Managing Water Resources within the Agricultural Landscape: Challenges and Progress

Presentation to:

Optimizing Land Use for Sustainable Growth: a CAPI Dialogue
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Presentation Overview

- Agriculture and water from a global perspective
- Nature of agricultural impacts on water resources
- Surface water and groundwater considerations
- Field evidence through a case study (Ontario)
- Future challenges and opportunities
Global Agriculture

- ~40% of Earth’s land area is used for agriculture (1)
- Agriculture accounts for 70% of global freshwater withdrawal
  - 90% of freshwater consumption (1)
- By 2050 food demand may increase by 70% and agricultural water demand by 50%. (2)

(1) http://data.worldbank.org/indicator/AG.LND.AGRI.ZS/countries
(2) 4th UN World Water Development Report (2012)
Global Agriculture

- Agriculture considered to be the largest source of water pollution globally \(^{(1)}\)
  - Nutrients, pesticides and pathogens

Nitrogen Management

A Global Grand Challenge, 2012
US National Academy of Engineering

\(^{(1)}\) The European Nitrogen Assessment (Sutton et. al, 2011)
Sutton et al., (2011) Europe

Wheater et al., (2013) Canada
Contributes to eutrophication in surface waters

- ecosystem health

The Global Nature Fund says Lake Winnipeg is the most threatened lake of the year for 2013.

Lake Erie

Lake Winnipeg Shoreline

http://www.nanohygiene.com/industrial/agriculture/
Nitrate in Groundwater

Harter et. al (2012)

Elevated nitrate concentrations in drinking water wells

• human health

37% of all wells tested contained one or more target contaminants at concentrations above Provincial drinking water standards.

31% of all wells tested exceed the maximum concentration for coliform bacteria.

20% had faecal coliform bacteria.

13% exceeded the maximum acceptable concentration for nitrate.

~1500 Farm Drinking Water Wells

- 37% of all wells tested contained one or more target contaminants at concentrations above Provincial drinking water standards.
- 31% of all wells tested exceed the maximum concentration for coliform bacteria.
- 20% had faecal coliform bacteria.
- 13% exceeded the maximum acceptable concentration for nitrate.

General Results of Well Survey
Agricultural Nitrate in Public Supply Wells
Anatomy of a Non-Point Source

Complicating Factors
• Nutrient application rate, timing & type
• Surface and subsurface characteristics
• Seasonal and extreme hydrology
• Long time lags in the subsurface
• Tile Drainage
A simple method to assess unsaturated zone time lag in the travel time from ground surface to receptor

Marcelo R. Sousa *, Jon P. Jones, Emil O. Frind, David L. Rudolph

University of Waterloo, Department of Earth and Environmental Sciences, 200 University Avenue West, Waterloo, Ontario, Canada N2L 3G1

JCH (2013)

1. Residence time in the unsaturated zone
2. Long travel times in the groundwater flow system
Tile Drainage

**Benefits**
- Plant earlier and harvest later
- Reduced soil compaction
- Improved root zone aeration
- Root zone warms earlier in spring

**Potential Concerns**
- Rapid drainage of shallow groundwater
- Loss of nutrients
Ontario Tile Drainage

1.626 million hectares tile drained
(~ 66% of total productive agricultural land)
Nitrogen Cycle

- **Saturated Zone**
- **Vadose Zone** Below Max. Root Depth
- **Root Zone** Depth ~ 1m

Esmaeili (2013)

Diagram showing the nitrogen cycle with various processes:
- Nitrogen in atmosphere (N₂)
- Symbiotic N Fixation
- Non-symbiotic N Fixation
- Plant nitrogen uptake
- Mineralization
- Immobilization
- Nitrification
- Ammonia Volatilization
- Atmospheric Deposition
- Fertilizers
- Crop harvest

Leaching

Nitrogen Cycle processes and root zone depths.
Regional Nutrient Management Strategies

- Beneficial Management Practices (BMPs) $^{(1,2,3)}$
  - Appropriate type, timing and amount of fertilizer
  - Crop rotation, types and cover cropping for N-fixation

- Being implemented world-wide, but with few documented performance studies. $^{(1,2,3)}$
  - Performance metrics
  - Long time lags in the subsurface
  - Commonly based on predictive simulations

(1) Addressing Nitrate In California’s Drinking Water (Harter et. al, 2012)
(2) The European Nitrogen Assessment (Sutton et. al, 2011)
(3) Water and Agriculture in Canada: Towards Sustainable Management of Water Resources (CCA, 2013)
Quantifying BMP Performance

Are we making progress?
Case Study: Woodstock, Ontario

- Primary water supply for City of Woodstock
- 5 production wells in sand and gravel aquifers.
- Average well depth 30 m
- Adjacent to active farm land where fertilizers applied for decades.
Public Well Nitrate Concentrations (Chronic)

Koch (2009)
Groundwater Nitrate Concentrations

Nitrate concentration [mg NO$_3$-N/L]

- >16
- 14 - 16
- 12 - 14
- 10 - 12
- 8 - 10

Wells 1, 5
Well 3

N 0.5 km

2. Reduced fertilizer rates and modified cropping practices (Beneficial Management Practice: BMP) in 2003.
   - *Maintain land in production.*

3. Rely on BMP performance as alternative to above ground treatment.
**Nutrient Management Strategy (2003)**

<table>
<thead>
<tr>
<th></th>
<th>Historical Practice</th>
<th>Modified Practice (2003)</th>
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</thead>
<tbody>
<tr>
<td><strong>Crops</strong></td>
<td>Cattle/Hog production; primarily corn cropping, some wheat and soy</td>
<td>Soy-wheat-corn rotation, some fields in permanent grass</td>
</tr>
<tr>
<td><strong>Applied Nutrients</strong></td>
<td>Synthetic Fertilizer some manure</td>
<td>Synthetic fertilizer, legume cover crop (red clover)</td>
</tr>
<tr>
<td><strong>Average N application</strong></td>
<td>100 lb/ac</td>
<td>54 lb/ac</td>
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<tr>
<td><strong>N - Balance</strong></td>
<td>( + ) 23 lb/ac</td>
<td>( - ) 25 lb/ac</td>
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</table>

*King and Wall (2004)*
Nitrate Monitoring Stations

Haslauer (2007); Bekeris (2007), Koch (2009)
Stored Nitrate Mass in Vadose Zone

Replicate Vadose Zone Soil Coring

Soil Sample Analysis
NO$_3^-$ & Moisture Content

Coring Locations

Haslauer (2007); Bekeris (2007)
Change in Stored Nitrate Mass

Year 1
BMPs begin

Year 2
Core 1

Year 3
Core 2

Year 4
Core 3

Change in Nitrate Mass

Bekeris (2007)
~60% reduction in total stored nitrate mass

Koch (2009)
Post BMP Nitrate Mass Flux

**Recharge**
[mm/yr]
- > 600
- 500 - 600
- 400 - 500
- 300 - 400

**Nitrate concentration**
[mg NO₃-N/L]
- > 12
- 8 - 12
- 4 - 8
- 1 - 4

**Mass flux**
[g NO₃-N/m²/yr]
- > 6
- 4-6
- 2-4
- 1-2
- < 1
Influence of the Nutrient Reductions

1. Avg. nitrate concentration beneath root zone decreased from
   \( \sim 20 \text{ mg/L} \) to \( \sim 8 \text{ mg/L} \)

2. Total nitrate mass loading decreased from 5.6 to 2.1 tonnes/year (from 2004 to 2009)
   * 60% reduction *

Historic corn yields: 135 bu/ac
Current corn yields: \( \sim 140 \text{ bu/ac} \)!
Groundwater Quality in Monitoring Well Network

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<td>1.30</td>
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<td><strong>Average</strong></td>
<td>11.63</td>
<td>12.40</td>
<td>9.51</td>
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<td><strong>Maximum</strong></td>
<td>16.50</td>
<td>15.70</td>
<td>17.90</td>
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<tr>
<td><strong>No. of wells</strong></td>
<td>9</td>
<td>20</td>
<td>18</td>
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<td>0.00</td>
<td>0.00</td>
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<tr>
<td><strong>Average</strong></td>
<td>11.17</td>
<td>10.16</td>
<td>8.57</td>
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<td><strong>Maximum</strong></td>
<td>16.20</td>
<td>16.30</td>
<td>17.60</td>
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Recent Trends in Nitrate Concentrations in the Production Wells

Rudolph et al. (2015)
Implications and Conclusions

1. Nutrient reduction BMPs implemented on purchased land have been successful at reducing groundwater nitrate concentrations.
   - *Nitrate levels in Thornton wells have reduced significantly*
   - *Crop yields have remained high*

2. Water treatment infrastructure for nitrate removal was not required.

3. **Full impact of the BMPs may take years to be realized.**
Final Points

1. Targeted nutrient reduction BMPs can significantly reduce long term water quality impacts yet maintain yield.
2. Long response times related to groundwater impacts.
3. Influence of increasing tile drainage not well understood.
4. Increasing variability in climatic conditions resulting in highly transient nutrient loss and mobility.
5. Slow release of nutrient species to surface water systems from groundwater may play a significant role in current observed surface water impacts.
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