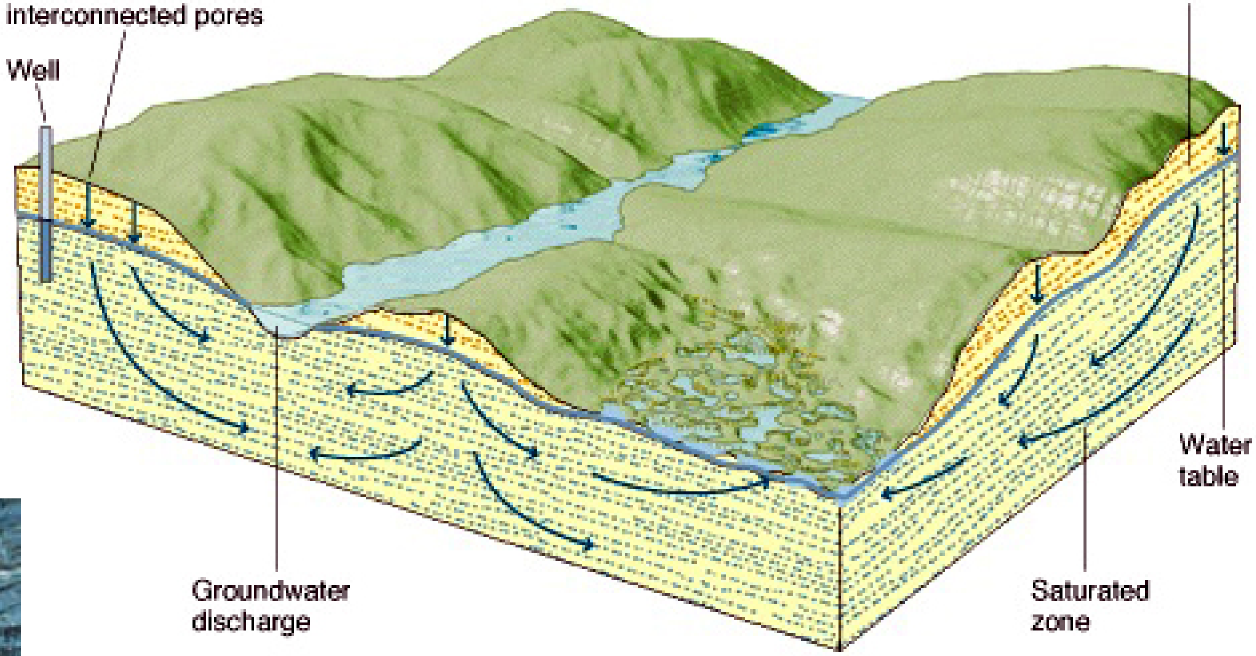
- Less infiltration
- Groundwater levels start to go down
- Less water in rivers, lakes and streams

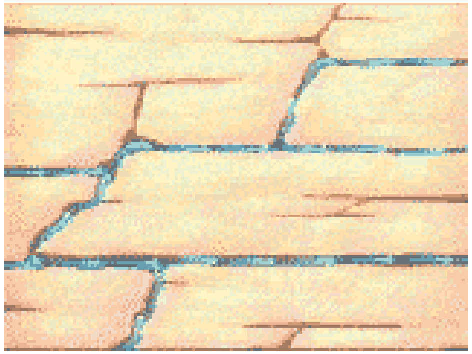

Base-flow Index
for Wisconsin
Baseflow
Percentage
of
Total Flow:
High : 80
Low : 20

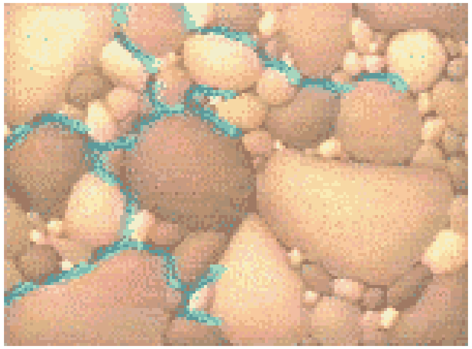


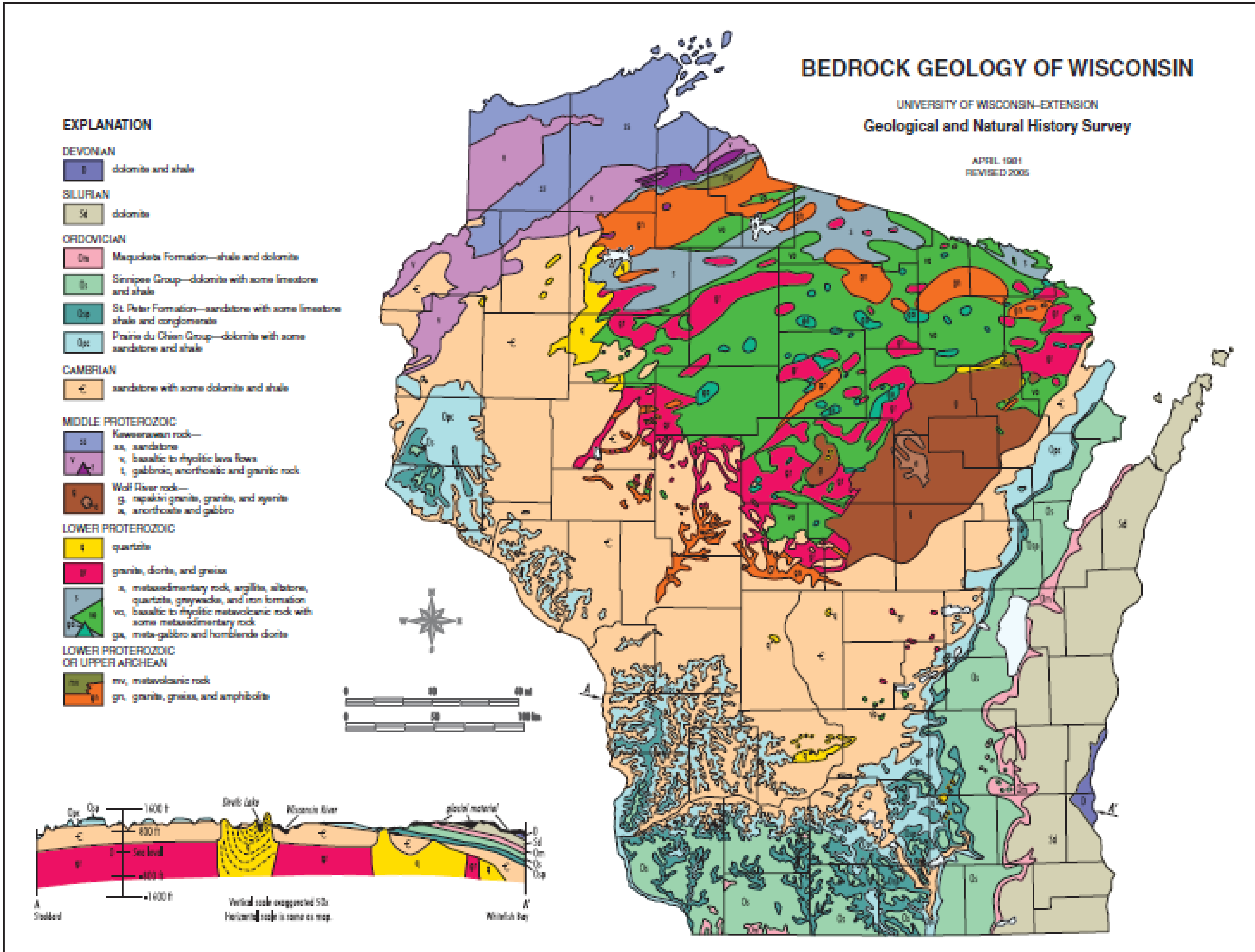
Base-flow Index
for Wisconsin
Baseflow
Percentage
of
Total Flow:
High : 80
Low : 20
Trout Stream

Groundwater Movement



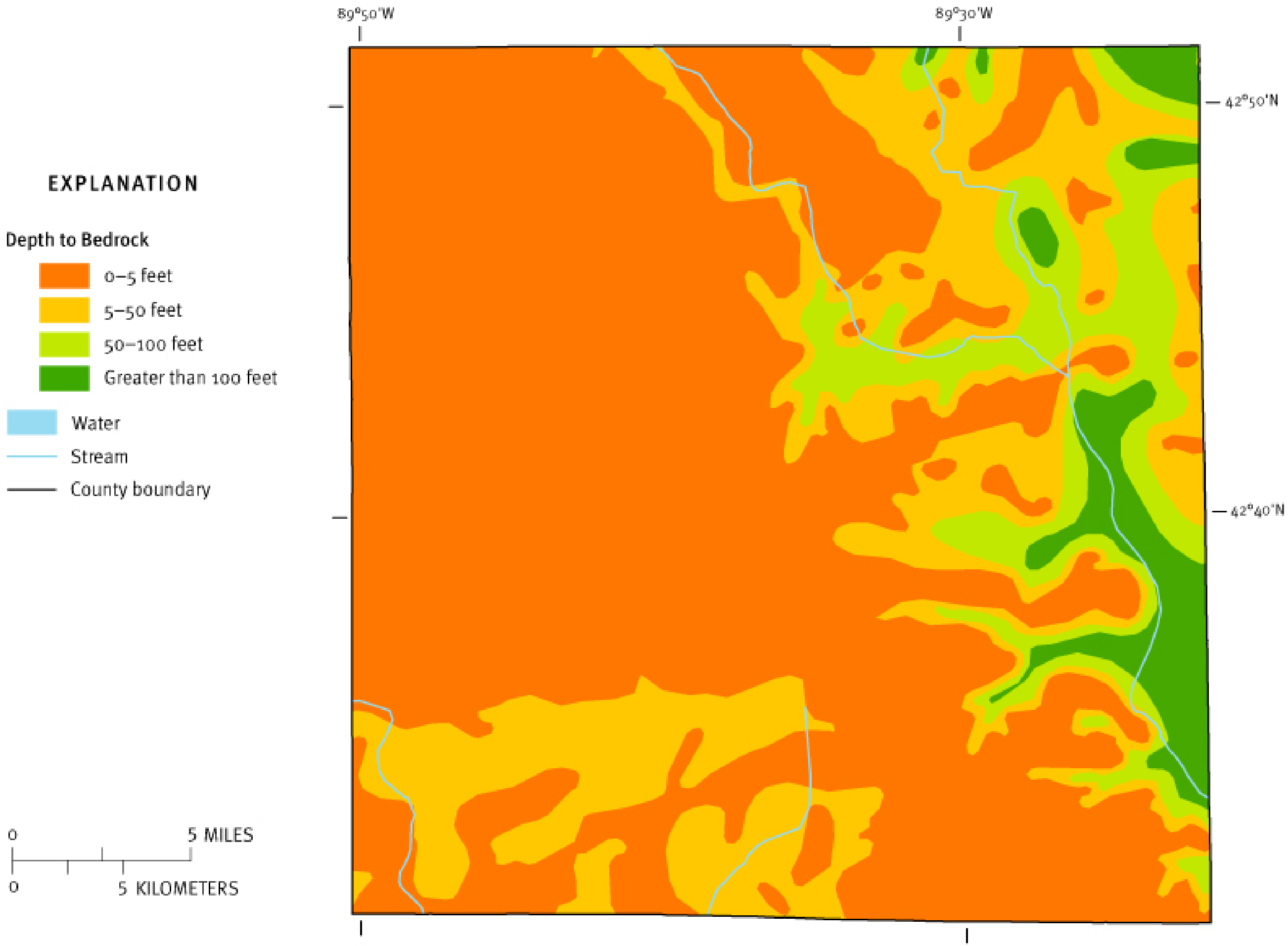






BEDROCK GEOLOGY OF WISCONSIN
UNIVERSITY OF WISCONSIN–EXTENSION
Geological and Natural History Survey
APRIL 1981
REVISED 2005
EXPLANATION
DEVONIAN
dolomite and shale
SILURIAN
dolomite
ORDOVICIAN
Maquoketa Formation—shale and dolomite
Sinnipee Group—dolomite with some limestone and shale
St. Peter Formation—sandstone with some limestone shale and conglomerate
Prairie du Chien Group—dolomite with some sandstone and shale
CAMBRIAN
sandstone with some dolomite and shale
MIDDLE PROTEROZOIC
Keweenawan rock—
ss, sandstone
v, basaltic to rhyolitic lava flows
t, gabbroic, anorthositic and granitic rock
Wolf River rock—
g, rapakivi granite, granite, and syenite
a, anorthosite and gabbro
LOWER PROTEROZOIC
quartzite
granite, diorite, and gneiss
s, metasedimentary rock, argillite, siltstone, quartzite, greywacke, and iron formation
vo, basaltic to rhyolitic metavolcanic rock with some metasedimentary rock
ga, meta-gabbro and hornblende diorite
LOWER PROTEROZOIC OR UPPER ARCHEAN
mv, metavolcanic rock
gn, granite, gneiss, and amphibolite

Green County – Depth to Bedrock

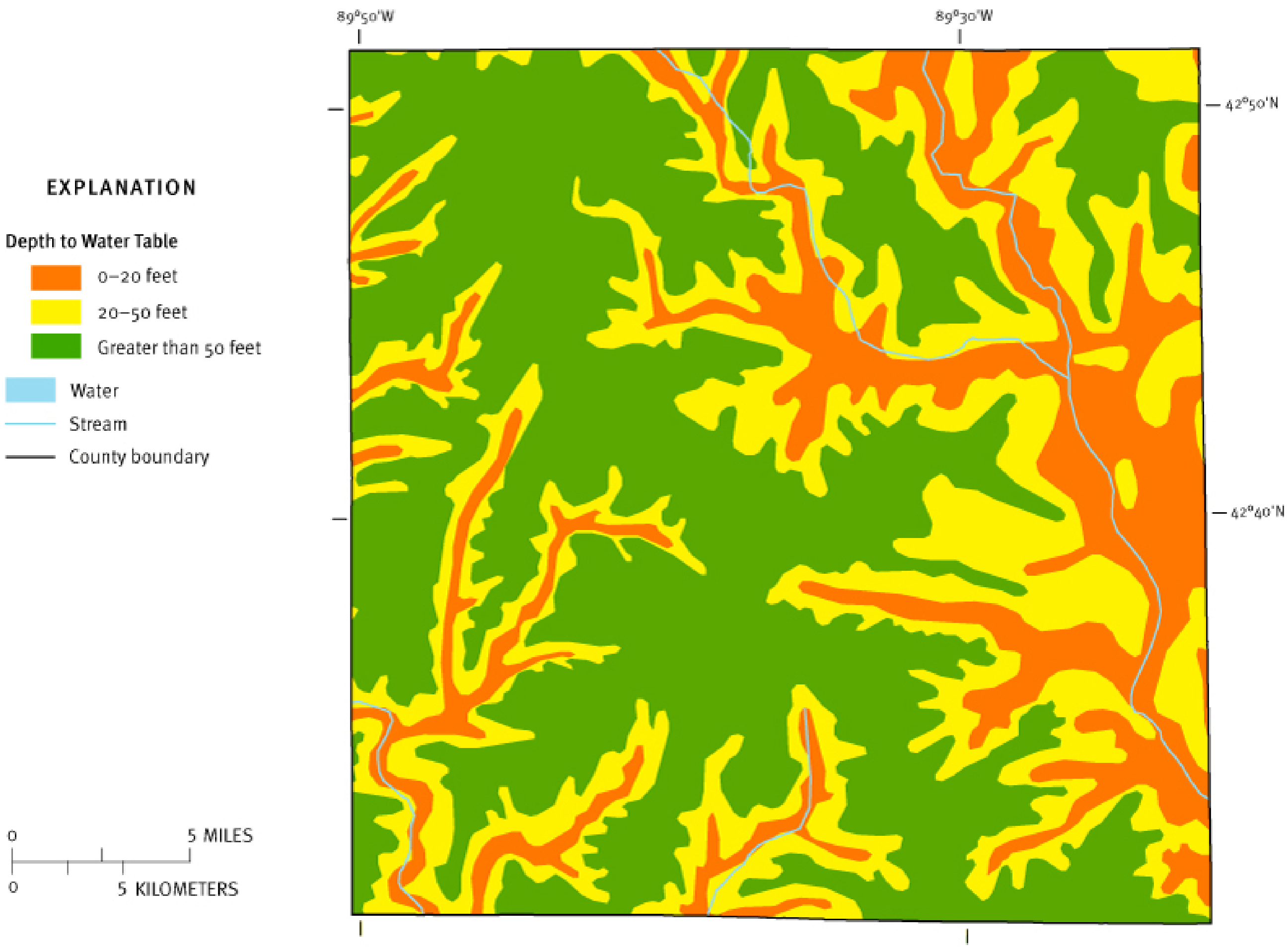


This resource characteristic map was derived from generalized statewide information at small scales, and cannot be used for any site-specific purposes.

Map source: Schmidt, R.R., 1987, Groundwater contamination susceptibility map and evaluation: Wisconsin Department of Natural Resources, Wisconsin's Groundwater Management Plan Report 5, PUBL-WR-177-87, 27 p.

Figure created for the "Protecting Wisconsin's Groundwater Through Comprehensive Planning" web site, 2007, *http://wi.water.usgs.gov/gwcomp/*

Green County – Depth to Water Table



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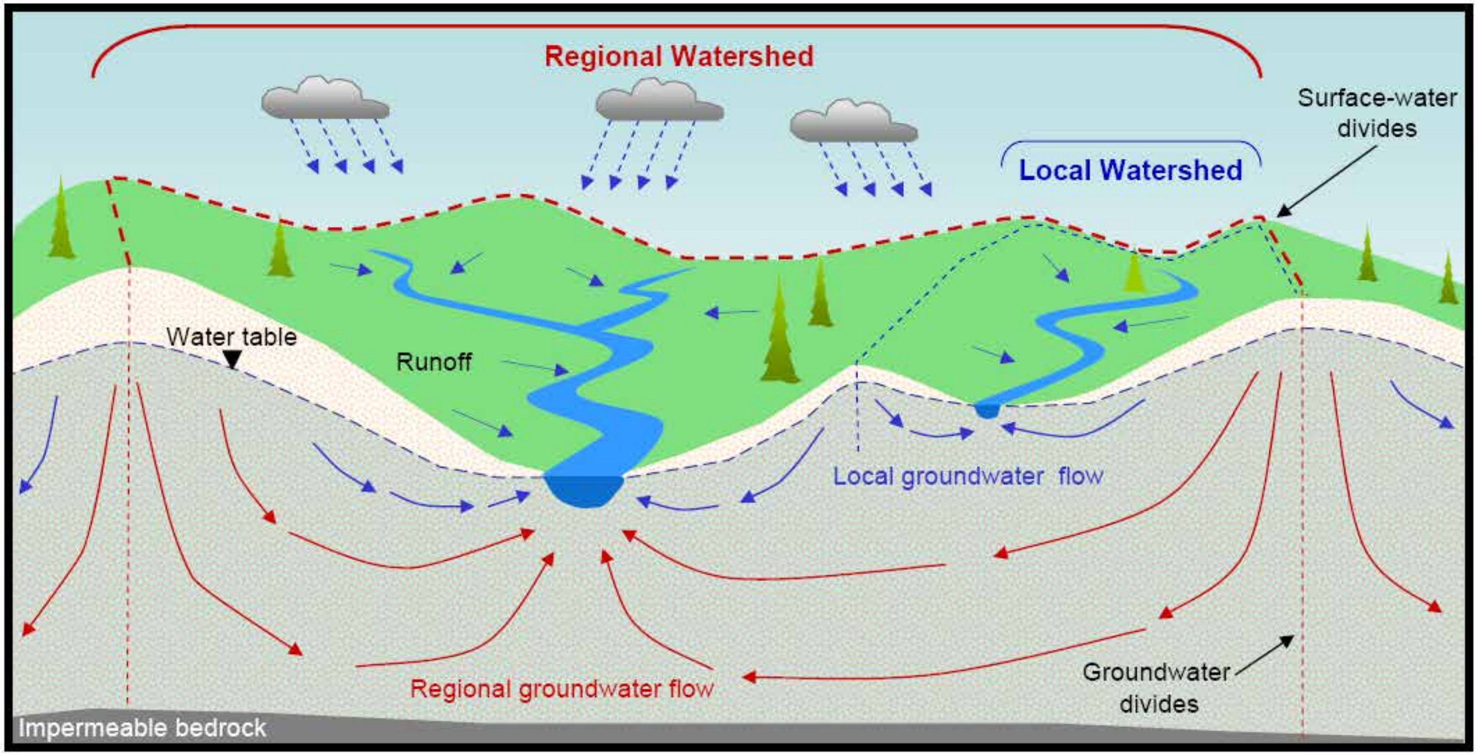
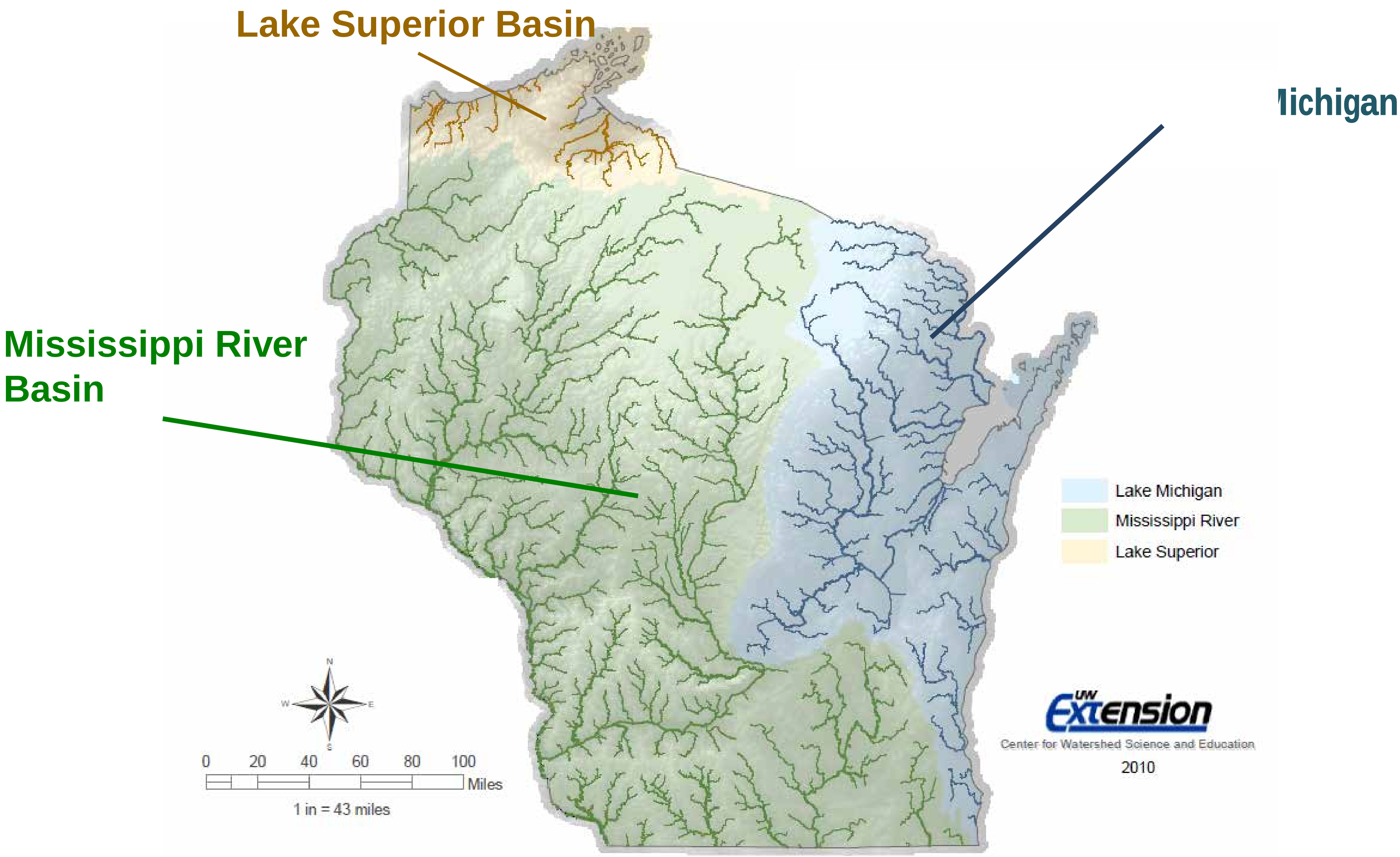
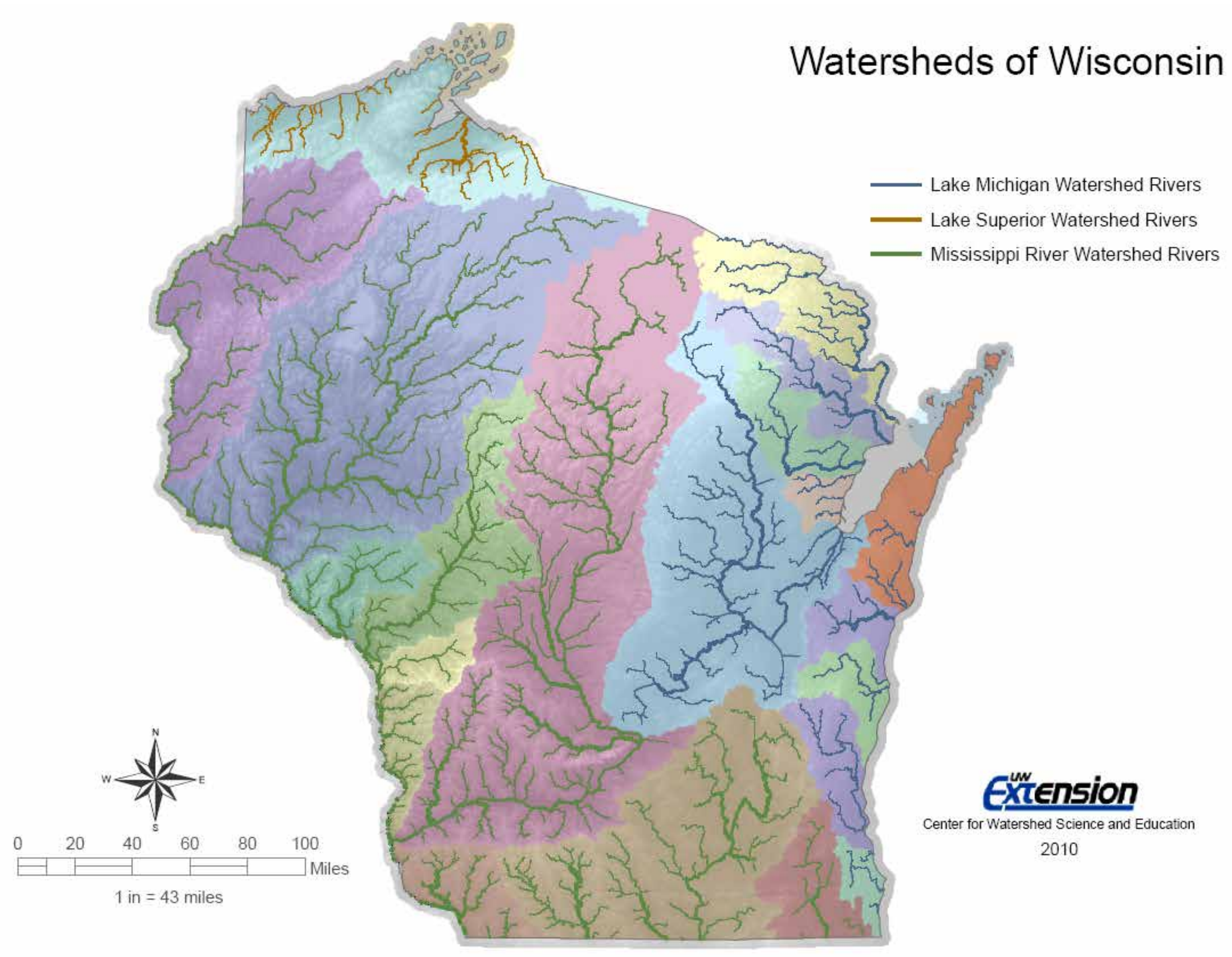
Watershed – Land area that contributes water to a common discharge feature

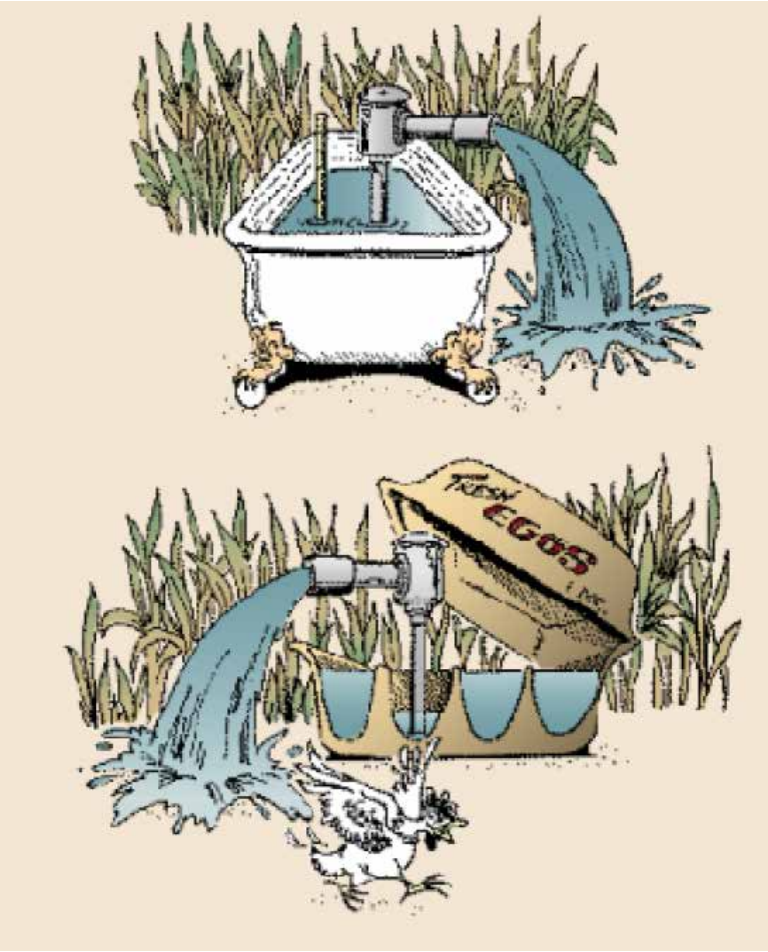


Wisconsin has 3 major basins




Watersheds of Wisconsin
Lake Michigan Watershed Rivers
Lake Superior Watershed Rivers
Mississippi River Watershed Rivers
N
W
E
S
0 20 40 60 80 100
Miles
1 in = 43 miles
UW Extension
Center for Watershed Science and Education
2010

Groundwater Issues in Wisconsin



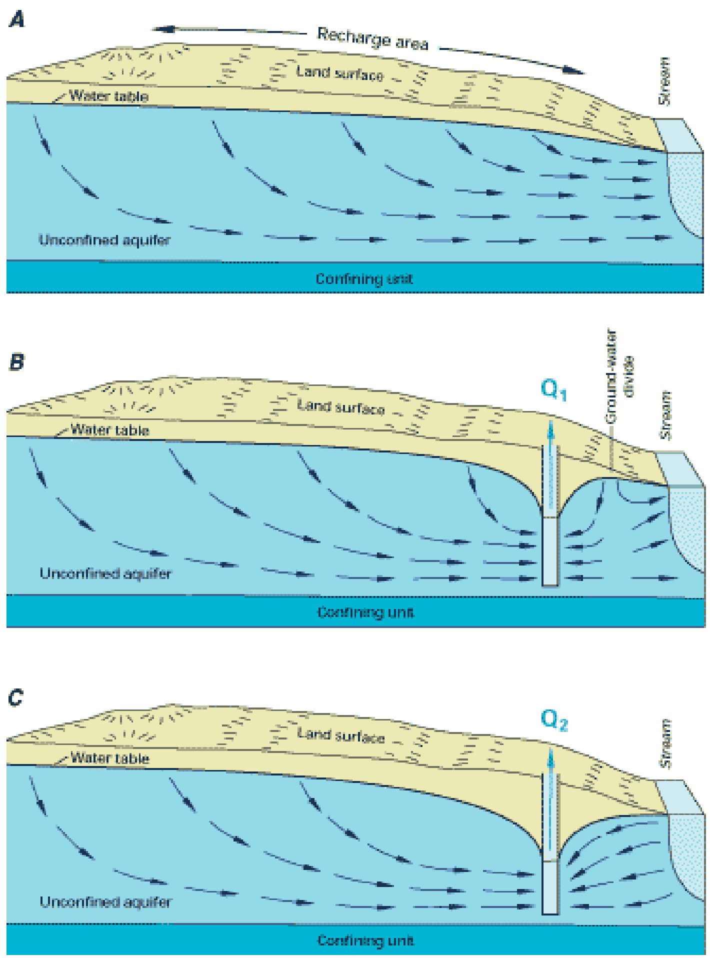
http://pubs.usgs.gov/circ/circ1186/pdf/circ1186.pdf

- Water Quantity
- Water Quality

Effect of wells on groundwater

- High capacity wells are capable of pumping at least 70 gallons per minute or more than 100,000 gallons per day

**Typical residential private wells do not pump enough water to create a cone of depression or affect groundwater flow direction.*



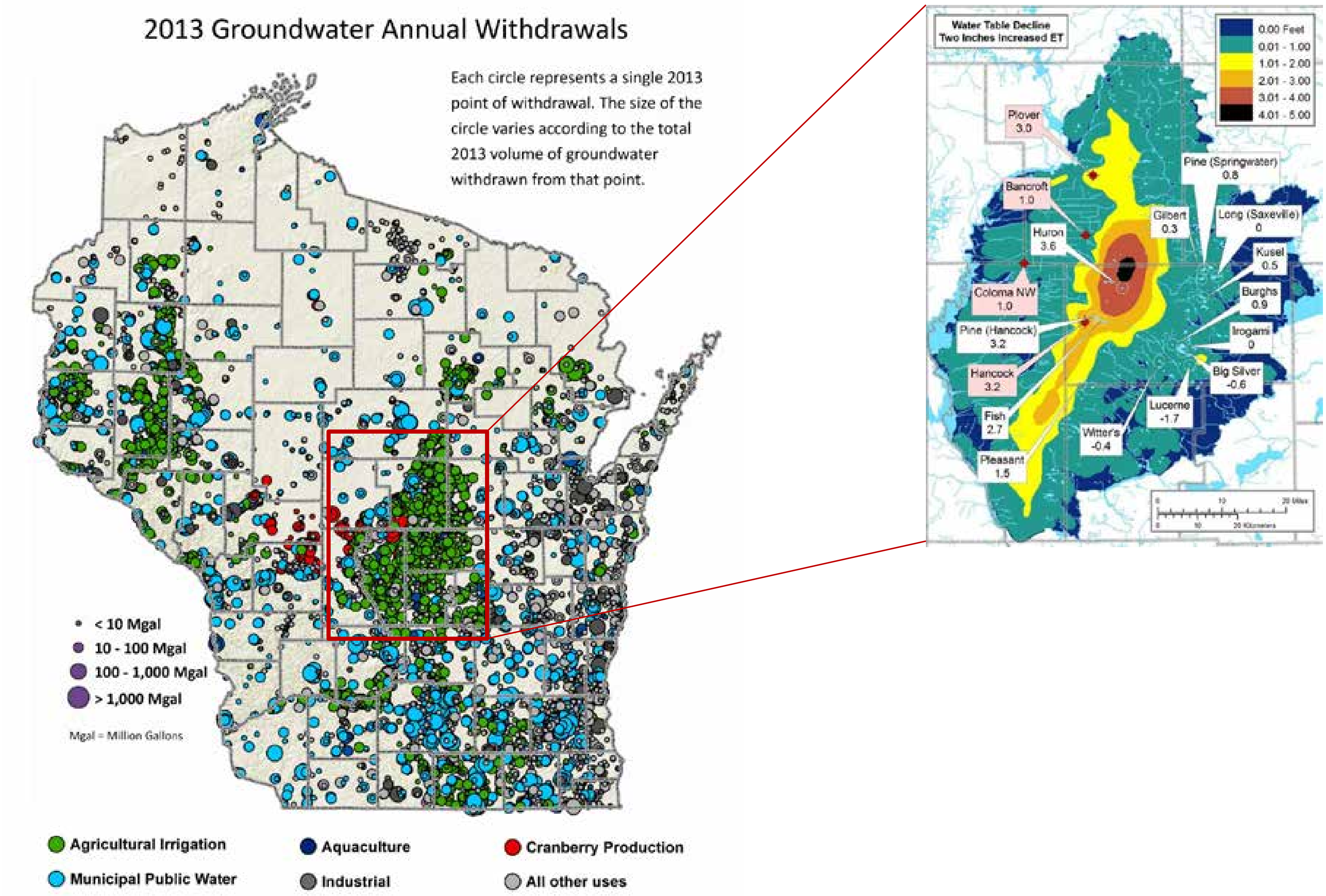
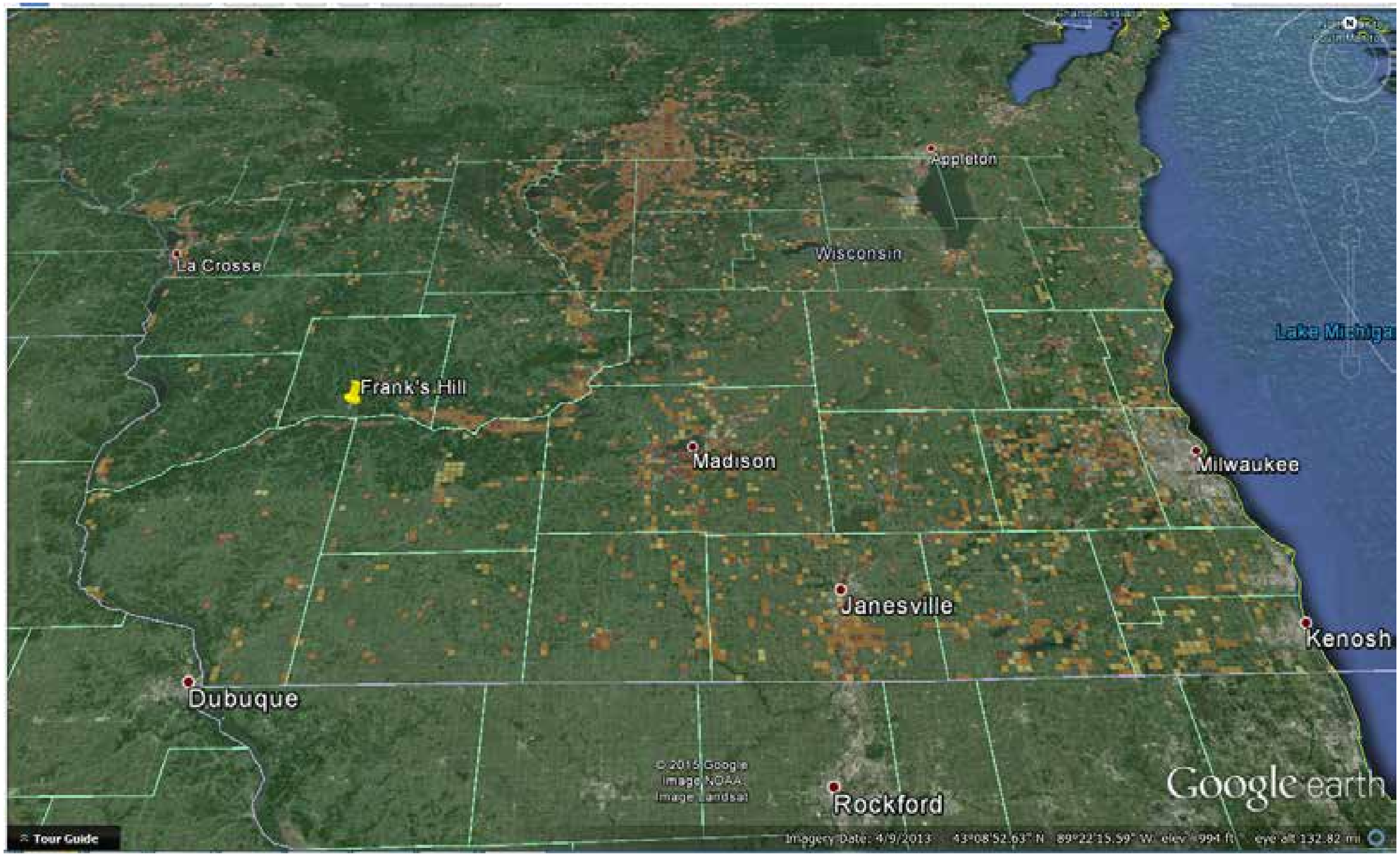


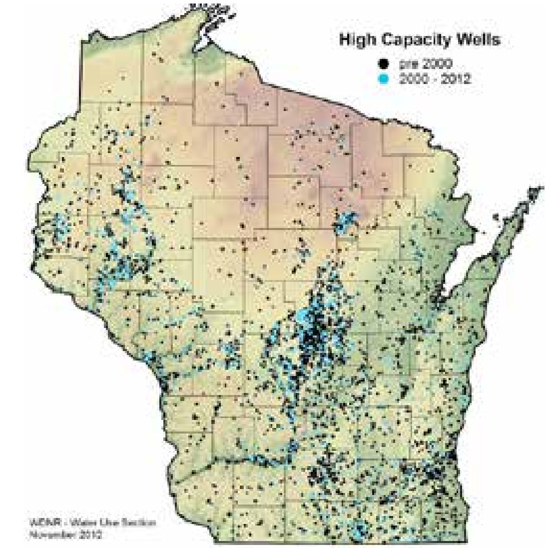
Figure 1. Location and category of high capacity wells in Wisconsin.

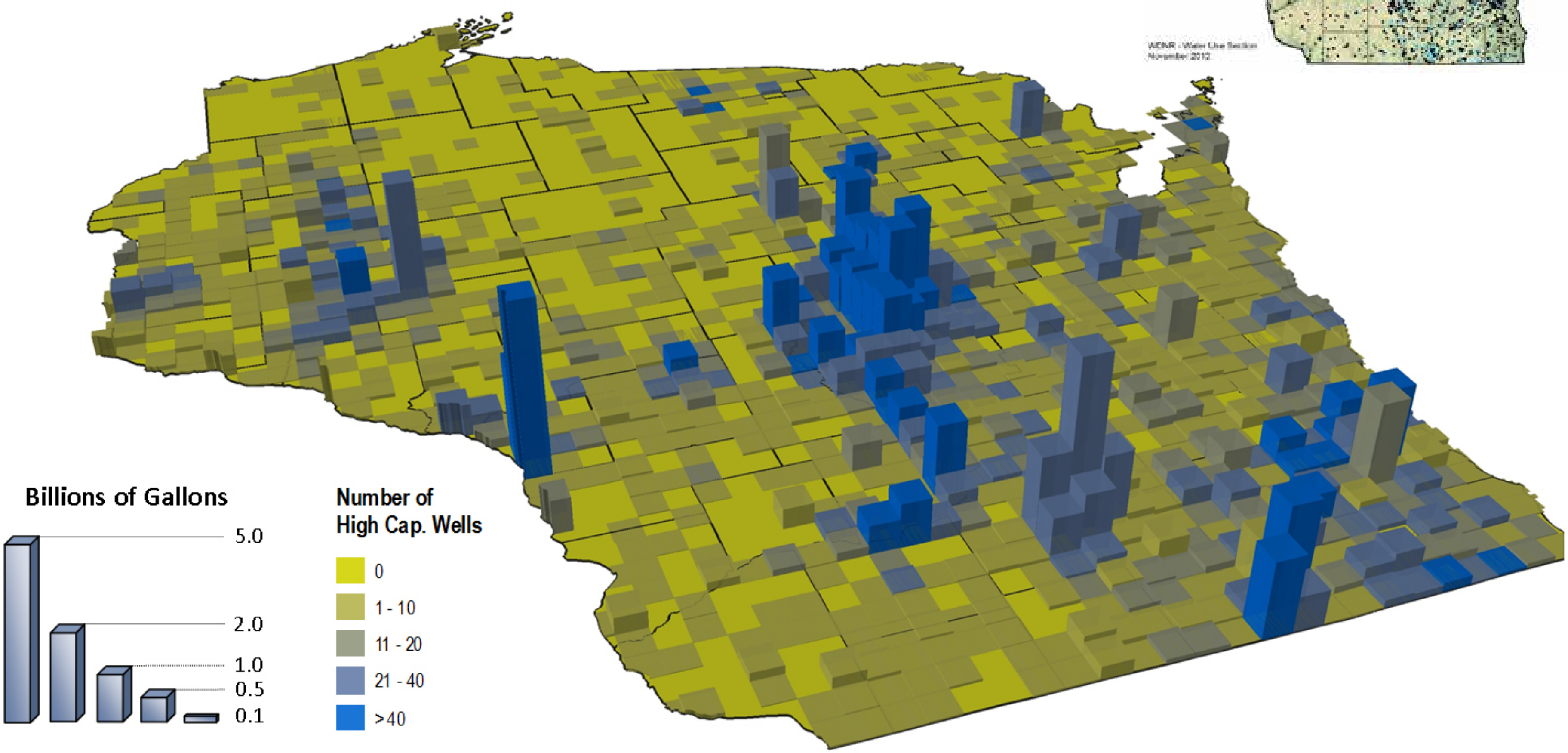
Graphic courtesy of Wisconsin Department of Natural Resources and available at http://dnr.wi.gov/topic/WaterUse/documents/WithdrawalReportDetail.pdf

Groundwater Withdrawals - 2011



WDNR, 2011

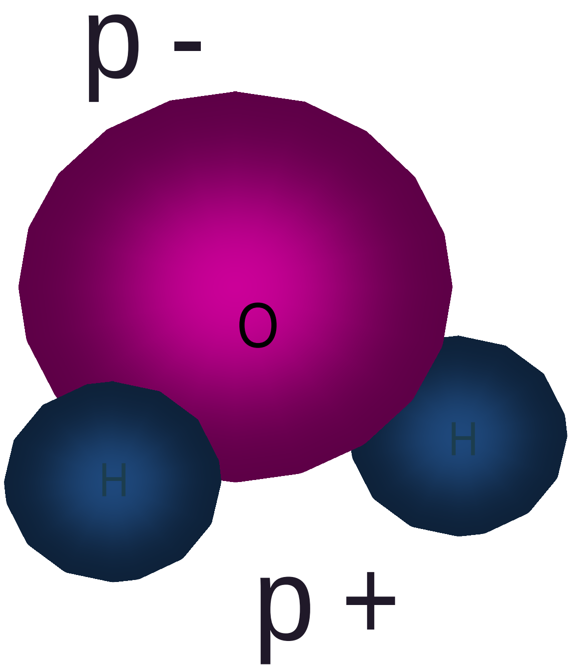




WDNR 2011 Groundwater Withdrawal Data, Graphic by Dan McFarlane

water quality basics

- "Universal Solvent"
- Naturally has "stuff" dissolved in it.
  - Impurities depend on rocks, minerals, land-use, plumbing, packaging, and other materials that water comes in contact with.
- Can also treat water to take "stuff" out



Private vs. Public Water Supplies

Public Water Supplies

- Regularly tested and regulated by drinking water standards.

Private Wells

- Not required to be regularly tested.
- Not required to take corrective action
- Owners must take special precautions to ensure safe drinking water.

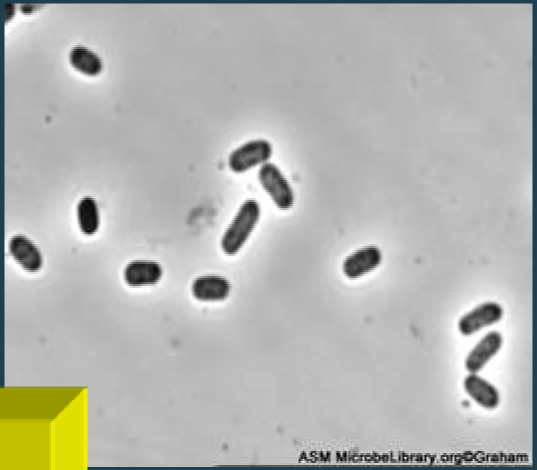
Coliform bacteria

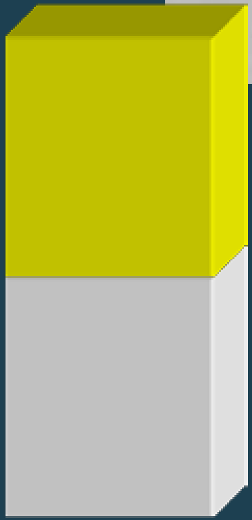
- Generally do not cause illness, but indicate a pathway for potentially harmful microorganisms to enter your water supply.
  - Harmful bacteria and viruses can cause gastrointestinal disease, cholera, hepatitis

- Sanitary water supply should not contain any coliform bacteria

- Recommend using an alternative source of water until a test indicates your well is absent of coliform bacteria

- Sources:
  - Live in soils and on vegetation
  - Human and animal waste
  - Sampling error





Present =Unsafe

Absent = Safe

If coliform bacteria was detected, the sample is checked for E.coli

- Confirmation that bacteria originated from a human or animal fecal source.
- E. coli are often present with harmful bacteria, viruses and parasites that can cause serious gastrointestinal illnesses.
- Any detectable level of E.coli means your water is unsafe to drink.

Contaminants	Sources	Symptoms
BACTERIA		
Escherichia coliform (E. coli) *Salmonella* *Campylobacter* *E. coli 0157* (Requires a special water test for detection. Causes similar, but more serious illness than other E.coli strains. Requires medical treatment.)	• Infected human and animal feces • Manure • Septic systems • Sewage	• Gastrointestinal illness • Low-grade fever • Begins 12 hrs - 7 days after exposure
Leptosporidia	• Urine of livestock, dogs and wildlife • Manure	• High fever, severe headache and red eyes • Gastrointestinal illness • Begins 2-28 days after exposure
MICROSCOPIC PARASITES		
Cryptosporidia *Giardia*	• Infected human and animal feces • Manure • Septic systems • Sewage	• Gastrointestinal illness • Begins 2-14 days after exposure
VIRUSES		
Norovirus	• Infected human feces and vomit • Septic systems • Sewage	• Gastrointestinal illness • Low-grade fever & headache • Begins 12-48 hrs after exposure
CHEMICALS		
Nitrate	• Fertilizers • Manure • Bio-solids • Septic systems	Methemoglobinemia or "Blue Baby Syndrome" – No documented cases in Door County, but elevated nitrate levels in well water may indicate risk of contamination by additional pathogens.
Atrazine (trade-name herbicide for control of broadleaf and grassy weeds)	Estimated to be most heavily used herbicide in the U.S. in 1987/89, with its most extensive use for corn and soybeans in the Midwest, including WI. In 1993, it became a restricted-use herbicide nationally. U.S. EPA set a max. contaminant level (MCL) at 3 parts per billion for safe drinking water.	Short-term exposure above the MCL may cause: congestion of heart, lungs and kidneys; low blood pressure; muscle spasms; weight loss; damage to adrenal glands. Long-term exposure above MCL may cause: weight loss, cardio-vascular damage, retinal and some muscle degeneration; cancer.

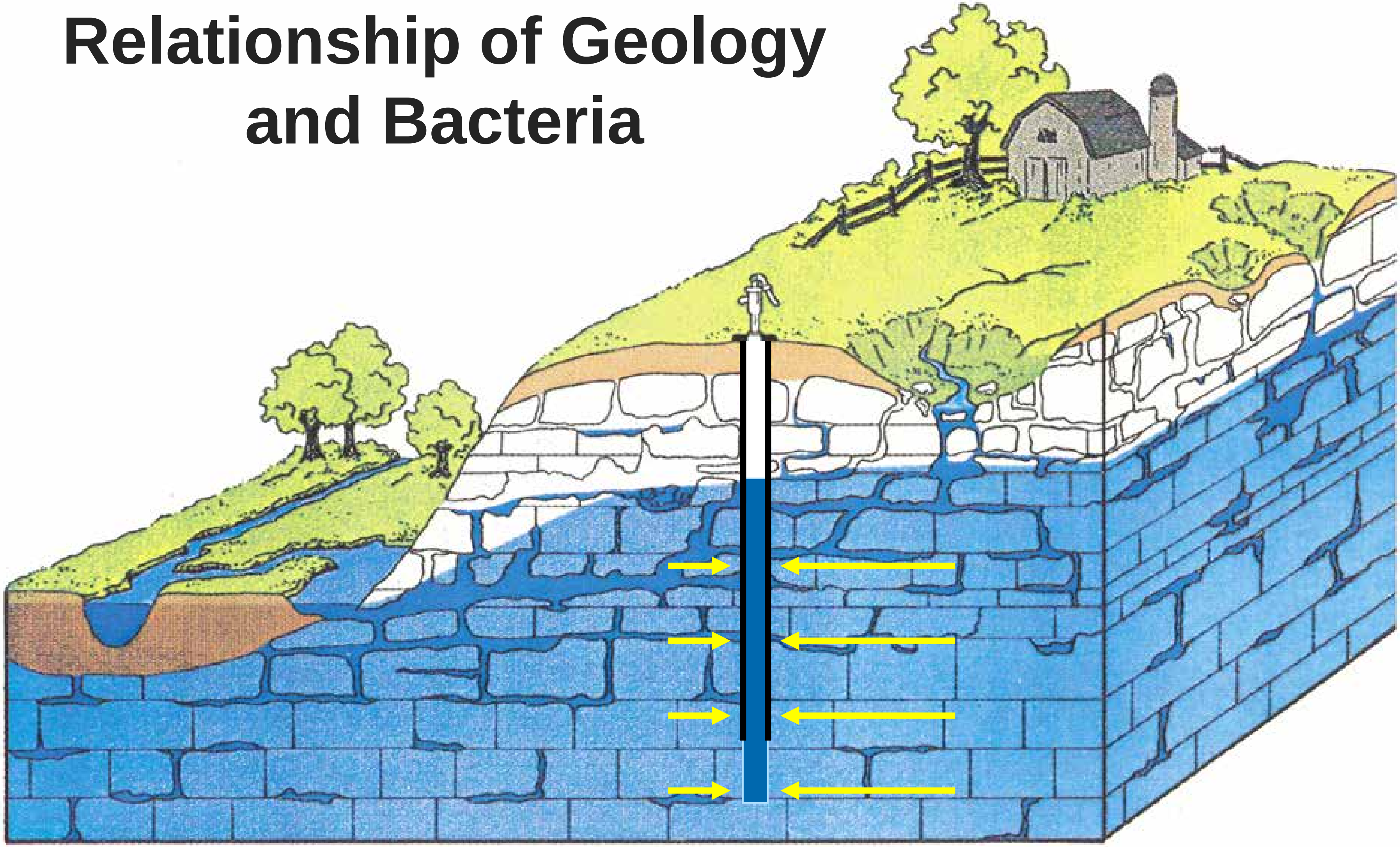
Information Sources: United States Department of Health and Human Services – Centers for Disease Control and Prevention (www.cdc.gov) and United States Environmental Protection Agency (www.epa.gov)

Well Construction

Photo: Sandy Heimke, WI DNR

Photos courtesy of: Matt Zoschke

Relationship of Geology and Bacteria



Nitrate Nitrogen

Health Effects

- Methemoglobinemia (blue baby disease)
- Possible links to birth defects, miscarriages (humans & livestock)
- Indicator of other contaminants

Environmental Effects

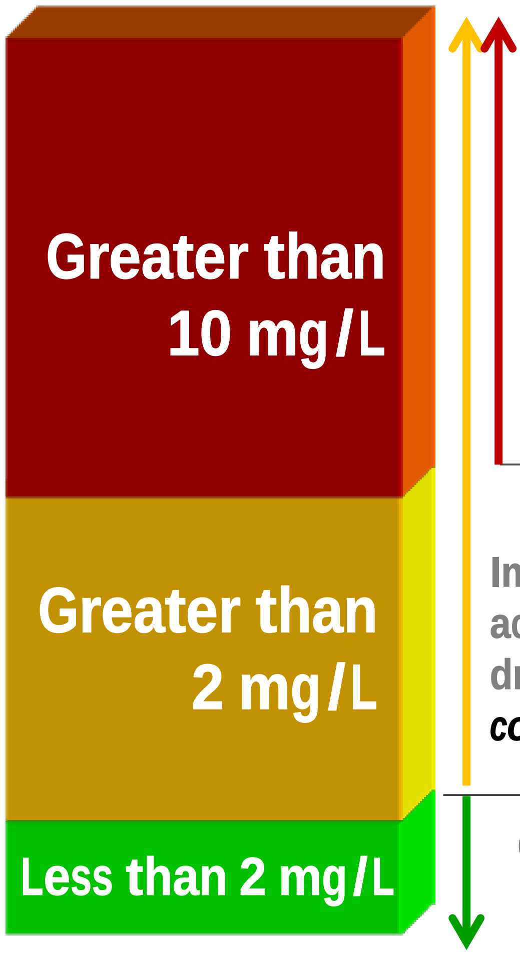
- Increased eutrophication of surface waters *(more plant growth and algae blooms)*
- Hypoxic zone (dead zone) in the Gulf of Mexico

Sources

- Agricultural fertilizer
- Lawn fertilizer
- Septic systems
- Animal wastes
- Decomposing wastes

Gulf of Mexico is over $1 Billion fishery.

Nitrate-Nitrogen Concentration



UNSAFE - for infants and pregnant women or women trying to have a baby; everyone should avoid long term consumption.

Impacted by local land use activities but suitable for drinking. ***May indicate other contaminants.***

Close to “natural” or background levels

Nitrate-impacted Municipal Wells

As of 2005 total of $24 million

- Amherst
- Cambria
- Chippewa Falls
- Crivitz Utilities
- Embarrass
- Fitchburg
- Fontana
- Janesville Water Utility
- Mattoon
- Morrisonville
- Oconomowoc
- Orfordville
- Plover
- Rome
- Sauk City
- Strum Waterworks
- Valders
- Village of Arlington
- Village of Clinton
- Village of Dalton
- Village of Footville
- Village of Friesland
- Waunakee
- Waupaca
- Whiting

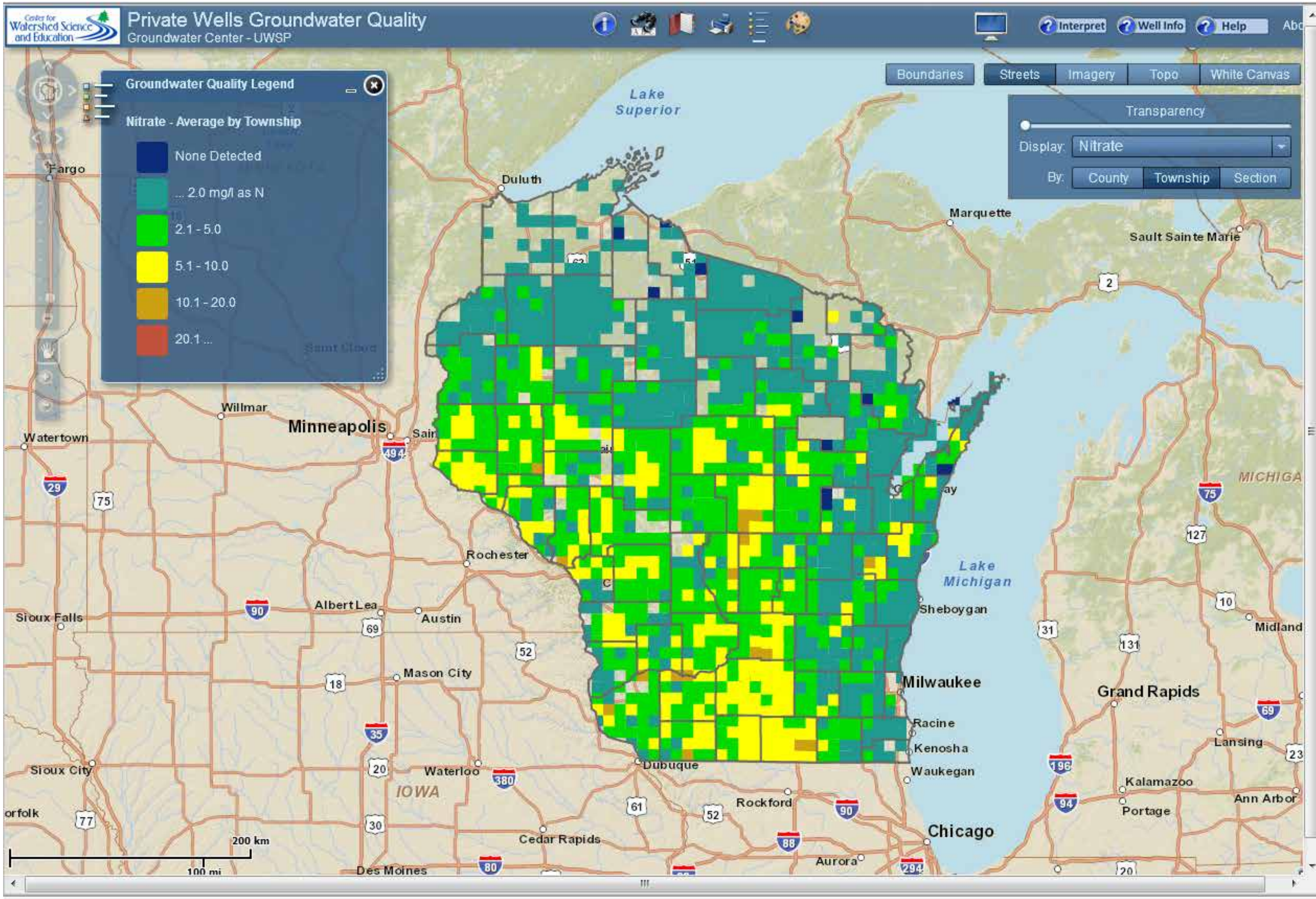
Data obtained from Laura Chern of WDNR

What can I do to reduce my nitrate levels?

- **Possible Long-term Solution:**
  - Reduce or eliminate nitrogen inputs

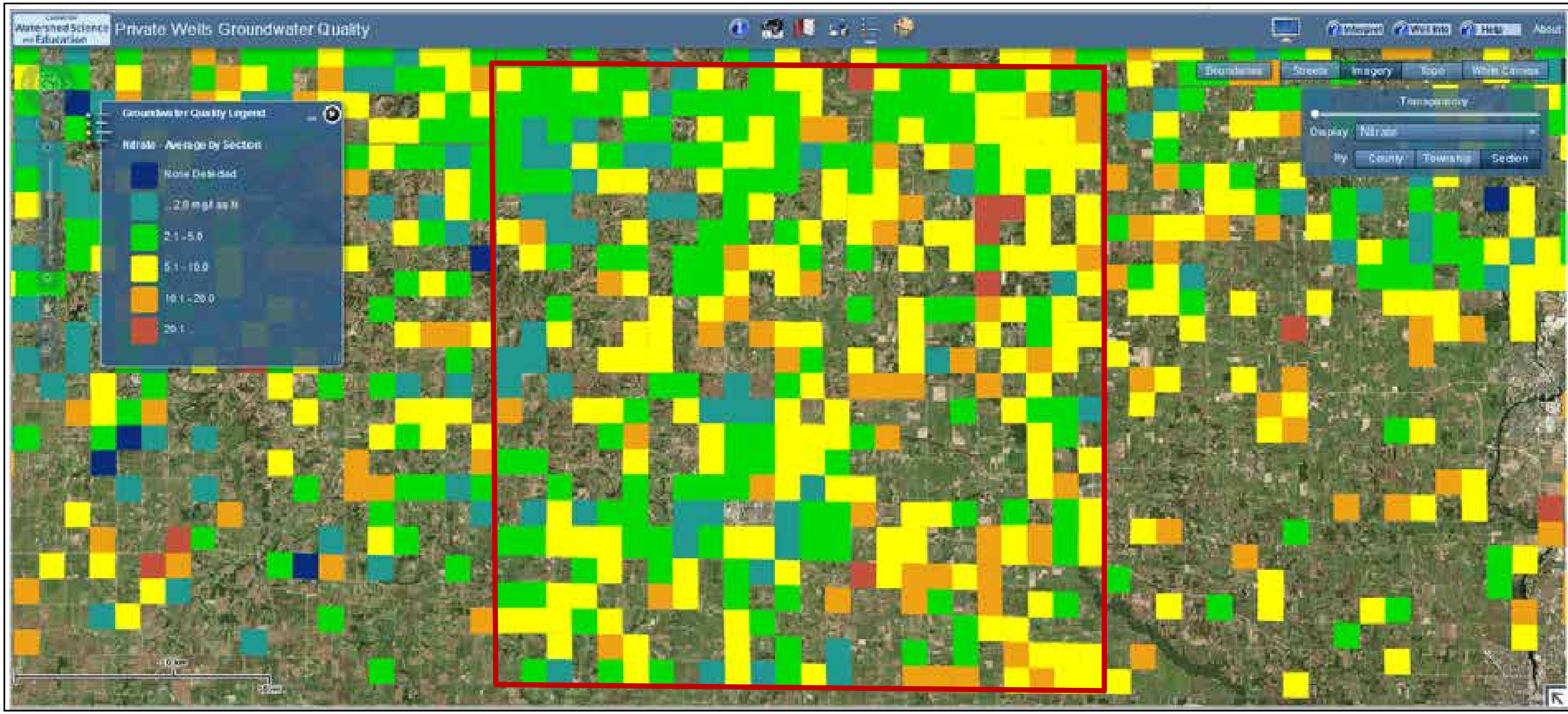
- **Short term** (Lewandowski et. al. 2008)
  - Change well depth or relocate well (not guaranteed) - $7,200
  - Bottled water - $190/person/year
  - Water treatment devices - $800 + 100/yr
    - Reverse osmosis
    - Distillation
    - Anion exchange

Nitrate in Wisconsin Groundwater



http://www.uwsp.edu/cnr-ap/watershed/Pages/wellwaterviewer.aspx

Average Nitrate-N concentration by section.



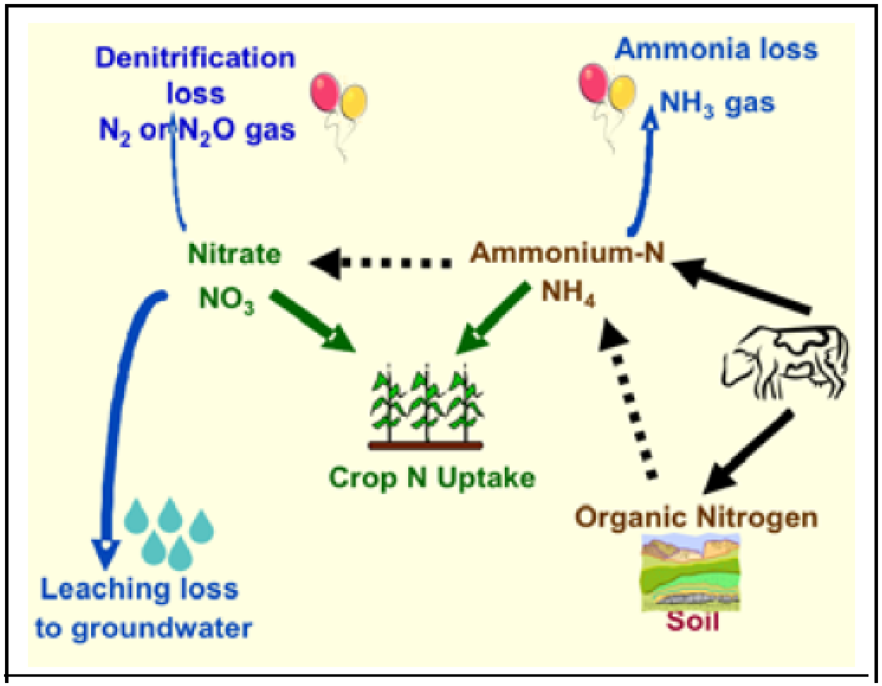
Range	Number	Percent	Summary
None Detected	194	7%	Minimum: No Detect
... 2.0	622	23%	
2.1 - 5.0	724	27%	Median: 4.1
5.1 - 10.0	694	26%	Average: 5.61288
10.1 - 20.0	364	14%	
20.1 ...	64	2%	Maximum: 69.9
Total	2662		
> 10 mg/l N	428	16%	Exceeds Health Standard

http://www.uwsp.edu/cnr-ap/watershed/Pages/wellwaterviewer.aspx

Green County
Nitrate Summary

Nitrogen Cycle

“Nitrogen is neither created nor destroyed”



http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/20528/em8954-e.pdf

The Environment and N Loss from Manures—Why Do We Care?

Plant-available N (PAN) losses from the soil represent lost fertilizer value. Nitrogen can be lost as ammonia, nitrate, or nitrous oxides (Figure 1, page 3). Besides losing a valuable resource, the lost PAN can contribute to off-site problems.

Ammonia lost to the atmosphere is an air pollution problem in some areas of the western U.S., particularly in winter when atmospheric inversions prevent air mixing. In the atmosphere, ammonia can react with dust and other compounds to reduce visibility and to acidify rain or fog. Ammonia emissions may contribute to:

- Human health problems (inhalation hazard)
- Changes in natural plant communities in forests and rangeland. (Nitrogen deposited in N-poor ecosystems can alter the balance between adapted species and N-loving invasive species.)
- Acid fog or rain damage to limestone buildings or cultural artifacts (for example, petroglyphs on limestone)
- Reduction in visibility (haze)

Nitrate moves with soil water. Nitrate lost from soil enriches groundwater or surface water and can contribute to:

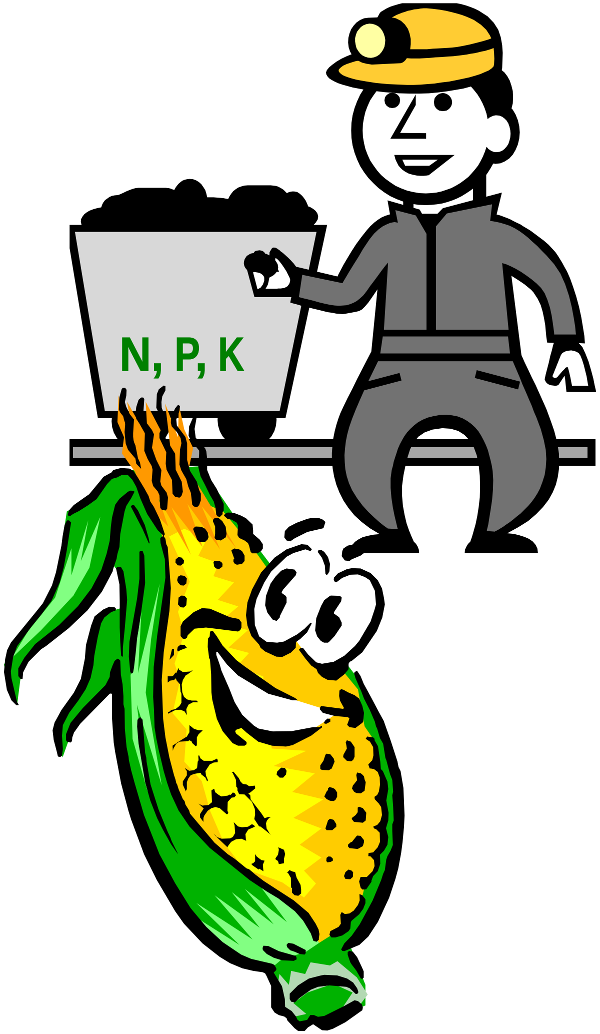
- Human health problems (blue baby syndrome, elevated cancer risk)
- Algae blooms in lakes or other slow-moving bodies of water
- Reduced survival and reproduction of some amphibians

Nitrous oxides lost to the atmosphere through denitrification can contribute to:

- Human health problems (inhalation hazard)
- Global warming (A molecule of nitrous oxide (N_2O) traps approximately 300 times more heat than a molecule of carbon dioxide.)
- Increased N deposits in sensitive ecosystems, resulting in soil acidification or change in plant communities
- Reduction in visibility (haze)

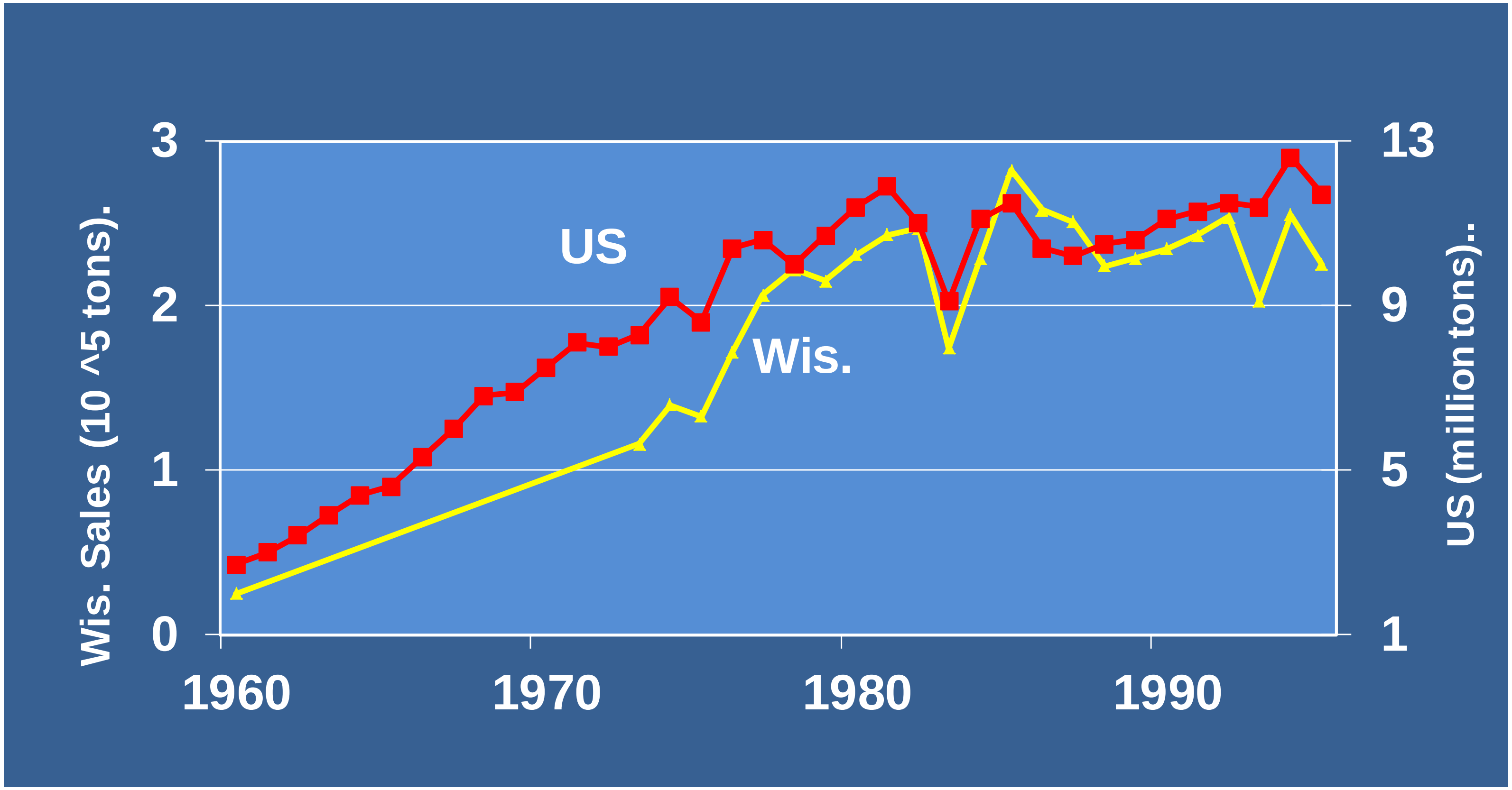
History of N Use

- N and agriculture
  - Ancient civilizations farmed flood plains
  - Animal manure
  - Crop rotations (legumes)
  - Industrial fixation of N leads to commercial fertilizer and dramatic increase in N applications
  - Begin to treat manure as waste product*

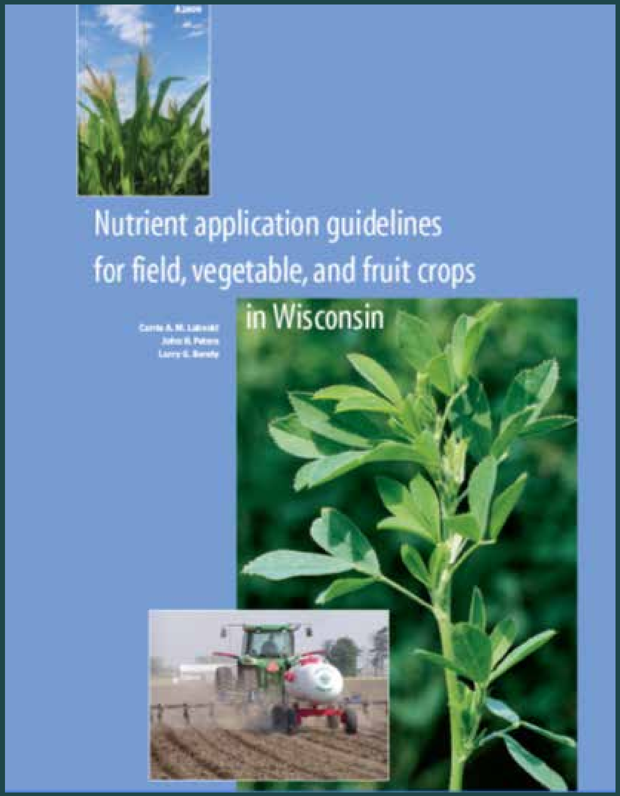


*It is getting better, but managing manure still challenging

US & Wis. fertilizer nitrogen use (1960-95)



Nutrient Management



- Provides guidance on the amount of nutrients (N, P, K) needed to achieve economic optimal production
- Provides recommended rate of nitrogen application for given crop and soil type.
- 4R's
    - Right Amount
    - Right Source
    - Right Time
    - Right Placement

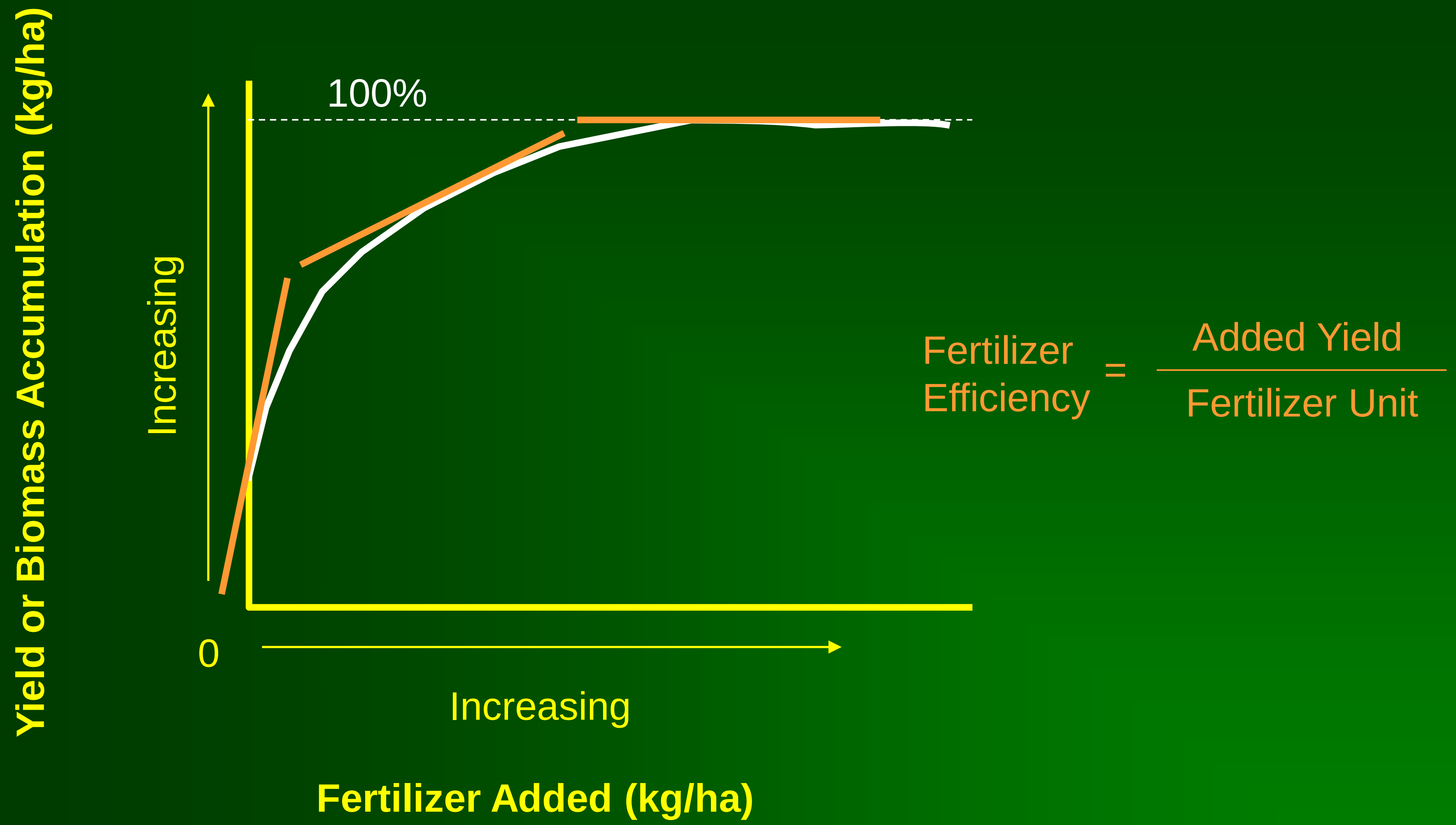
Nutrient Management and Nitrogen Recommendations

Nitrogen Fertilizer Added (lb/acre)

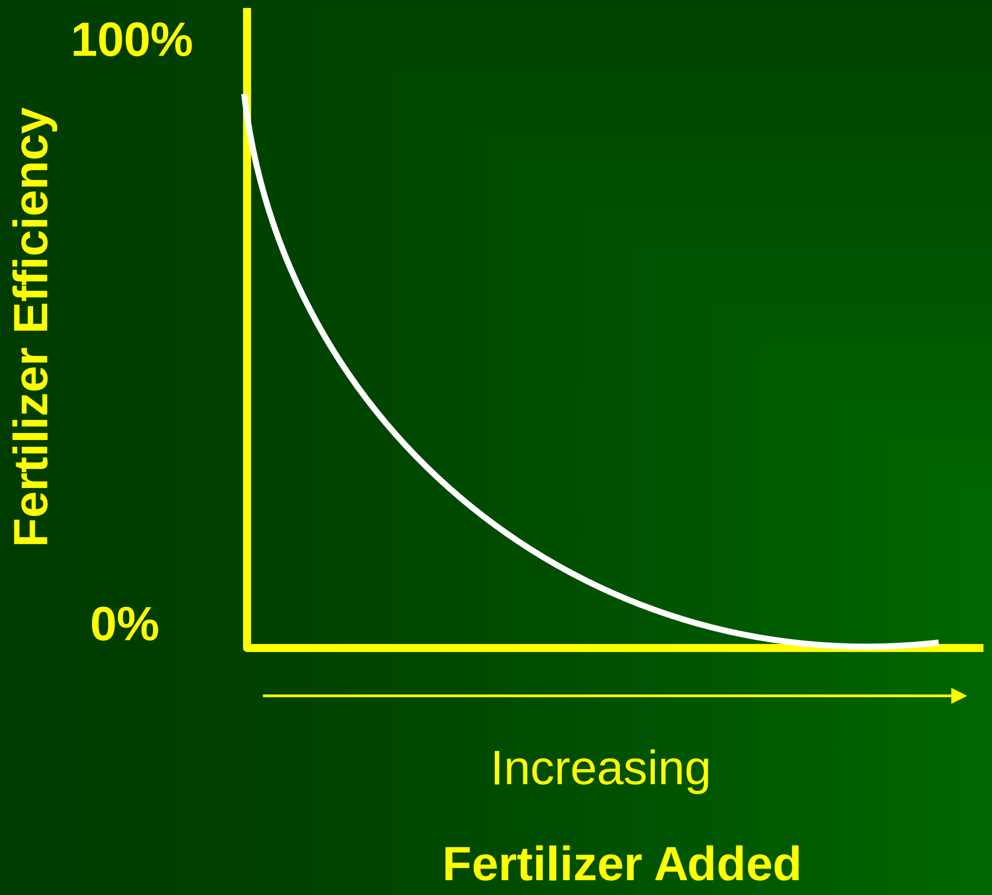
Low ⟷ High

Picture Courtesy of:
https://www.facebook.com/University-of-Minnesota-Nutrient-Managment-Group-275963965756114/timeline/

Fertilizer Response Curve

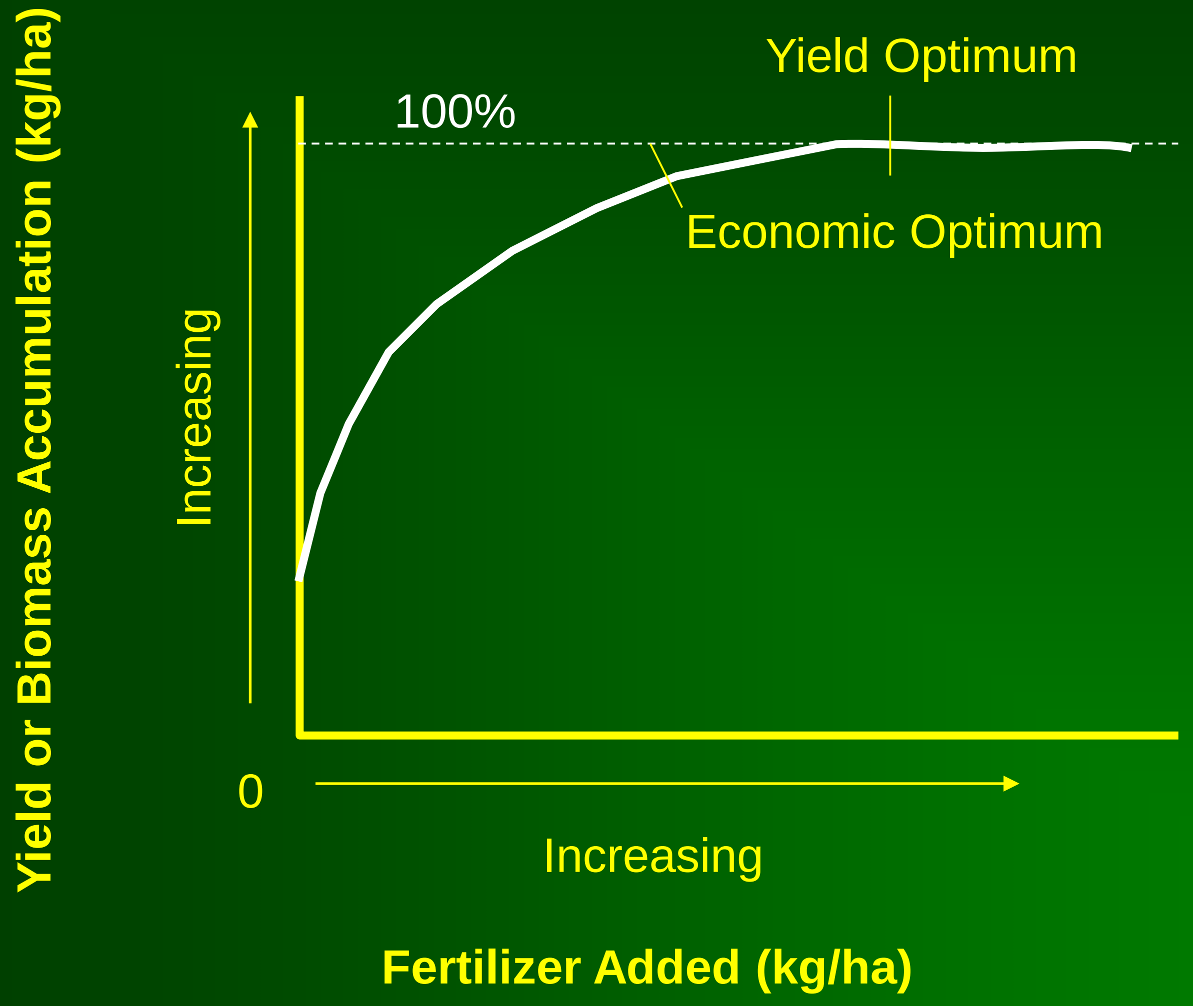


Fertilizer Efficiency



Increasing the amount of fertilizer decreases the efficiency of the fertilizer.

Fertilizer Response Curve



http://www.youtube.com/watch?v=iFCdAgeMGOA

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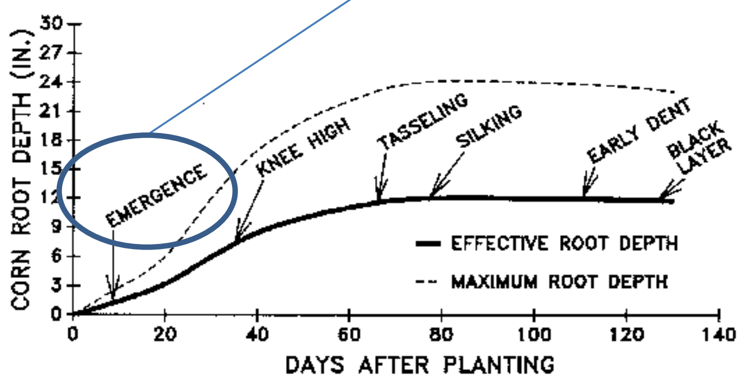
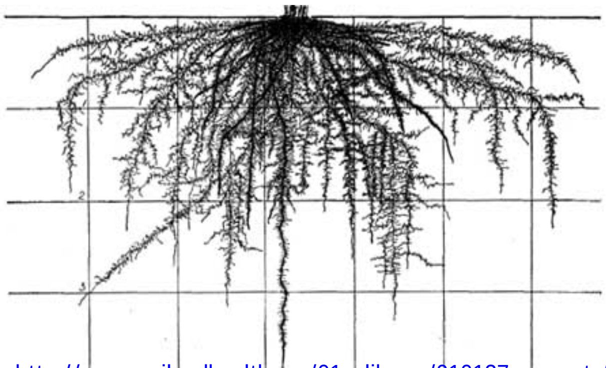


http://www.bae.ncsu.edu/programs/extension/evans/ag452-1.html

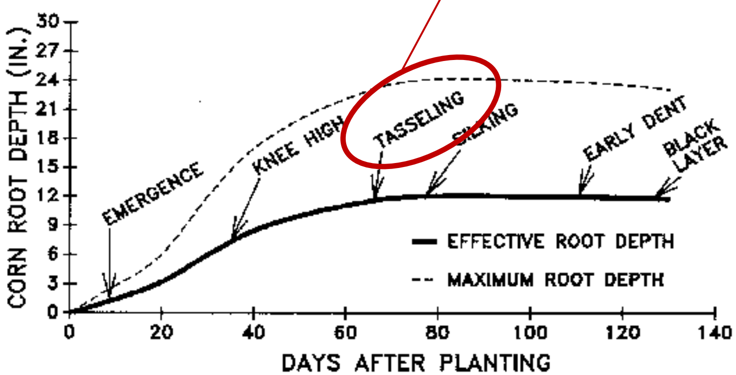
Plants are not 100% efficient at removing nutrients from the soil

N fertilizer efficiency averages 37% for maize systems (Cassman et. al. 2002)

Corn Plant



http://www.soilandhealth.org/01aglibrary/010137veg.roots/010137ch2.html



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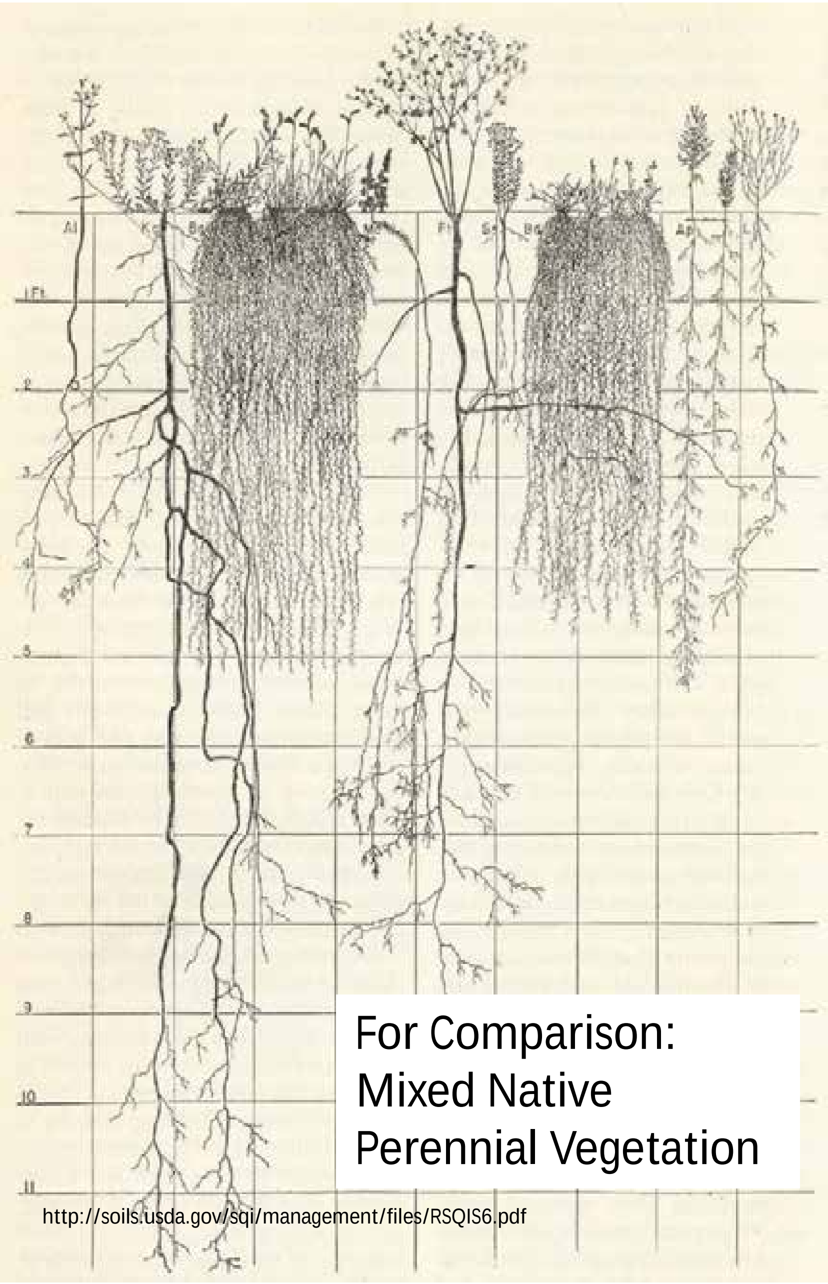


For Comparison: Mixed Native Perennial Vegetation

http://soils.usda.gov/sqi/management/files/RSQIS6.pdf

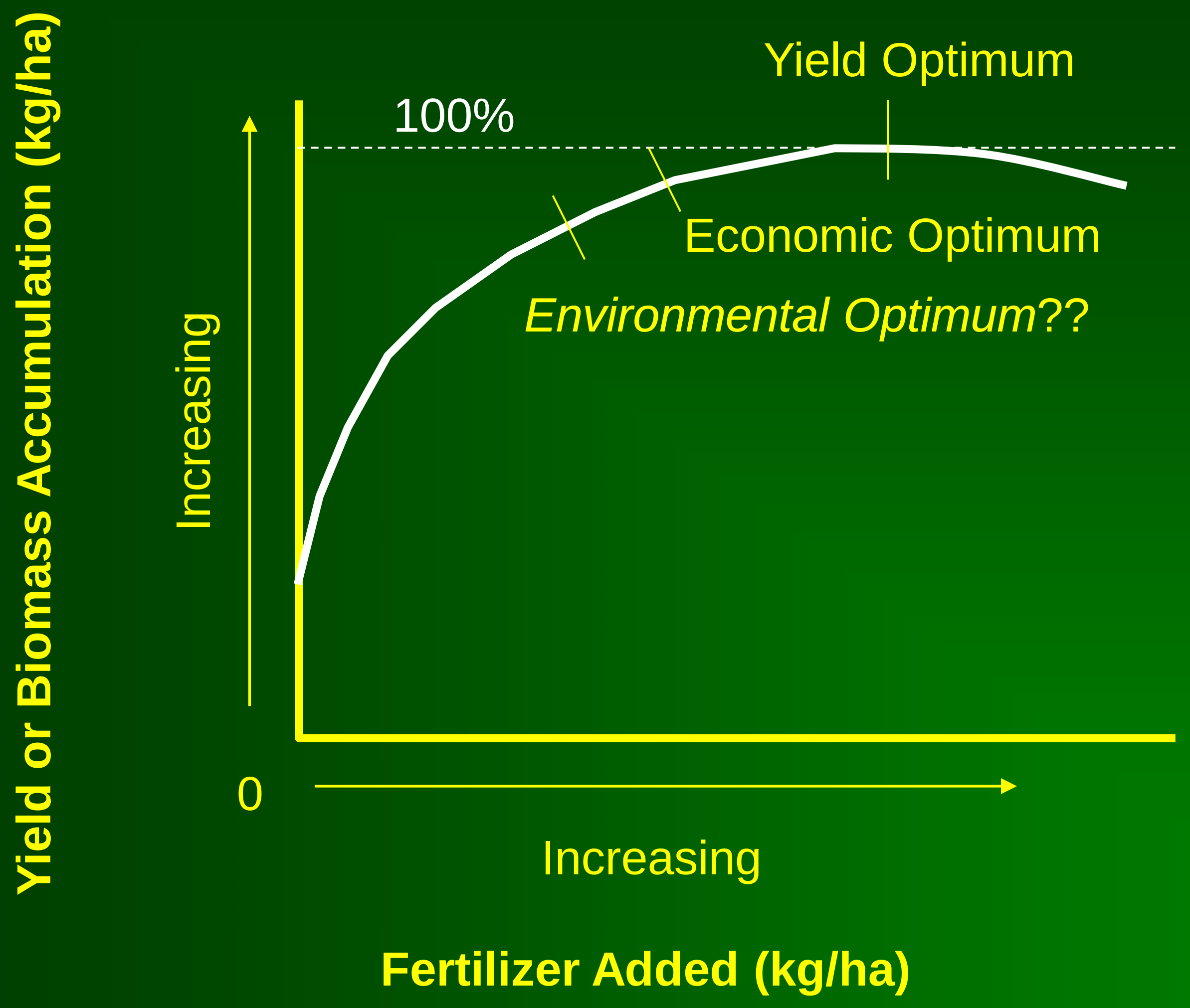
Nitrogen Fertilizer Added (lb/acre)

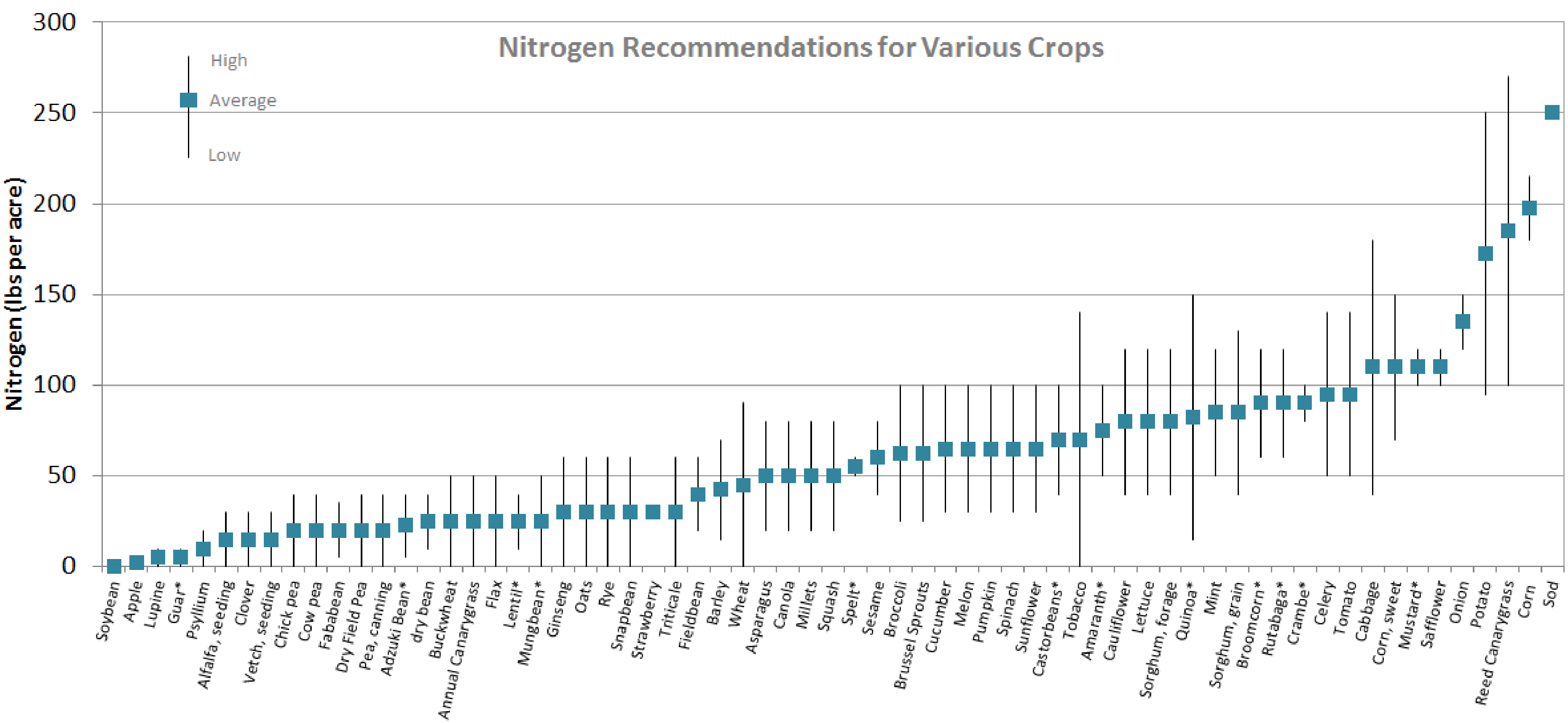
Low ⟷ High

Nitrogen Leaching Loss

What is the ability of nitrogen nutrient recommendations to meet groundwater performance standards?

What is an Optimal Fertilization Rate?



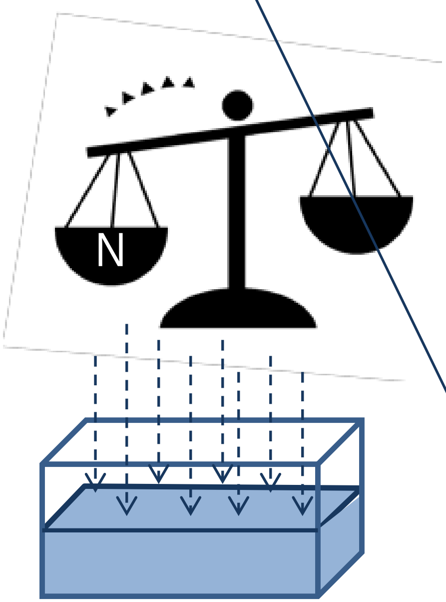


*Alternative Field Crops Manual, 1989. University of Minnesota and University of Wisconsin -Madison
Nutrient application guidelines for field, vegetable and fruit crops

How much nitrogen does it take to raise groundwater nitrate 1 ppm?

The actual amount will vary based on the amount of recharge. For Wisconsin this is likely somewhere between 6 and 10 inches depending on where you live. For Spring Green we will assume that nitrogen not taken up by the plant will mineralize and nitrify.

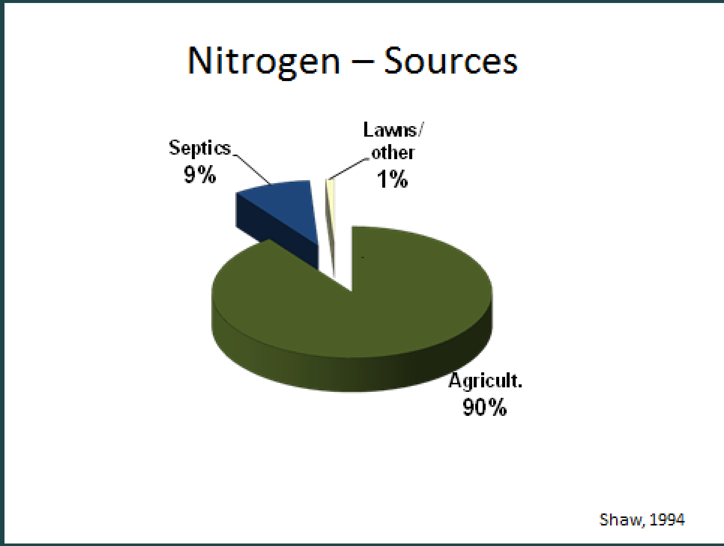
$$\frac{8\ \text{in.}}{} \times \frac{10\ \text{mg}\ NO_3\text{-}N}{\text{liters}} \times \frac{43{,}560\ \text{ft}^2}{1\ \text{acre}} \times \frac{1\ \text{ft.}}{12\ \text{in.}} \times \frac{28.32\ \text{liters}}{1\ \text{ft}^3} \times \frac{1\ \text{g}}{1000\ \text{mg}} \times \frac{1\ \text{kg}}{1000\ \text{g}} \times \frac{2.2\ \text{lbs}}{1\ \text{kg}} = 18.1\ \text{lbs N per acre}$$



	Nitrate-Nitrogen Concentration (mg/L)									
	1	2	3	4	5	10	15	20	30	40
Inches of Recharge	lbs of Nitrogen per acre									
1	0.2	0.5	0.7	0.9	1.1	2.3	3.4	4.5	6.8	9.0
2	0.5	0.9	1.4	1.8	2.3	4.5	6.8	9.0	13.6	18.1
3	0.7	1.4	2.0	2.7	3.4	6.8	10.2	13.6	20.4	27.1
4	0.9	1.8	2.7	3.6	4.5	9.0	13.6	18.1	27.1	36.2
5	1.1	2.3	3.4	4.5	5.7	11.3	17.0	22.6	33.9	45.2
6	1.4	2.7	4.1	5.4	6.8	13.6	20.4	27.1	40.7	54.3
7	1.6	3.2	4.7	6.3	7.9	15.8	23.7	31.7	47.5	63.3
8	1.8	3.6	5.4	7.2	9.0	18.1	27.1	36.2	54.3	72.4
9	2.0	4.1	6.1	8.1	10.2	20.4	30.5	40.7	61.1	81.4
10	2.3	4.5	6.8	9.0	11.3	22.6	33.9	45.2	67.8	90.5

Comparing Land-use Impacts

	Corn[1] (per acre)	Prairie[1] (per acre)	Septic[2] System
Total Nitrogen Inputs (lb)	169	9	20-25
Nitrogen Leaching Loss (lb)	36	0.04	16-20
Amount N lost to leaching (%)	20	0.4	80-90



1 Data from Masarik, Economic Optimum Rate on a silt-loam soil, 2003
2 Data from Tri-State Water Quality Council, 2005 and EPA 625/R-00/008

Comparing Land-use Impacts

20 acres

36 lbs	36 lbs	36 lbs	36 lbs
36 lbs	36 lbs	36 lbs	36 lbs
36 lbs	36 lbs	36 lbs	36 lbs
36 lbs	36 lbs	36 lbs	36 lbs
36 lbs	36 lbs	36 lbs	36 lbs

36 lbs/ac x 20 acres = 720 lbs

16 mg/L

20 acres

20 lbs

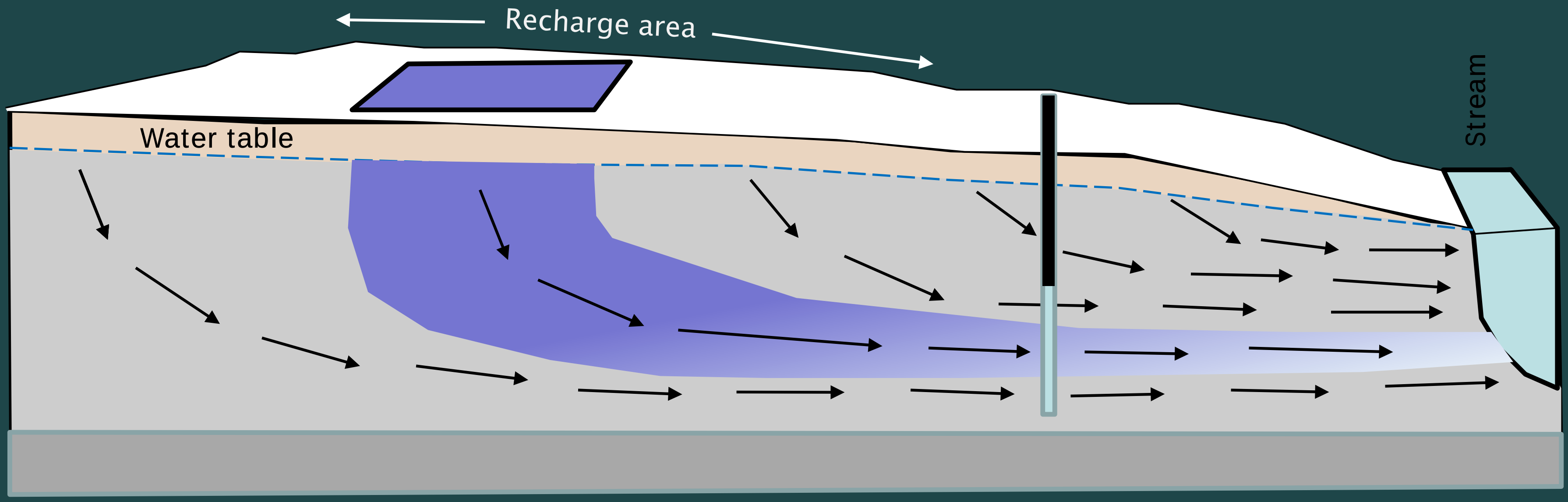
20 lbs/septic system x 1 septic systems = 20 lbs

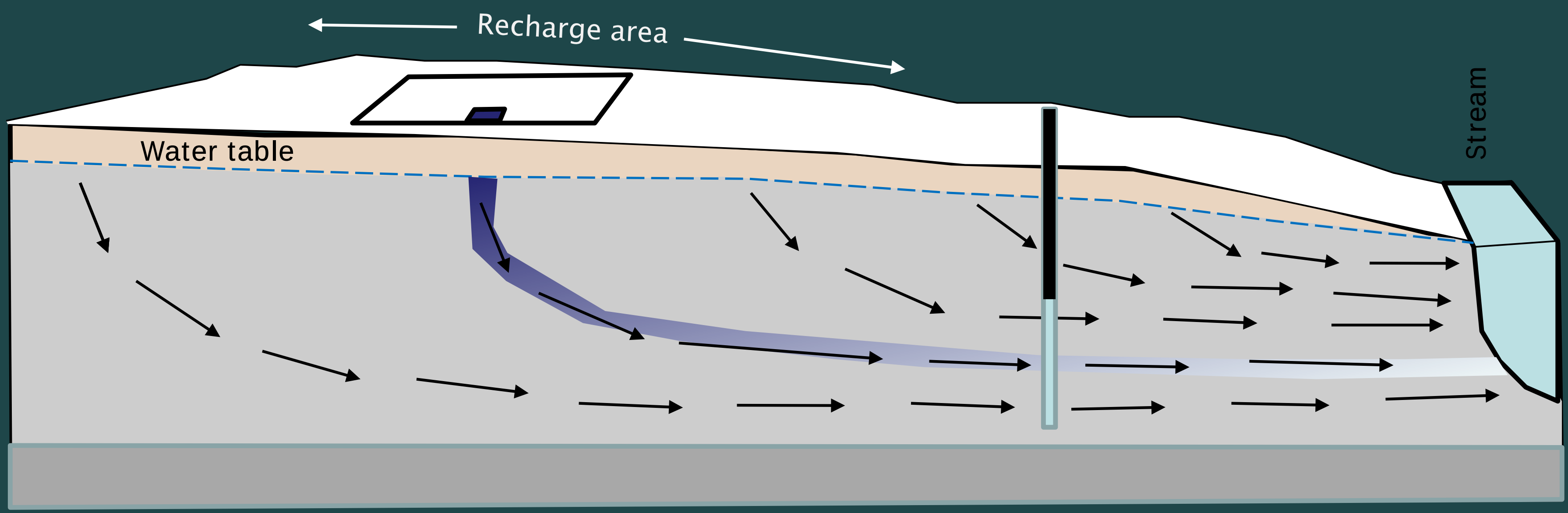
1/36th the impact on water quality

0.44 mg/L

Assuming 10 inches of recharge -

36 lbs/ac x 20 acres = 720 lbs





20 lbs/septic system

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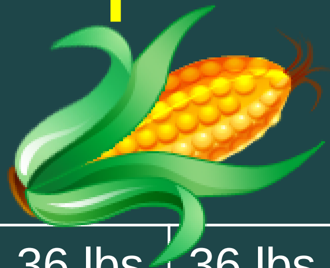
Comparing Land-use Impacts



20 acres

36 lbs	36 lbs	36 lbs	36 lbs
36 lbs	36 lbs	36 lbs	36 lbs
36 lbs	36 lbs	36 lbs	36 lbs
36 lbs	36 lbs	36 lbs	36 lbs
36 lbs	36 lbs	36 lbs	36 lbs

36 lbs/ac x 20 acres = 720 lbs

20 acres

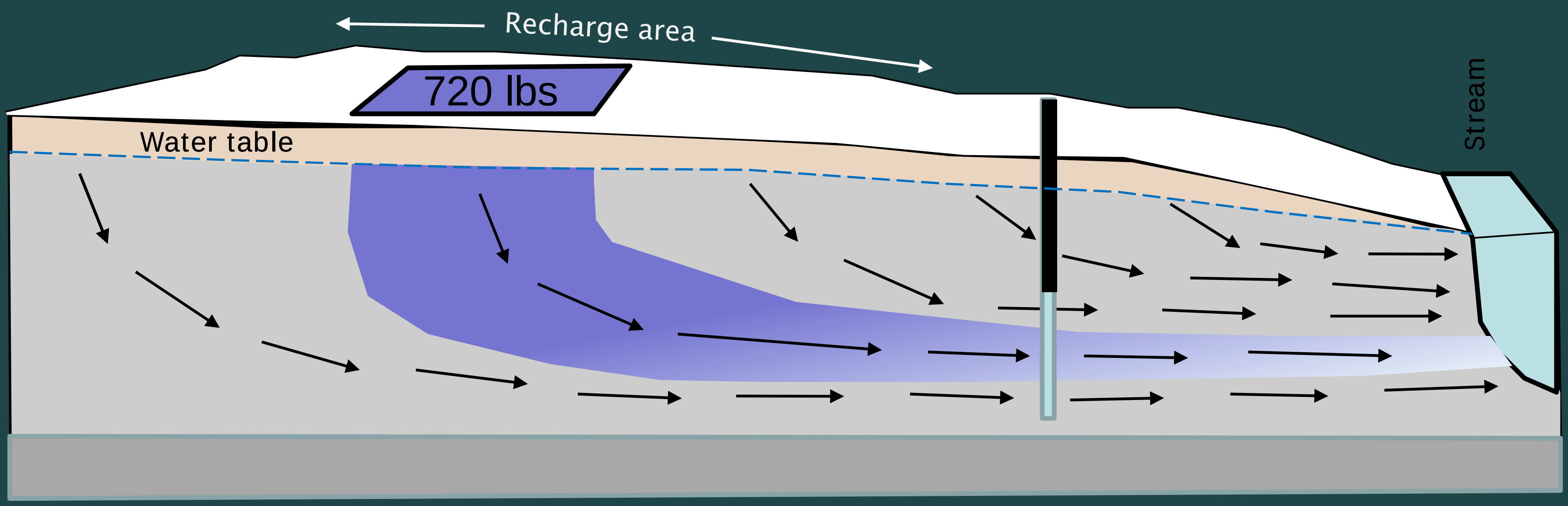
20 lbs	20 lbs	20 lbs	20 lbs
20 lbs	20 lbs	20 lbs	20 lbs
20 lbs	20 lbs	20 lbs	20 lbs
20 lbs	20 lbs	20 lbs	20 lbs
20 lbs	20 lbs	20 lbs	20 lbs
20 lbs	20 lbs	20 lbs	20 lbs
20 lbs	20 lbs	20 lbs	20 lbs
20 lbs	20 lbs	20 lbs	20 lbs
20 lbs	20 lbs	20 lbs	20 lbs

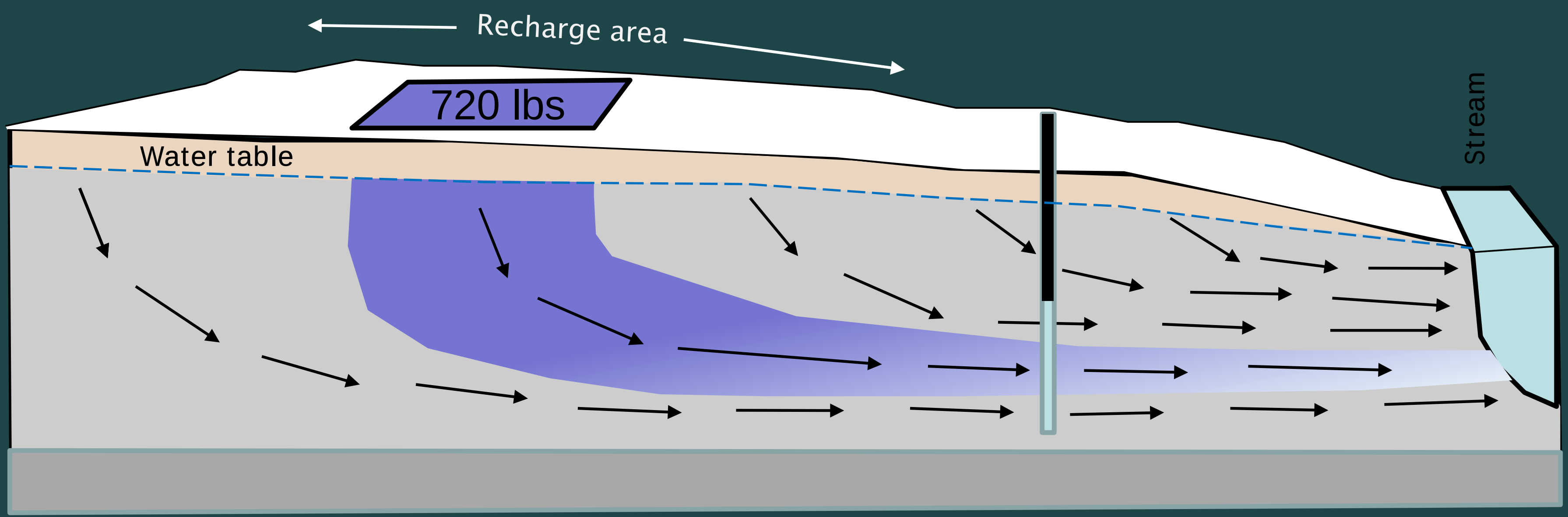
20 lbs/septic system x 36 septic systems = 720 lbs

Using these numbers: 36 septic systems on 20 acres (0.55 acre lots) needed to achieve same impact to water quality as 20 acres of corn

Masarik, UW-Extension

36 lbs/ac x 20 acres = 720 lbs

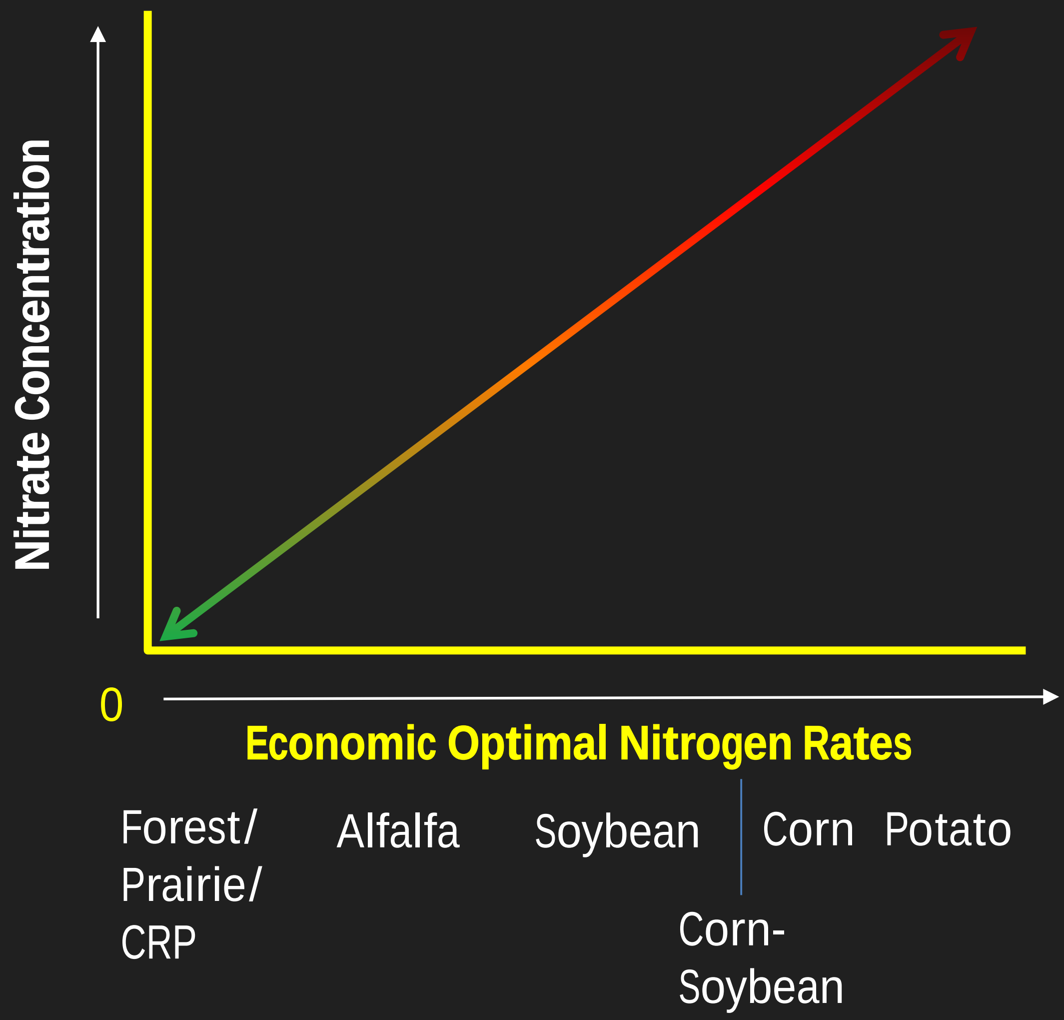




20 lbs/septic system x 36 septic systems = 720 lbs

Masarik, UW-Extension

Generalized Nitrate Leaching Potential



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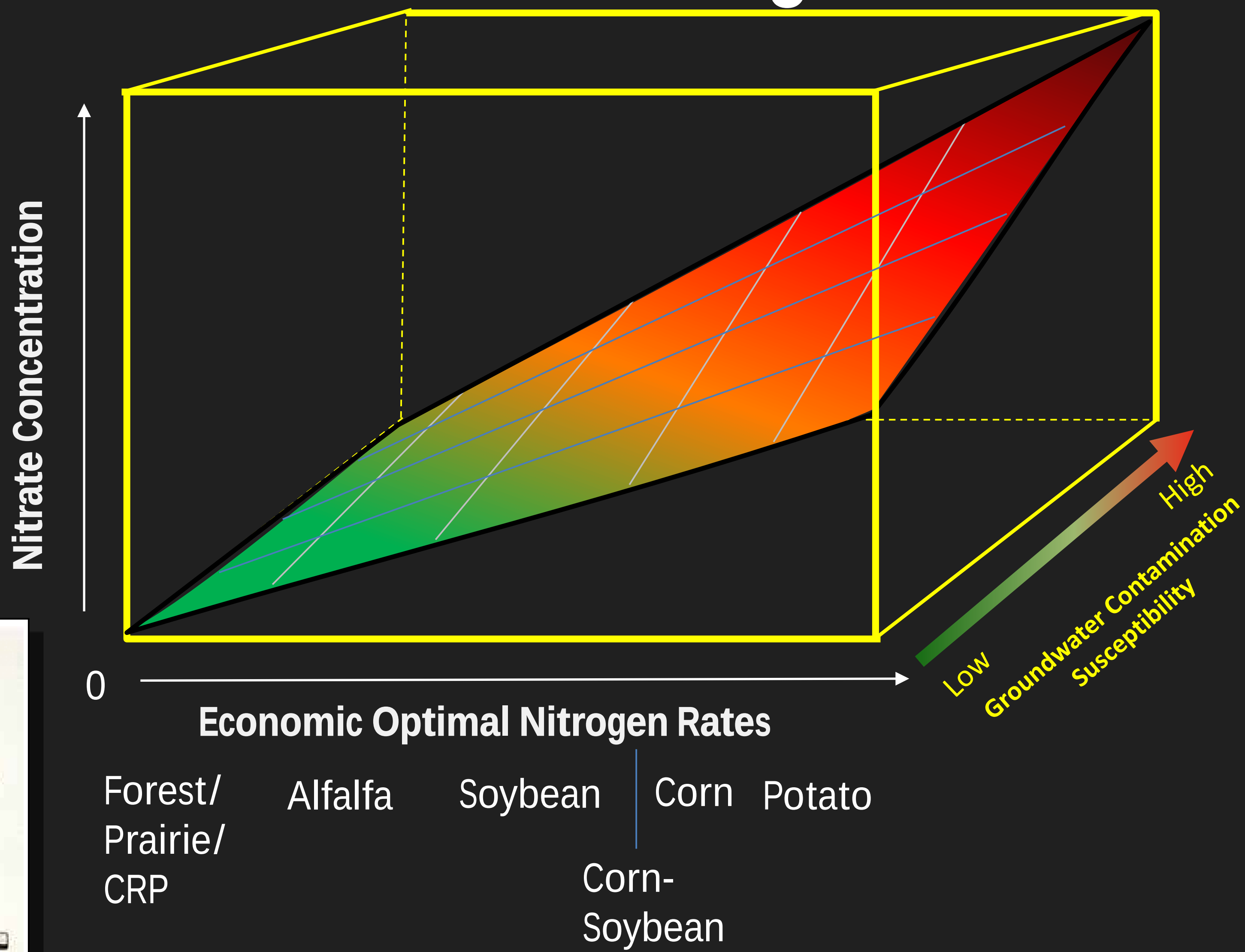
Generalized Nitrate Leaching Potential



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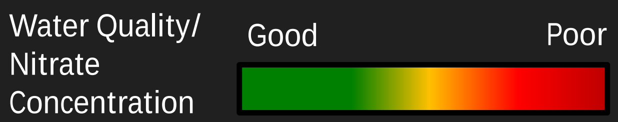
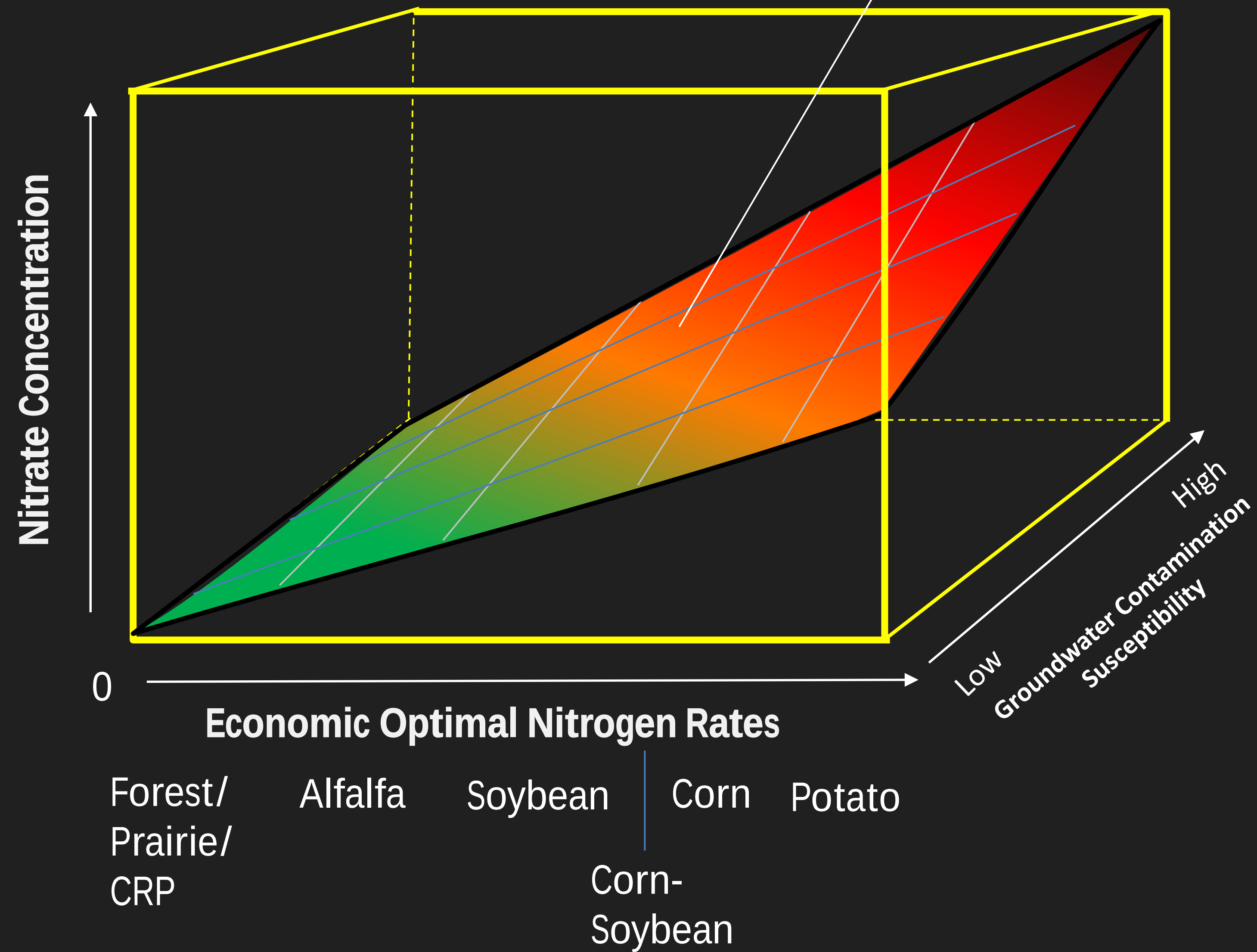
Nitrogen Fertilizer Recommendations get us to a baseline Level of nitrate concentration in groundwater ~ *Right Amount*





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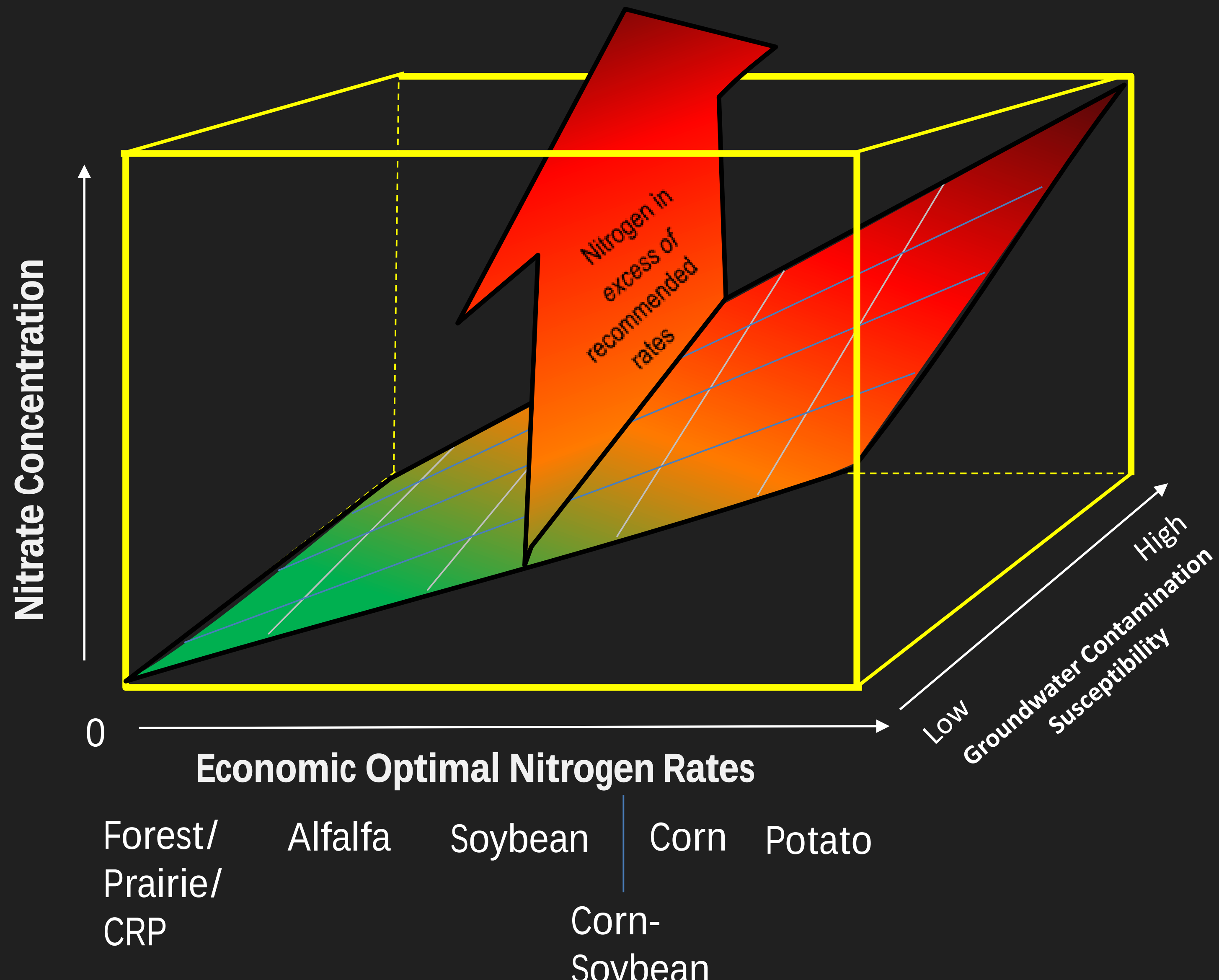
Nitrogen in excess of economic optimal rates



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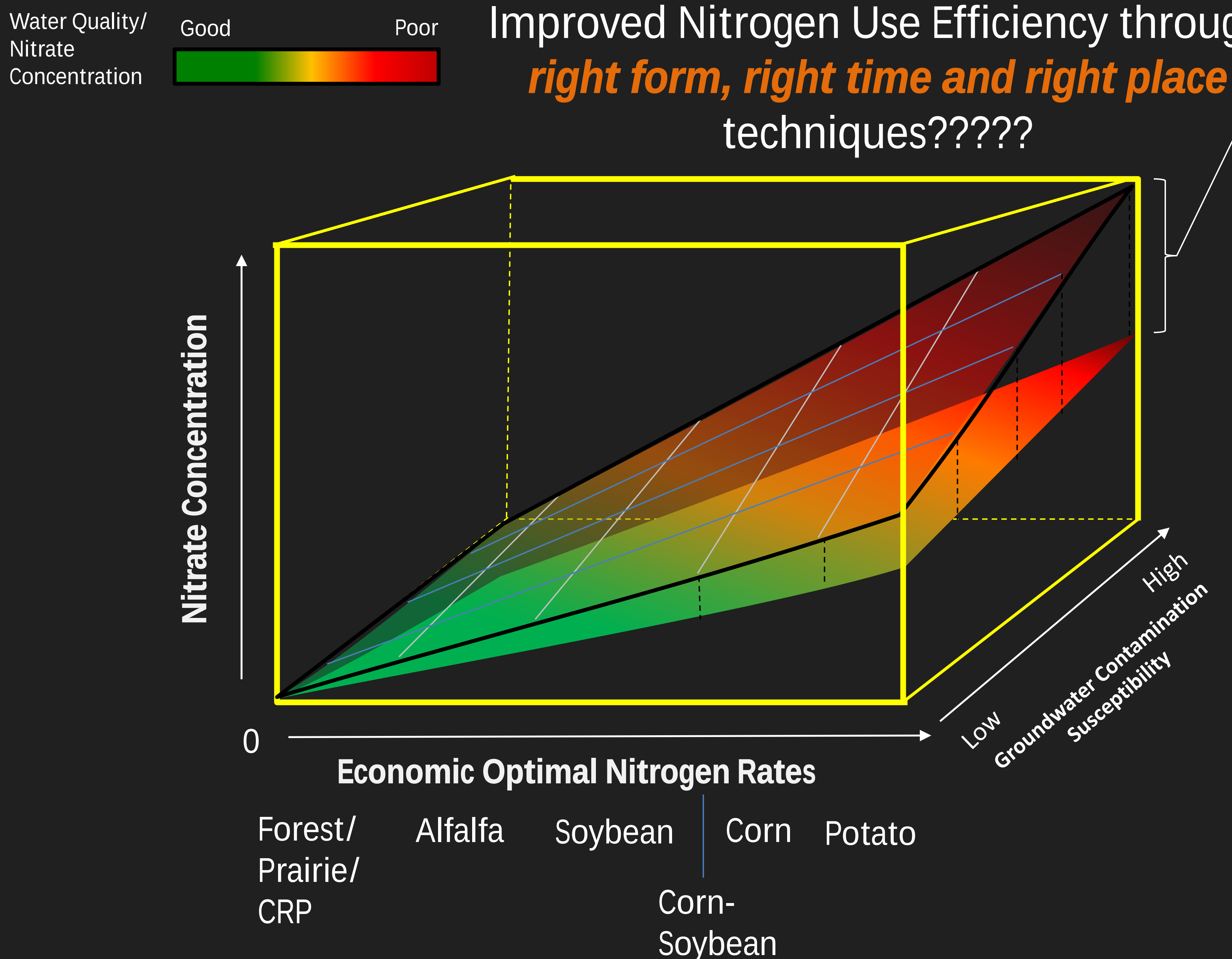
Improved Nitrogen Use Efficiency through *right form, right time and right place* techniques?????



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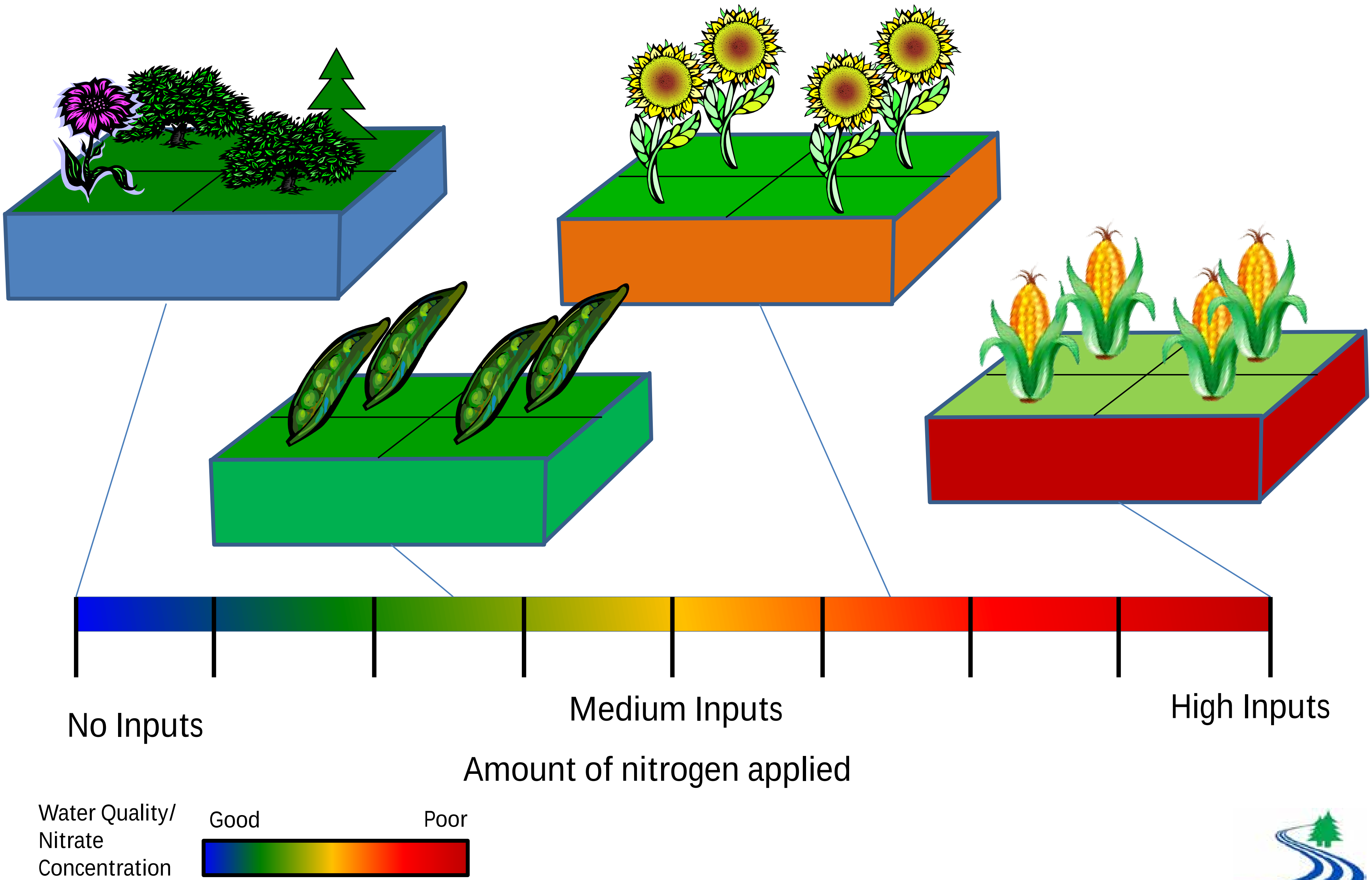
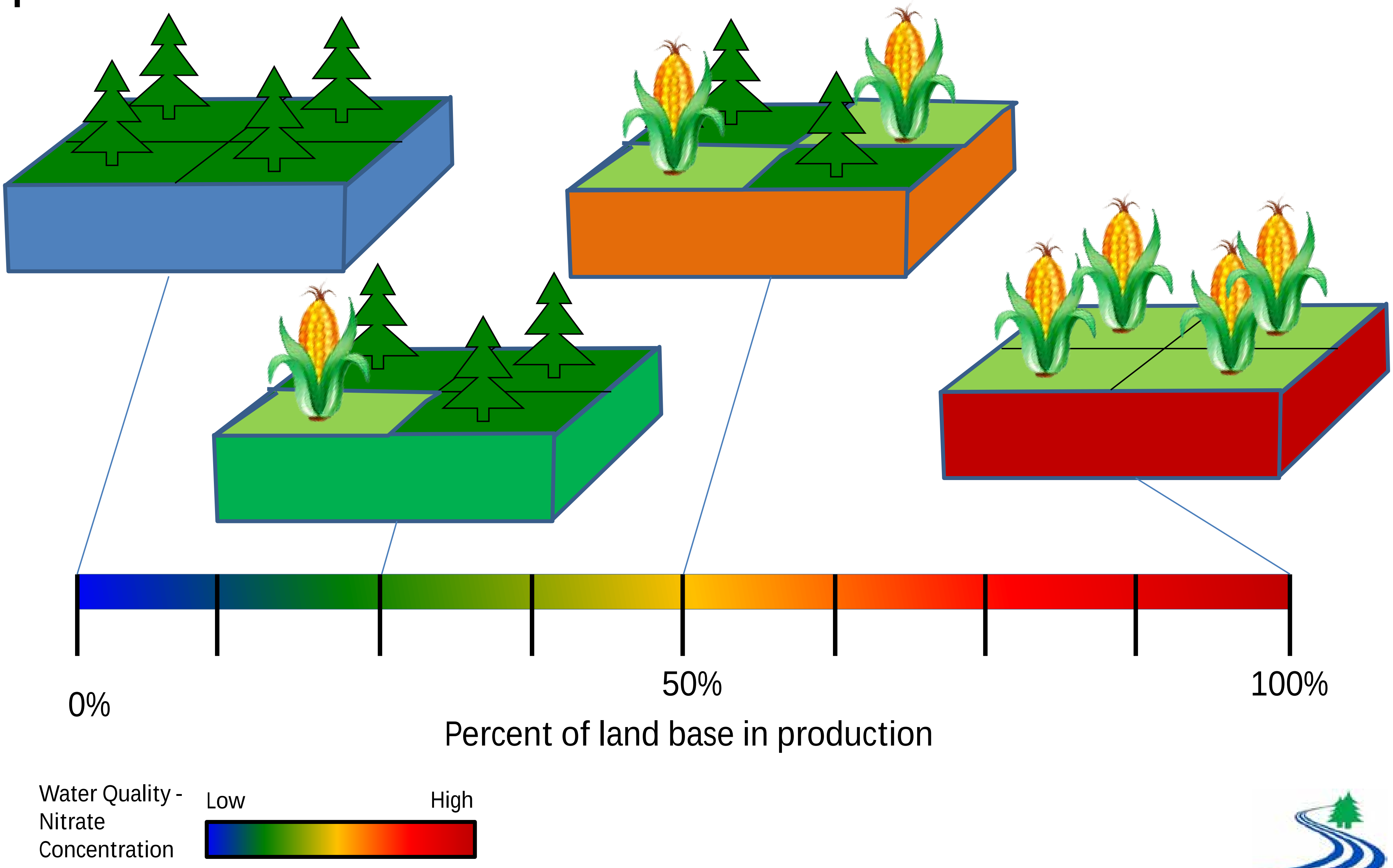
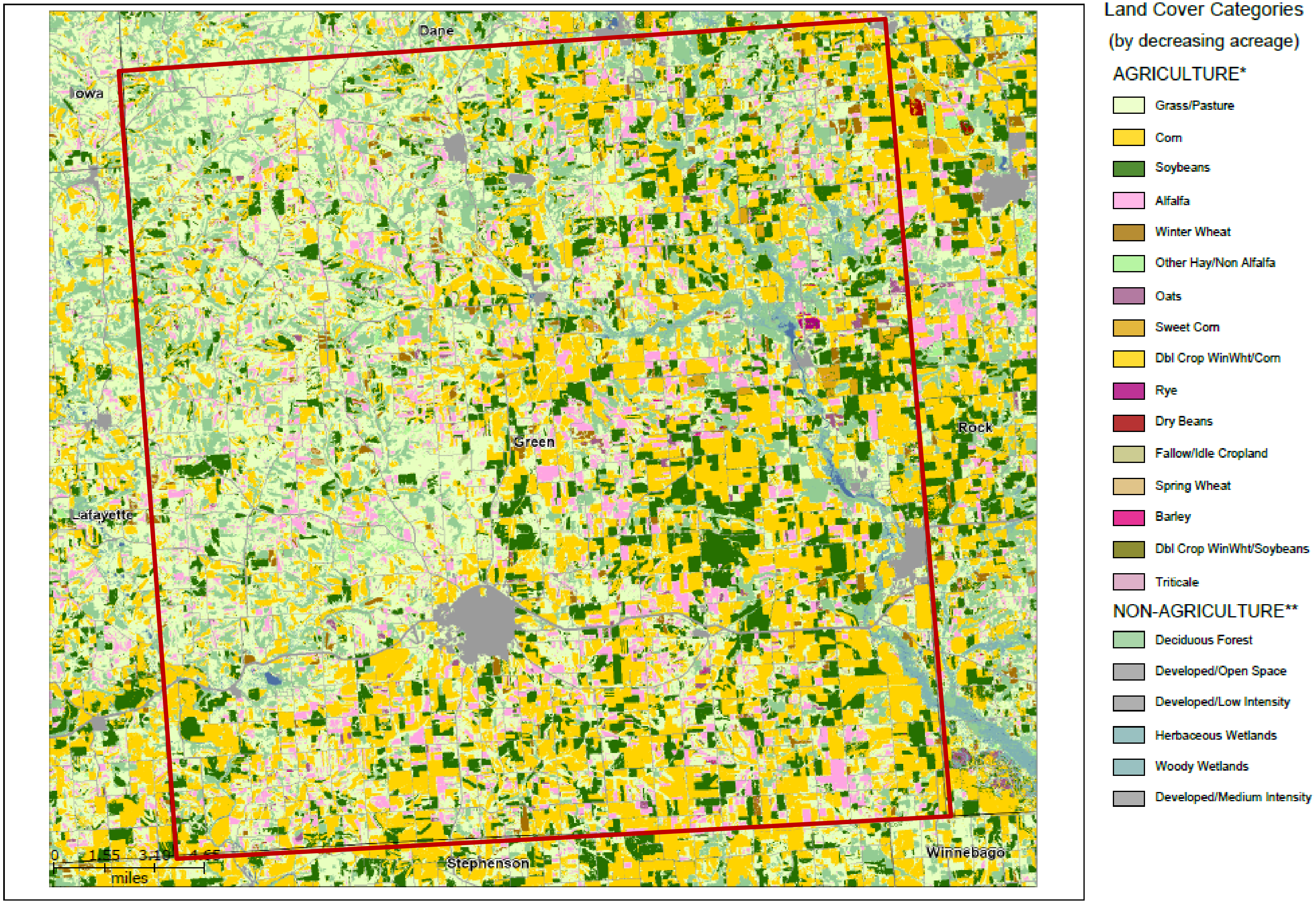
Water quality as a function of crop N recommendations



Water quality as a function of watershed area in production



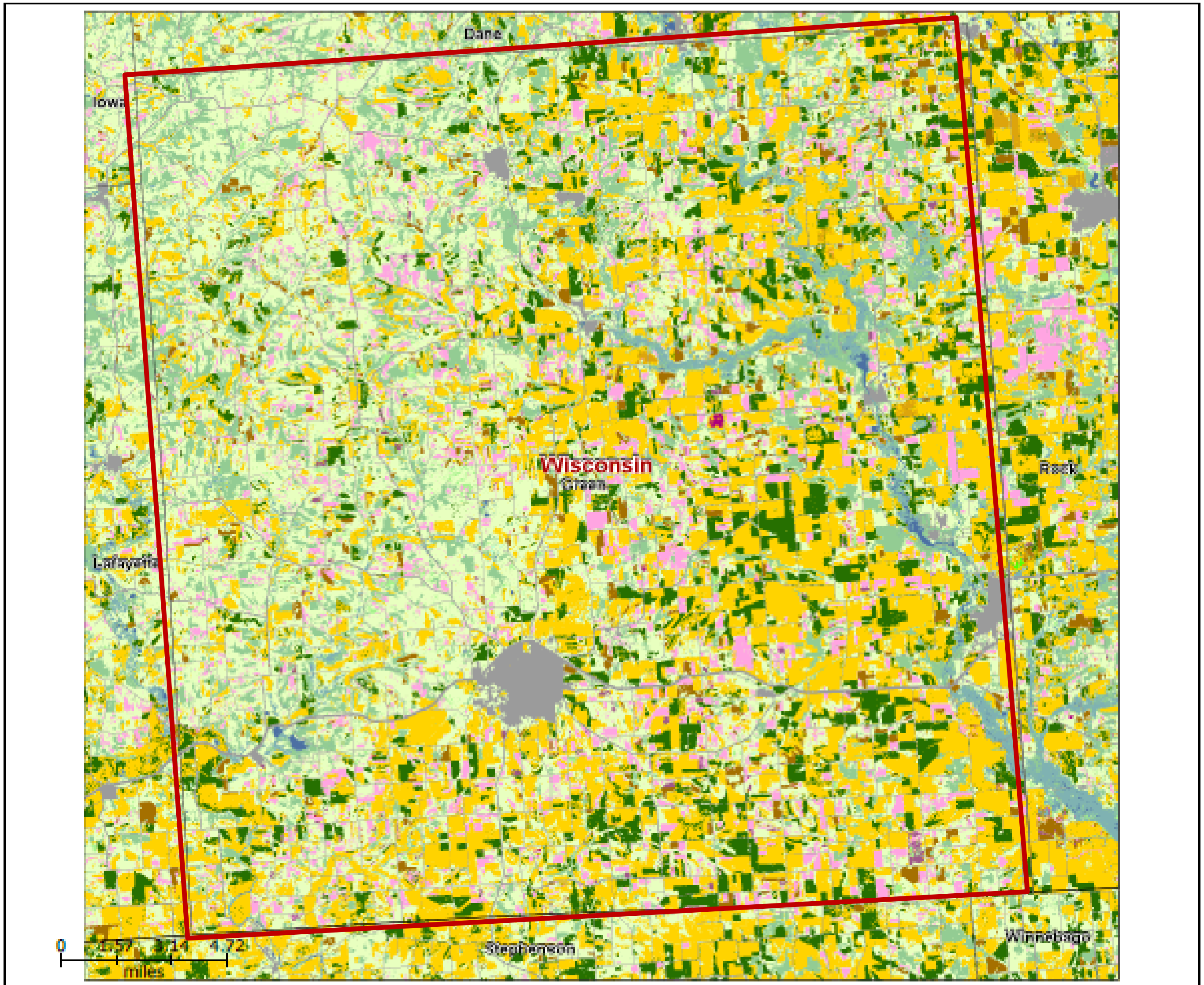
2014 Area of Interest



Produced by CropScape - http://nassgeodata.gmu.edu/CropScape

* Only top 16 agriculture categories are listed. ** Only top 6 non-agriculture categories are listed.

2013 Area of Interest



Land Cover Categories
(by decreasing acreage)

AGRICULTURE*

- Grass/Pasture
- Corn
- Soybeans
- Alfalfa
- Winter Wheat
- Other Hay/Non Alfalfa
- Oats
- Sweet Corn
- Dbl Crop WinWht/Corn
- Rye
- Fallow/Idle Cropland
- Sorghum
- Peas
- Dbl Crop WinWht/Soybeans
- Sod/Grass Seed
- Dbl Crop Soybeans/Oats

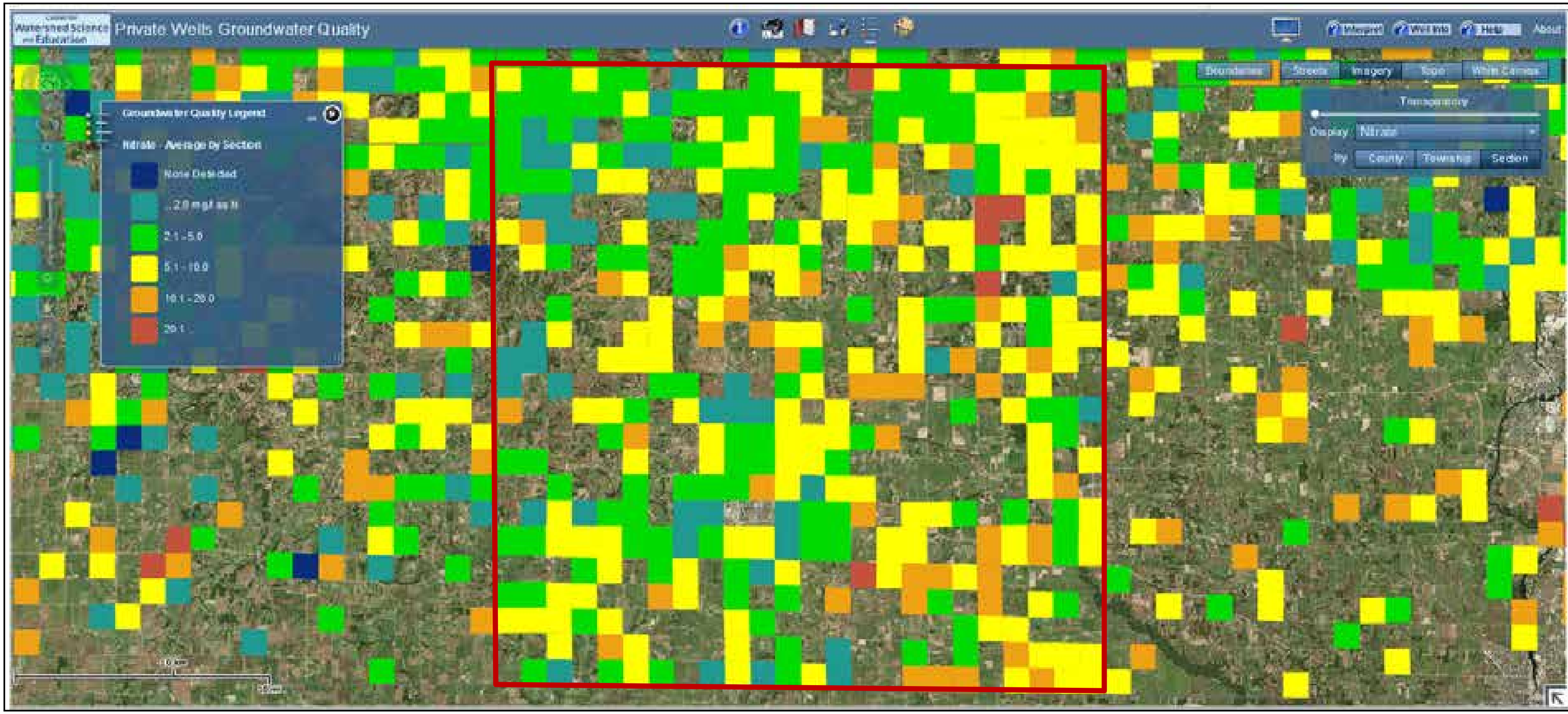
NON-AGRICULTURE**

- Deciduous Forest
- Developed/Open Space
- Developed/Low Intensity
- Herbaceous Wetlands
- Woody Wetlands
- Developed/Medium Intensity

Produced by CropScape - http://nassgeodata.gmu.edu/CropScape

* Only top 16 agriculture categories are listed. ** Only top 6 non-agriculture categories are listed.

Average Nitrate-N concentration by section.



Range	Number	Percent	Summary
None Detected	194	7%	Minimum: No Detect
... 2.0	622	23%	
2.1 - 5.0	724	27%	Median: 4.1
5.1 - 10.0	694	26%	Average: 5.61288
10.1 - 20.0	364	14%	
20.1 ...	64	2%	Maximum: 69.9
Total	2662		
> 10mg/l N	428	16%	Exceeds Health Standard

http://www.uwsp.edu/cnr-ap/watershed/Pages/wellwaterviewer.aspx

Green County
Nitrate Summary

Factors affecting nitrogen loss to groundwater

Within our control

- Amount of nitrogen applied
  - As a function of cropping system
  - Nitrogen application rate relative to economic optimum – *right amount*
  - When, where, what form
- Percent of land base in production

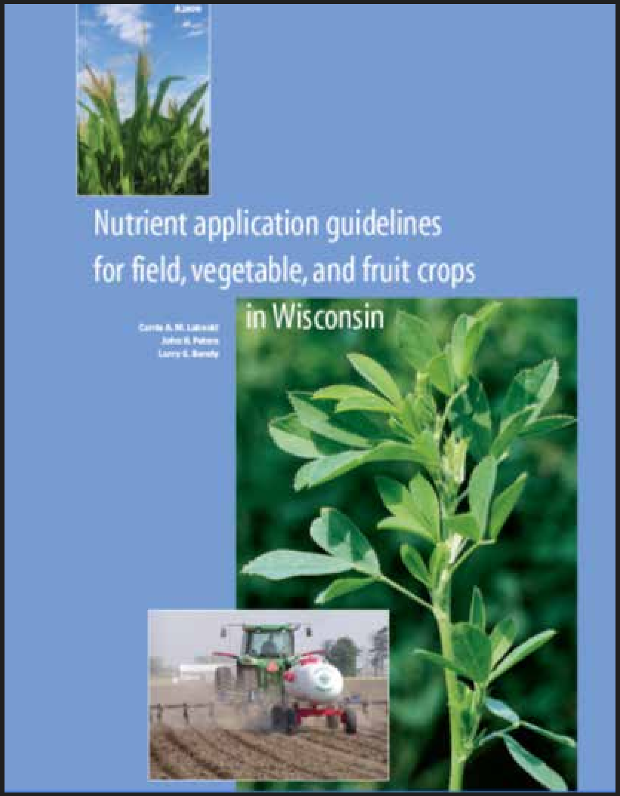
Out of our control

- Geology
- Soil Type
- Precipitation / Climate

Nutrient Guidelines and Nutrient Management*

- **Do** save farmers money by ensuring nitrogen is used efficiently
- **Do** allow farms to maximize profitability while holding everyone accountable to some standard
- **Do** prevent fields from being treated as dumping grounds for manure and other bio-solids
- **Do** help reduce excessively high concentrations of nitrate in groundwater

- **Don't** prevent nitrate from leaching into groundwater
- **Don't** ensure groundwater quality meets drinking water standards
- **Don't** ensure that groundwater quality in areas that already apply at economic optimum rates will get better over time



*Risk management strategy, does not eliminate environmental impacts

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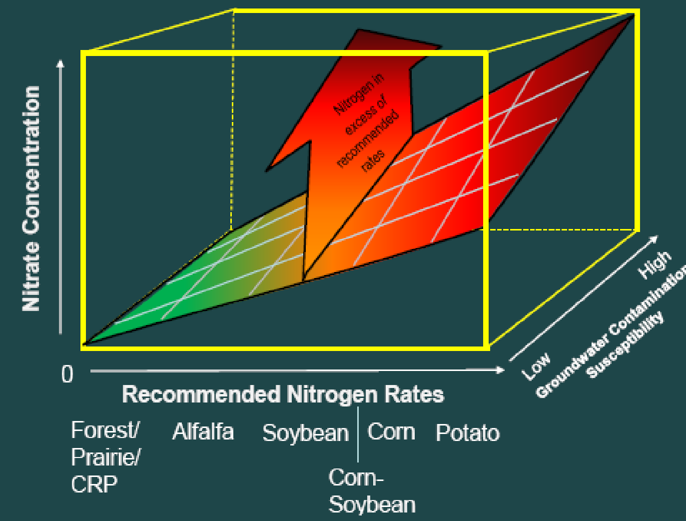
Conclusions

- Nutrient management is a first step that creates a baseline concentration of nitrate in groundwater that reflects crop rotation and geology/soils.
- Significant nitrate leaching can occur even when nitrogen recommendations are followed – no environmental optimum rate
- Nutrient management and crediting of N will help reduce extreme nitrate concentrations in groundwater and reduce risk of brown water incidents in groundwater
- May take years or decades for groundwater quality to reflect changes in land-use practices

Nitrate = f(Crop + Excess N + soils/geology)



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Center for Watershed Science and Education
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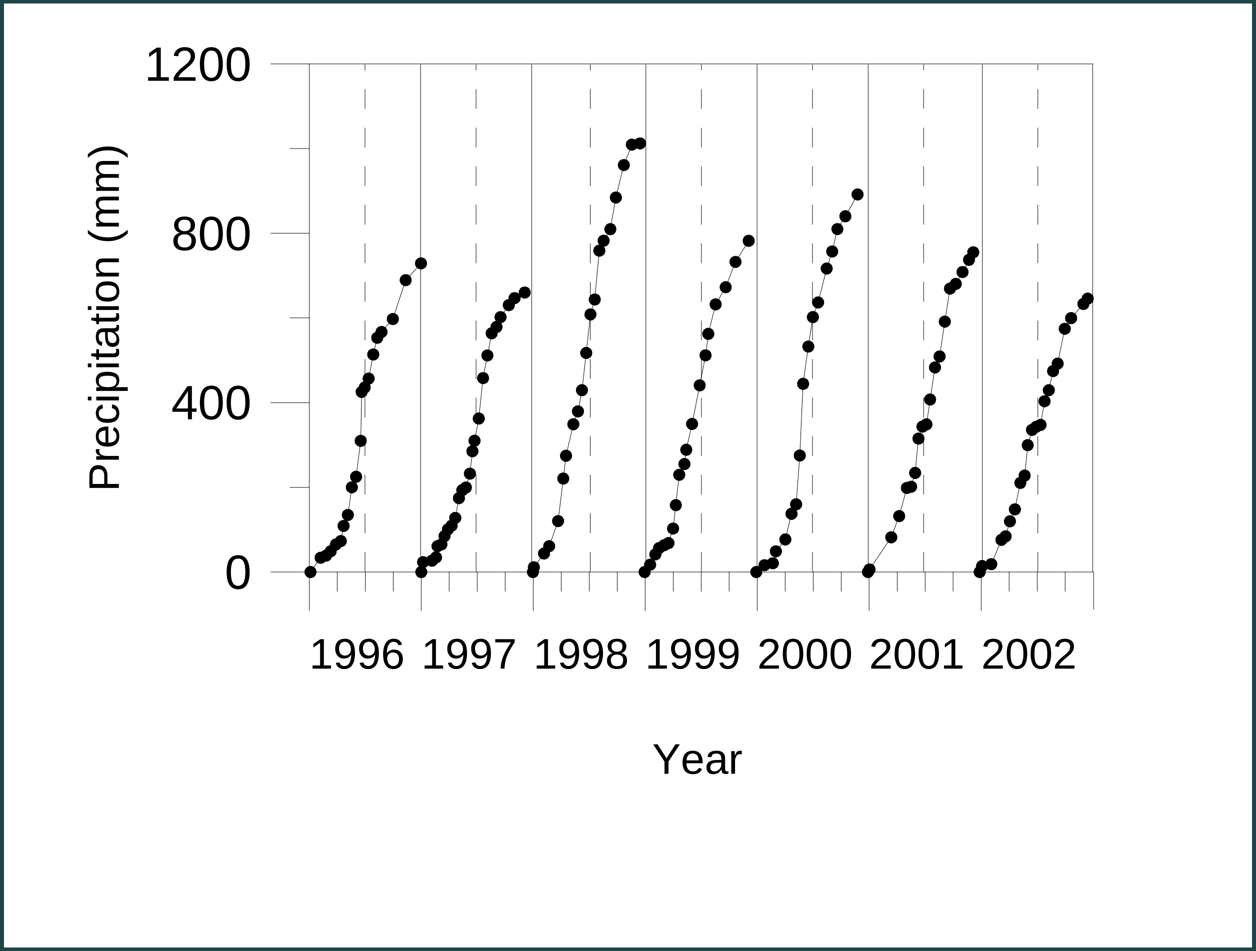
Stevens Point, WI 54481
715-346-4276
kmasarik@uwsp.edu

http://www.youtube.com/watch?v=BKrN2HdvGp4

Annual Cumulative Precipitation

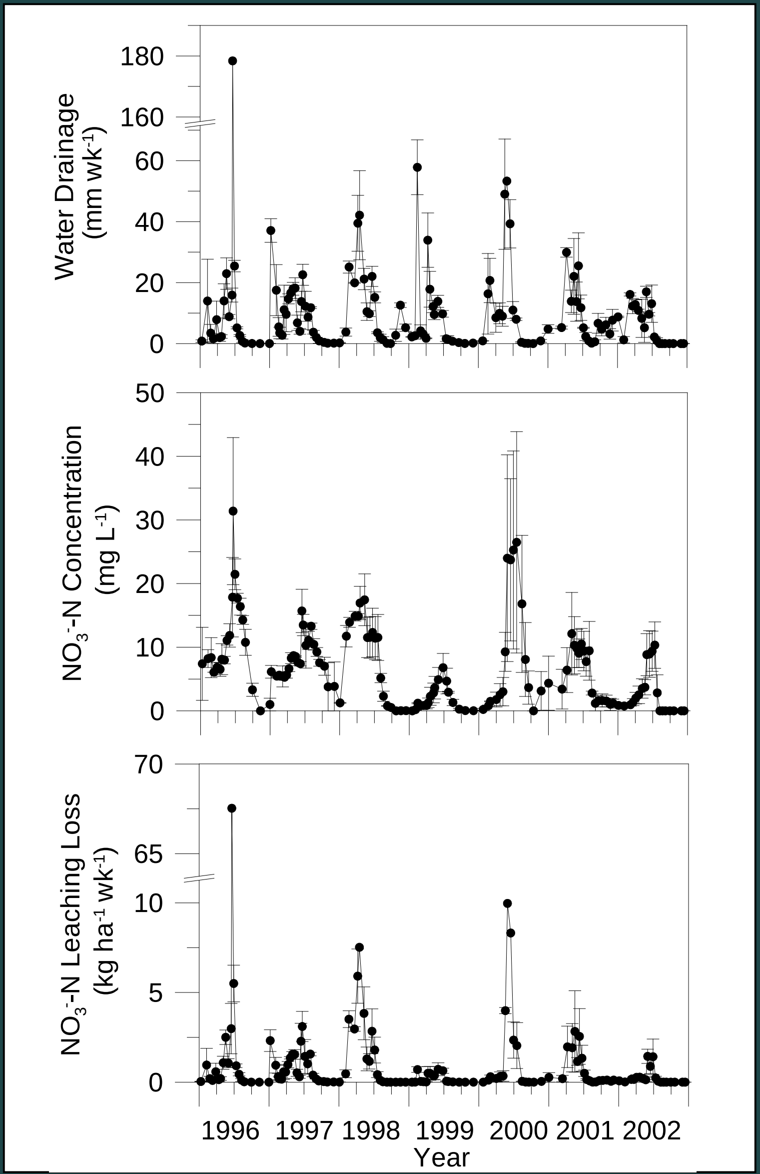


Long-term Nitrate Leaching Study

Water drainage
(mm)

NO_3-N concentration
(mg L^{-1})

NO_3-N leaching loss
(kg ha^{-1})



Annual Cumulative Water Drainage & Nitrate Leaching