Managing Water Resources within the Agricultural Landscape:
Challenges and Progress

Presentation to:

CAPI ICPA

Optimizing Land Use for Sustainable Growth: a CAPI Dialogue
April 24, 2019

David L. Rudolph
Professor and Chair
Department of Earth and Environmental Sciences
University of Waterloo

University of Waterloo

the water INSTITUTE University of Waterloo

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

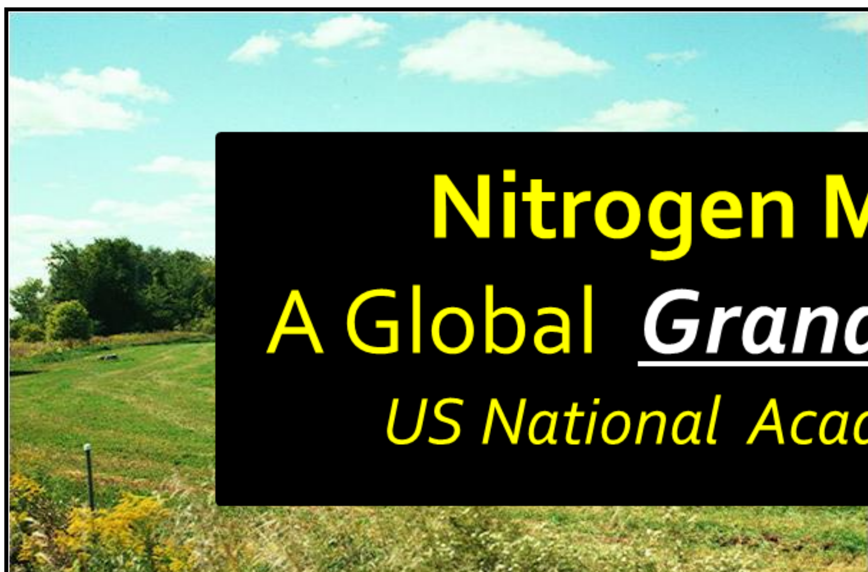
- ~ ***40%*** of Earth's land area is used for agriculture [1]
- Agriculture accounts for 70% of global freshwater withdrawal
  - *90% of freshwater consumption* [1]
- By 2050 food demand may increase by ***70%*** and agricultural water demand by ***50%***. [2]

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

http://www.nanohygienics.com/industrial/agriculture/

Global Agriculture

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

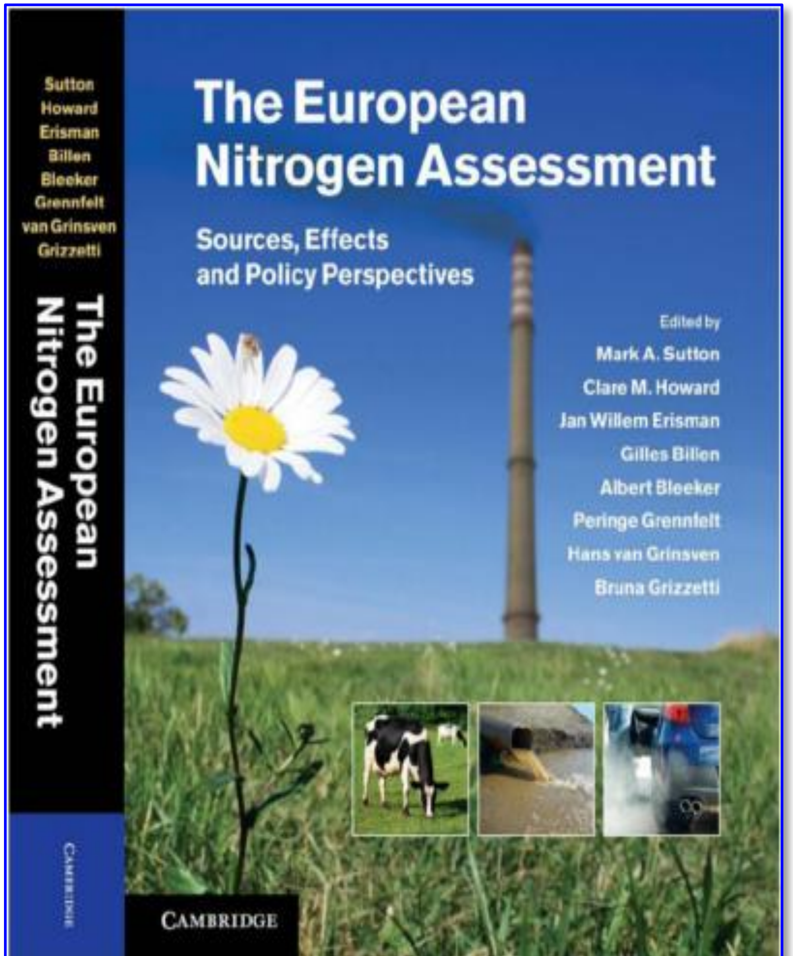


Nitrogen Management

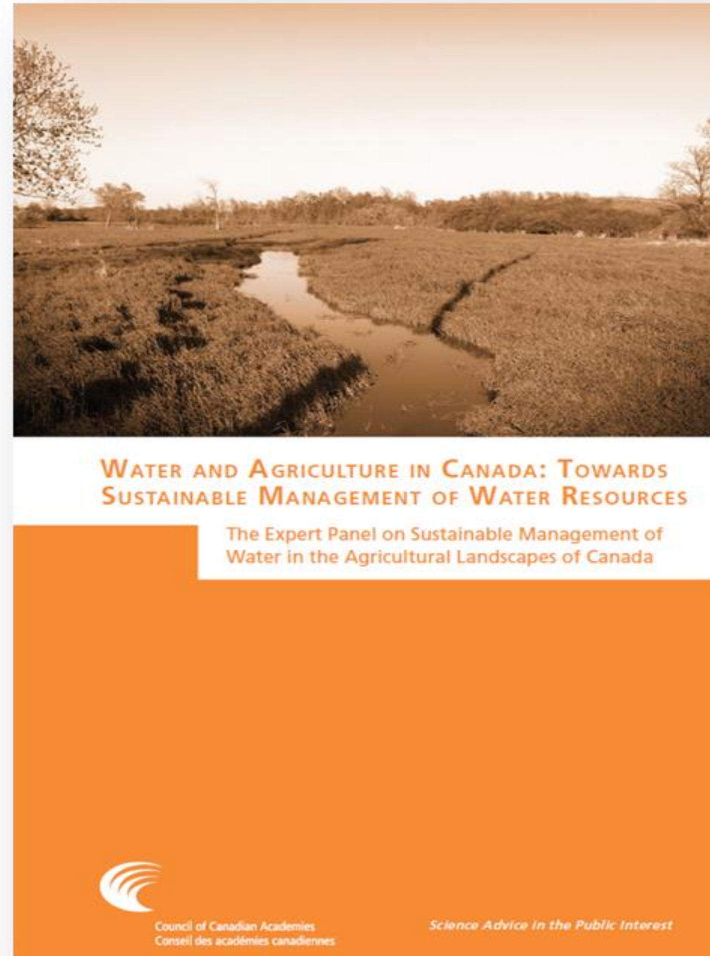
A Global ***Grand Challenge*, 2012**

US National Academy of Engineering

(1) The European Nitrogen Assessment (Sutton et. al, 2011)

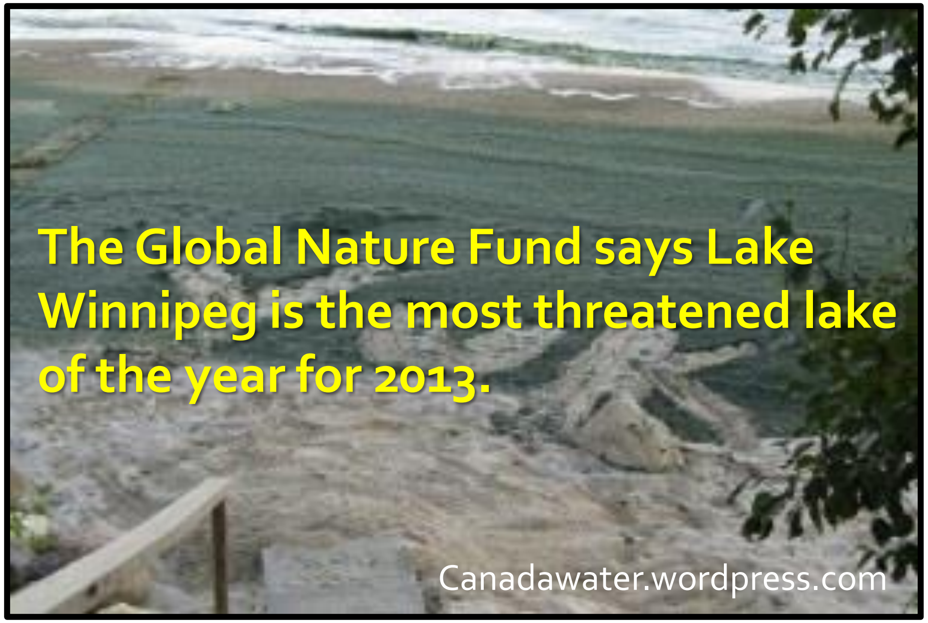


Sutton et al., (2011)
Europe



Wheater et al., (2013)
Canada

Nutrients in Surface Waters

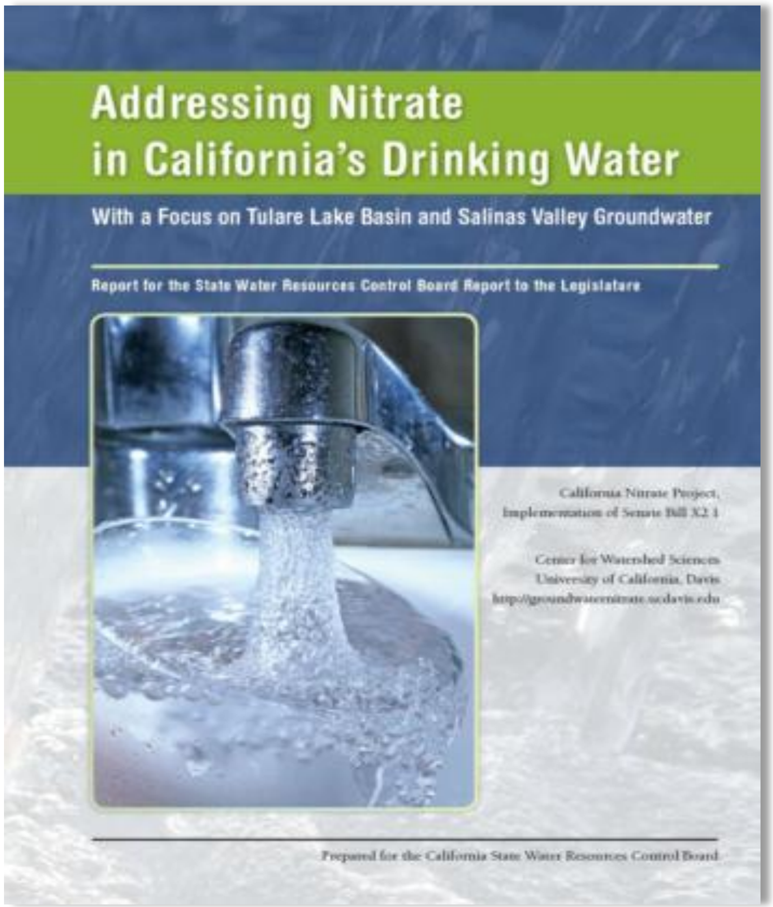


Lake Winnipeg Shoreline

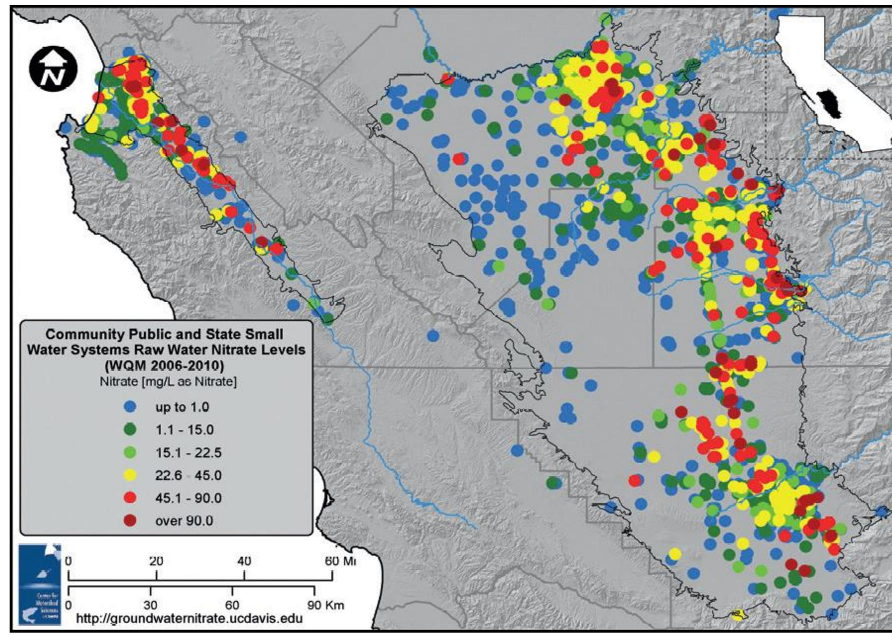
Contributes to eutrophication in surface waters

- *ecosystem health*

Nitrate in Groundwater

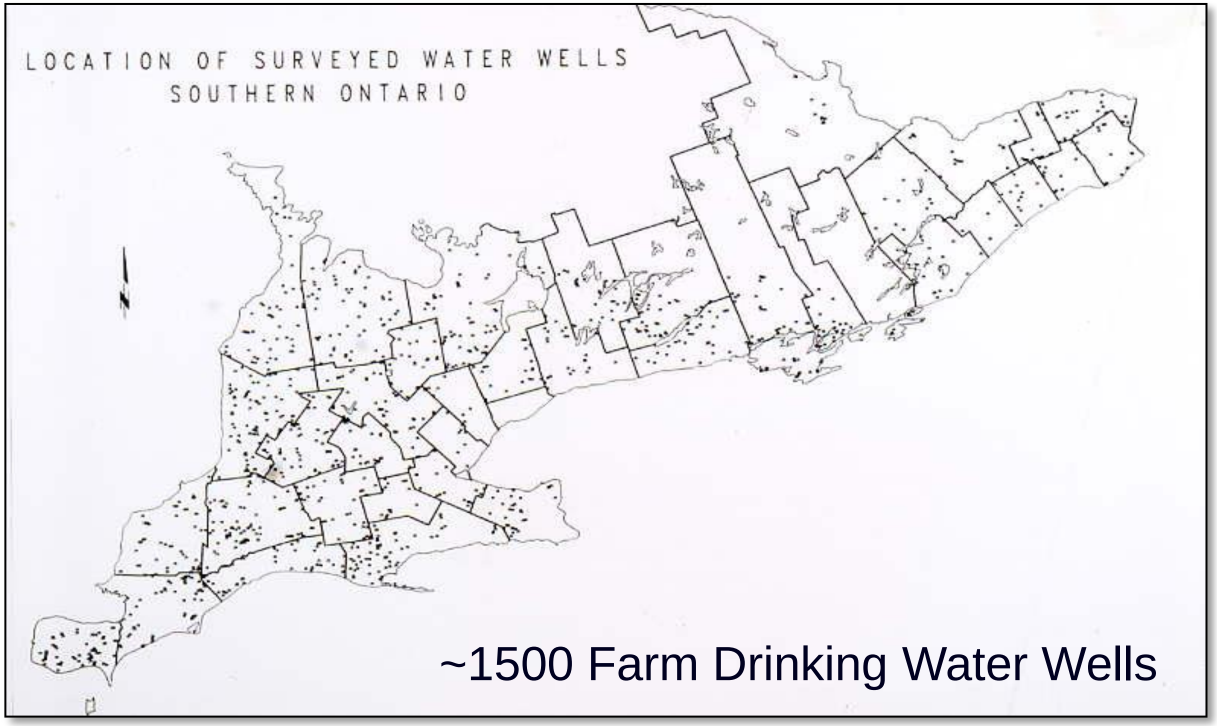


Harter et. al (2012)



Elevated nitrate concentrations in drinking water wells

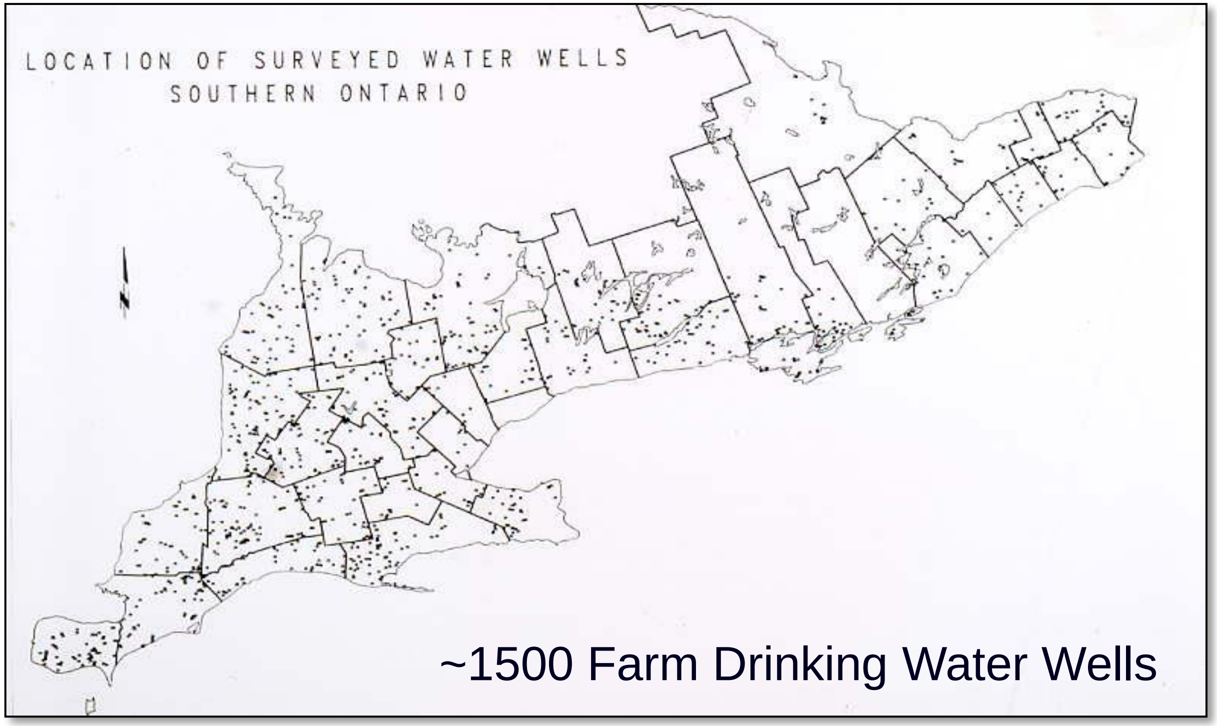
- *human health*



General Results of Well Survey

- 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.

Goss, M. J., Barry, D. A. J. and Rudolph, D. L., 1998.



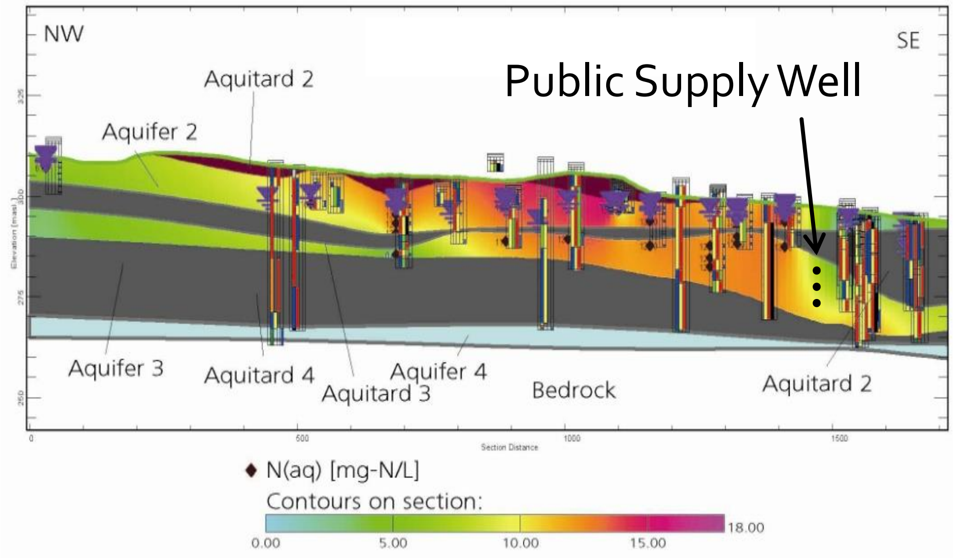
General Results of Well Survey

- 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.**

Goss, M. J., Barry, D. A. J. and Rudolph, D. L., 1998.

Agricultural Nitrate in Public Supply Wells

Anatomy of a Non-Point Source



Complicating Factors

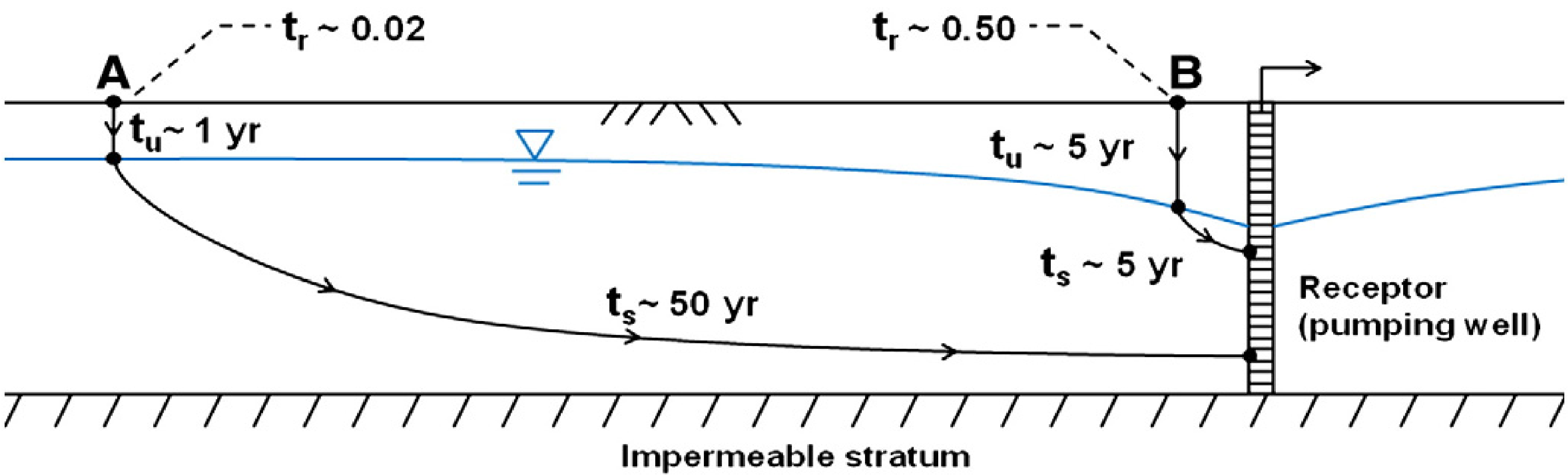
- *Nutrient application rate, timing & type*
- *Surface and subsurface characteristics*
- *Seasonal and extreme hydrology*
- *Long time lags in the subsurface*
- *Tile Drainage*

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

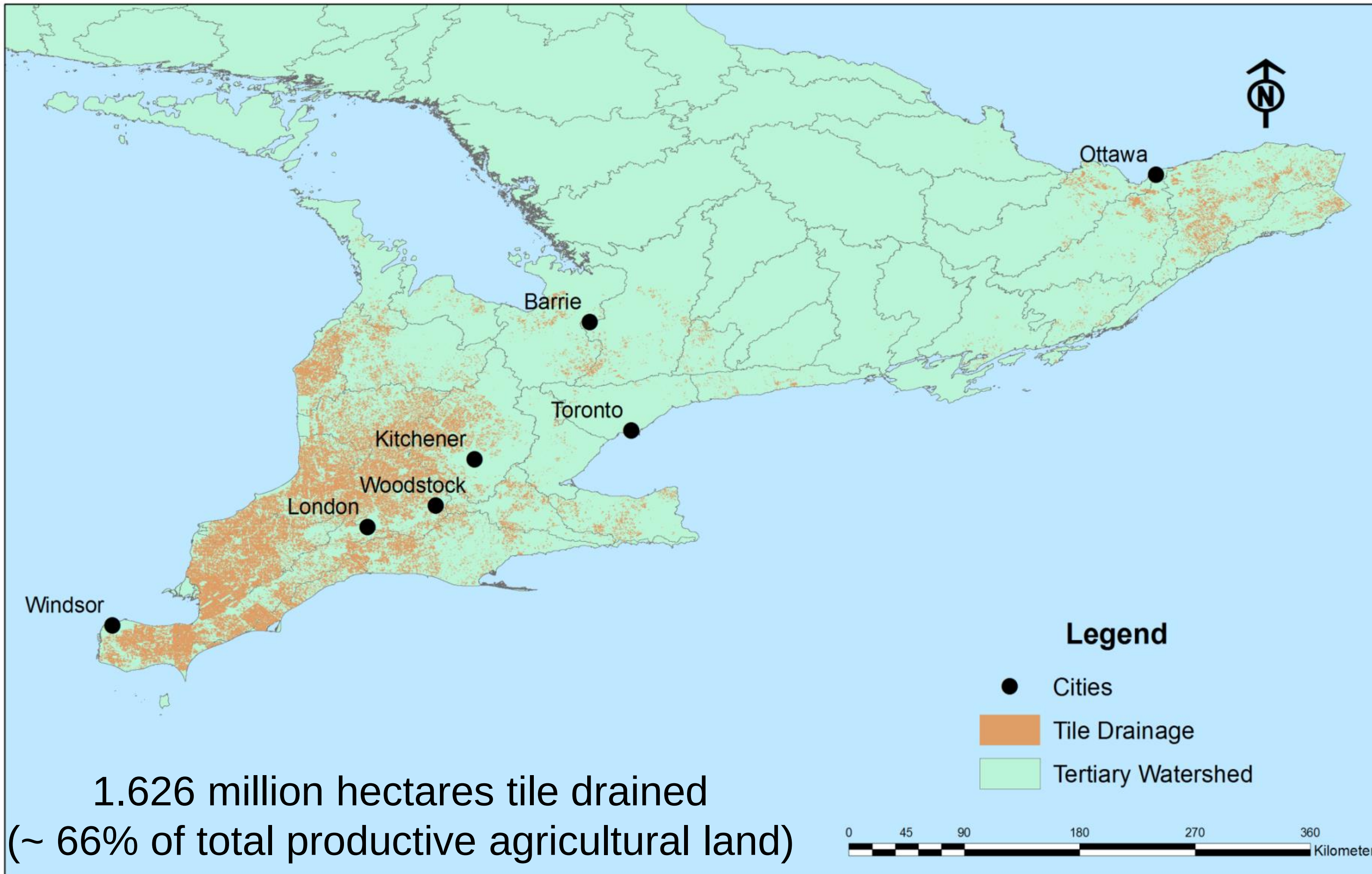
Benefits

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

Potential Concerns

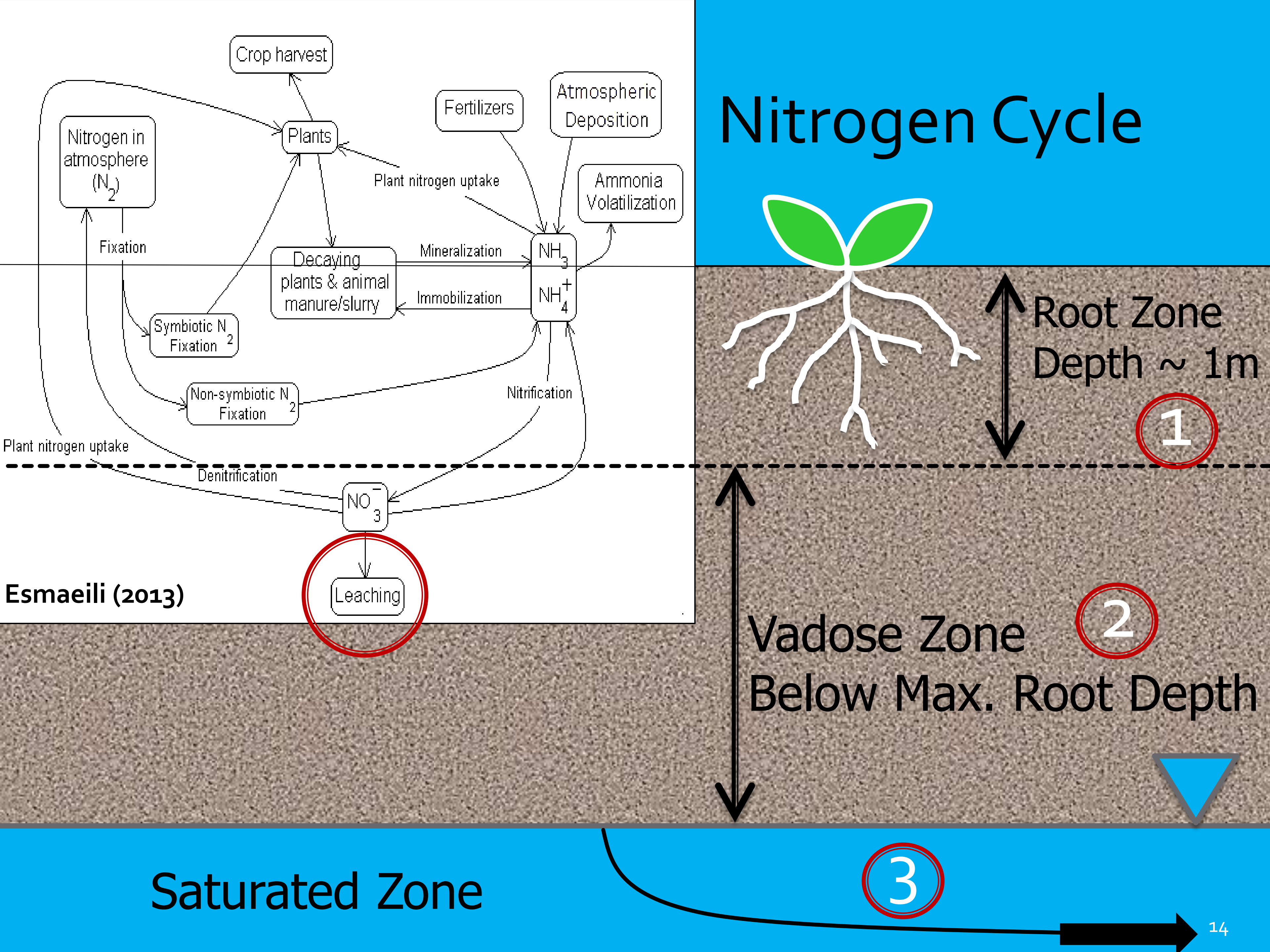
- Rapid drainage of shallow groundwater
- Loss of nutrients

Ontario Tile Drainage



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

Nitrogen Cycle



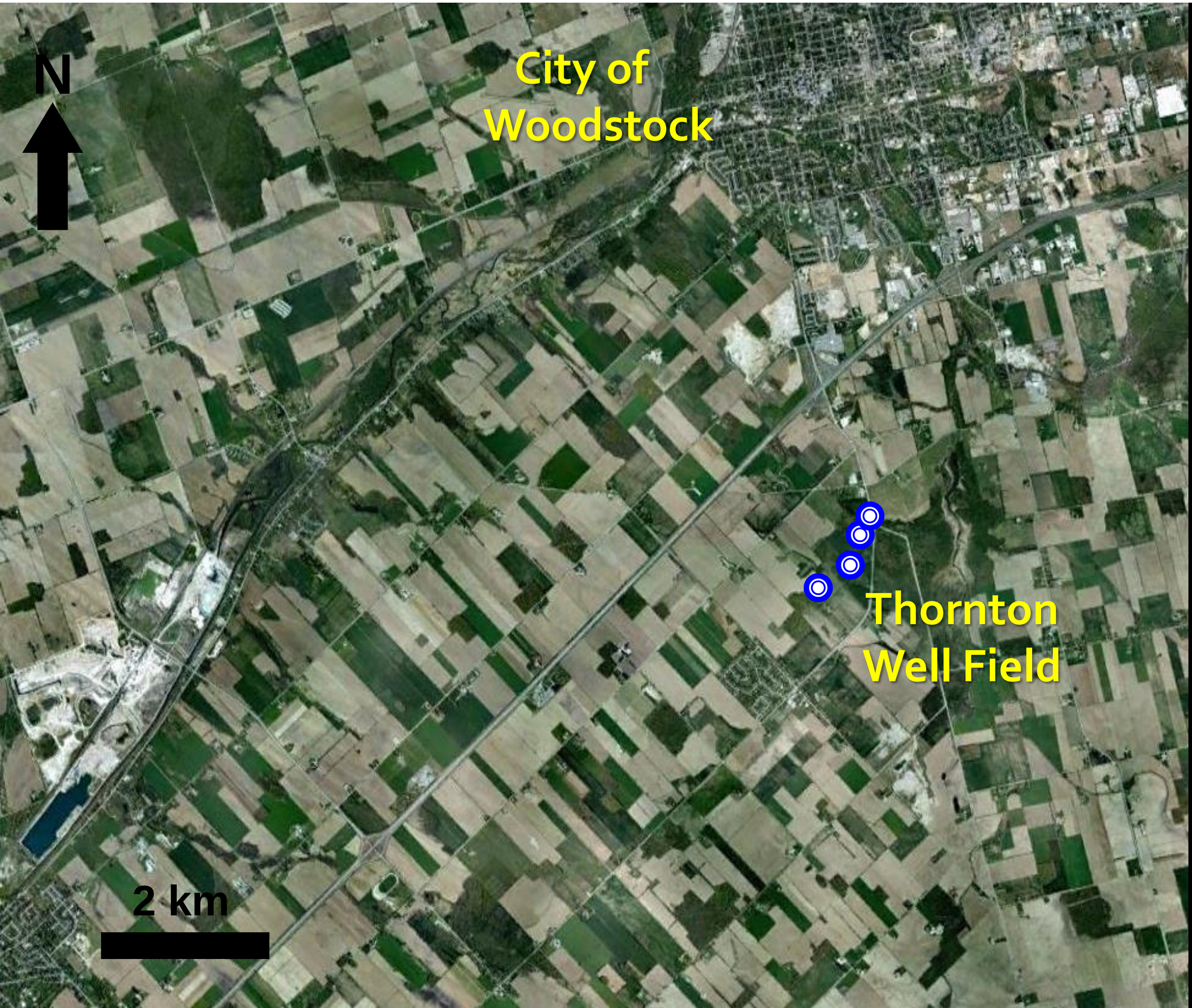
Regional Nutrient Management Strategies

- 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*

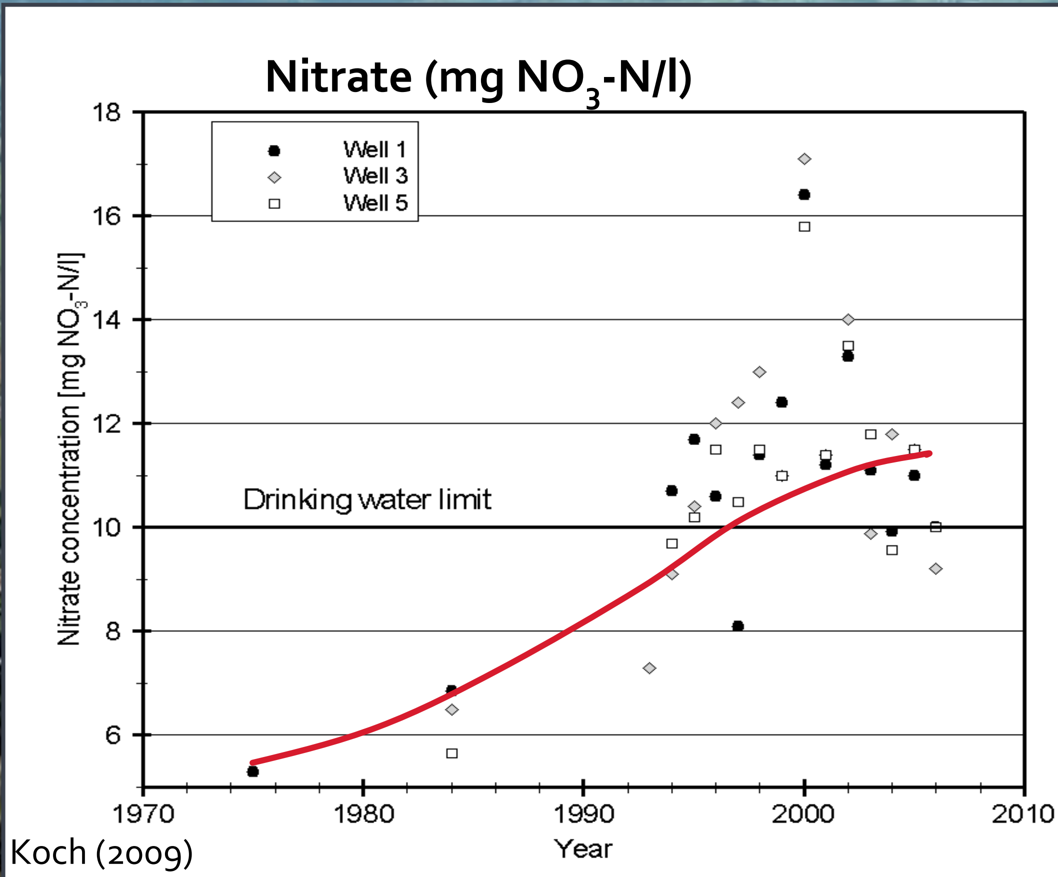
(1) Addressing Nitrate In California's Drinking Water (Harter et. al, 2012)
(2) The European Nitrogen Assessment (Sutton et. al, 2011)
(3) Water and Agriculture in Canada: Towards Sustainable Management of Water Resources (CCA, 2013)

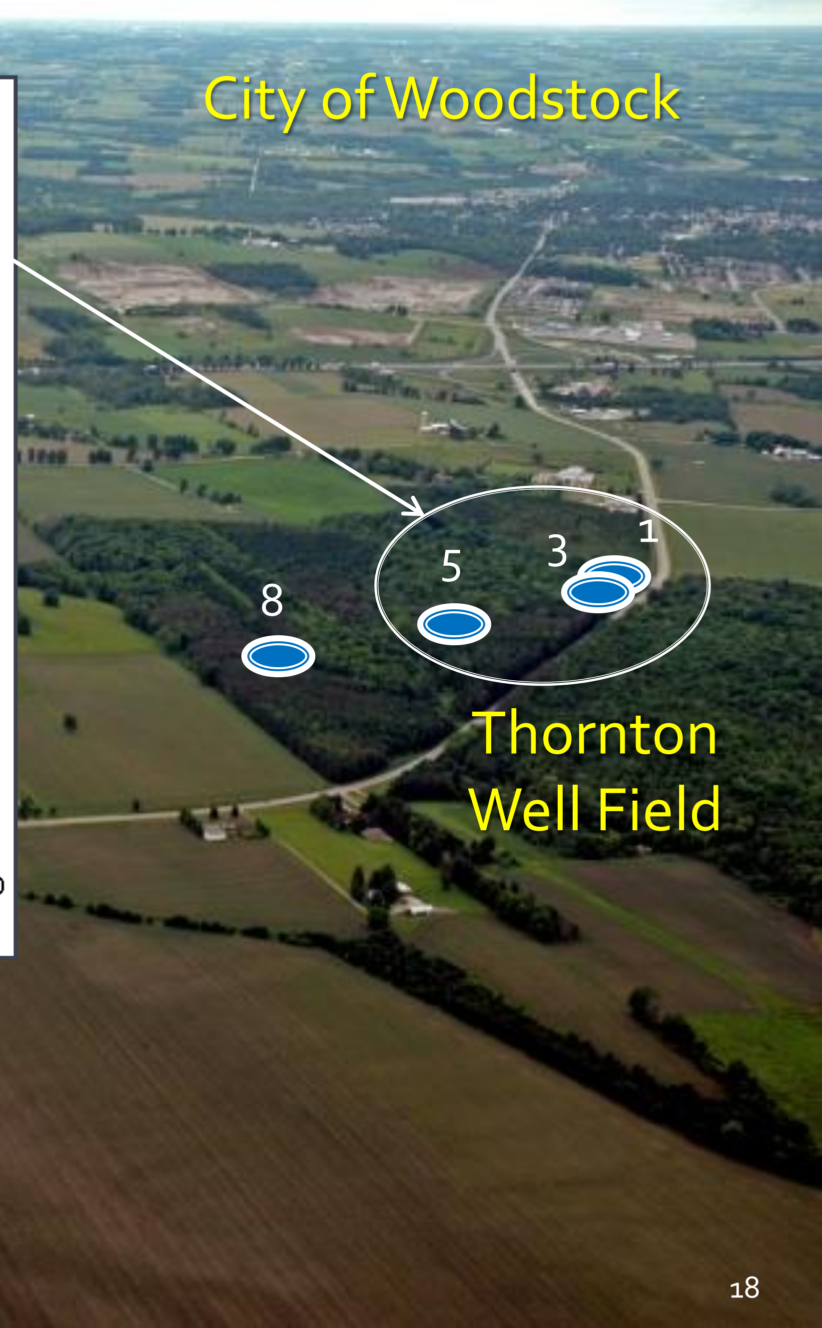
Quantifying BMP Performance
Are we making progress?

Case Study: Woodstock, Ontario



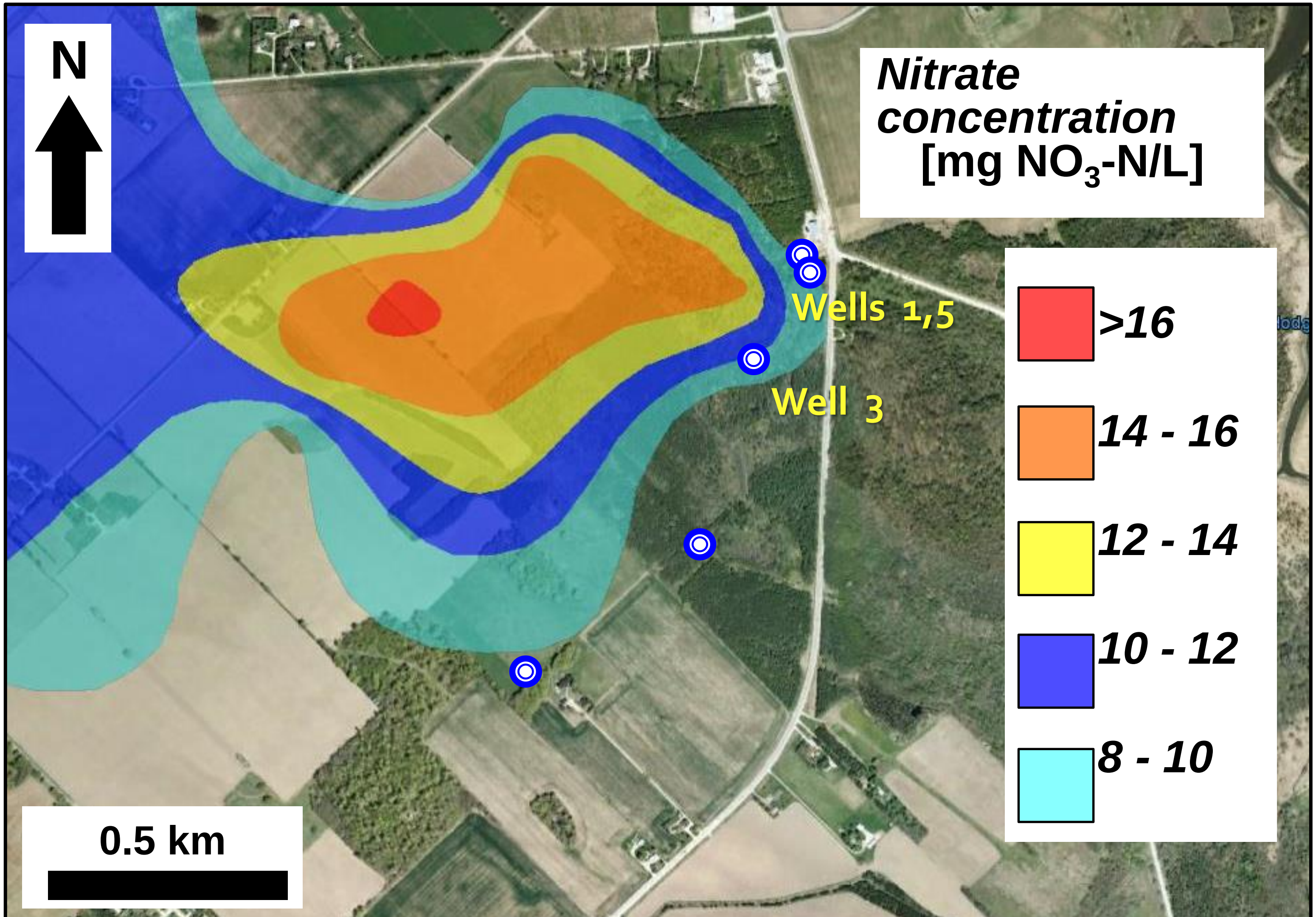
- Primary water supply for City of Woodstock
- 5 production wells in sand and gravel aquifers.
- Average well depth 30 m
- *Adjacent to active farm land where fertilizers applied for decades.*





Public Well Nitrate Concentrations *(Chronic)*

Groundwater Nitrate Concentrations



Groundwater Management Strategy

Municipality of Oxford County, Ontario

1. Purchase agricultural land within the *2-year* time of travel (2002/2003).

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

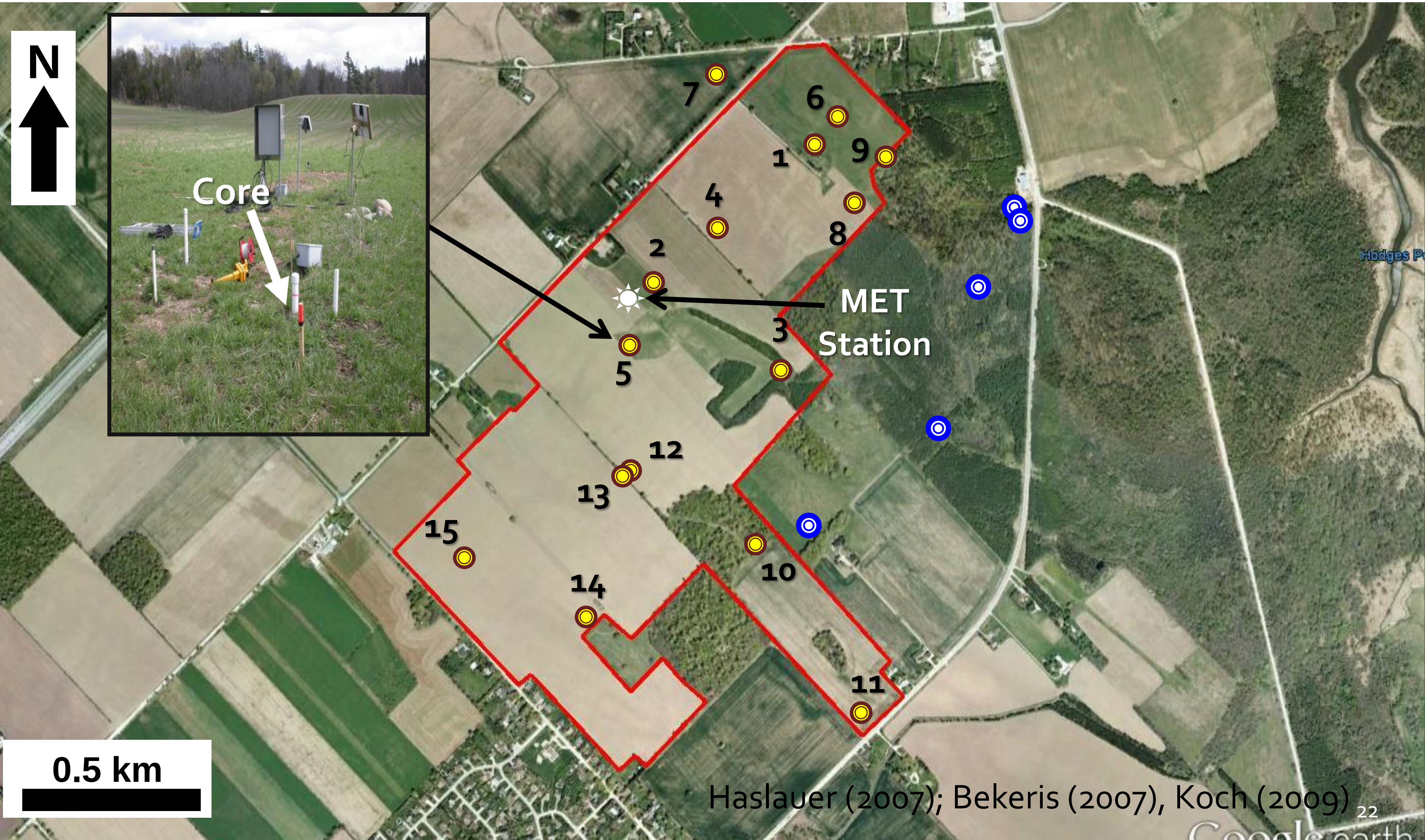
3. Rely on BMP performance as alternative to above ground treatment.

Nutrient Management Strategy (2003)

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

King and Wall (2004)

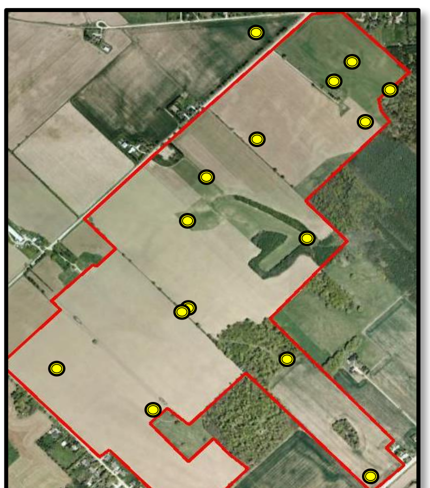
Nitrate Monitoring Stations



Haslauer (2007); Bekeris (2007), Koch (2009)

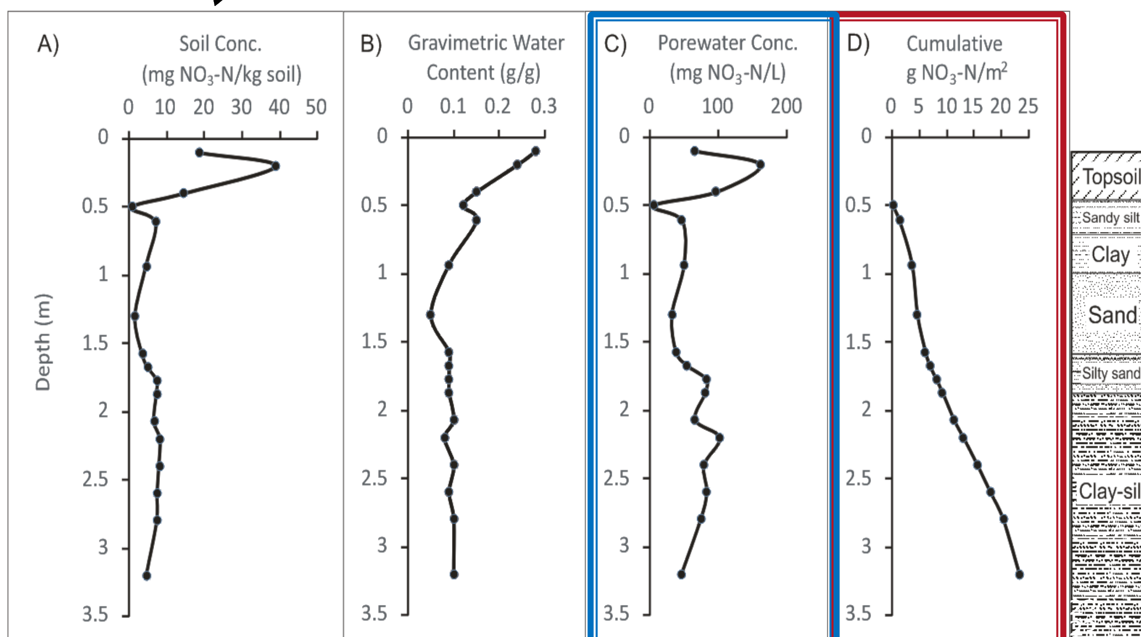
Stored Nitrate Mass in Vadose Zone

Replicate Vadose Zone Soil Coring



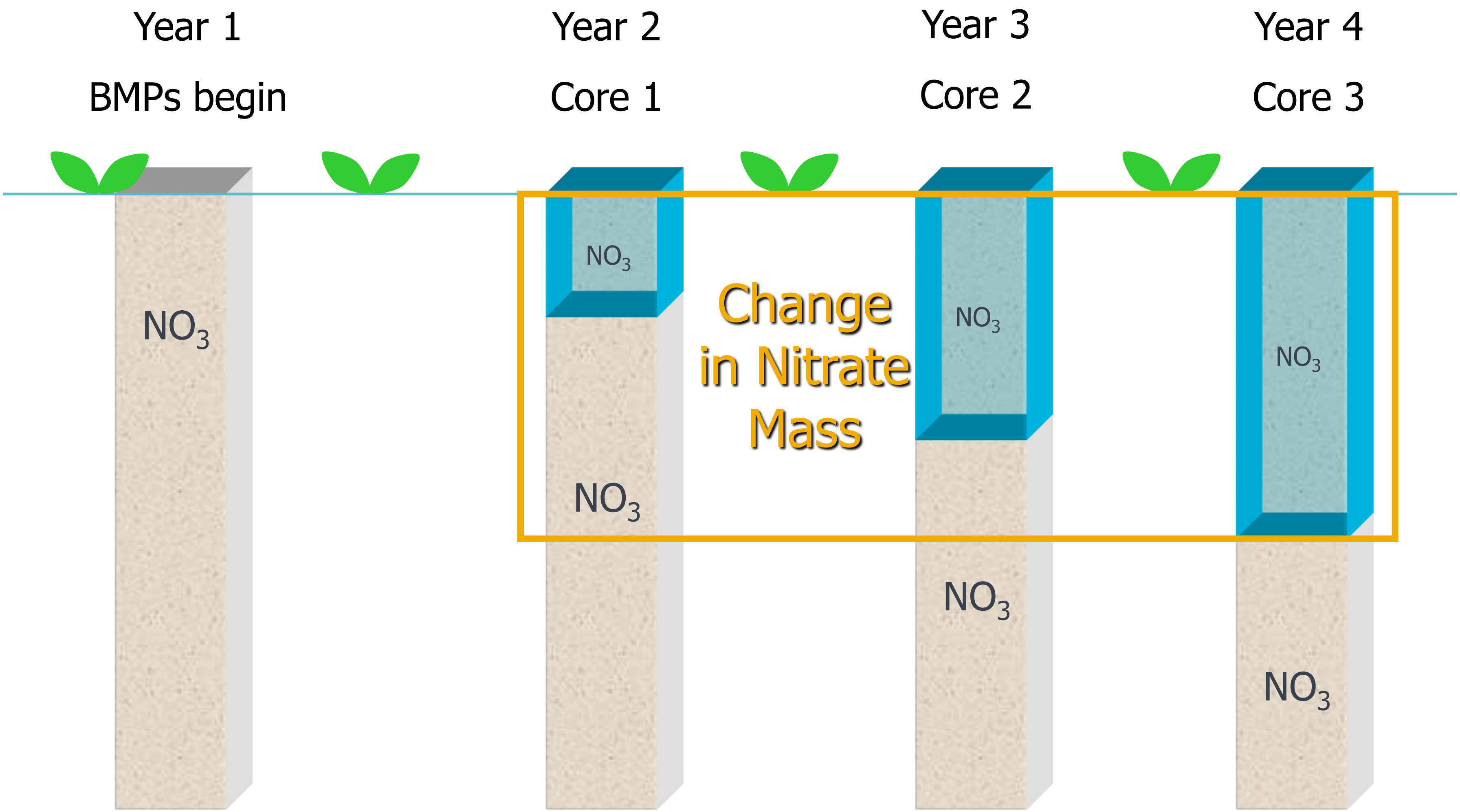
Coring Locations

Soil Sample Analysis
NO_3, & Moisture Content



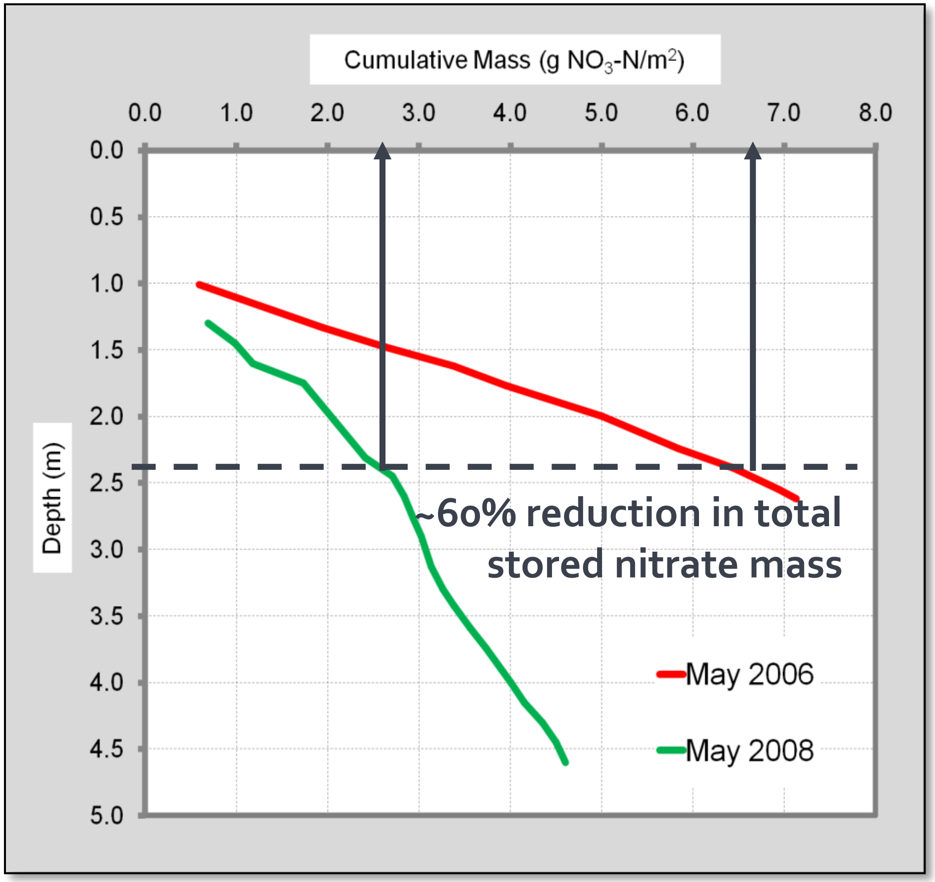
Haslauer (2007); Bekeris (2007)

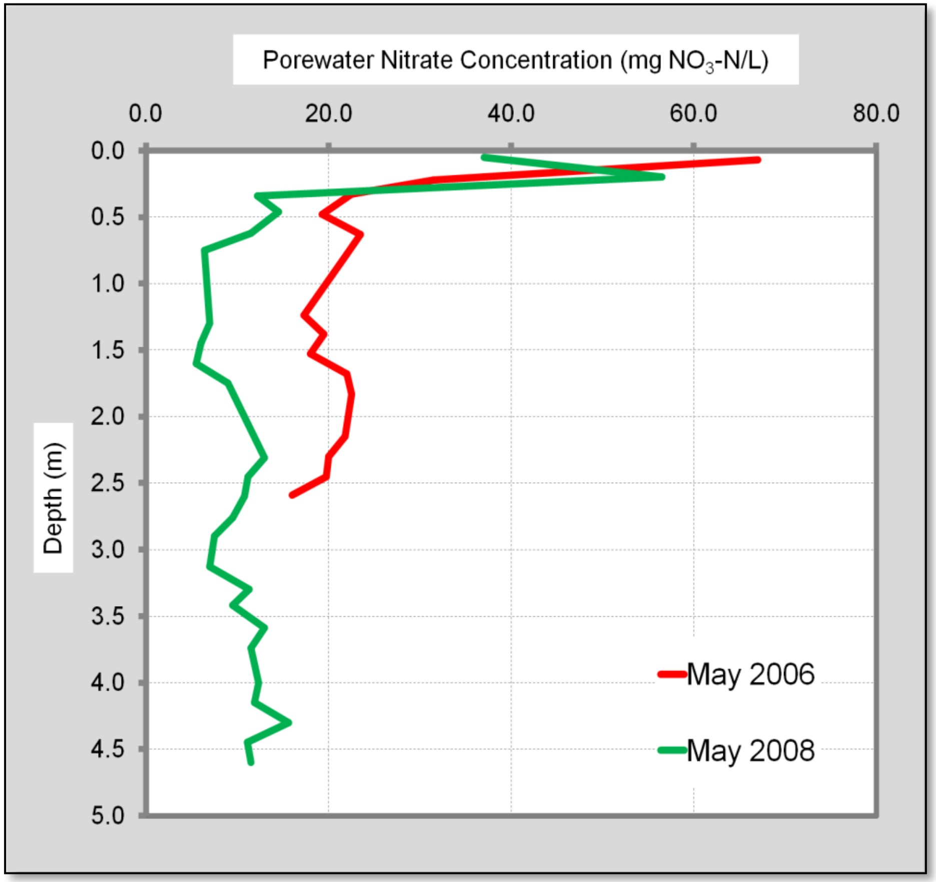
Change in Stored Nitrate Mass



Bekeris (2007)

Change in Stored Nitrate Mass
(e.g. Station 4)

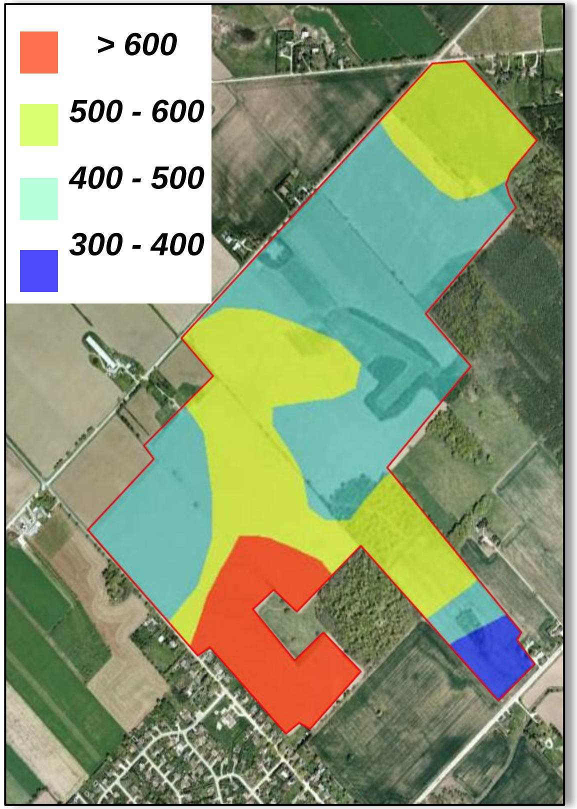




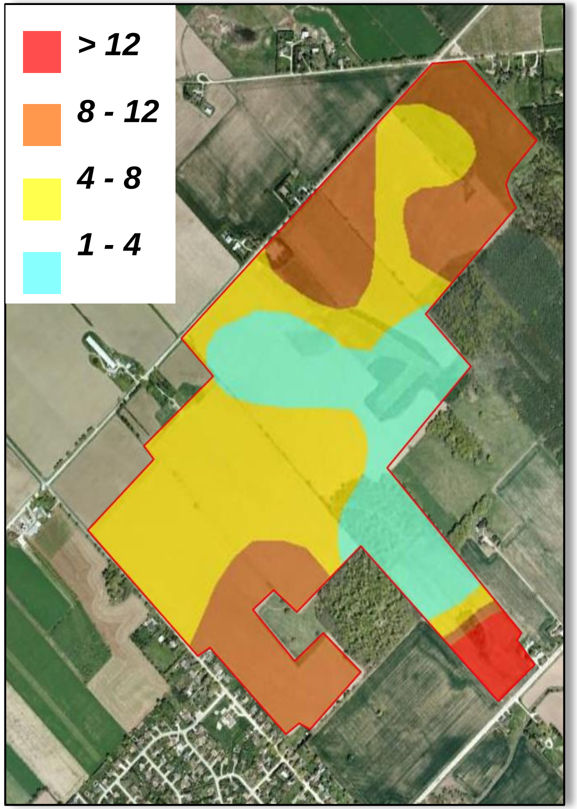
Koch (2009)

Post BMP Nitrate Mass Flux

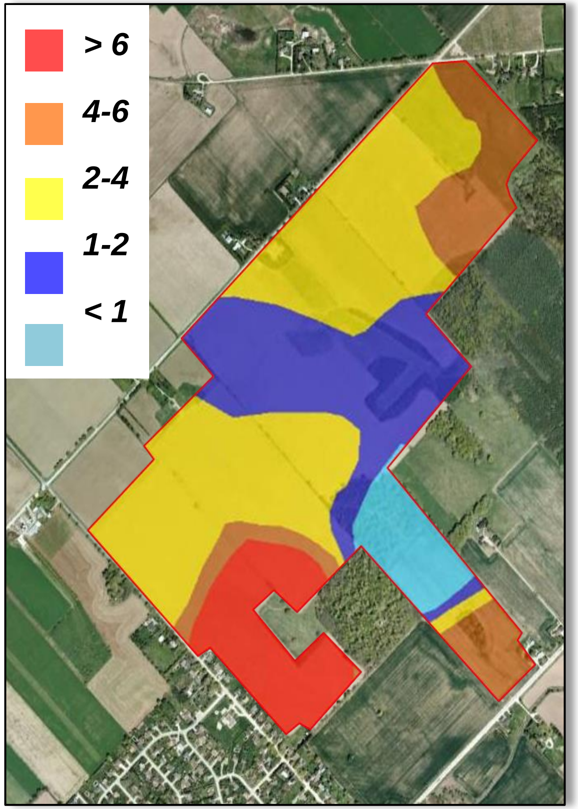
Recharge
[mm/yr]



Nitrate concentration
[mg NO_3-N/L]



Mass flux
[g NO_3-N/m^2/yr]



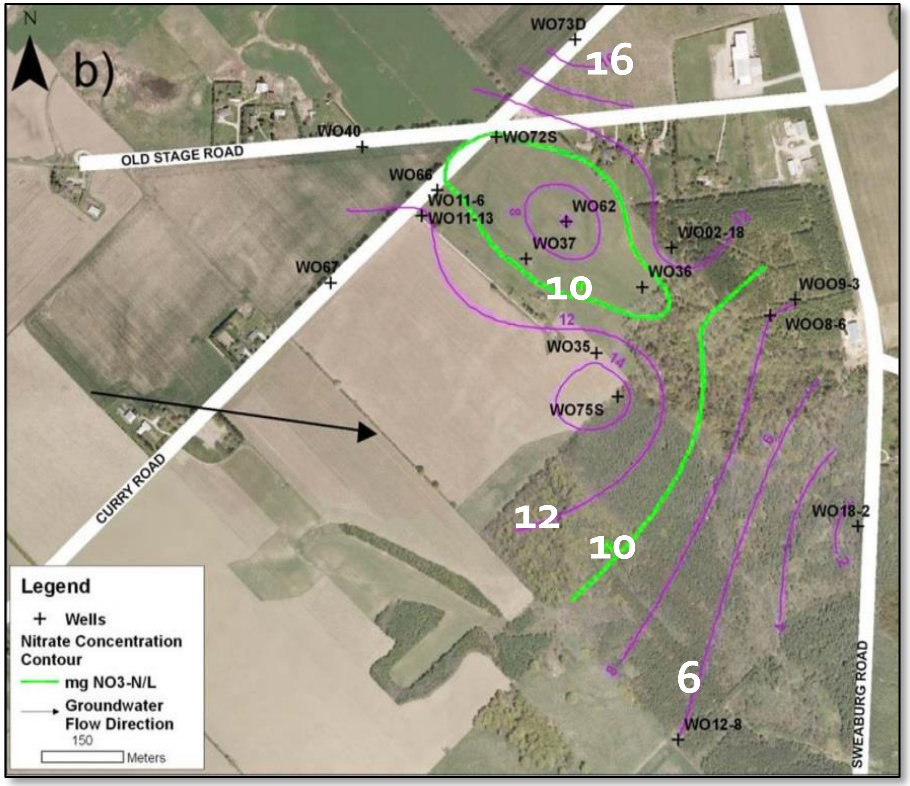
Influence of the Nutrient Reductions

1. Avg. nitrate concentration beneath root zone decreased from
   ~ *20 mg/L to ~ 8 mg/L*

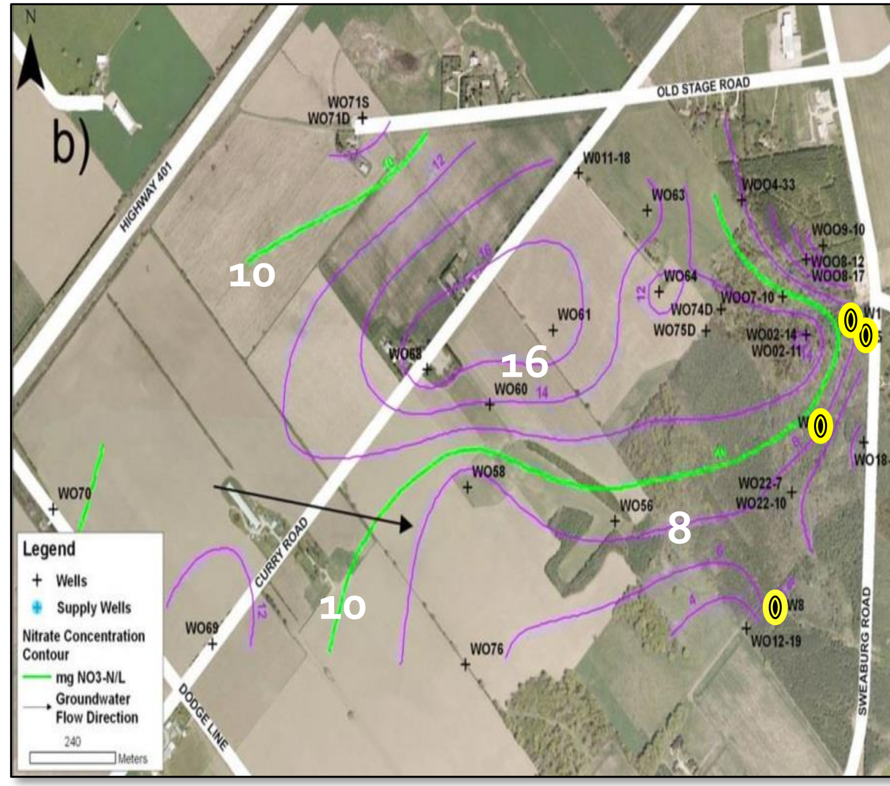
2. Total nitrate mass loading decreased from 5.6 to 2.1 tonnes/year (from 2004 to 2009)
   ** 60% reduction **

Historic corn yields: 135 bu/ac
Current corn yields: ~140 bu/ac!

Groundwater Quality in Monitoring Well Network



Aquifer 2, May 2008

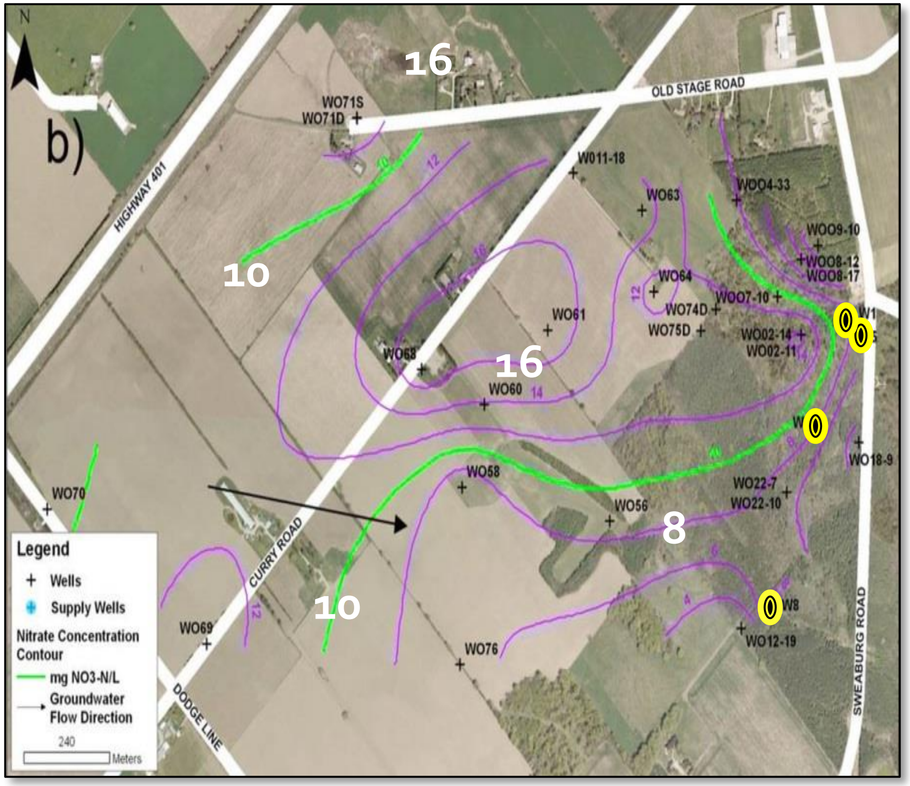


Aquifer 3, May 2008

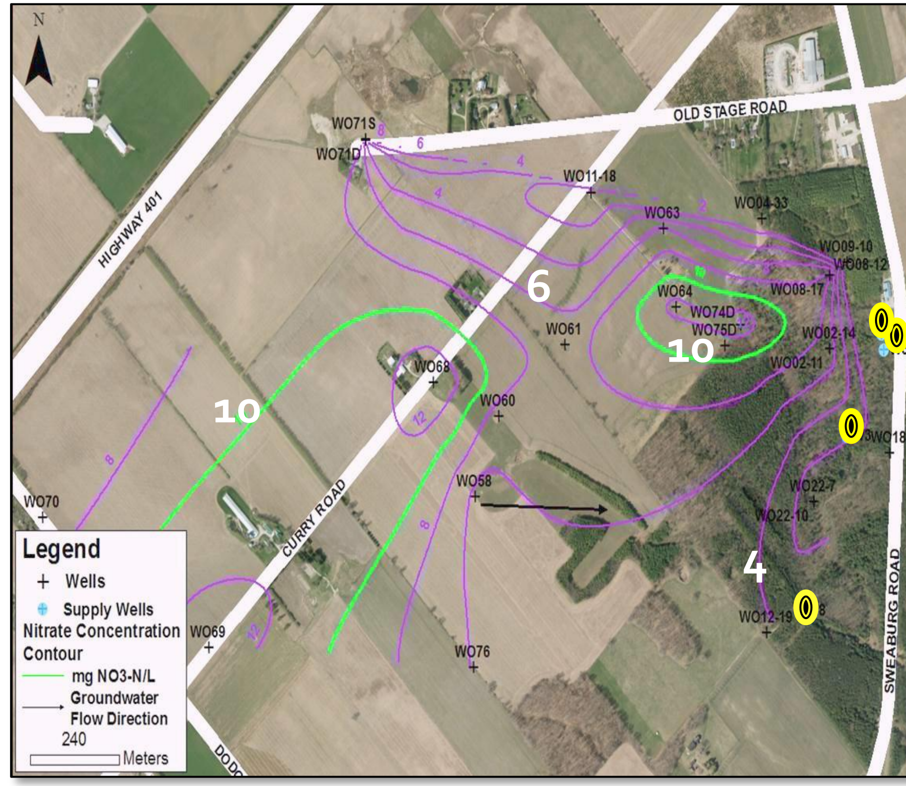
	Sep-Oct 2004	Oct-Nov 2007	May 2008
Minimum	0.20	1.30	0.40
Average	**11.63**	**12.40**	**9.51**
Maximum	16.50	15.70	17.90
No. of wells	9	20	18
Source	Haslauer (2005)	Koch (2009)	Koch (2009)

	Sep-Oct 2004	Oct-Nov 2007	May 2008
Minimum	6.30	0.00	0.00
Average	**11.17**	**10.16**	**8.57**
Maximum	16.20	16.30	17.60
No. of wells	6	23	27
Source	Haslauer (2005)	Koch (2009)	Koch (2009)

Groundwater Quality in Monitoring Well Network



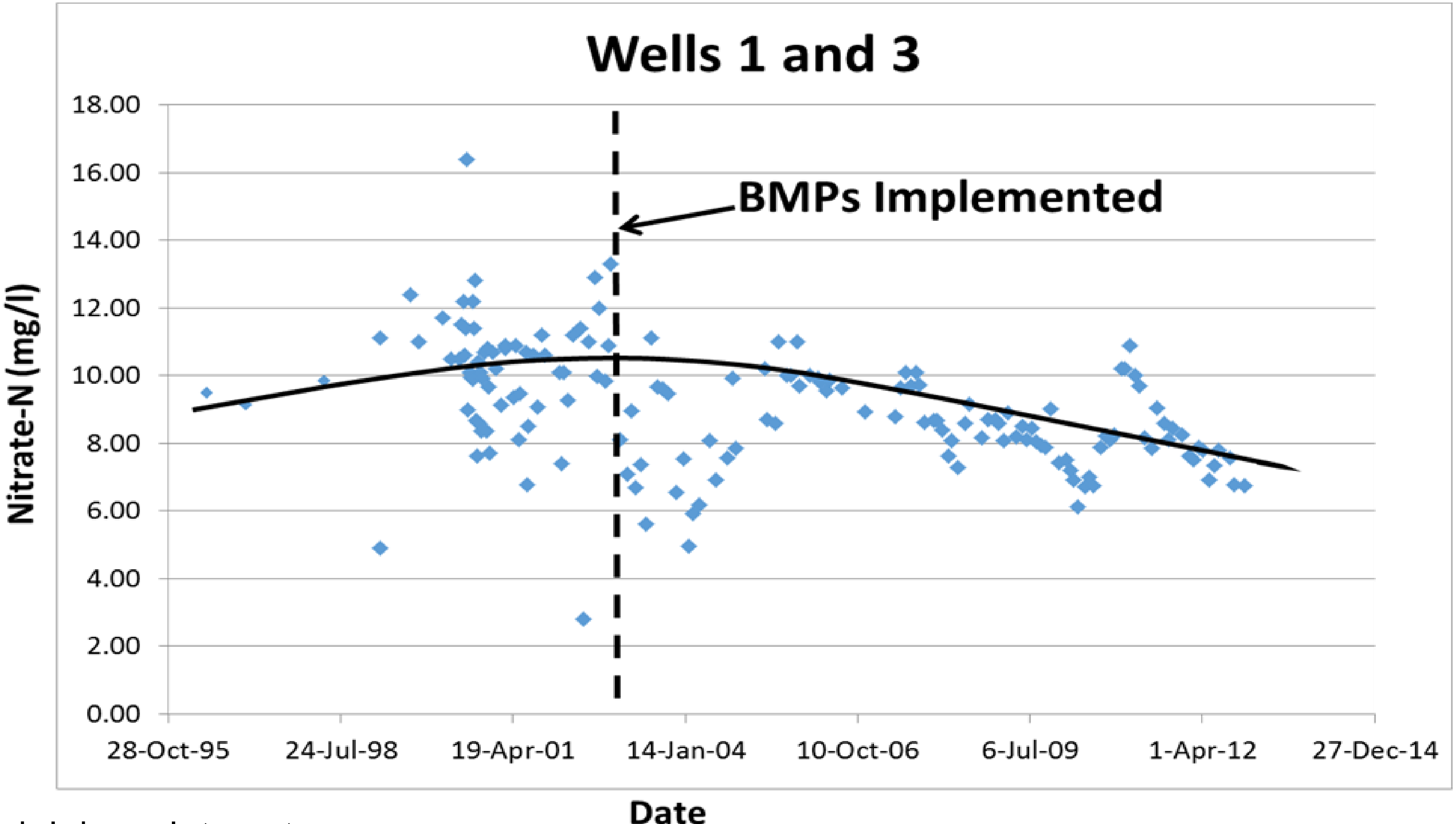
Aquifer 3, May 2008



Aquifer 3, August 2014

	Sep 2004	Oct-Nov 2007	May 2008	Aug 2014
Minimum	6.30	0.00	0.00	0.06
Average	**11.17**	**10.16**	**8.57**	**6.29**
Maximum	16.20	16.30	17.60	14.11
No. of wells	6	23	27	23
Source	Haslauer (2005)	Koch (2009)	Koch (2009)	(unpublished)

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.

Acknowledgements

Collaborators

- Marcelo Sousa
- Loren Bekeris
- Claus Haslauer
- Jamie Koch
- Greg Padusenko
- Sara Esmaeili
- Andrew Wiebe
- Neil Thomson
- Brewster Conant
- Matthias Loschko
- Thomas Wohling
- Olaf Cirpka