Agricultural Production and Effects on Groundwater

• Pathogens
• Nitrate
• Pesticides

Kevin Masarik

Center for Watershed Science and Education
Private vs. Public Water Supplies

Public Water Supplies

- Regularly tested and regulated by drinking water standards.

Private Wells
(1/3 of WI population)

- Not required to be regularly tested.
- Not required to take corrective action.
- Owners must take special precautions to ensure safe drinking water.
Private wells installed 1988-2006

% Change in Dairy Cow Numbers from 1983-2012 by County

Figure 4
Prime Farmland by Land Cover/Use
Between 1982 and 2007 the state lost nearly 800,000 acres of prime cropland. About half was likely diverted to other agricultural uses (CRP, pasture, forest, other) while the remainder may have been permanently converted to non-agricultural uses.
Coliform bacteria test

- 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

- Well Code: “Properly constructed well should be able to provide bacteria free water continuously without the need for treatment”

- 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

Zero bacteria

Absent = Safe

Greater than or equal to 1
If coliform bacteria was detected, we also checked for E.coli bacteria test

- 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.
Manure Contamination of Groundwater

• Bacteria and other pathogens are the most immediate health concerns related to drinking water.
• Areas most at risk have shallow fractured bedrock
• Technology better at determining source but generally not cost effective for the average homeowner
• “Known” Incidents of manure contamination of wells will likely increase:
  – As development spills out into agricultural regions
  – As dairy operations get larger
  – Climate change??
Nitrate-Nitrogen Concentration

- **Less than 2 mg/L**
  - Close to “natural” or background levels
  - Impacted by local land use activities but suitable for drinking. *May indicate other contaminants.*

- **Greater than 2 mg/L**
  - UNSAFE - for infants and pregnant women; everyone should avoid long term consumption.

- **Greater than 10 mg/L**
  - UNSAFE - for infants and pregnant women; everyone should avoid long term consumption.

**Sources**
- Agricultural fertilizer
- Lawn fertilizer
- Septic systems
- Animal wastes
- Decomposing wastes
US & Wis. fertilizer nitrogen use (1960-95)

Nitrate concentrations in groundwater will get worse before they stabilize.
Comparing Land-use Impacts

<table>
<thead>
<tr>
<th></th>
<th>Corn(^1) (per acre)</th>
<th>Prairie(^1) (per acre)</th>
<th>Septic(^2) System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Nitrogen Inputs (lb)</td>
<td>169</td>
<td>9</td>
<td>20-25</td>
</tr>
<tr>
<td>Nitrogen Leaching Loss (lb)</td>
<td>36</td>
<td>0.04</td>
<td>16-20</td>
</tr>
<tr>
<td>Amount N lost to leaching (%)</td>
<td>20</td>
<td>0.4</td>
<td>80-90</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>36 lbs/acre x 20 acres</th>
<th>20 lb septic system x 1 septic system</th>
</tr>
</thead>
<tbody>
<tr>
<td>36 lbs</td>
<td>20 lbs</td>
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<td>36 lbs</td>
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<td>36 lbs</td>
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</tr>
</tbody>
</table>

36 lbs/acre x 20 acres = 720 lbs

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

1/36th the impact on water quality

Assuming 10 inches of recharge -

16 mg/L

0.44 mg/L

Masarik, UW-Extension
### Comparing Land-use Impacts

<table>
<thead>
<tr>
<th>36 lbs » 20 acres</th>
<th>20 lbs » 36 septic systems</th>
</tr>
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<tbody>
<tr>
<td>36 lbs</td>
<td>20 lbs</td>
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</tr>
</tbody>
</table>

- **36 lbs/ac x 20 acres = 720 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.

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What can I do to reduce my nitrate levels?

- **Long-term:**
  - 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
Chippewa Falls Nitrate Removal

Total Costs
• $2.3 million = Capital Costs
• $72,000 = Operating and Maintenance

Cost per pound of NO$_3$-N
• $0.82 per pound (just O & M)
• $2.12 per pound (includes capital costs/20 y)
Private Well Nitrate Removal

- Most residential treatment systems are point-of-use systems.
  - Reverse Osmosis
  - Distillation
- Treat only a small quantity of water (~10 gal/d)
- $83 per pound
  - Conservative estimate, includes only cost of equipment assuming lifespan of 20 years.
Pesticides in Drinking Water

- Insecticides, herbicides, fungicides and other substances used to control pests.
- Health standards usually only account for parent compound.
- Parent compounds breakdown over time.
- Little research into health effects from the combination of chemicals.

Most frequently detected pesticides in WI:
- Alachlor* (Lasso) and its chemical breakdown products (Alachlor ESA)
- Metolachlor (Dual) and its chemical breakdown products (Metolachlor ESA)
- Atrazine** and its chemical breakdown products
- Metribuzin
- Cyanazine and its chemical breakdown products.

* WI public health groundwater standard for breakdown component Alachlor ESA.
** WI public health groundwater standard is for the total chlorinated atrazine residue.
Agricultural Chemicals in Wisconsin Groundwater

- The statewide estimates of the proportion of wells containing atrazine, atrazine TCR, nitrate-nitrogen over 10 mg/l, metolachlor ESA and alachlor ESA did not show statistically-significant changes between 2001 and 2007.
- The estimate for the proportion of wells that exceeded the 10 mg/l enforcement standard for nitrate-nitrogen was 9.0%.
- The statewide estimate of the proportion of wells that contained a detectable level of a pesticide or pesticide metabolite was 33.5%.
- Alachlor ESA and metolachlor ESA were the most commonly detected herbicide compounds with identical proportion estimates of 21.6%.
- The statewide estimate of the proportion of wells that contained atrazine TCR was 11.7%.
- The estimate for the proportion of wells that exceeded the 3 ug/l enforcement standard for atrazine TCR was 0.4%.

**Table 2b**

<table>
<thead>
<tr>
<th>NASS Strata</th>
<th>Strata Description</th>
<th>Number of Samples</th>
<th>Atrazine TCR</th>
<th>Alachlor ESA</th>
<th>Metolachlor ESA</th>
<th>Nitrate-N</th>
<th>Nitrate-N&gt;10 mg/l</th>
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</thead>
<tbody>
<tr>
<td>11</td>
<td>&gt;75% Cultivated</td>
<td>134</td>
<td>5.2</td>
<td>17</td>
<td>36</td>
<td>46</td>
<td>63</td>
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<tr>
<td>12</td>
<td>51-75% Cultivated</td>
<td>50</td>
<td>2.0</td>
<td>20</td>
<td>28</td>
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<td>20</td>
<td>15-50% Cultivated</td>
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<td>13</td>
<td>20</td>
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<tr>
<td>40</td>
<td>&lt;15% Cultivated</td>
<td>59</td>
<td>8.1</td>
<td>5.1</td>
<td>12</td>
<td>10</td>
<td>47</td>
</tr>
</tbody>
</table>

* quantifiable and non-quantifiable detects
** the percentages for the Agri-Urban stratum are not included because of the small number of samples
Bacteria and Nitrate Issues

Shallow soils overlying fractured Silurian dolomite
Sandy Regions
Elevated Nitrate Regions

Well drained soils and high density of corn/soybean cropping systems
Transient Non-Community Well Water Systems
8,594 systems

Was the linear regression analysis significant at the 95% confidence level?  
Yes  
No  
5,701

Was the rate of change greater than 1 mg/L over a 10 year period?  
Yes  
No  
7447 (87%) showed no trend or rate of change not significant  
726 (8%) had an increasing trend  
421 (5%) had a decreasing trend

1,147  
1,746  
726  
421

Increasing trend  
Decreasing trend
Transient Non-Comm Systems

Linear Regression Results

• Orange-Red – Increasing
• Blue – Decreasing
• Yellow – no significant trend
% Difference = % Increasing - % Decreasing

<table>
<thead>
<tr>
<th>CTY_NAME</th>
<th>N</th>
<th>N* Mean</th>
<th>SE Mean</th>
<th>StDev</th>
<th>SIG DECREASE</th>
<th>NOT SIG</th>
<th>SIG_INCREASE</th>
<th>TOTAL</th>
<th>% DECREASE</th>
<th>% NO CHANGE</th>
<th>% INCREASE</th>
<th>% INCREASE_RANK</th>
<th>MEAN_RANK</th>
<th>%_difference</th>
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<tbody>
<tr>
<td>Pepin</td>
<td>21</td>
<td>0.333</td>
<td>0.105</td>
<td>0.483</td>
<td>0</td>
<td>14</td>
<td>7</td>
<td>21</td>
<td>0.0</td>
<td>33.3</td>
<td>66.7</td>
<td>3.1</td>
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<tr>
<td>Rock</td>
<td>160</td>
<td>0.2438</td>
<td>0.0441</td>
<td>0.5579</td>
<td>10</td>
<td>101</td>
<td>49</td>
<td>160</td>
<td>6.3</td>
<td>30.6</td>
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<td>2</td>
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<td>Chippewa</td>
<td>169</td>
<td>0.1183</td>
<td>0.0383</td>
<td>0.4978</td>
<td>12</td>
<td>125</td>
<td>32</td>
<td>169</td>
<td>7.1</td>
<td>18.9</td>
<td>74.0</td>
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<td>54</td>
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<td>68</td>
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<td>79</td>
<td>26</td>
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<td>66.9</td>
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<td>5</td>
<td>11.0</td>
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<td>Kewaunee</td>
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<td>0.1042</td>
<td>0.0446</td>
<td>0.3087</td>
<td>6</td>
<td>43</td>
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<td>48</td>
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<td>5.4</td>
<td>98.6</td>
<td>24</td>
<td>6</td>
<td>10.4</td>
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<tr>
<td>Columbia</td>
<td>119</td>
<td>0.1008</td>
<td>0.0468</td>
<td>0.5108</td>
<td>10</td>
<td>87</td>
<td>22</td>
<td>119</td>
<td>8.4</td>
<td>18.5</td>
<td>73.1</td>
<td>6</td>
<td>7</td>
<td>10.1</td>
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<tr>
<td>Marathon</td>
<td>191</td>
<td>0.0995</td>
<td>0.0337</td>
<td>0.4652</td>
<td>12</td>
<td>148</td>
<td>31</td>
<td>191</td>
<td>6.3</td>
<td>16.2</td>
<td>77.5</td>
<td>8</td>
<td>8</td>
<td>9.9</td>
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<tr>
<td>Shawano</td>
<td>112</td>
<td>0.0982</td>
<td>0.0439</td>
<td>0.4642</td>
<td>7</td>
<td>87</td>
<td>18</td>
<td>112</td>
<td>6.3</td>
<td>16.1</td>
<td>77.7</td>
<td>10</td>
<td>9</td>
<td>9.8</td>
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<tr>
<td>Sauk</td>
<td>166</td>
<td>0.0904</td>
<td>0.034</td>
<td>0.4379</td>
<td>9</td>
<td>133</td>
<td>24</td>
<td>166</td>
<td>5.4</td>
<td>14.5</td>
<td>80.1</td>
<td>11</td>
<td>10</td>
<td>9.0</td>
</tr>
</tbody>
</table>
31% of private well samples above the standard.
Town of Spring Green, Sauk County, WI

Nitrate-Nitrogen Concentration (mg/L)
- Less than 2
- 2 - 5
- 5 - 10
- 10 - 20
- Greater than 20

Disclaimer: This map contains voluntarily submitted private well water data from the Center for Watershed Science and Education. It also contains data from the Wisconsin Dept. of Natural Resources Groundwater Retrieval Network. It does not represent all wells and is not considered a scientific study.
Nitrogen Recommendations for Various Crops

*Alternative Field Crops Manual 1990, University of Minnesota and University of Wisconsin-Madison
Nutrient application guidelines for field, vegetable, and fruit crops
Water quality as a function of Nitrogen Use Efficiency

Studies show efficiency typically about 30-50% (Cassman et. al. 2002)

- Less nitrogen than economic optimal results in the same or greater yield.
- Economic optimal nitrogen application results in greater yield.
- Increased nitrogen application results in increased yield but nitrogen use efficiency decreases.
- Increased nitrogen application results in increased yield without an increase in efficiency.

Baseline or Reference Condition

Water Quality - Nitrate Concentration

- Less
- More
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.

<table>
<thead>
<tr>
<th>Inches of Recharge</th>
<th>lbs of Nitrogen per acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.2 0.5 0.7 0.9 1.1 2.3 3.4 4.5 6.8 9.0</td>
</tr>
<tr>
<td>2</td>
<td>0.5 0.9 1.4 1.8 2.3 4.5 6.8 9.0 13.6 18.1</td>
</tr>
<tr>
<td>3</td>
<td>0.7 1.4 2.0 2.7 3.4 6.8 10.2 13.6 20.4 27.1</td>
</tr>
<tr>
<td>4</td>
<td>0.9 1.8 2.7 3.6 4.5 9.0 13.6 18.1 27.1 36.2</td>
</tr>
<tr>
<td>5</td>
<td>1.1 2.3 3.4 4.5 5.7 11.3 17.0 22.6 33.9 45.2</td>
</tr>
<tr>
<td>6</td>
<td>1.4 2.7 4.1 5.4 6.8 13.6 20.4 27.1 40.7 54.3</td>
</tr>
<tr>
<td>7</td>
<td>1.6 3.2 4.7 6.3 7.9 15.8 23.7 31.7 47.5 63.3</td>
</tr>
<tr>
<td>8</td>
<td>1.8 3.6 5.4 7.2 9.0 18.1 27.1 36.2 54.3 72.4</td>
</tr>
<tr>
<td>9</td>
<td>2.0 4.1 6.1 8.1 10.2 20.4 30.5 40.7 61.1 81.4</td>
</tr>
<tr>
<td>10</td>
<td>2.3 4.5 6.8 9.0 11.3 22.6 33.9 45.2 67.8 90.5</td>
</tr>
</tbody>
</table>

\[ 8 \text{ in.} \times 10 \text{ mg} \frac{\text{NO}_3-\text{N}}{43,560 \text{ ft}^2} \times 1 \text{ ft} = 1 \text{ acre} \times 12 \text{ in.} \times 28.32 \text{ liters} \times 1 \text{ g} \times 1 \text{ kg} = 2.2 \text{ lbs per acre} \]

\[ = 18.1 \text{ lbs N per acre} \]
Generalized Nitrate Leaching Potential

- Forest/Prairie/CRP
- Alfalfa
- Soybean
- Corn
- Potato
- Corn-Soybean

Economic Optimal Nitrogen Rates

Nitrate Concentration

Masarik, UW-Extension
Water quality as a function of crop N recommendations

- **No Inputs**
  - Water Quality/Nitrate Concentration: Good

- **Medium Inputs**
  - Water Quality/Nitrate Concentration: Good

- **High Inputs**
  - Water Quality/Nitrate Concentration: Poor
Generalized Nitrate Leaching Potential

Nitrate Concentration

Economic Optimal Nitrogen Rates

Forest/Prairie/CRP

Alfalfa

Soybean

Corn

Potato

Corn-Soybean

Groundwater Contamination Susceptibility

Low

High

Masarik, UW-Extension
GW NO3-N = f(Crop N Requirements, Excess N, Soils, Geology)

Masarik, UW-Extension
UW Nitrogen Guidelines get us to a baseline Level of nitrate concentration in groundwater.
Water quality as a function of watershed area in production

Water Quality - Nitrate Concentration

Low

High

Percent of land base in production

0%

50%

100%
Factors affecting nitrogen loss to groundwater

- Amount of nitrogen applied
  - As a function of crop type
  - Nitrogen application rate relative to economic optimum
- Percent of land base in production
- Nitrogen use efficiency
- Geology
- Soil Type
- Precipitation / Climate

Some factors are somewhat fixed, limited ability to adjust, or out of our control.