Nitrate in the Abbotsford-Sumas Aquifer, British Columbia and Northwest Washington State

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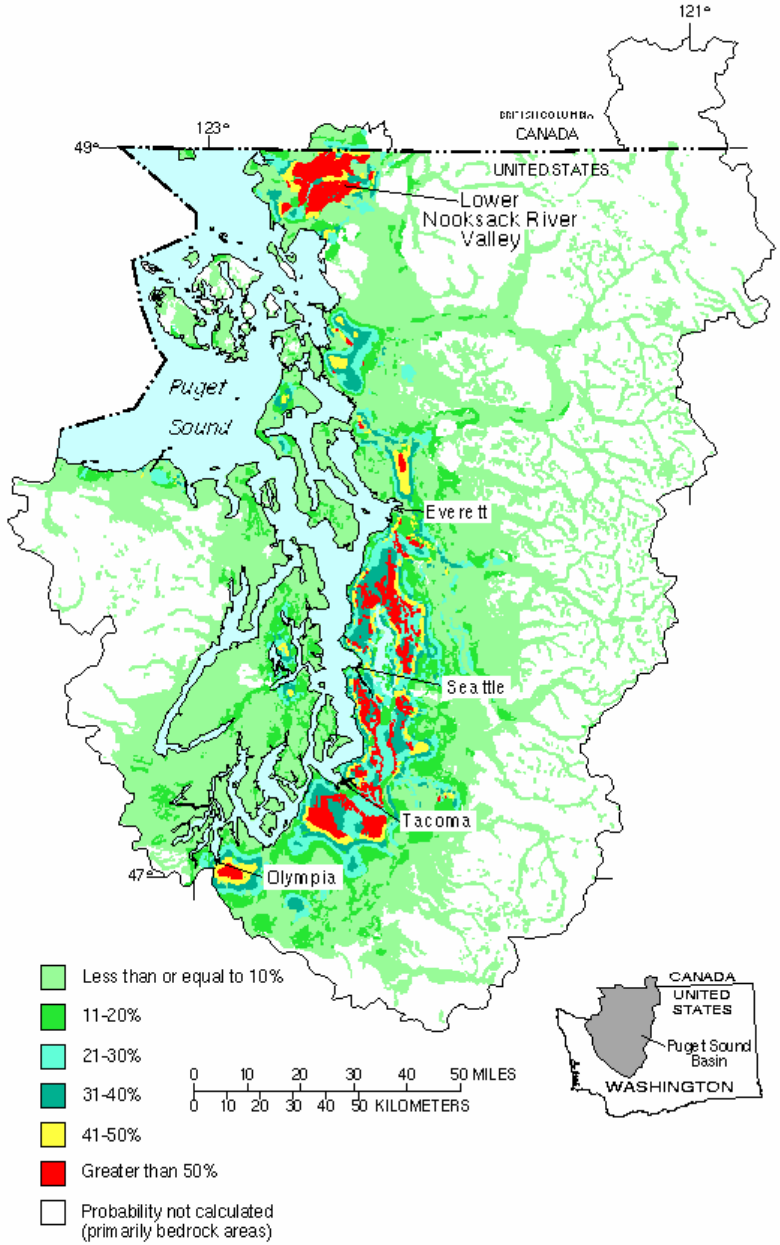
Nitrate Vulnerability Map

USGS Fact Sheet FS-061-97
by M.L. Erwin and A.J. Tesoriero
June 1997

The red areas on this map indicate regions that are highly susceptible to groundwater nitrate contamination.

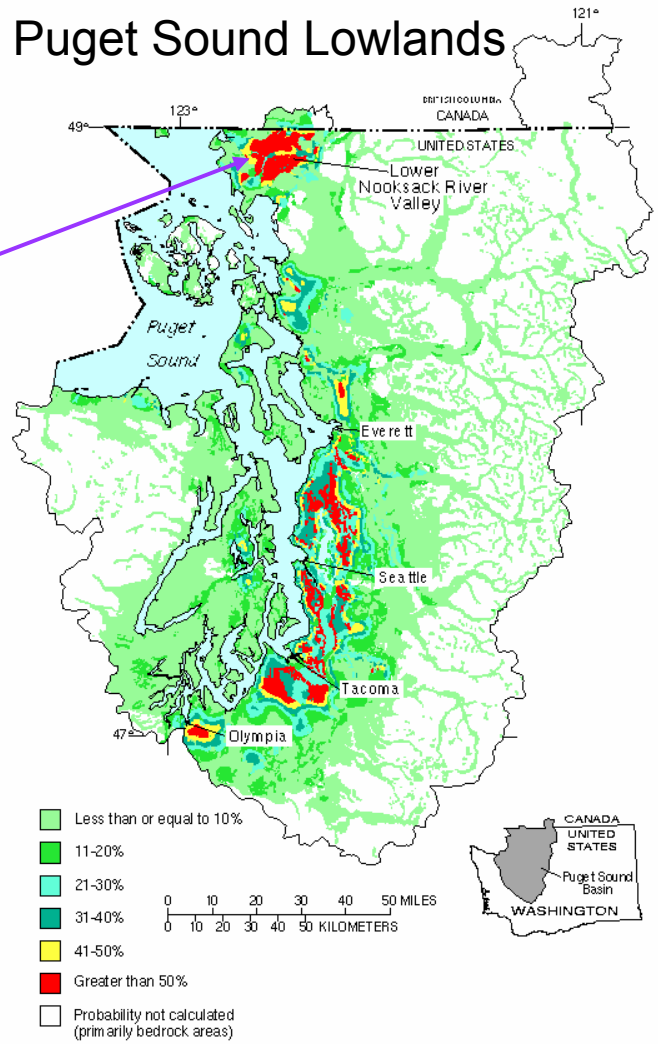


Vulnerability map. Probability (in percent) of detecting nitrate at concentrations of 3 milligrams per liter or greater in wells that are 50 feet deep in the Puget Sound Basin. USGS FS-061-97

Agricultural Impacts on Water Quality

Liquid manure spreading

Puget Sound Lowlands



Vulnerability map. Probability (in percent) of detecting nitrate at concentrations of 3 milligrams per liter or greater in wells that are 50 feet deep in the Puget Sound Basin. USGS FS-061-97

What is nitrate?

Nitrate is a chemical found in most fertilizers, in manure, and in the liquid waste discharged from septic tanks. Natural bacteria in soil can convert nitrogen into nitrate.

Why is nitrate in drinking water a problem?

Nitrate can affect red blood cells and reduce their ability to carry oxygen to the body. In most adults and children these affected blood cells rapidly return back to normal. However the blood cells of infants can take much longer to return to normal. As a result, infants who are given water with high levels of nitrate (or foods made with nitrate contaminated water) may develop a serious health condition due to the lack of oxygen. This condition is called methemoglobinemia or "blue baby syndrome." Some scientists think that diarrhea can make this problem even worse.

Can nitrate affect adults?

Most older children and adults will not be affected because their red blood cells will be quickly converted back to normal. Some people have conditions that make them susceptible to having health problems from nitrate. This includes: Individuals who don't have enough stomach acids. Individuals with an inherited lack of the enzyme that converts affected red blood cells back to normal (methemoglobin reductase). Some studies have found an increased risk of spontaneous abortion or certain birth defects if the mother drank water high in nitrate. Women who are pregnant or who are trying to become pregnant should not consume water that is high in nitrate.

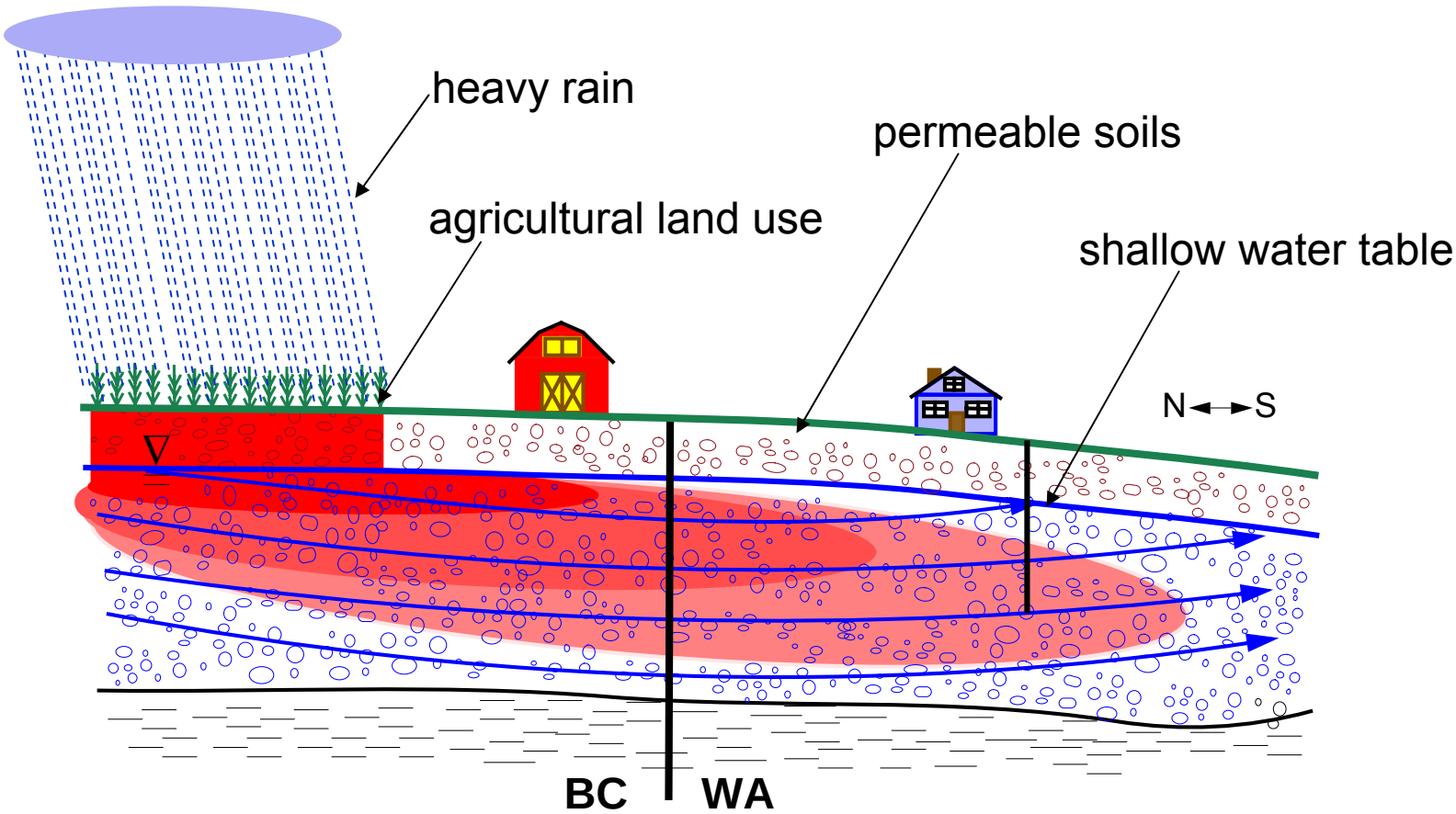
How is nitrate in drinking water regulated?

The U.S. Environmental Protection Agency has established a federal drinking water standard, called a Maximum Contaminant Level of 10 milligrams per liter (mg/L), or 10 parts per million (ppm) for nitrate. Washington State's drinking water quality standard is also 10 mg/L. Public water systems are required to sample for various contaminants, including nitrate, on a regular basis. There is no required sampling of private individual wells. However, private well owners are encouraged to test their well for nitrate on a regular basis.

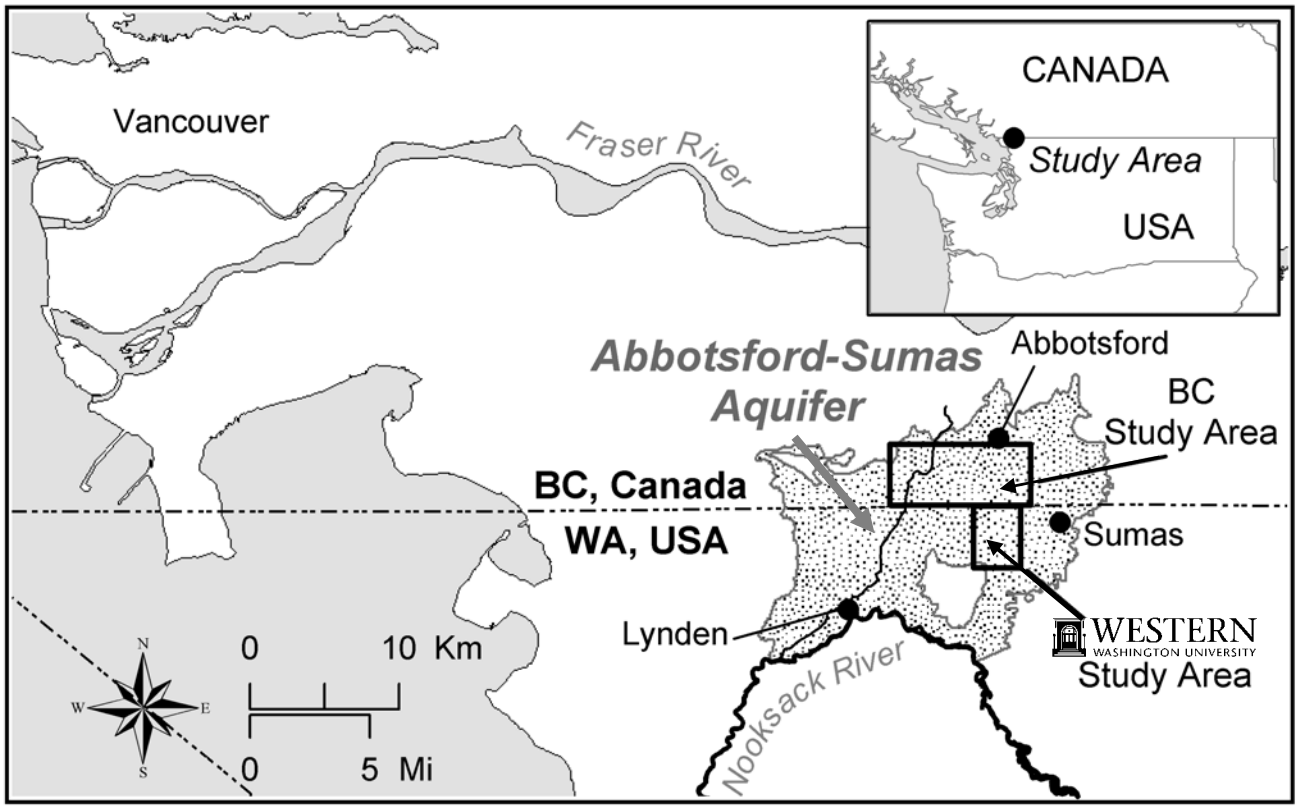
The above information was extracted from a State of Washington Department of Health Fact Sheet (DOH PUB. # 331-214).

http://www.doh.wa.gov/ehp/dw/Publications/nitrate_english_spanish.htm

Groundwater is vulnerable because of a combination of

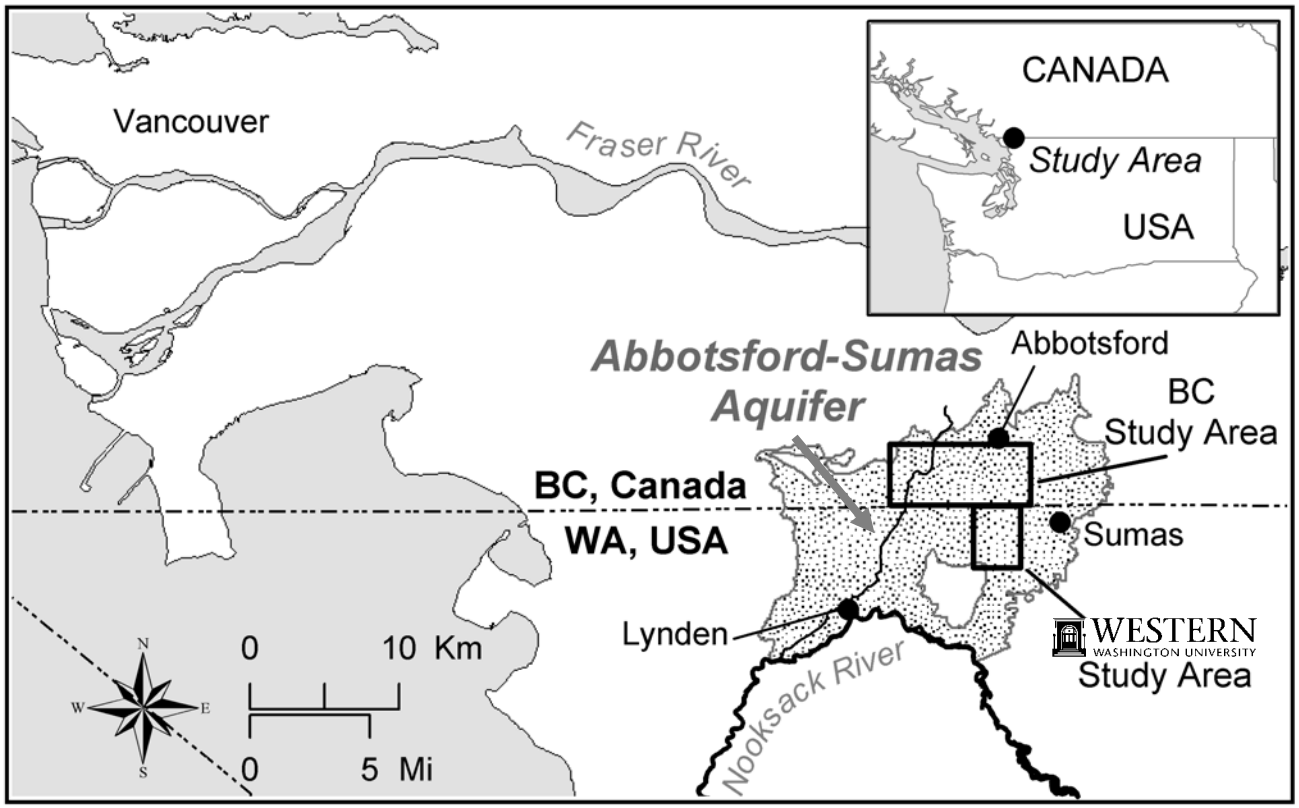


A region that is vulnerable in Whatcom County is the Abbotsford-Sumas Aquifer



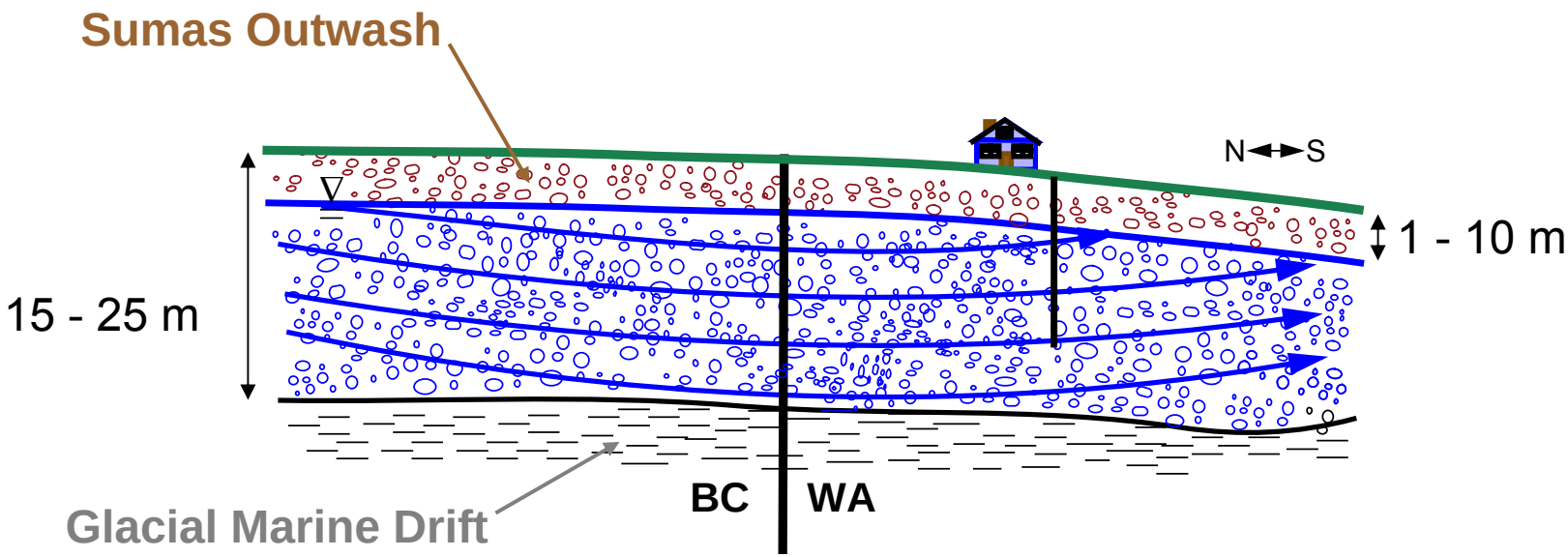
Abbotsford-Sumas Aquifer

The aquifer covers approximately 200 km^2 and serves as a water supply for approximately 110,000 people in BC and WA.



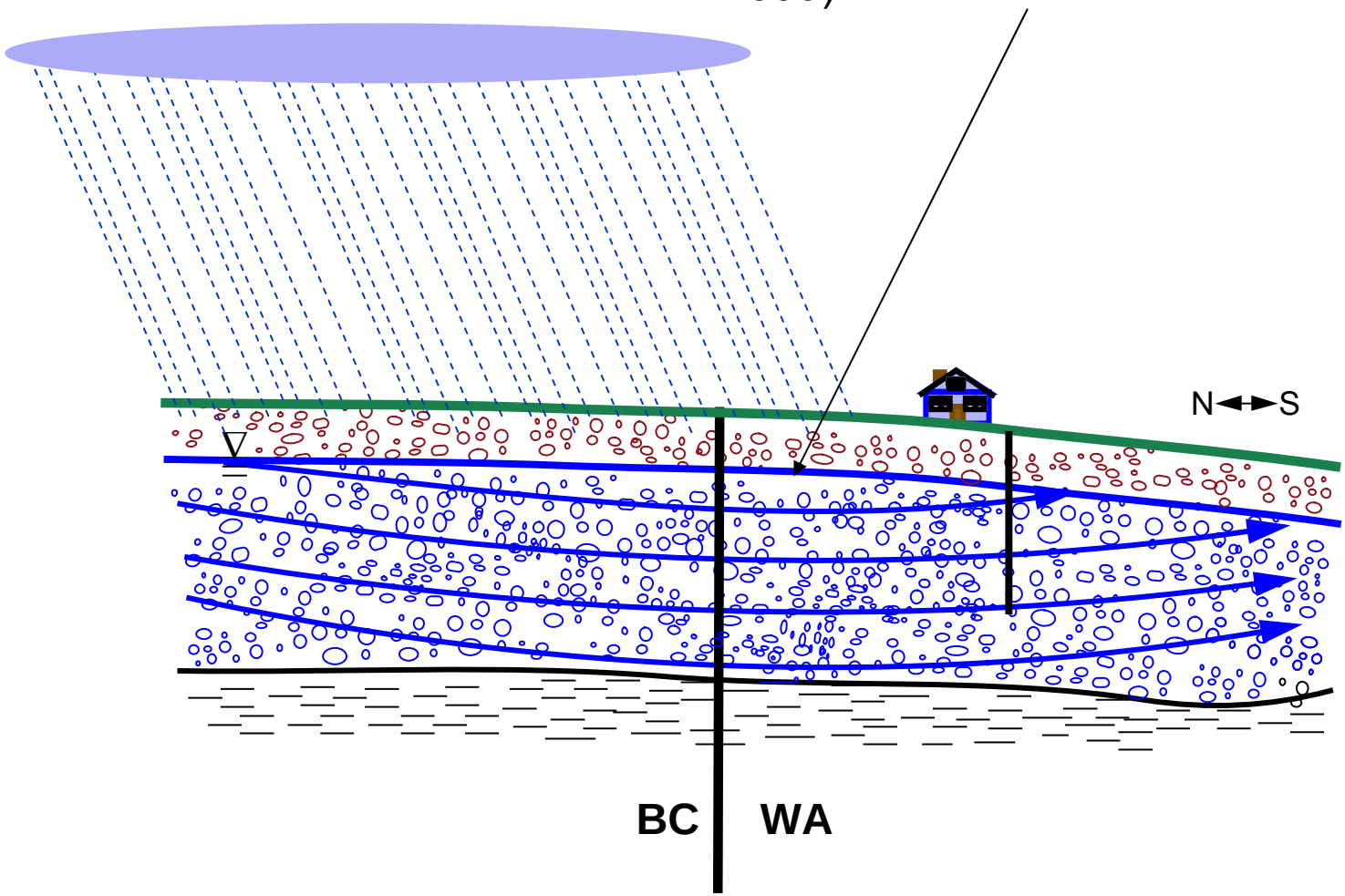
Abbotsford-Sumas Aquifer

The aquifer is unconfined and comprised of glacial outwash sands and gravels (Sumas Outwash) deposited about 10,000 years ago.



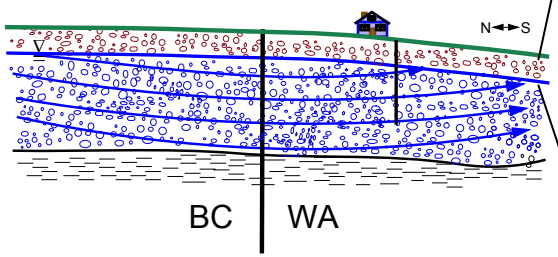
The groundwater flows from north to south in the aquifer at a rate of about 1 to 5 meters per day (Cox and Kahle, 1999).

About 60% of the annual precipitation that falls on the ground surface percolates down and recharges the aquifer (Cox and Kahle, 1999).



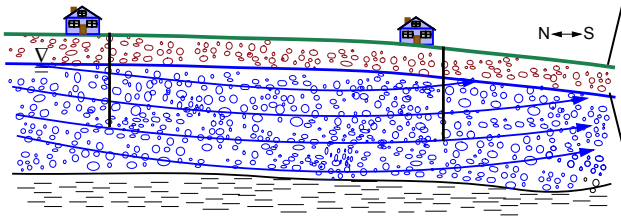
A good view into the aquifer material is via gravel mines. This picture was taken at Aggregates West mine south of Judson Lake.

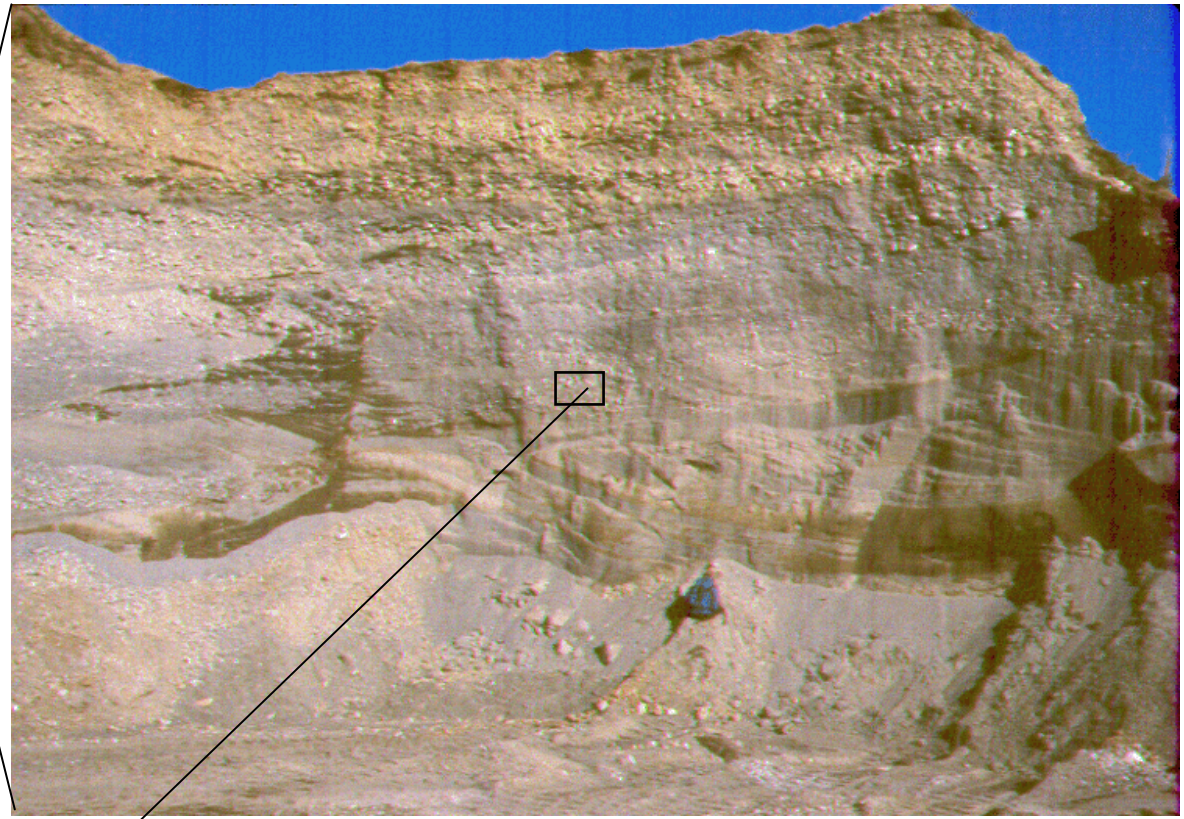
Sumas Outwash



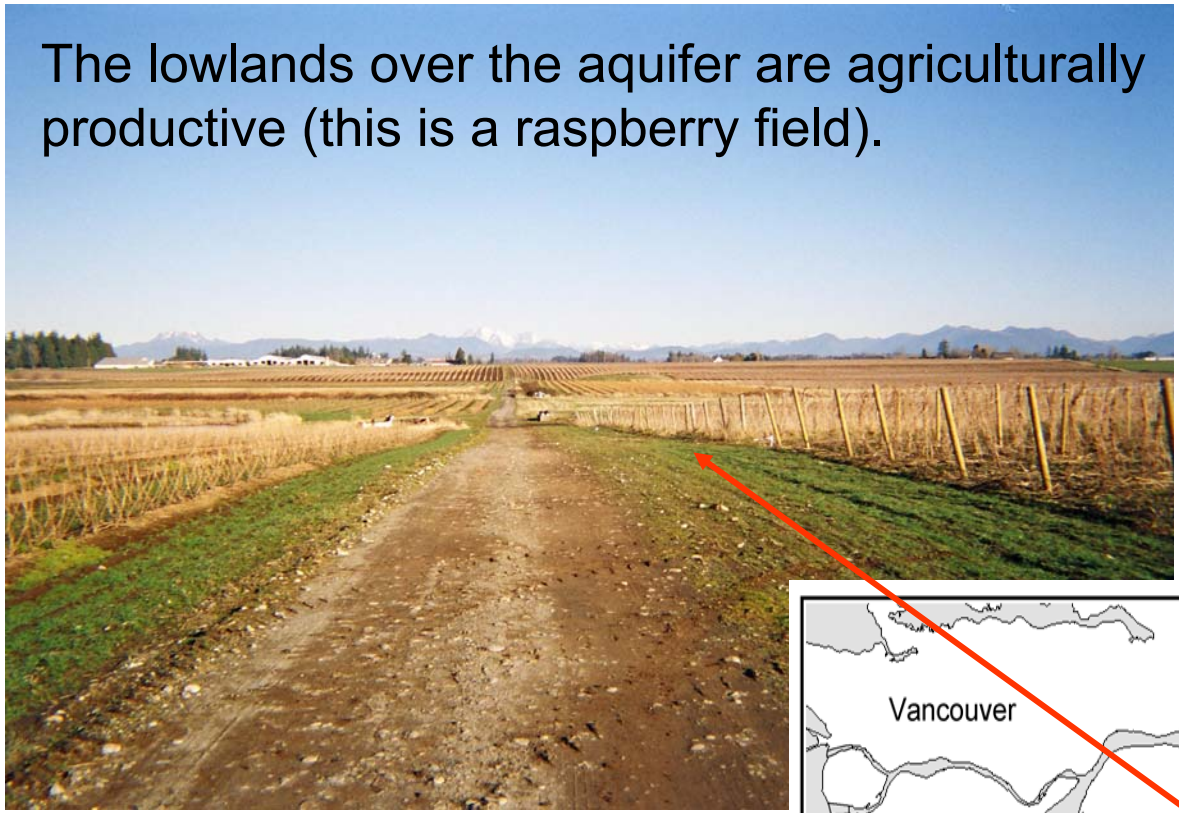
Water table is just below the ground surface

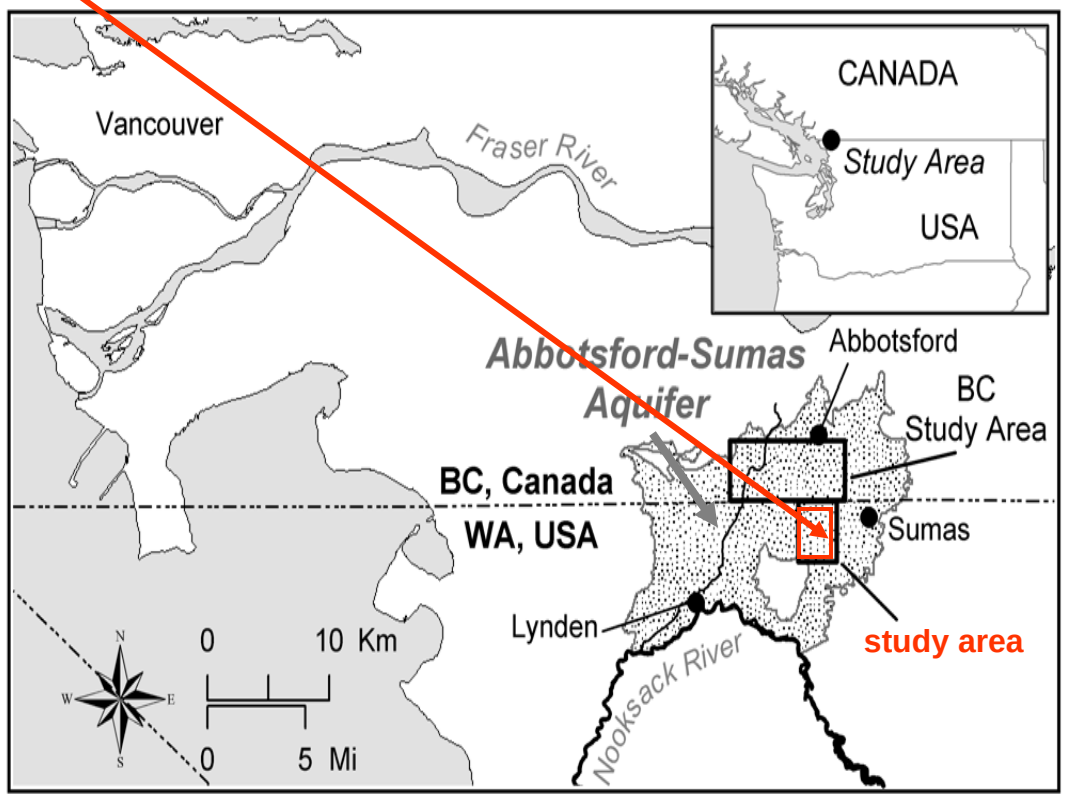
Sumas Outwash





The lowlands over the aquifer are agriculturally productive (this is a raspberry field).





Abbotsford

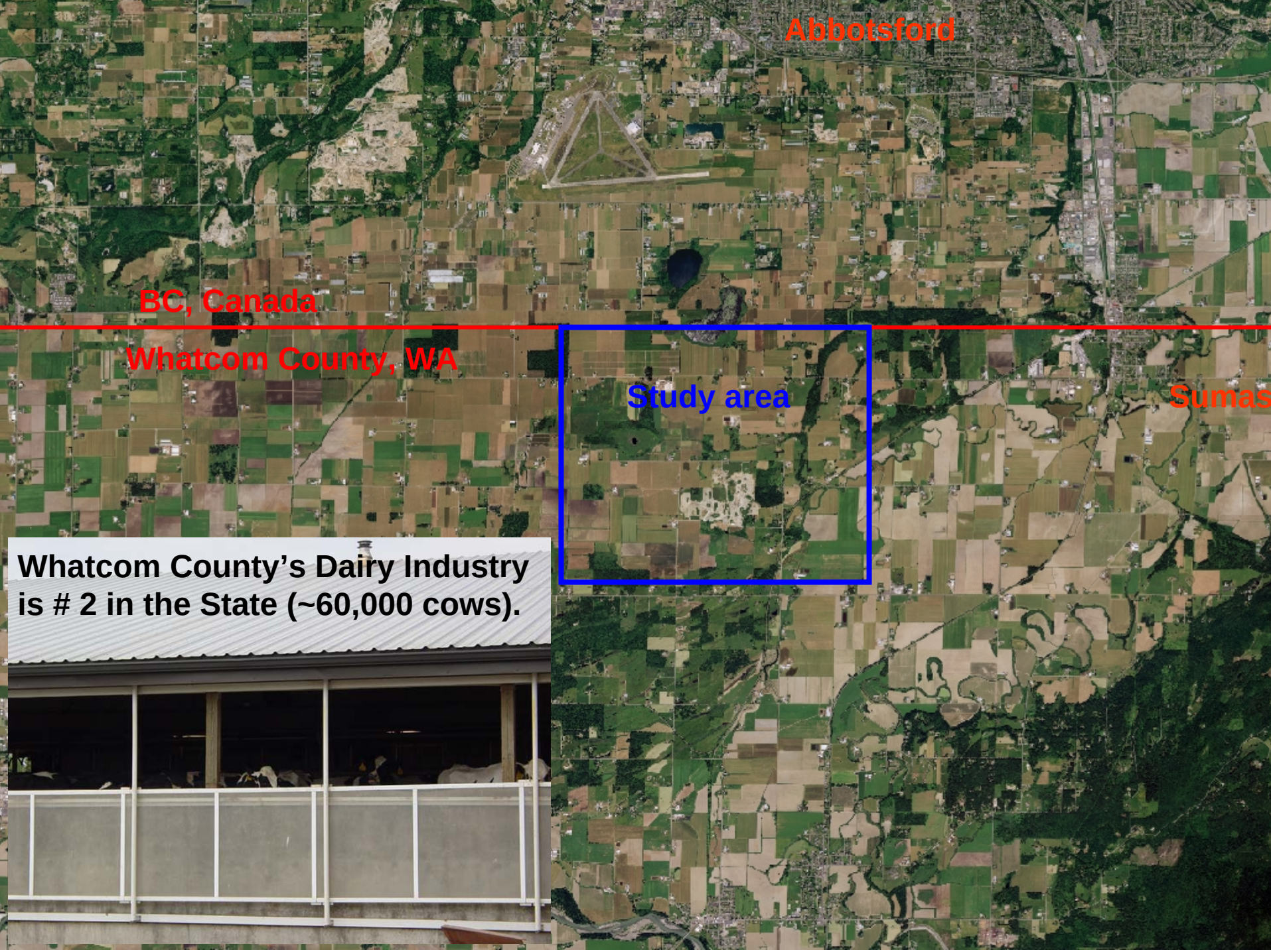
BC, Canada

Whatcom County, WA

Study area

Sumas

Whatcom County's Raspberry Industry is # 1 in the Nation.



Whatcom County's Dairy Industry is # 2 in the State (~60,000 cows).

Southern BC is dominated by raspberry and …

… poultry industries

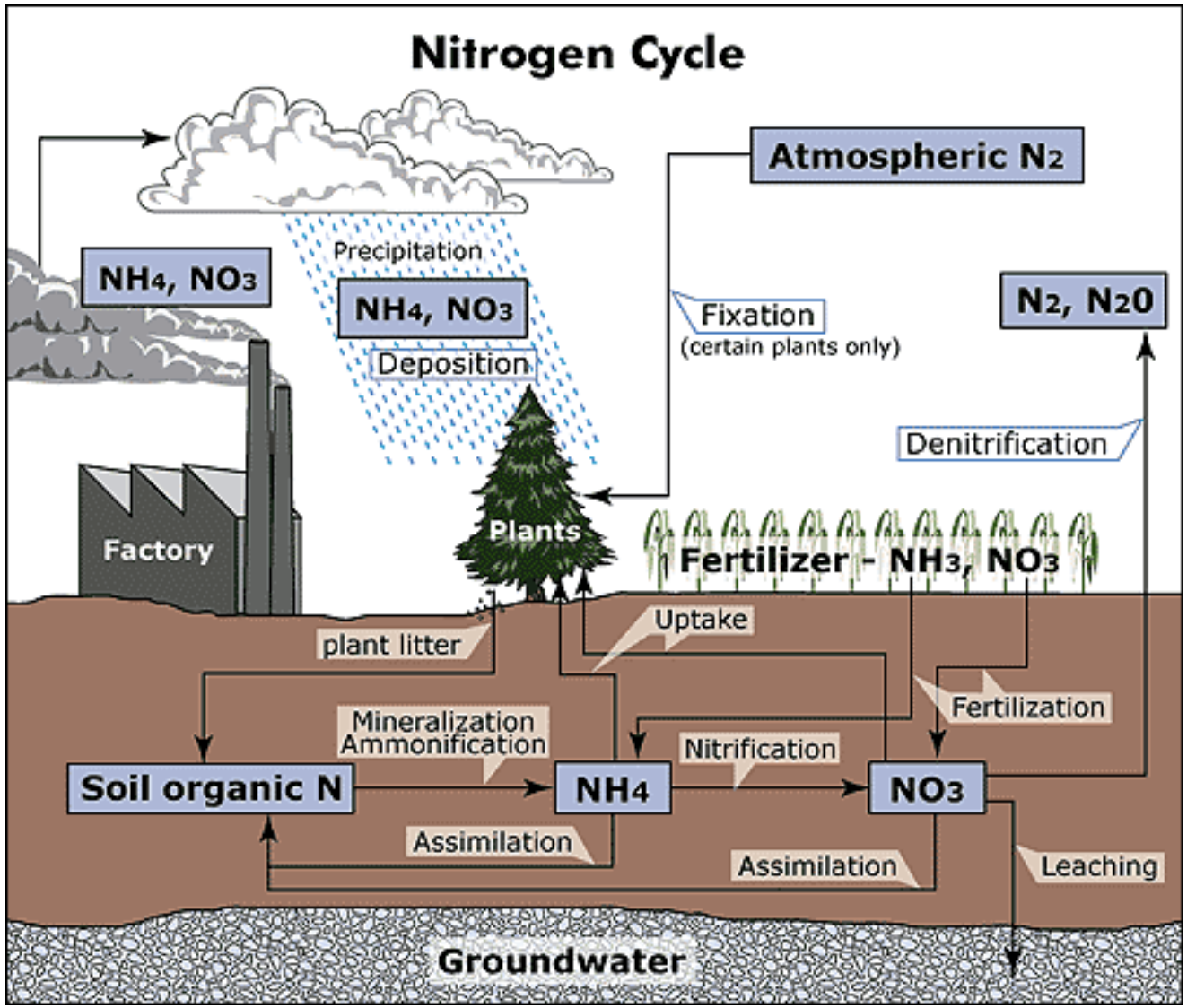
BC, Canada

Whatcom County, WA

Study area

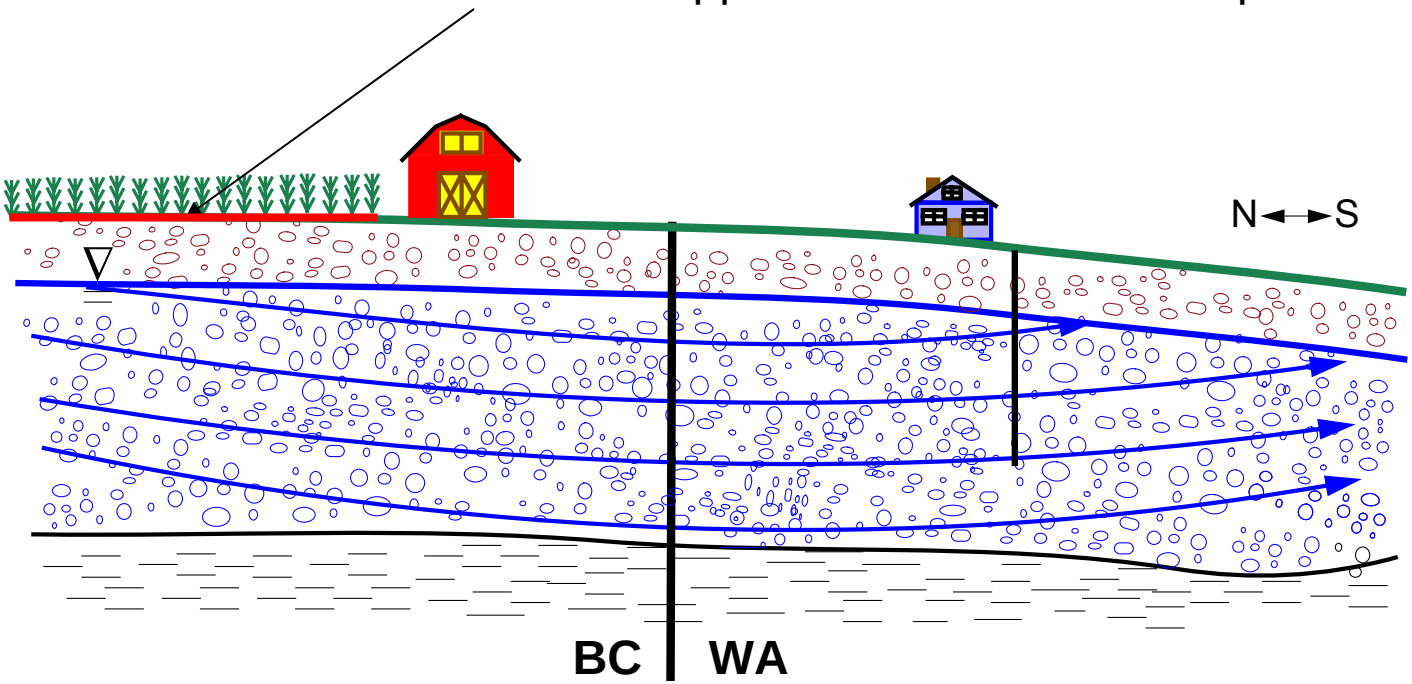
Sumas

Nooksack River


Nitrogen Cycle
Atmospheric N2
Precipitation
NH4, NO3
NH4, NO3
Deposition
Fixation
(certain plants only)
N2, N20
Denitrification
Factory
Plants
Fertilizer - NH3, NO3
Uptake
plant litter
Fertilization
Mineralization
Ammonification
Nitrification
Soil organic N
NH4
NO3
Assimilation
Assimilation
Leaching
Groundwater

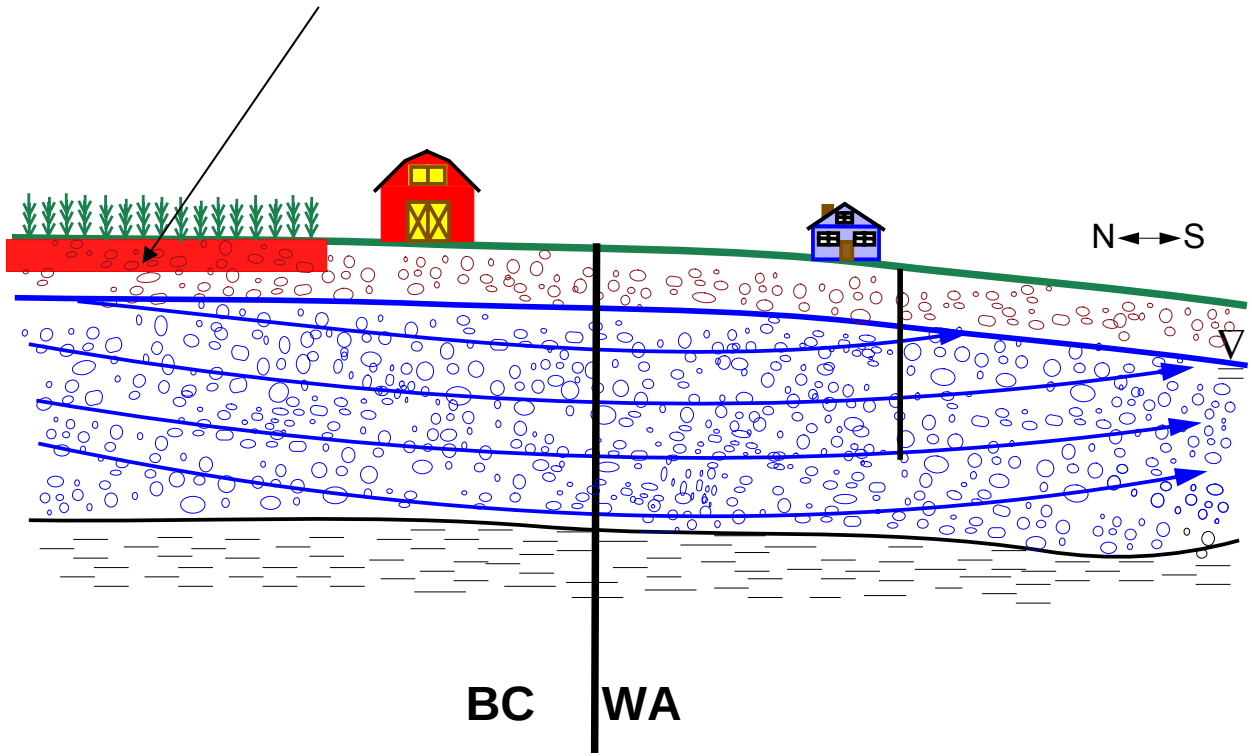
Nitrogen Fertilizers

Nitrogen inorganic commercial and organic manure fertilizers are added to the soil to supplement nutrients for crops.



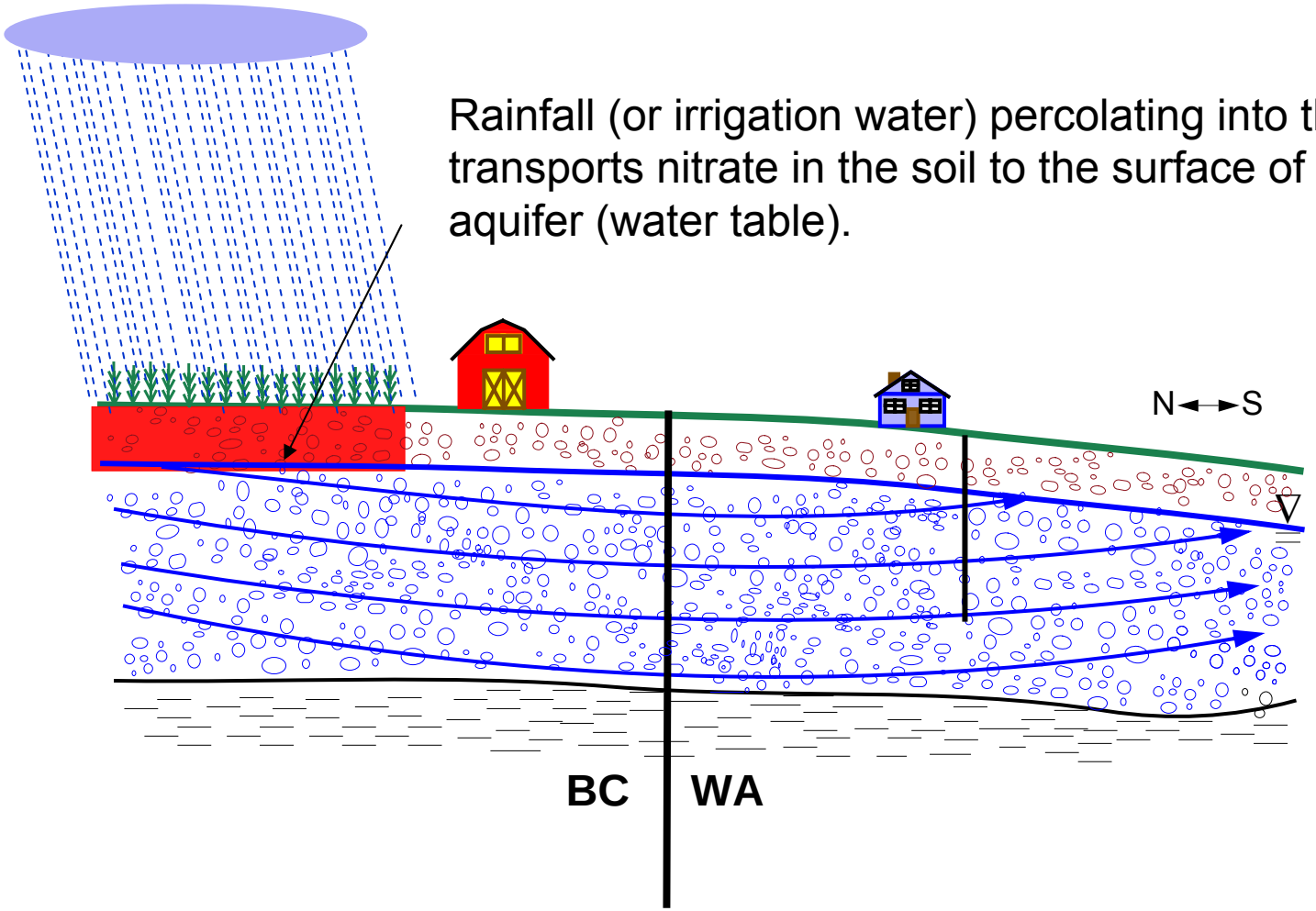
Mineralization and Nitrification

Excess nitrogen in the soil is converted to nitrate by the help of bacteria



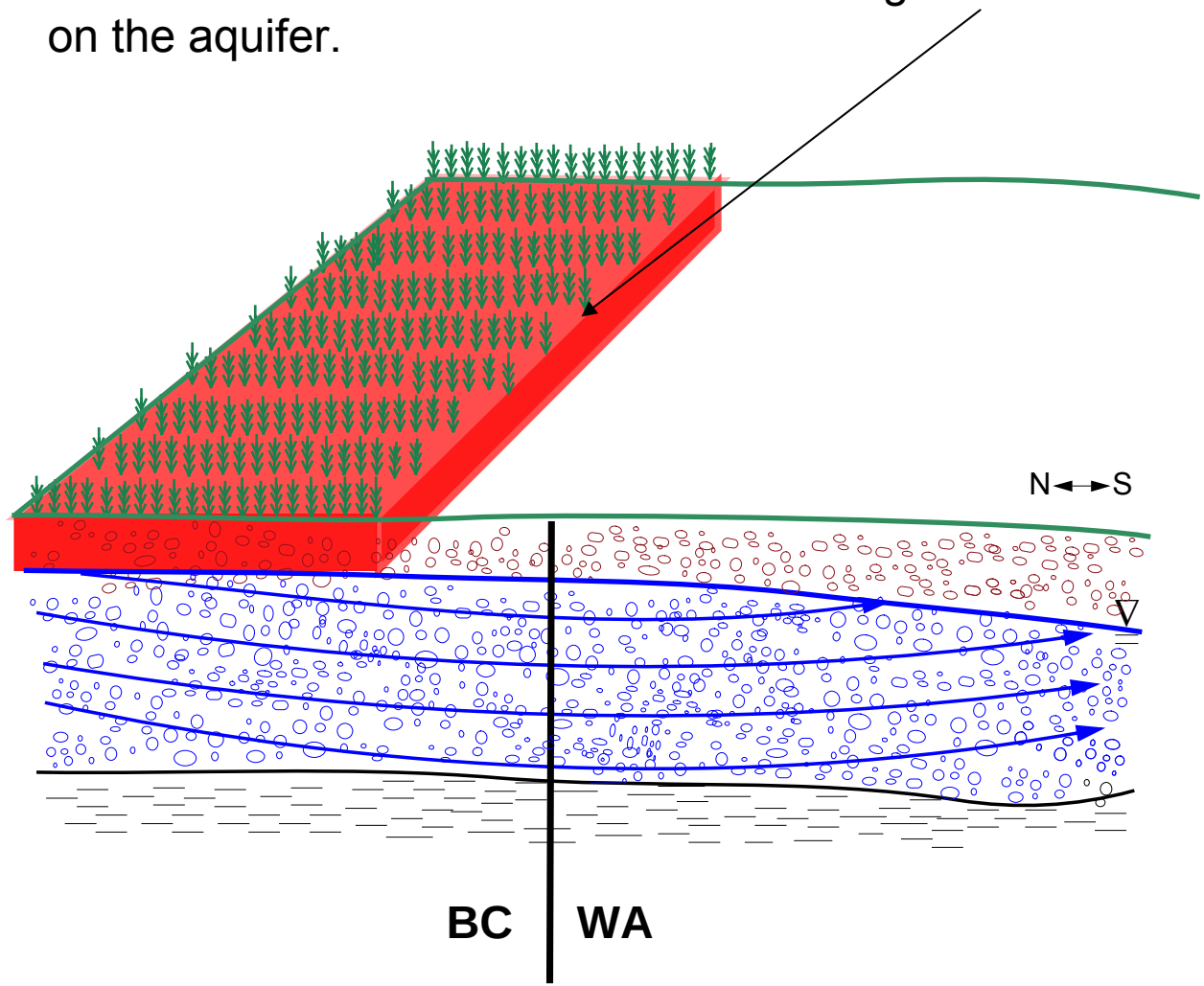
Nitrate Leaching

Rainfall (or irrigation water) percolating into the soil transports nitrate in the soil to the surface of the aquifer (water table).



Nitrate Contamination

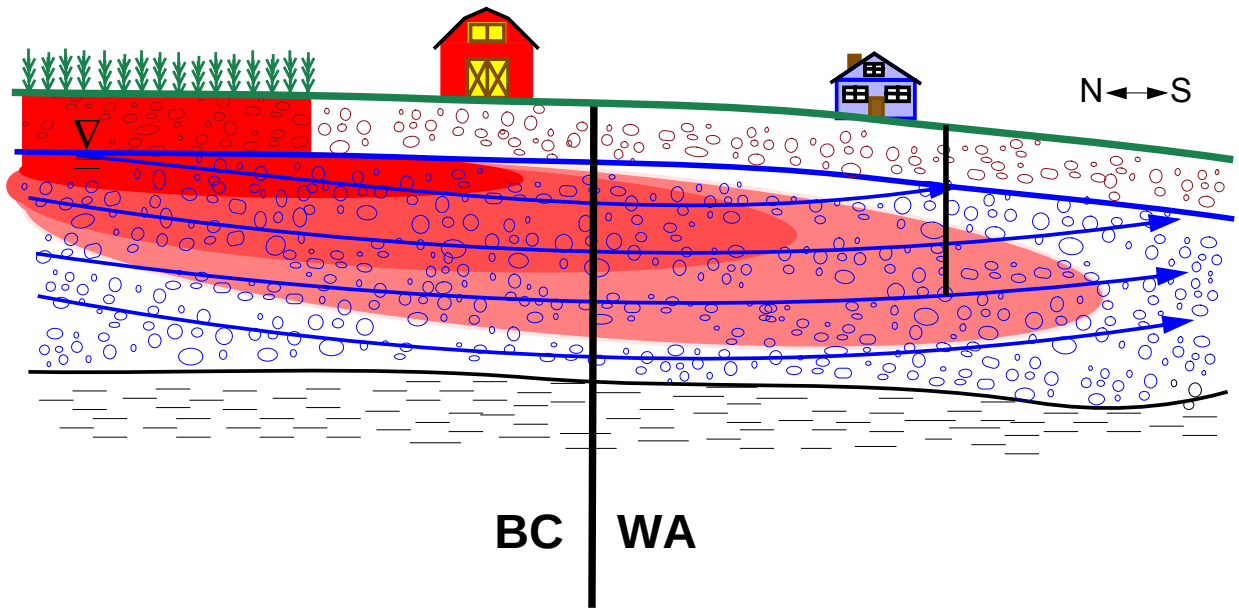
Nitrate derived from fertilized fields is called a “non-point” source contaminant because it covers large surface areas on the aquifer.



Nitrate Transport in the Aquifer

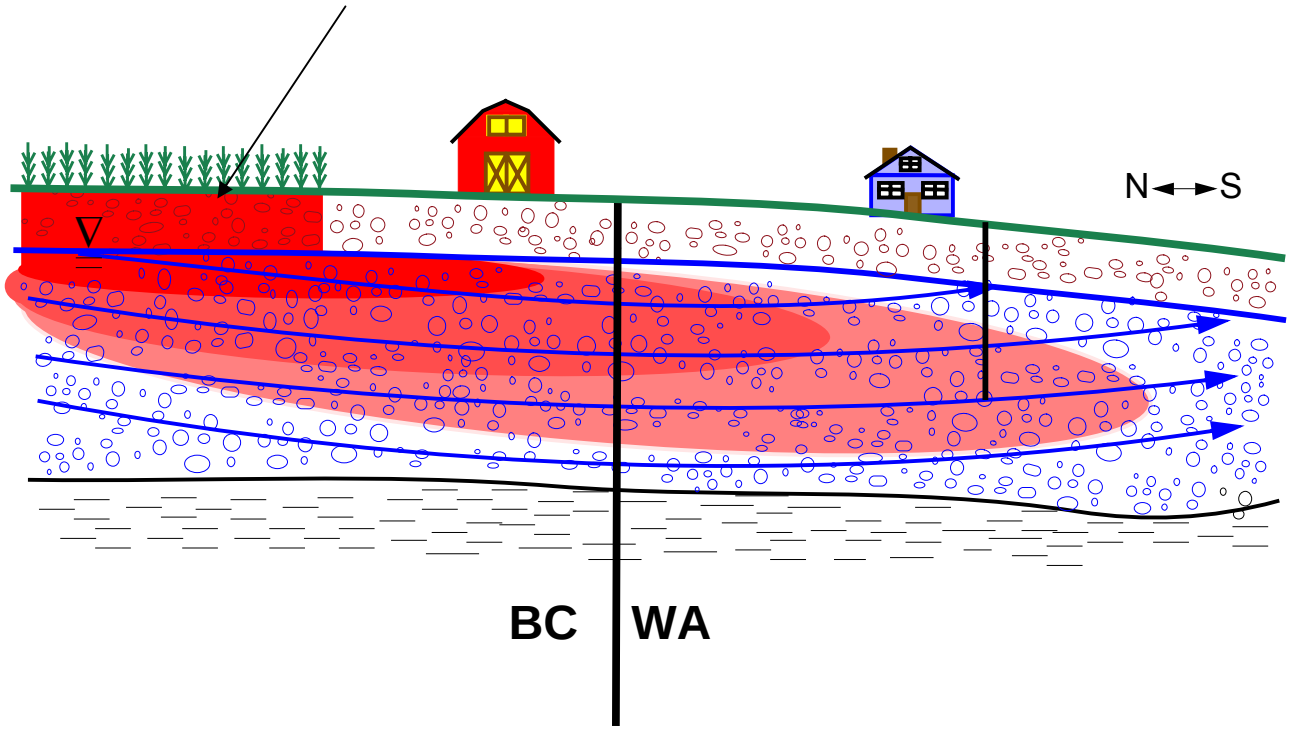
Nitrate is transported through the aquifer by groundwater, which moves fast in the Sumas outwash (1 to 5 meters per day).

Because groundwater flows south, nitrate derived in BC is transported into the Whatcom County portion of the aquifer.



Nitrate Contamination in British Columbia

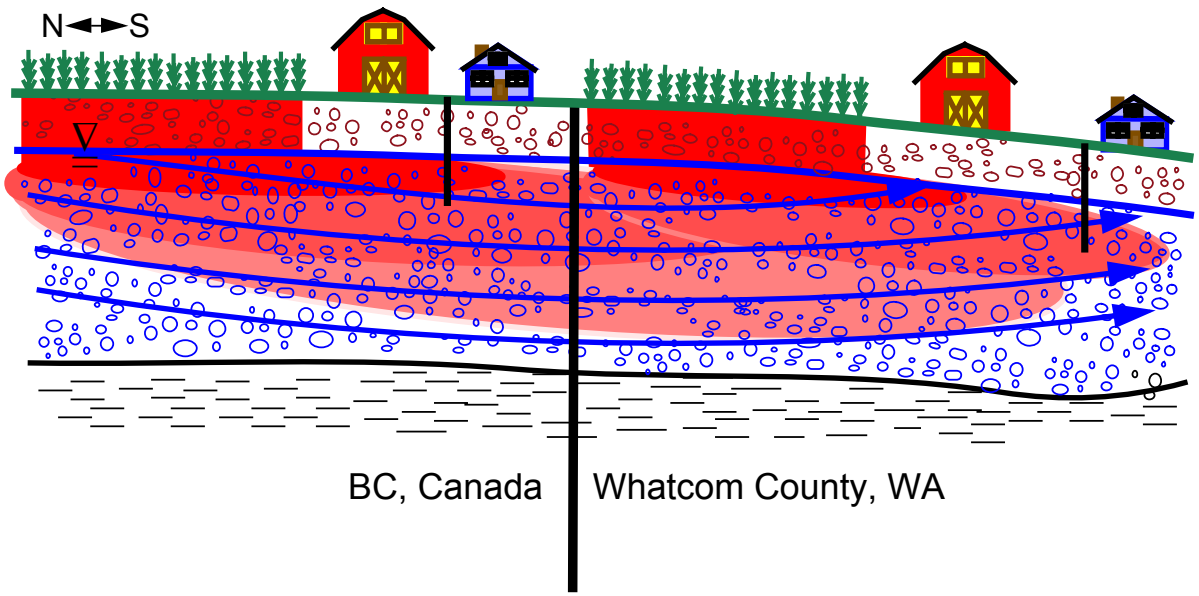
Non-point sources of nitrate in BC include a mix of poultry manure and inorganic commercial fertilizers



Nitrate Contamination in Whatcom County, WA

Agricultural practices in Whatcom County also contribute to the problem.

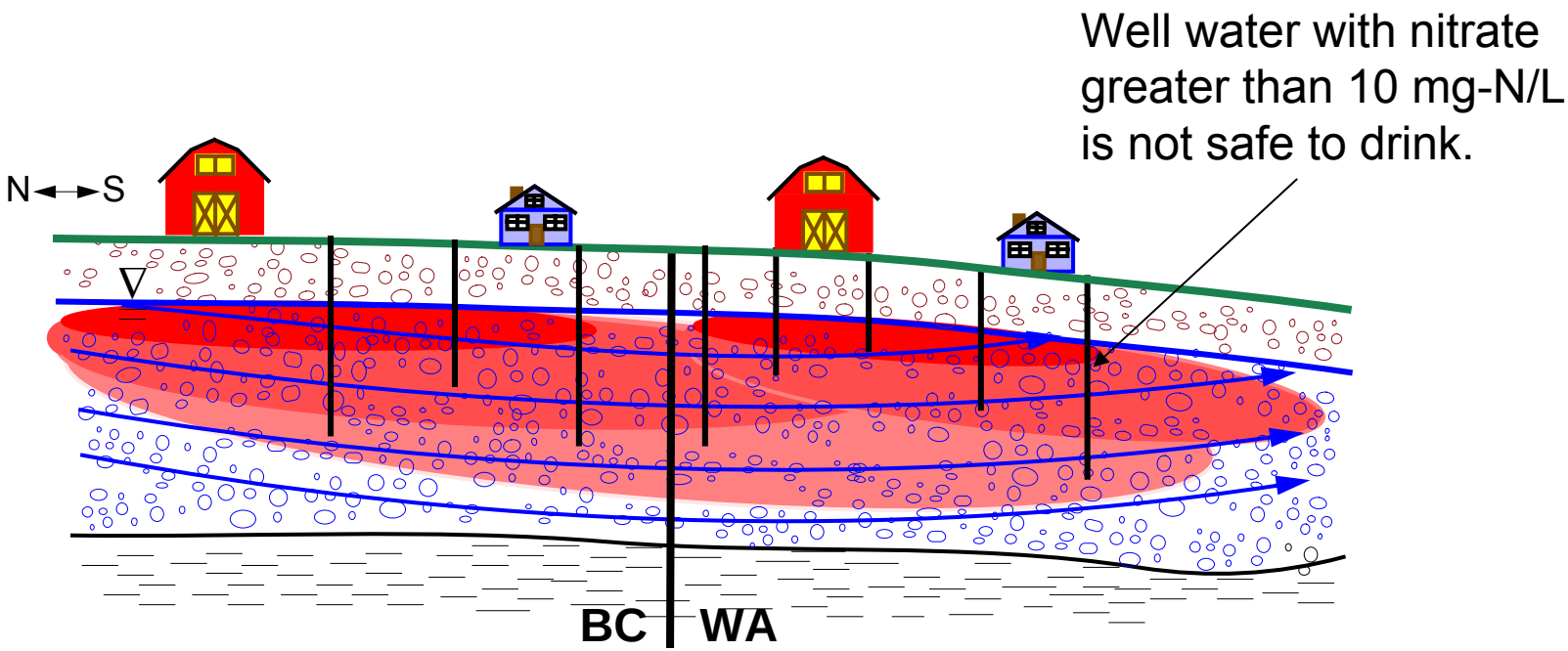
Non-point sources in the county include a mix of dairy manure and inorganic commercial fertilizers



Problem

Elevated nitrate concentrations in the aquifer are due to agricultural practices on both sides of the border.

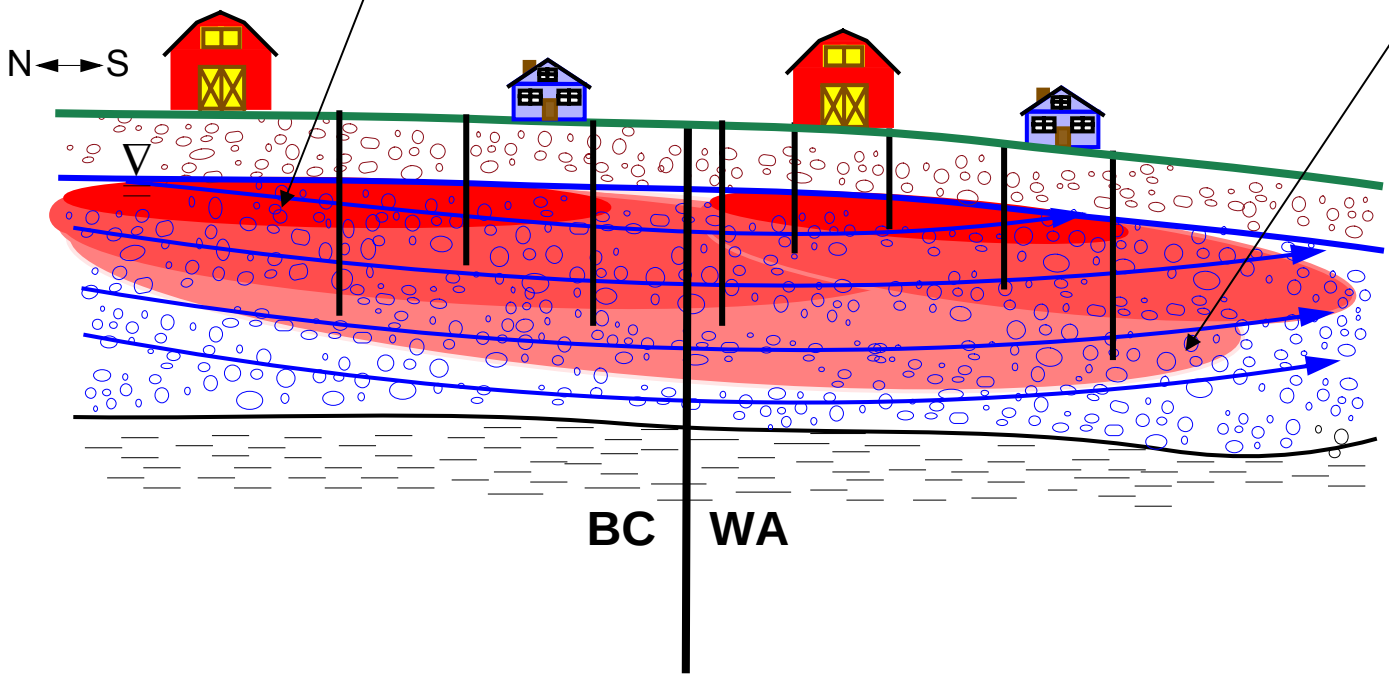
The concentrations can exceed the US-EPA maximum contaminant level (MCL) of 10 mg-N/L.



Nitrate Concentration Stratification

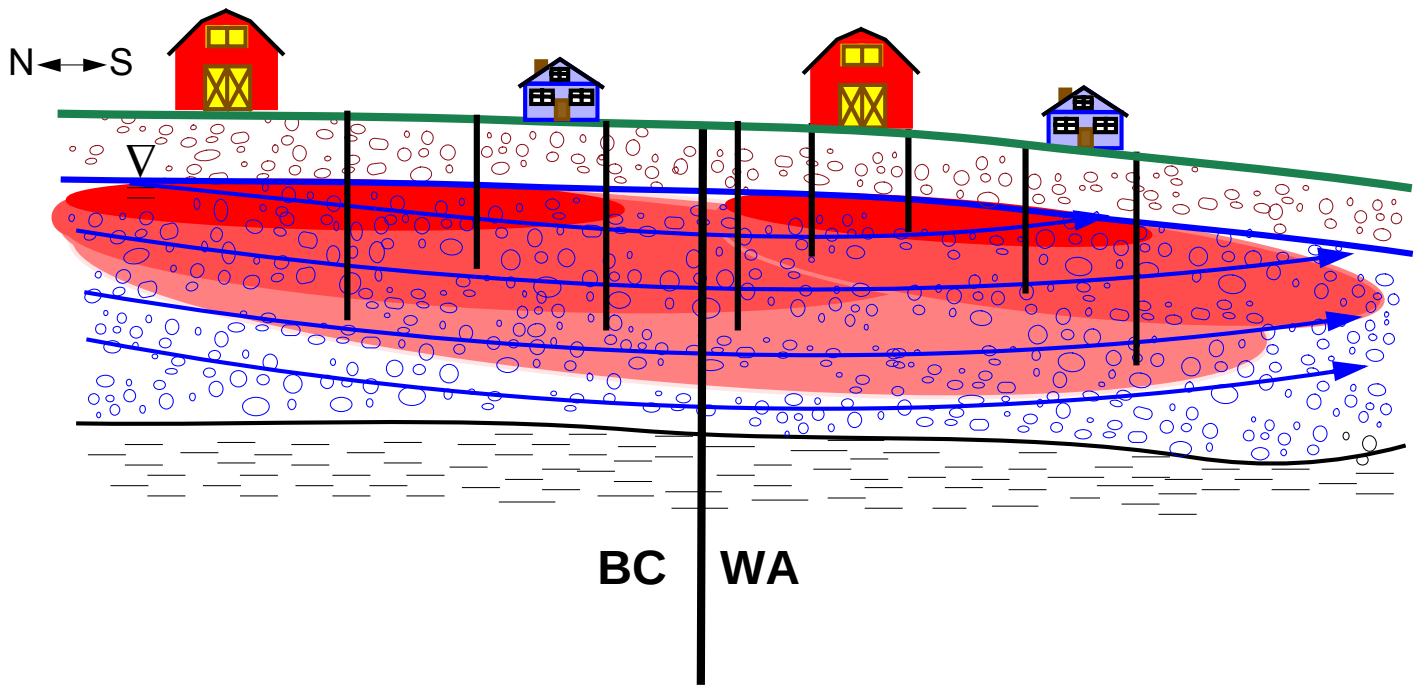
The nitrate concentrations are higher near the water table because it's closer to the surface sources.

Lower concentrations occur deeper in the aquifer because of mixing and dilution.



Problem

Nutrient management in Whatcom County is difficult to assess because of nitrate transport from BC



International Mitigation Strategy

In 1992 the **Abbotsford-Sumas International Task Force** was formed to coordinate groundwater protection efforts in the aquifer.

Members represent government agencies, tribes, cities and counties on both side of the border. Their goals are to

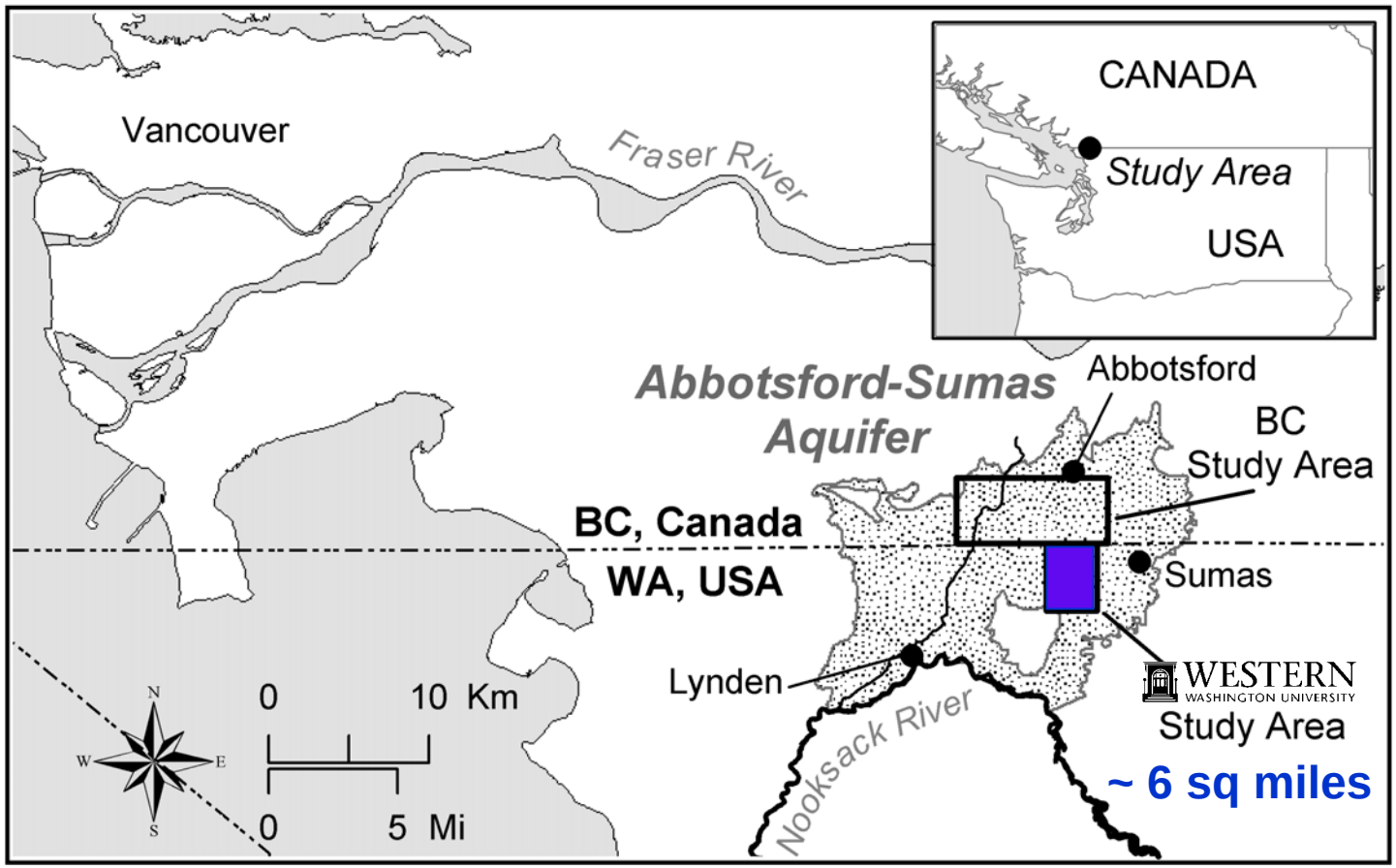
- ✓ Collect and Coordination Scientific Data
- ✓ Manage Activities Threatening the Aquifer
- ✓ Assist with Legislation and Policy Advice

Our Objectives at WESTERN WASHINGTON UNIVERSITY

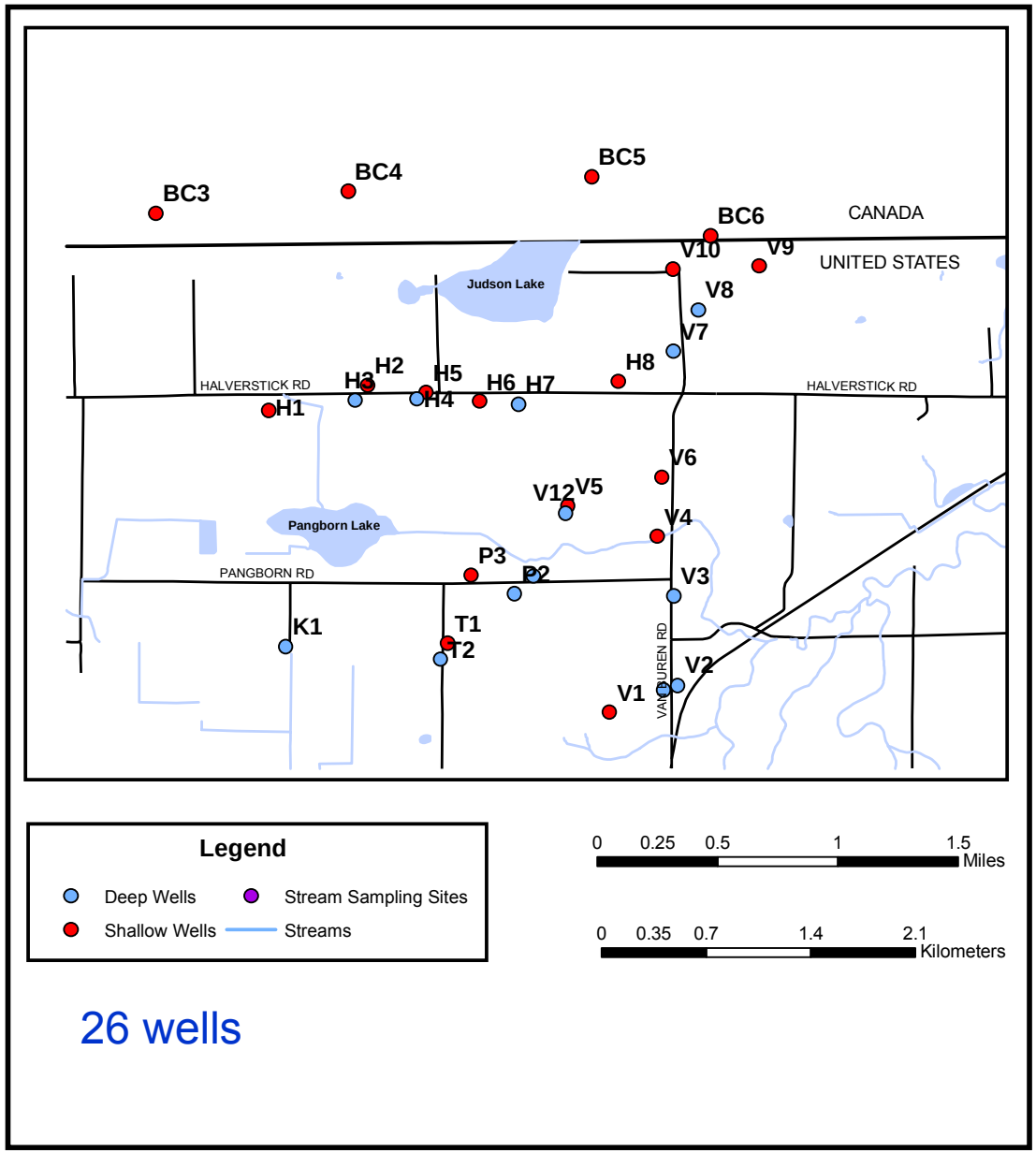
- Quantify nitrate concentrations and distributions in a study site adjacent to the International border.
- Attempt to distinguish BC nitrate sources from sources in Washington.
  - ✓ Monitor groundwater quality using shallow and deep domestic wells.
  - ✓ Measure nitrogen isotope values as a means to identify nitrogen sources.
  - ✓ Monitor surface-water quality in perennial streams.

Funding provided by the Washington State Department of Ecology (Centennial Clean Water Fund).

Study Area

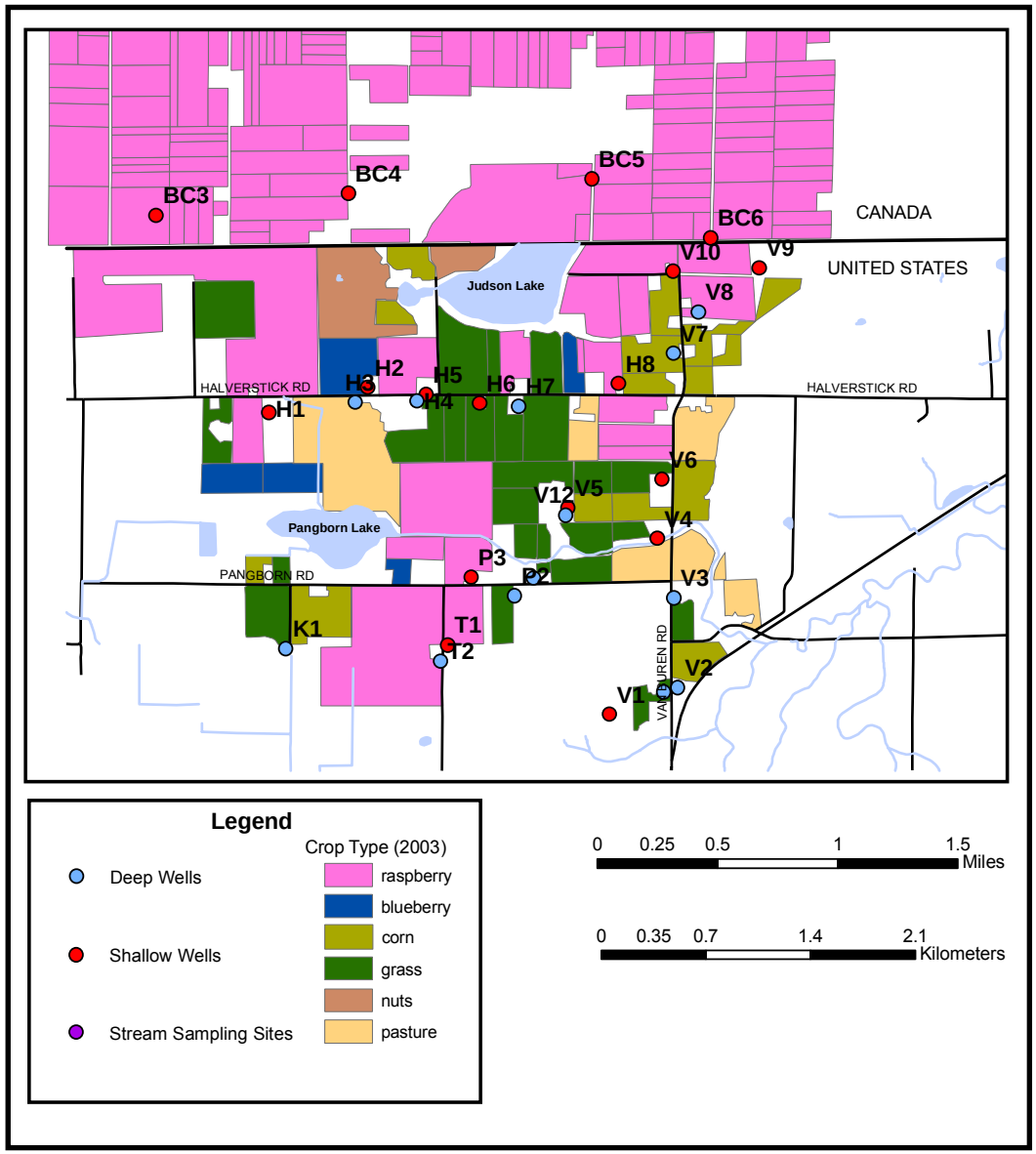

CANADA
Study Area
USA
Vancouver
Fraser River
Abbotsford-Sumas Aquifer
Abbotsford
BC Study Area
BC, Canada
WA, USA
Sumas
Lynden
WESTERN WASHINGTON UNIVERSITY
Study Area
~ 6 sq miles
Nooksack River
N
W
E
S
0
10 Km
0
5 Mi

Well Sampling Sites



26 wells

Land Use

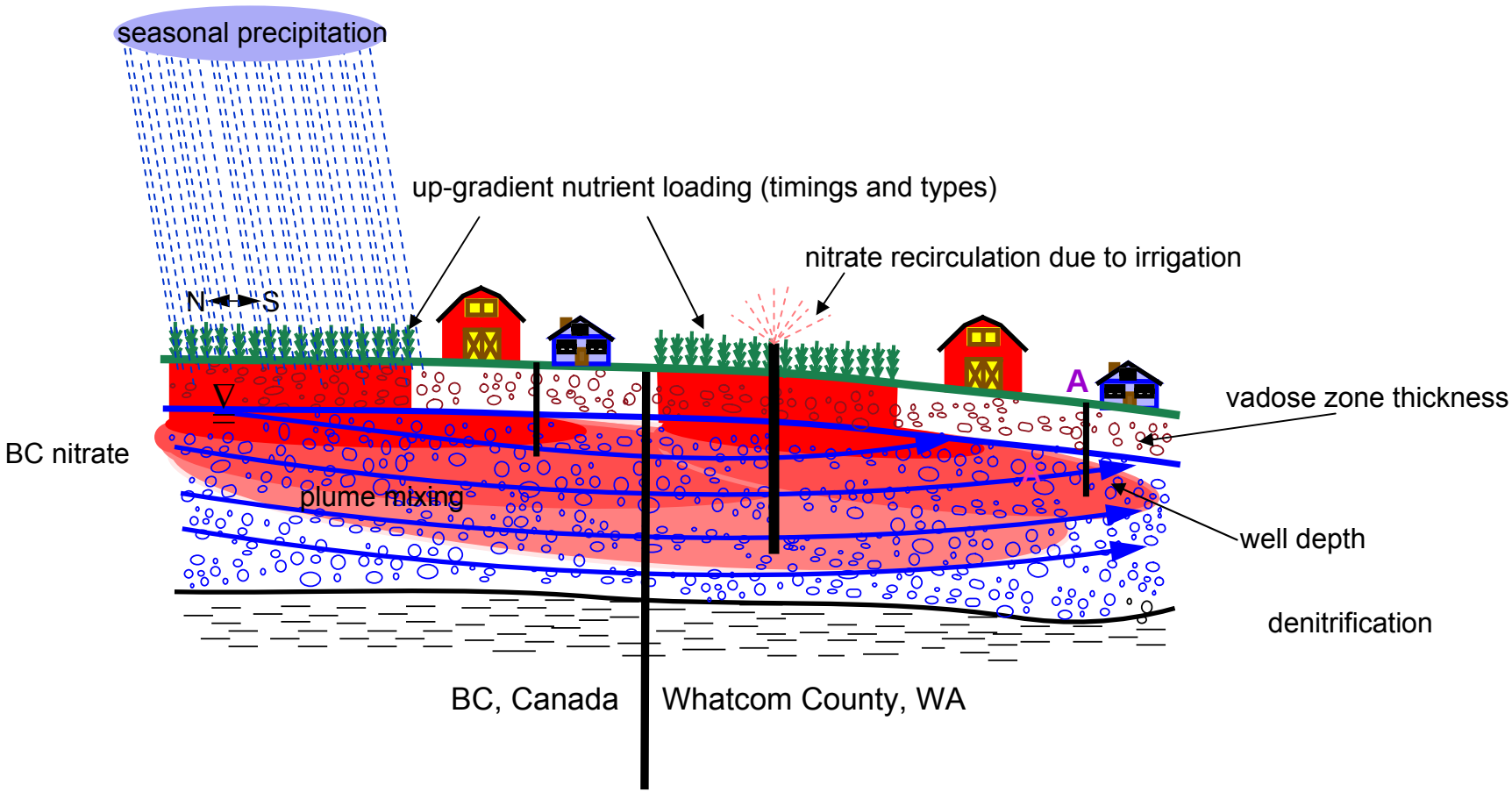

BC3
BC4
BC5
BC6
CANADA
UNITED STATES
V10
V9
V8
V7
Judson Lake
H8
H2
H3
H5
H6
H7
H4
H1
HALVERSTICK RD
HALVERSTICK RD
V6
V12
V5
V4
Pangborn Lake
P3
P2
V3
PANGBORN RD
K1
T1
T2
VAN BUREN RD
V2
V1
Legend
Crop Type (2003)
Deep Wells
Shallow Wells
Stream Sampling Sites
raspberry
blueberry
corn
grass
nuts
pasture
0 0.25 0.5 1 1.5
Miles
0 0.35 0.7 1.4 2.1
Kilometers

Domestic wells were sampled monthly for 2 years

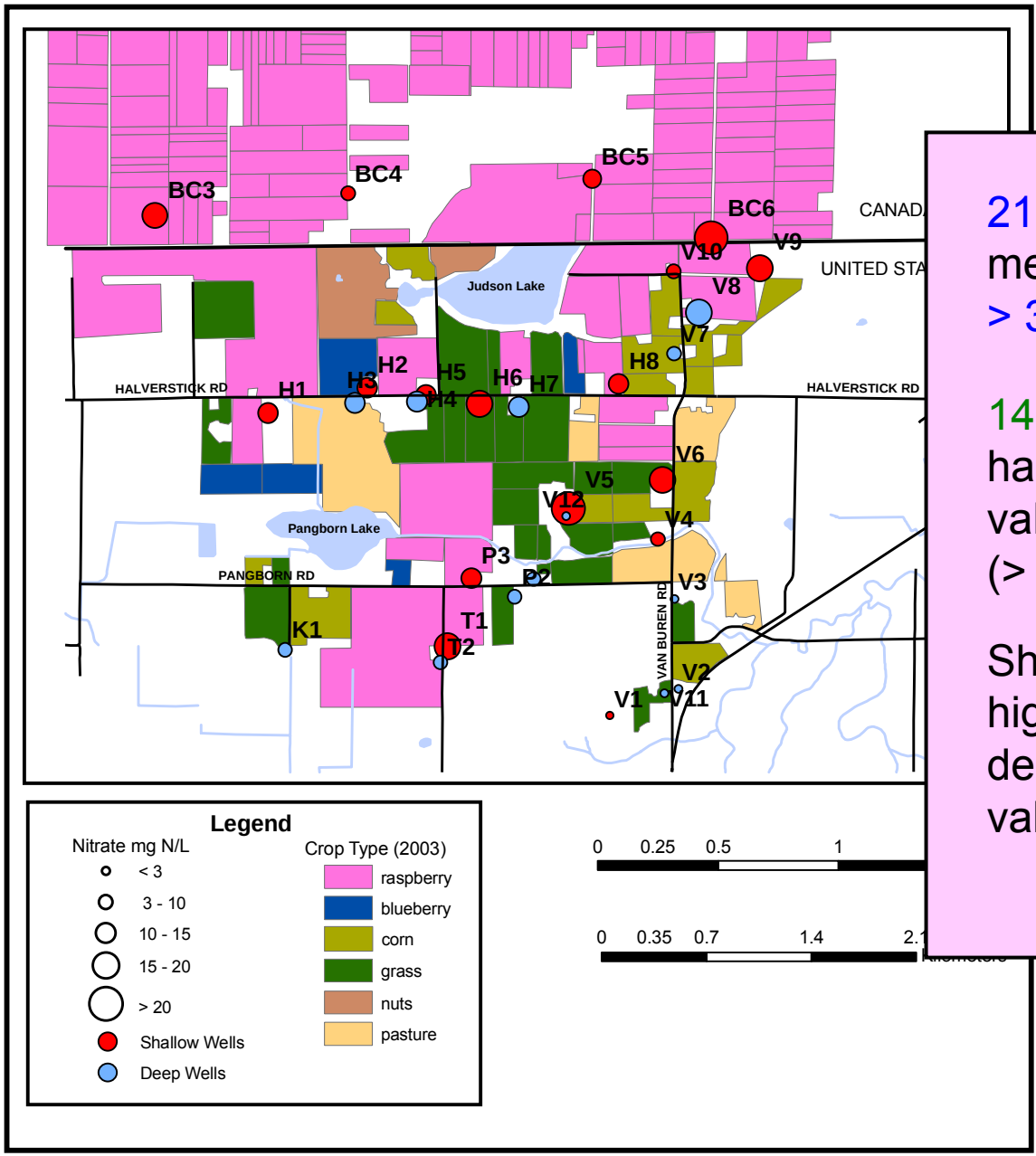
Water Quality Parameters were measured at the Institute for Watershed Studies Water-Quality Lab

WESTERN WASHINGTON UNIVERSITY

Numerous factors may influence a nitrate concentration measured at well A, including:



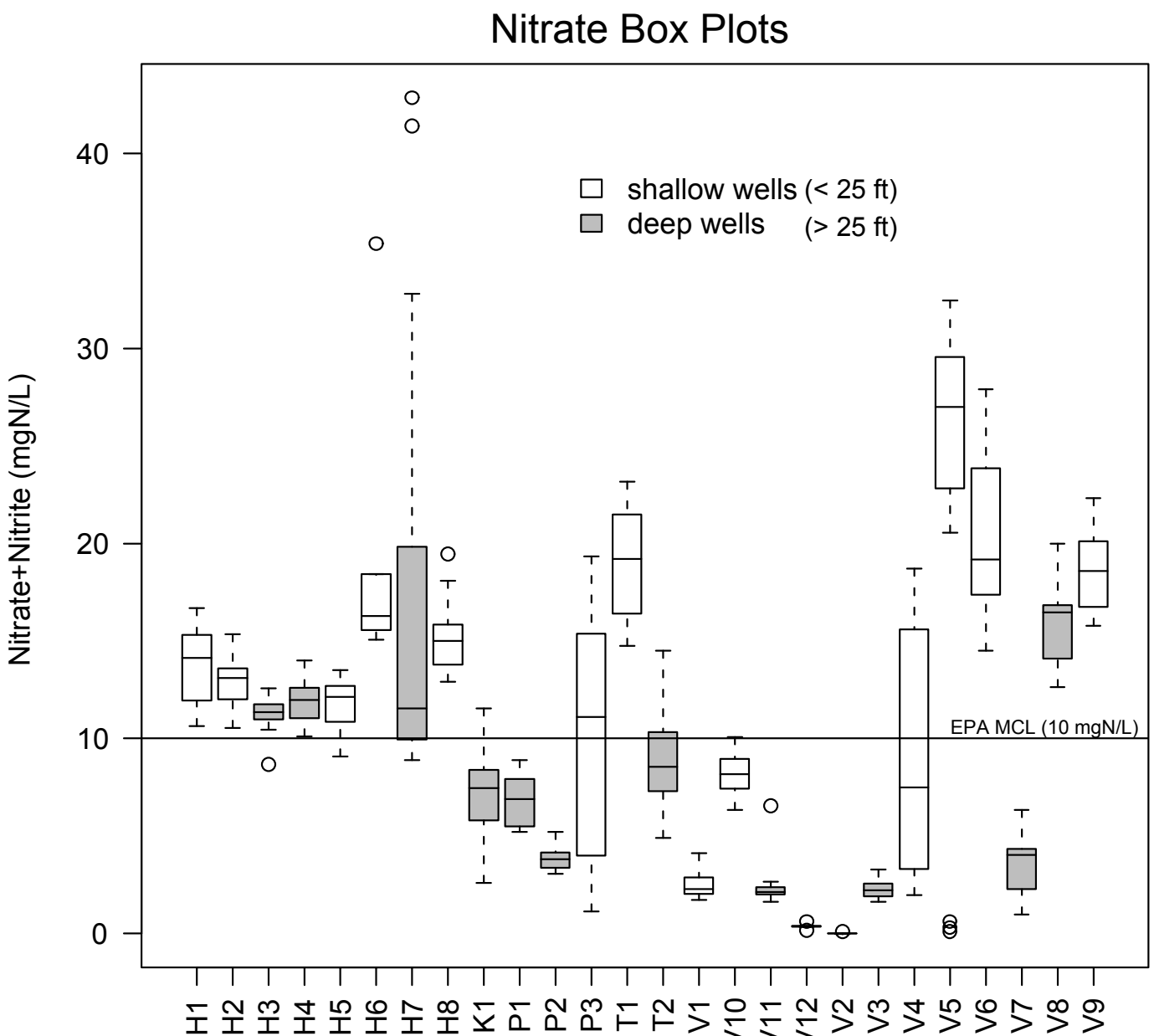
Groundwater Median Nitrate Values



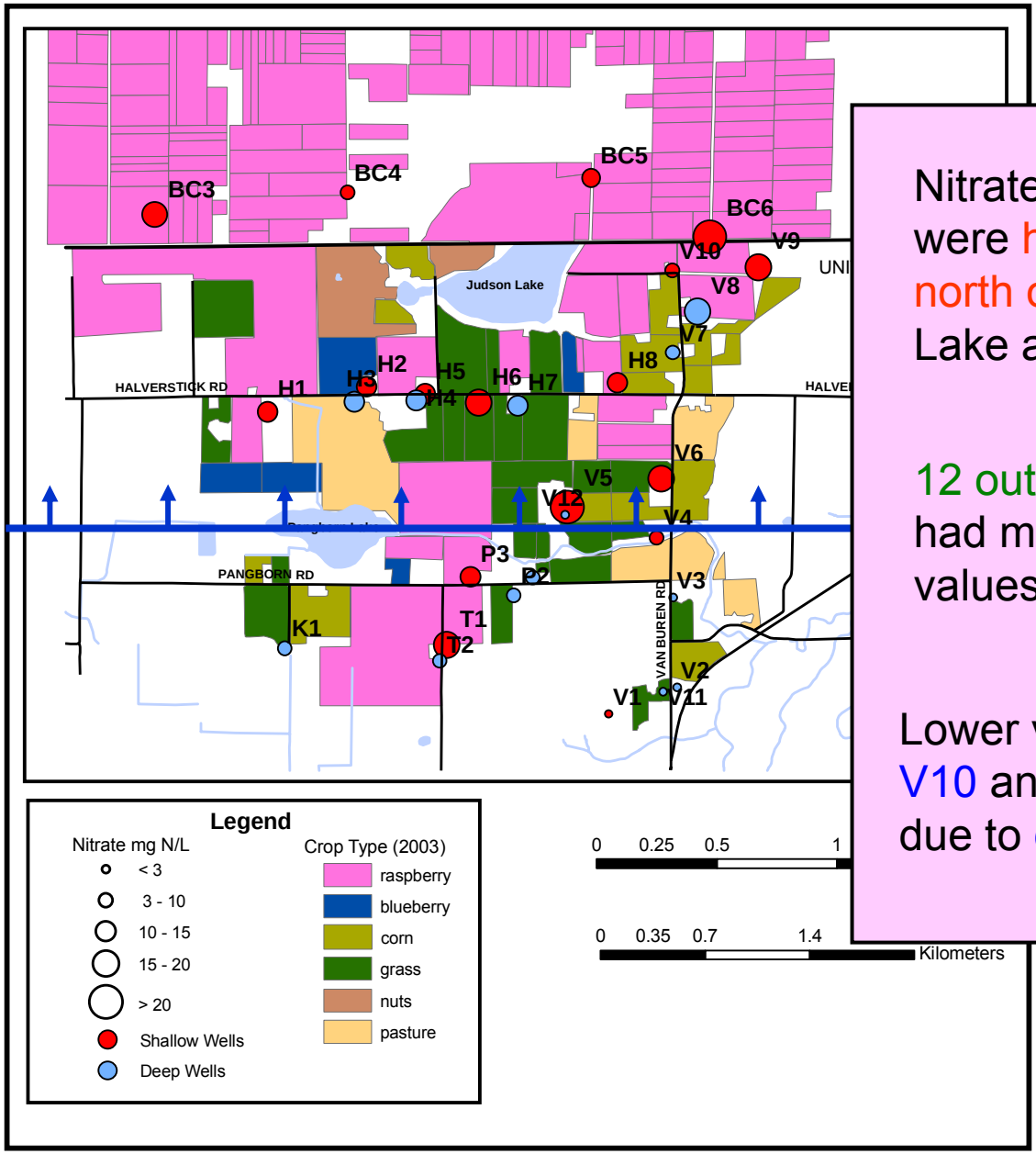
21 out of 26 wells had median nitrate values > 3 mg-N/L

14 out of 26 wells had median nitrate values > 10 mg-N/L (> EPA MCL)

Shallow wells had higher values then deeper wells, highest value was 43 mg-N/L


Nitrate Box Plots
shallow wells (< 25 ft)
deep wells (> 25 ft)
EPA MCL (10 mgN/L)
Nitrate+Nitrite (mgN/L)
0
10
20
30
40
H1
H2
H3
H4
H5
H6
H7
H8
K1
P1
P2
P3
T1
T2
V1
V10
V11
V12
V2
V3
V4
V5
V6
V7
V8
V9

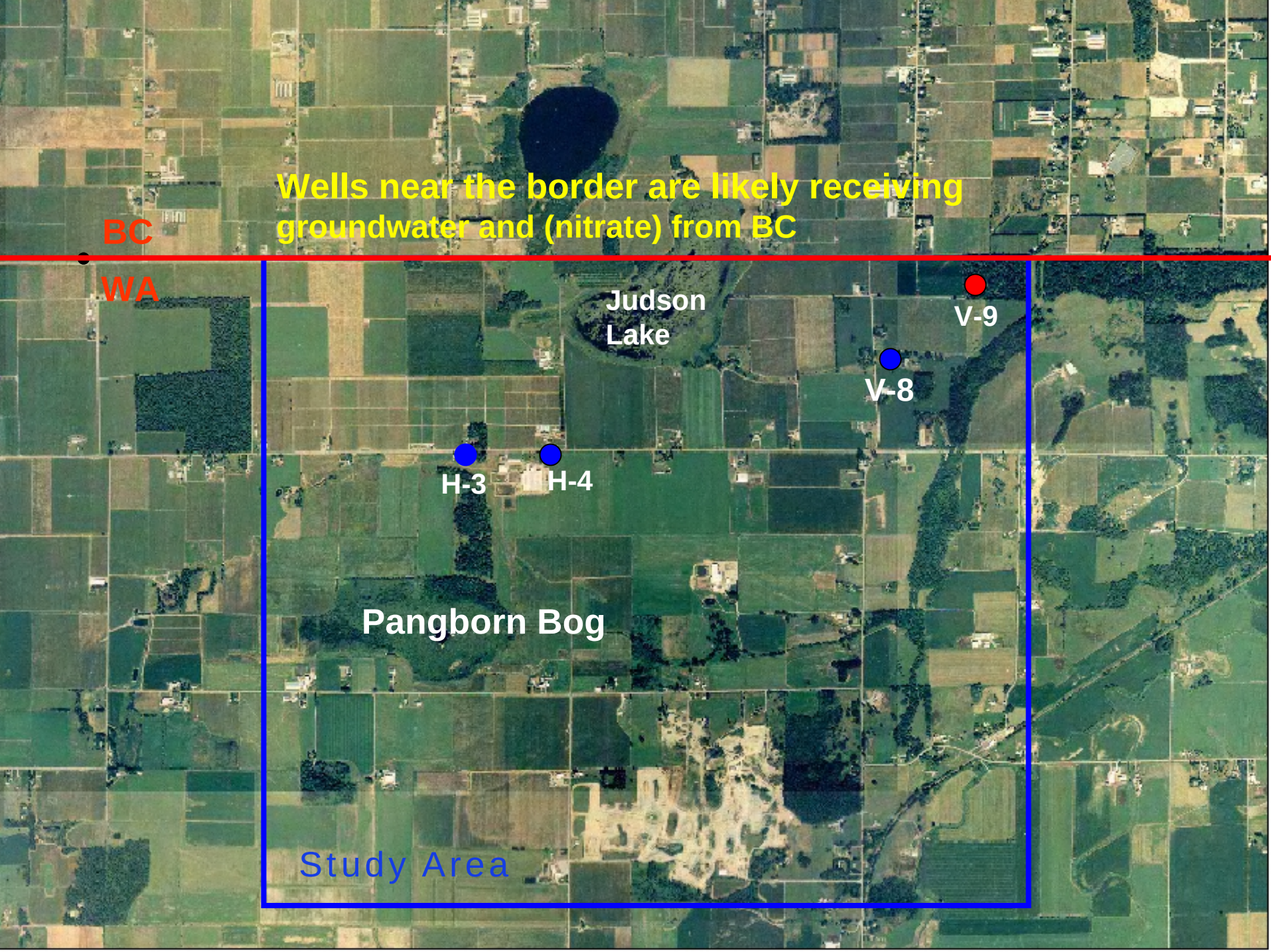
Groundwater Median Nitrate Values



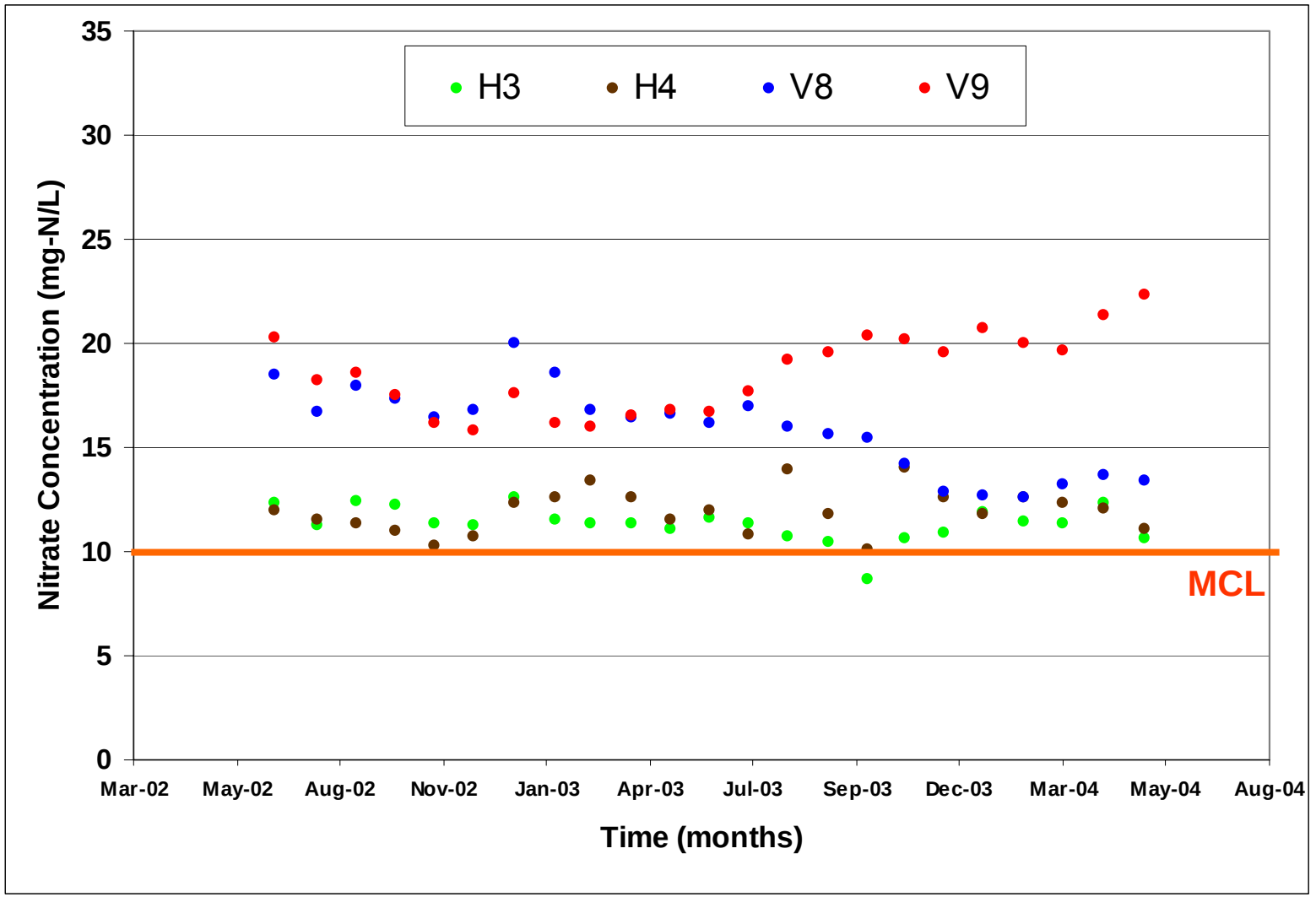
Nitrate concentrations were higher in wells north of Pangborn Lake and Creek

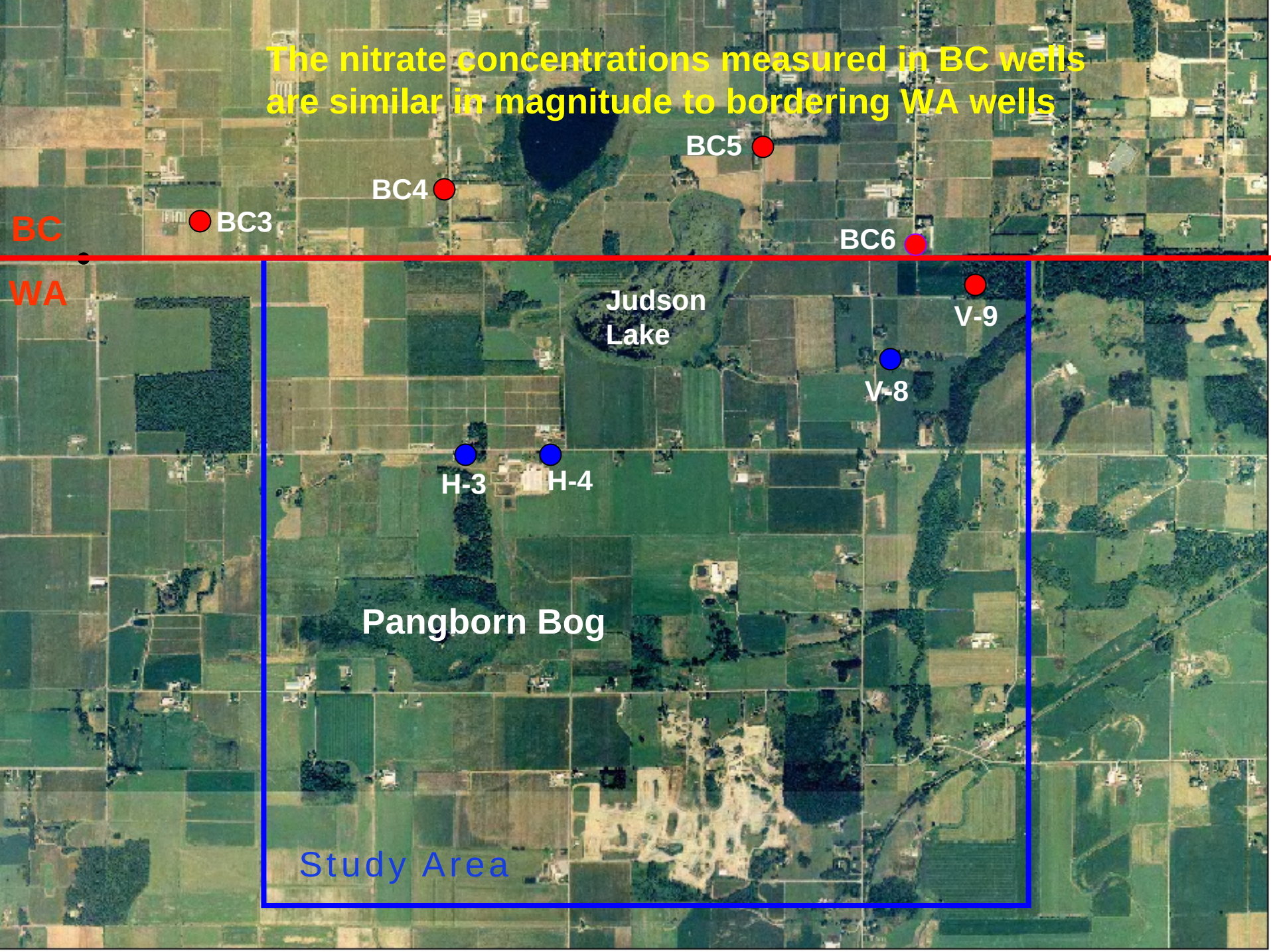
12 out of 15 wells had median nitrate values > 10 mg-N/L

Lower values at V7, V10 and V12 are likely due to denitrification.

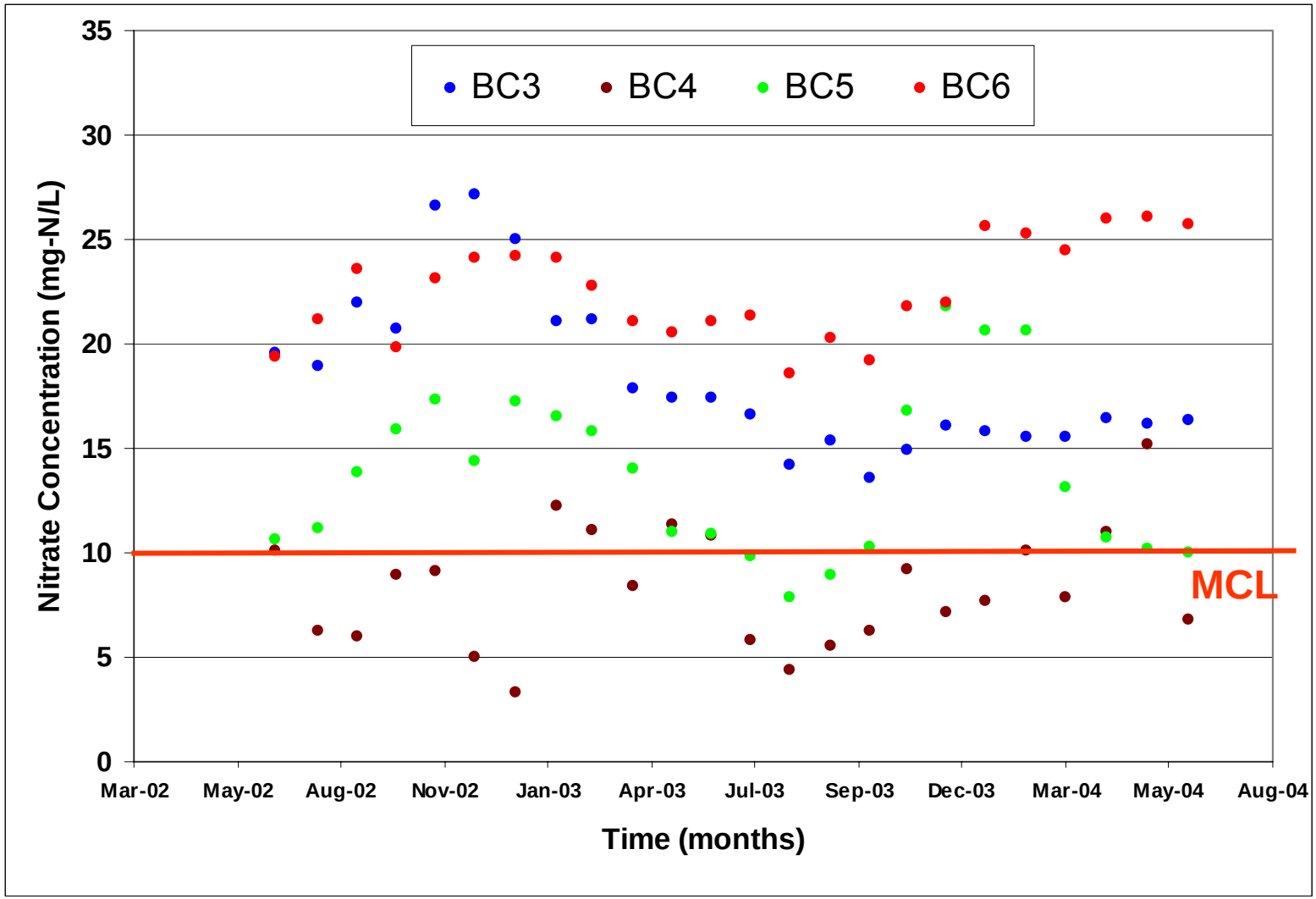

Wells near the border are likely receiving groundwater and (nitrate) from BC
BC
WA
Judson Lake
V-9
V-8
H-3
H-4
Pangborn Bog
Study Area

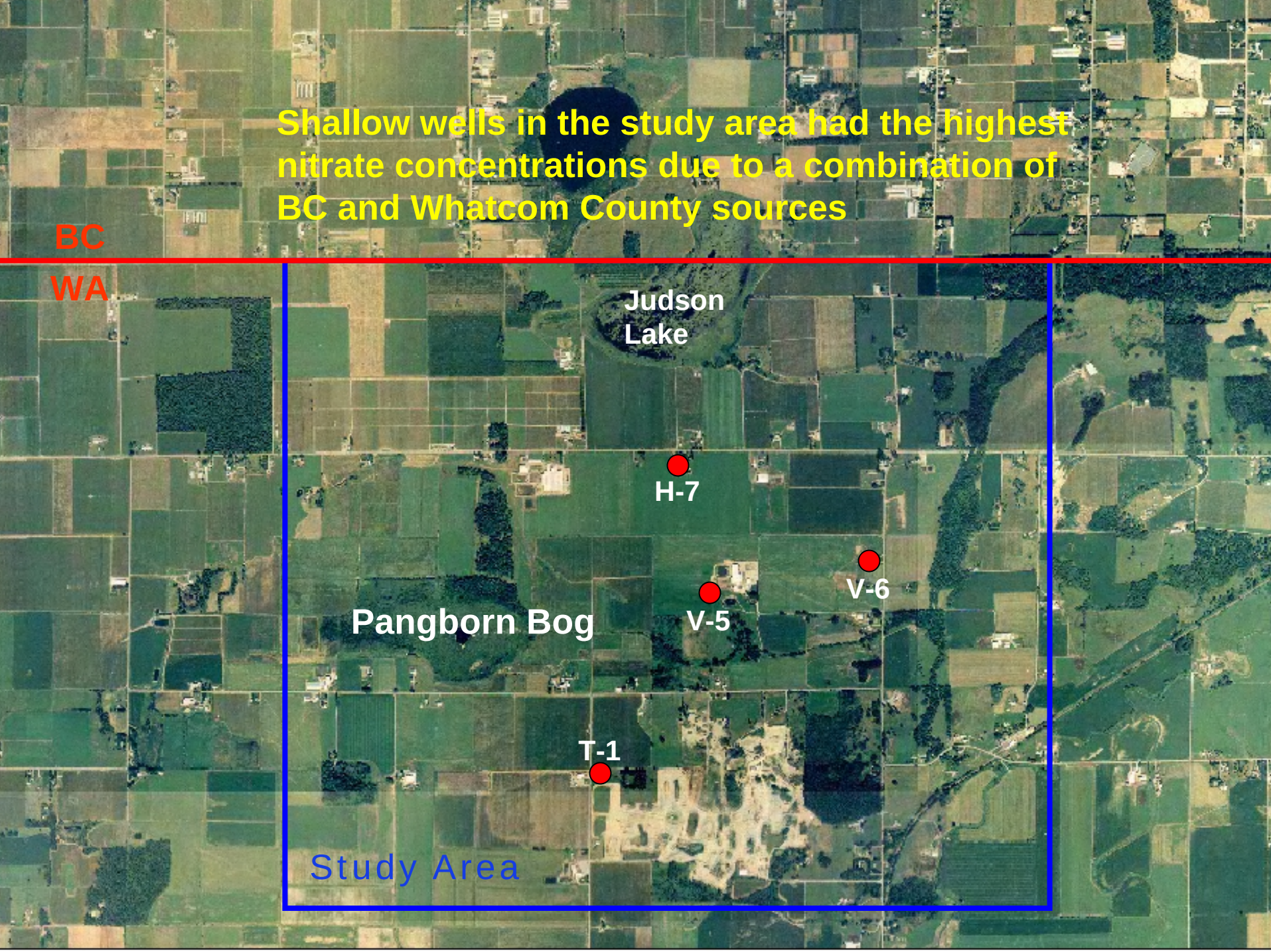
Deep Wells Near the Border



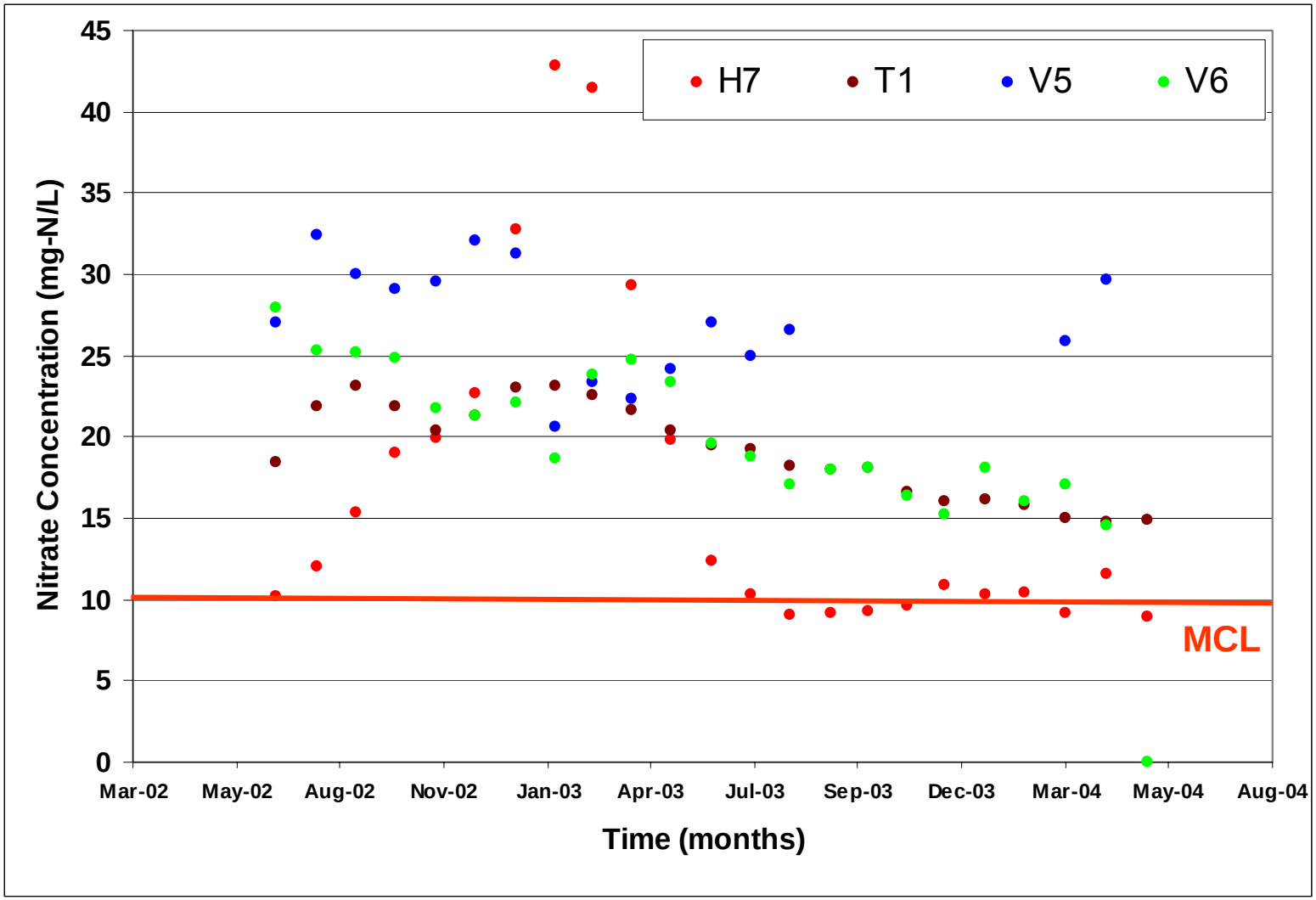

The nitrate concentrations measured in BC wells are similar in magnitude to bordering WA wells
BC5
BC4
BC3
BC
BC6
WA
Judson Lake
V-9
V-8
H-3
H-4
Pangborn Bog
Study Area

BC Wells Near the Border

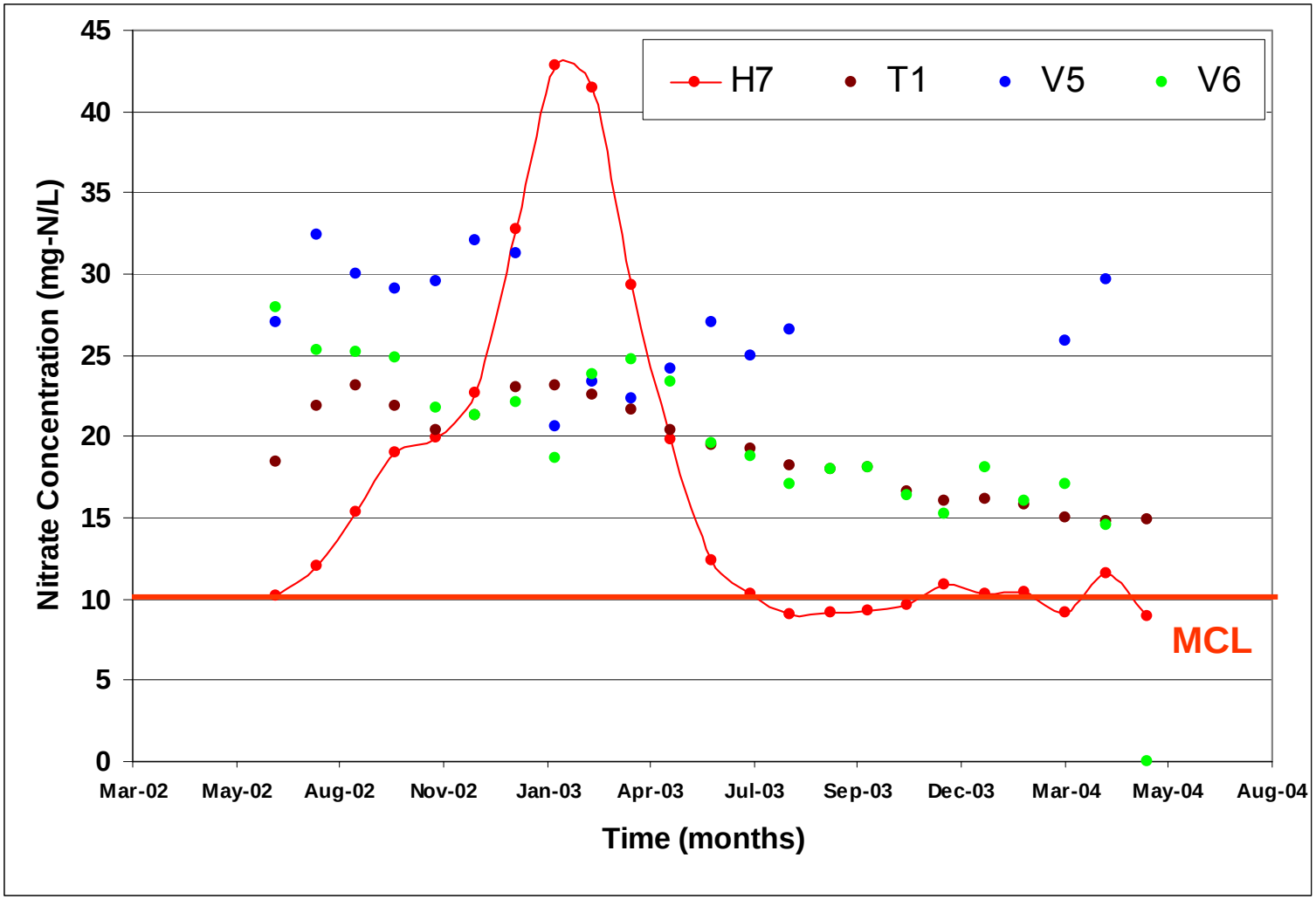


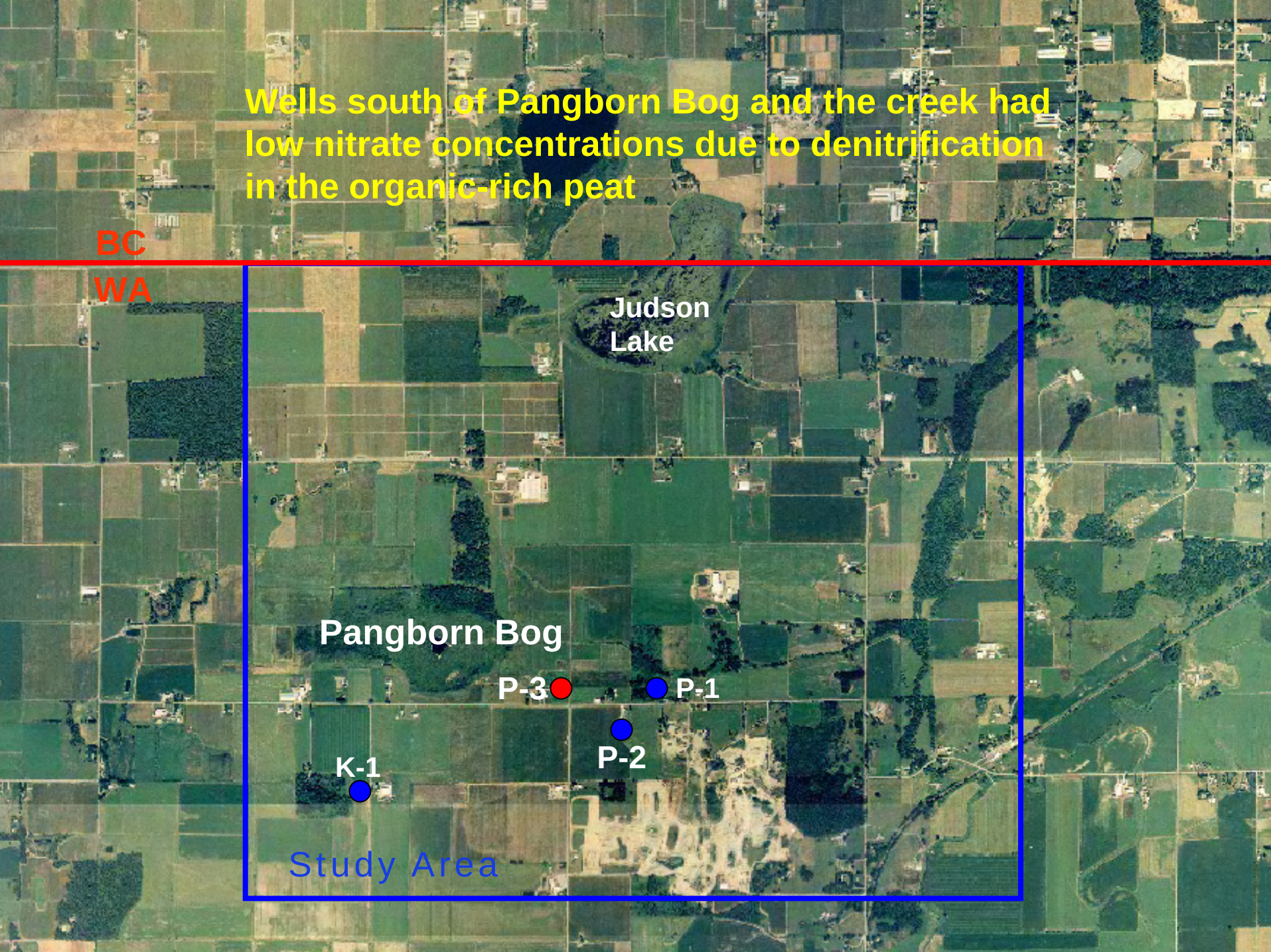

Shallow wells in the study area had the highest nitrate concentrations due to a combination of BC and Whatcom County sources
BC
WA
Judson Lake
H-7
V-6
V-5
Pangborn Bog
T-1
Study Area

Shallow Wells in the Study Area

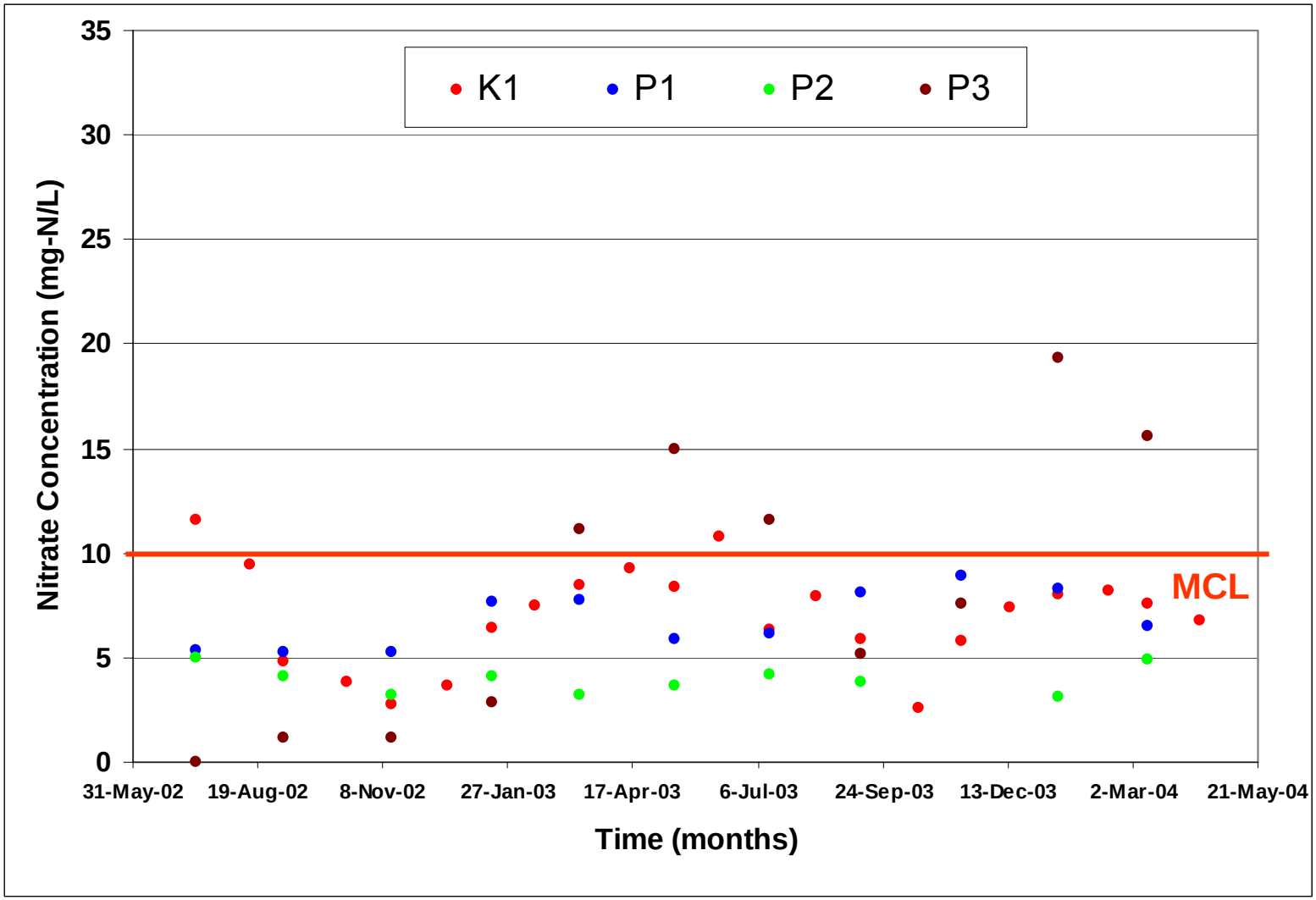


Shallow Wells in the Study Area

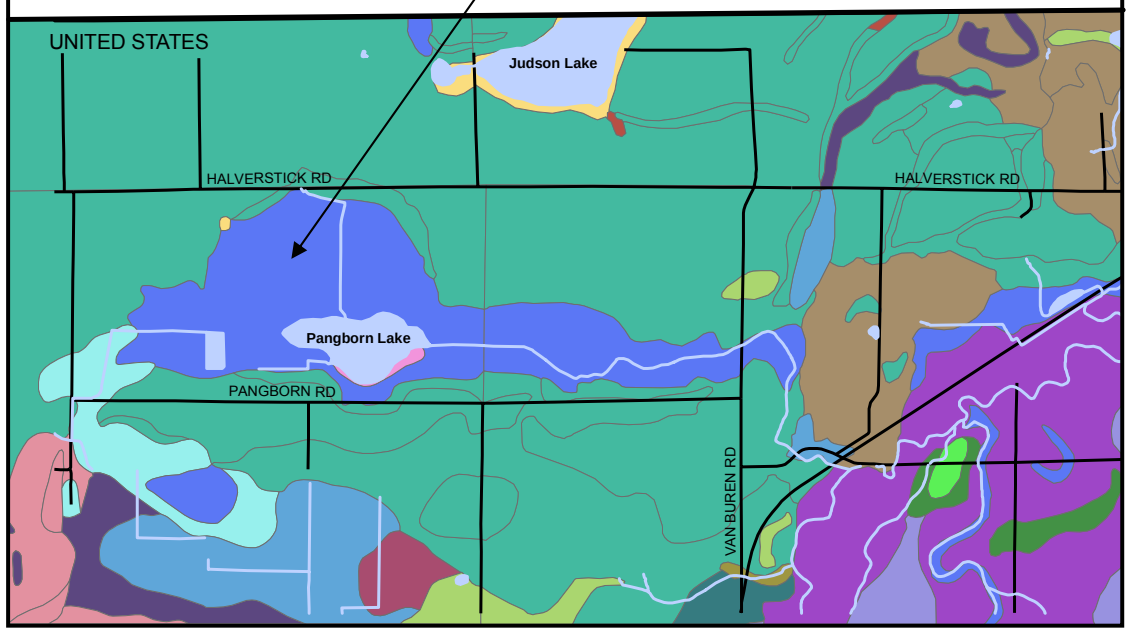



Wells south of Pangborn Bog and the creek had low nitrate concentrations due to denitrification in the organic-rich peat
BC
WA
Judson Lake
Pangborn Bog
P-3
P-1
P-2
K-1
Study Area

Wells South of Pangborn Bog



Soils Map
(peat is blue)



Legend

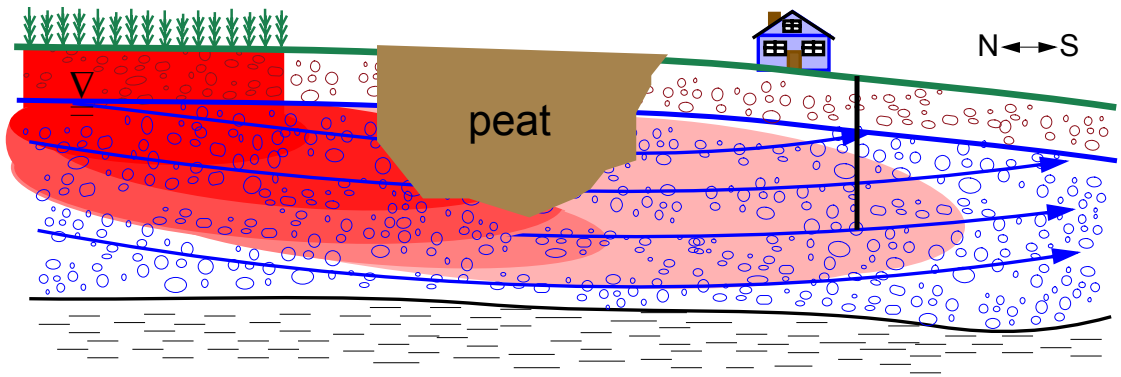
Soil Type

- PUGET
- SKIPOPA
- SUMAS
- TERRIC MEDISAPRISTS
- TROMP
- WATER
- WHATCOM
- PANGBORN
- PANGBORN VARIANT
- BRISCOT
- CAGEY
- EVERETT
- HALE
- HISTOSOLS
- KICKERVILLE
- LABOUNTY
- LAXTON
- ORIDIA

0 0.25 0.5 1 1.5 Miles

0 0.25 0.5 1 1.5 Kilometers

Peat has excellent denitrification potential



Denitrification proceeds through some combination of the following steps.

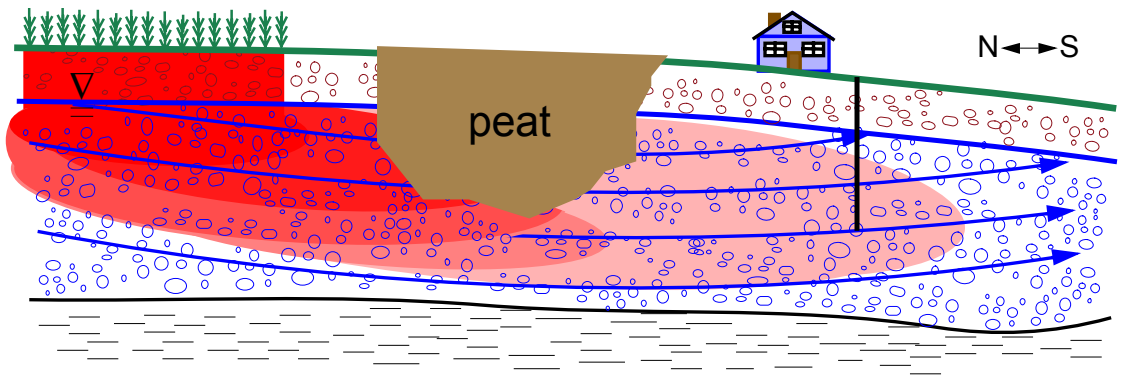
nitrate → nitrite → nitric oxide → nitrous oxide → dinitrogen gas

$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$

The reactions are mediated by anaerobic bacteria.

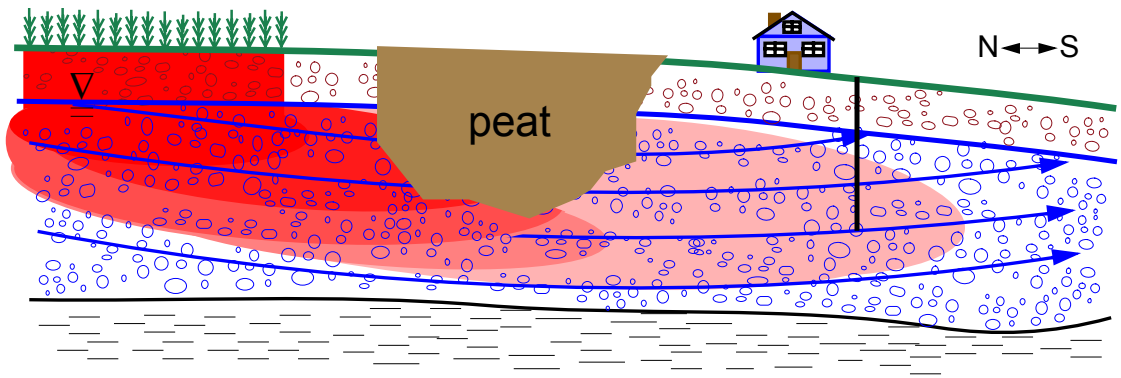
Peat has excellent denitrification potential

- high organic content



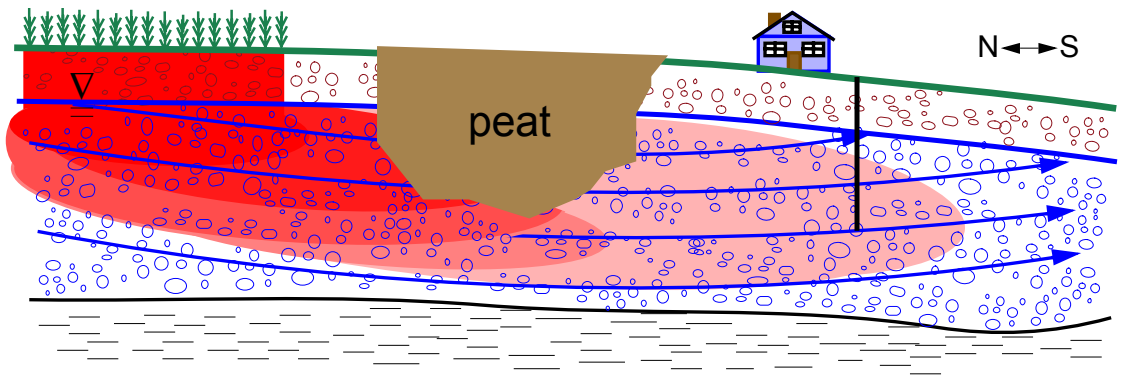
Peat has excellent denitrification potential

- high organic content
- reducing conditions



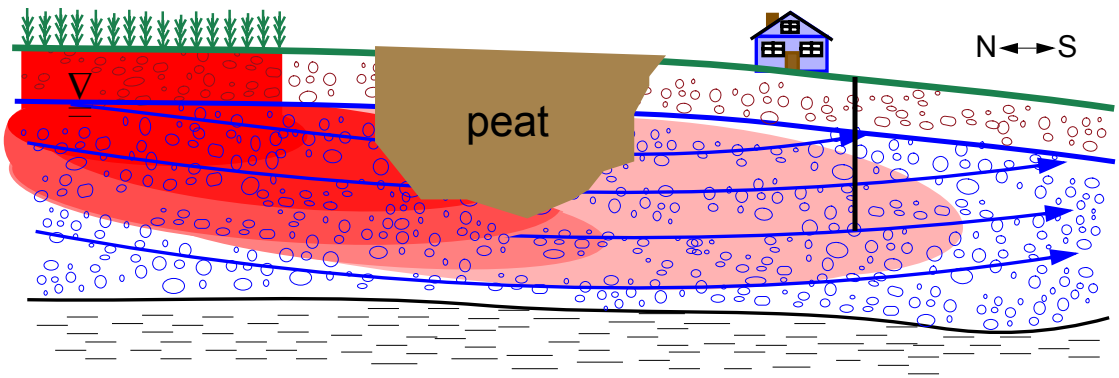
Peat has excellent denitrification potential

- high organic content
- reducing conditions
- iron and manganese



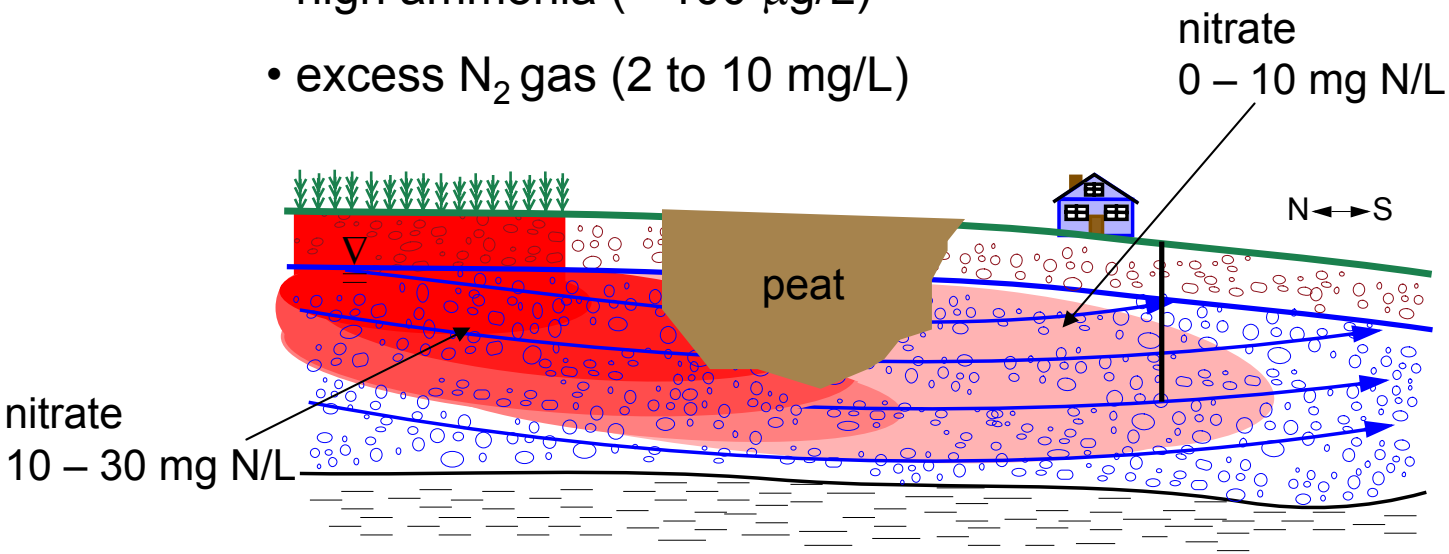
Peat has excellent denitrification potential

- high organic content
- reducing conditions
- iron and manganese
- nitrate input

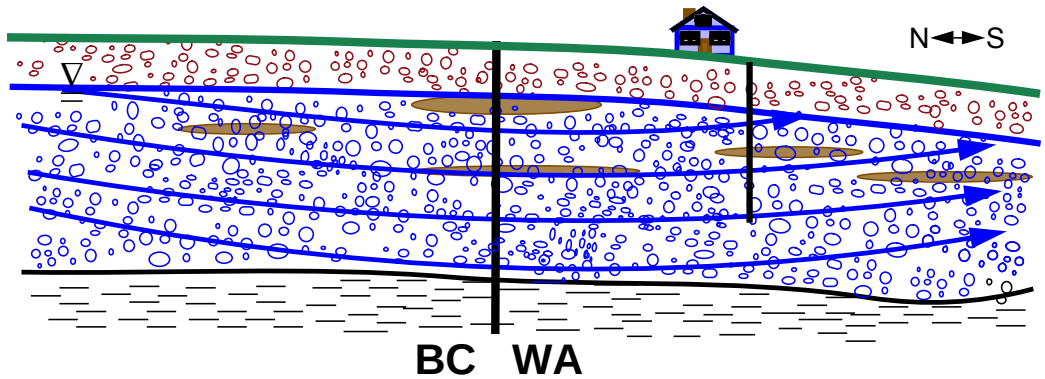


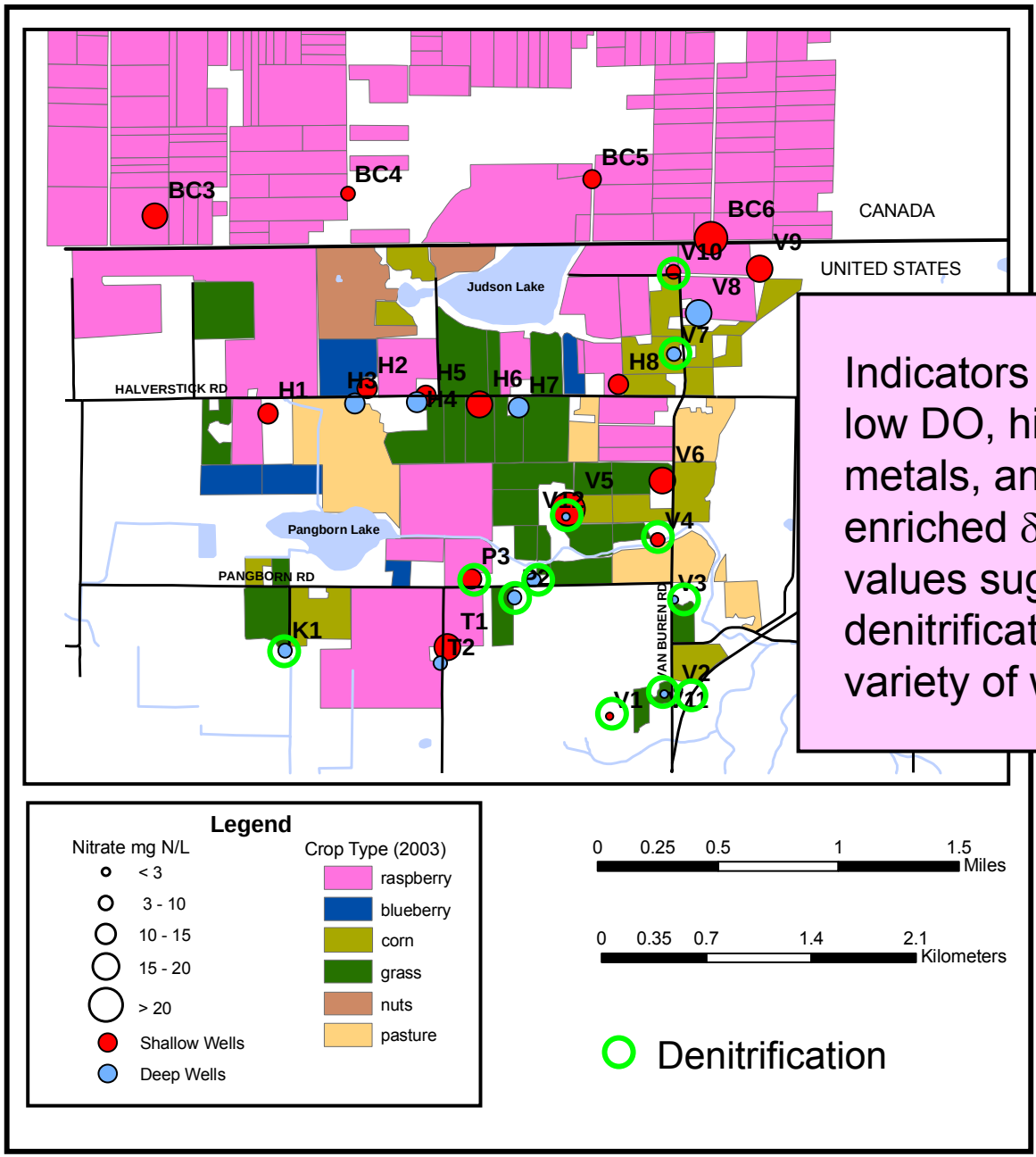
Denitrification Evidence

- low nitrate concentrations
- low DO (< 1 mg N/L)
- enriched $\delta^{15}N$ values (> 12 $^{0}/_{00}$)
- high ammonia (> 100 μg/L)
- excess N_2 gas (2 to 10 mg/L)



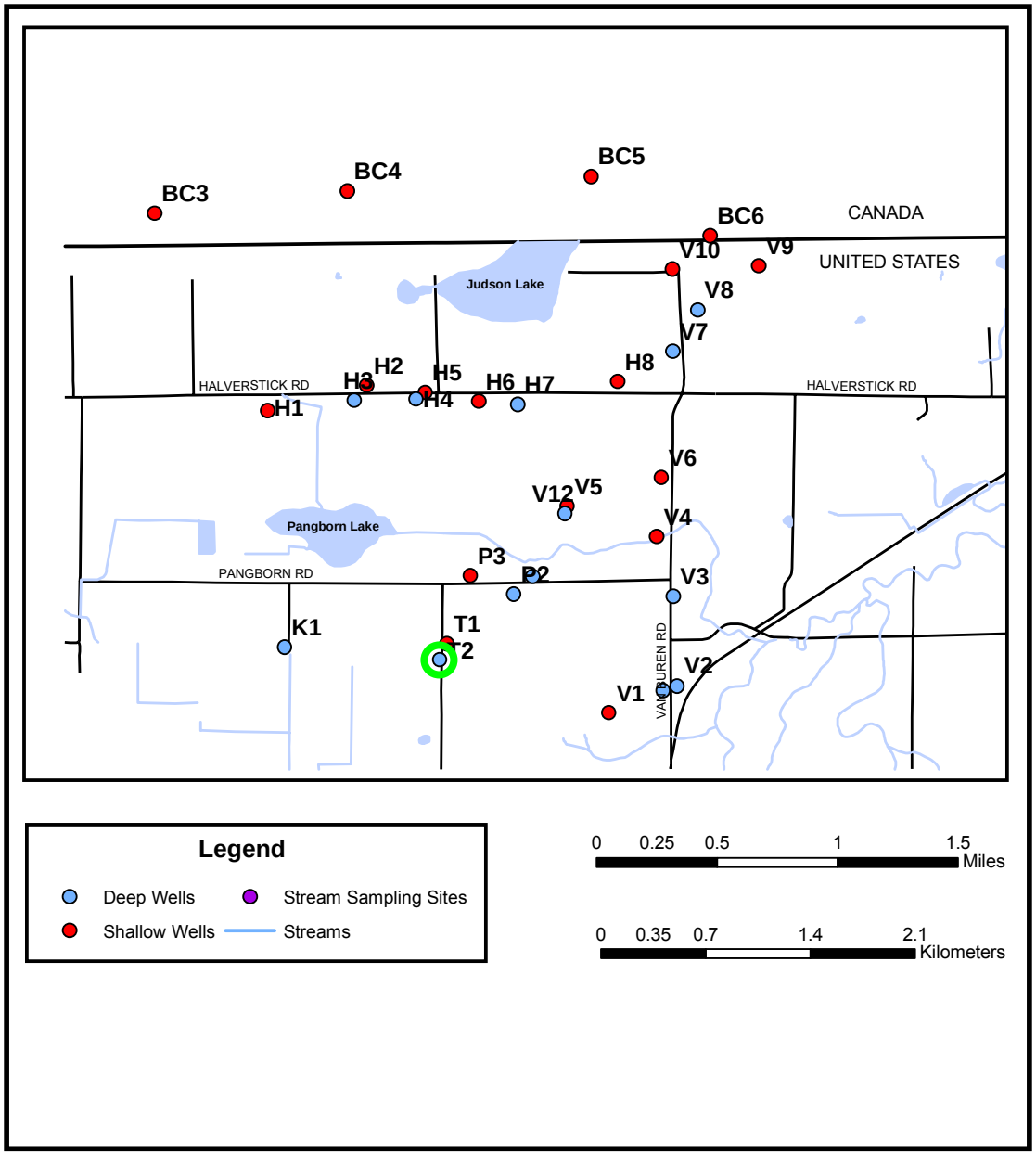
It is likely that peat occurs at various depths due to multiple glacial phases during the Sumas Stade.

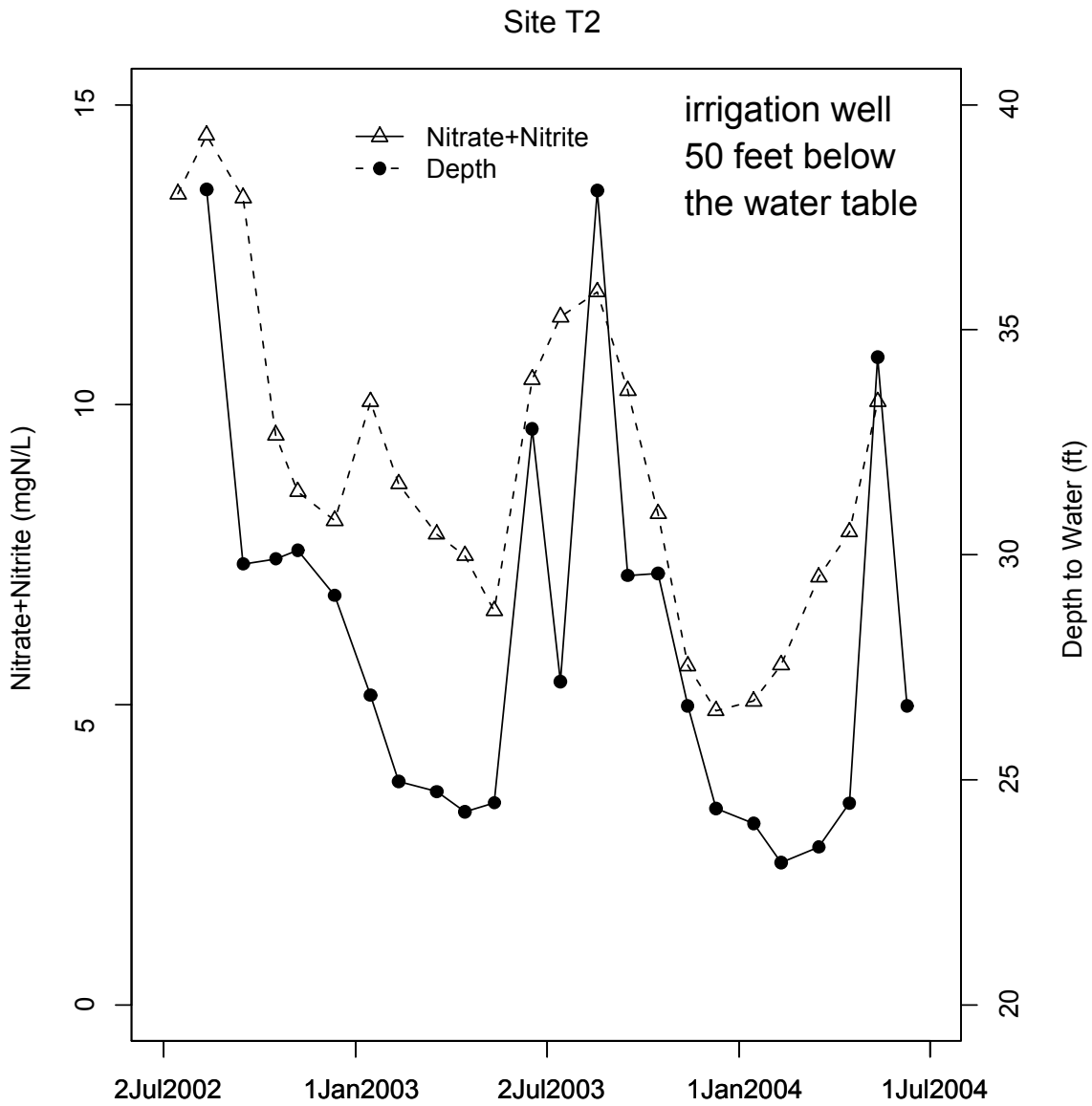


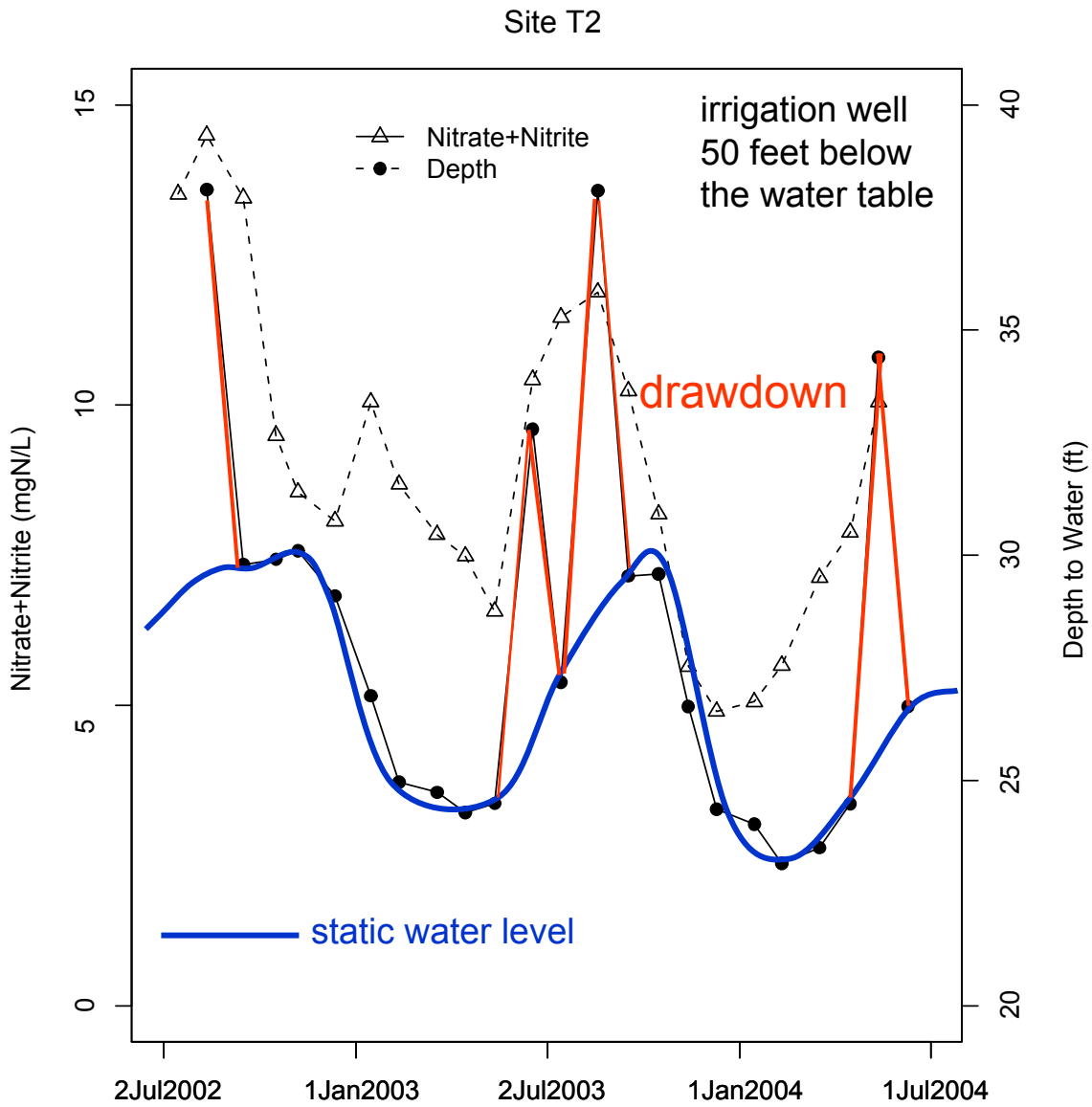


Indicators such as low DO, high metals, and/or enriched $\delta^{15}N$ values suggest denitrification at a variety of wells.

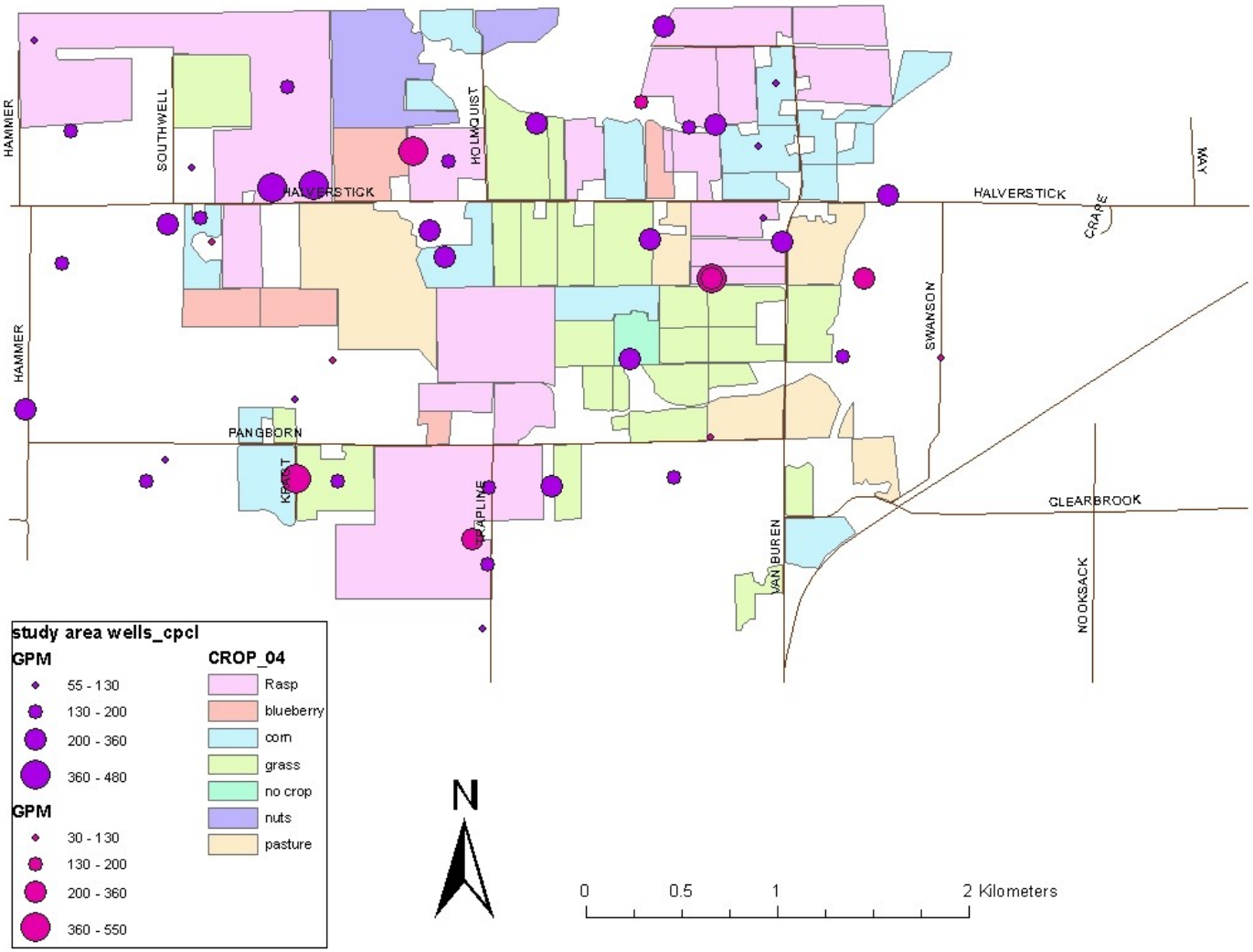
Irrigation Well




Site T2
irrigation well
50 feet below
the water table
Nitrate+Nitrite
Depth
Nitrate+Nitrite (mgN/L)
Depth to Water (ft)
0
5
10
15
20
25
30
35
40
2Jul2002
1Jan2003
2Jul2003
1Jan2004
1Jul2004


Site T2
Nitrate+Nitrite
Depth
irrigation well
50 feet below
the water table
drawdown
static water level
Nitrate+Nitrite (mgN/L)
Depth to Water (ft)
0
5
10
15
20
25
30
35
40
2Jul2002
1Jan2003
2Jul2003
1Jan2004
1Jul2004

Irrigation Wells



Sources of Nitrate

animal manure

and

commercial-inorganic fertilizer

Both contain varying amounts of the stable isotopes ^{14}N and ^{15}N

The ratio of $^{15}N/^{14}N$ in the water can be used to estimate the relative contributions of the various sources.

The notation used to express the high abundance of ^{15}N is

$$\delta^{15}N = [(^{15}N/^{14}N_{sample} - {}^{15}N/^{14}N_{standard})/(^{15}N/^{14}N_{standard})] (1000\ ‰)$$

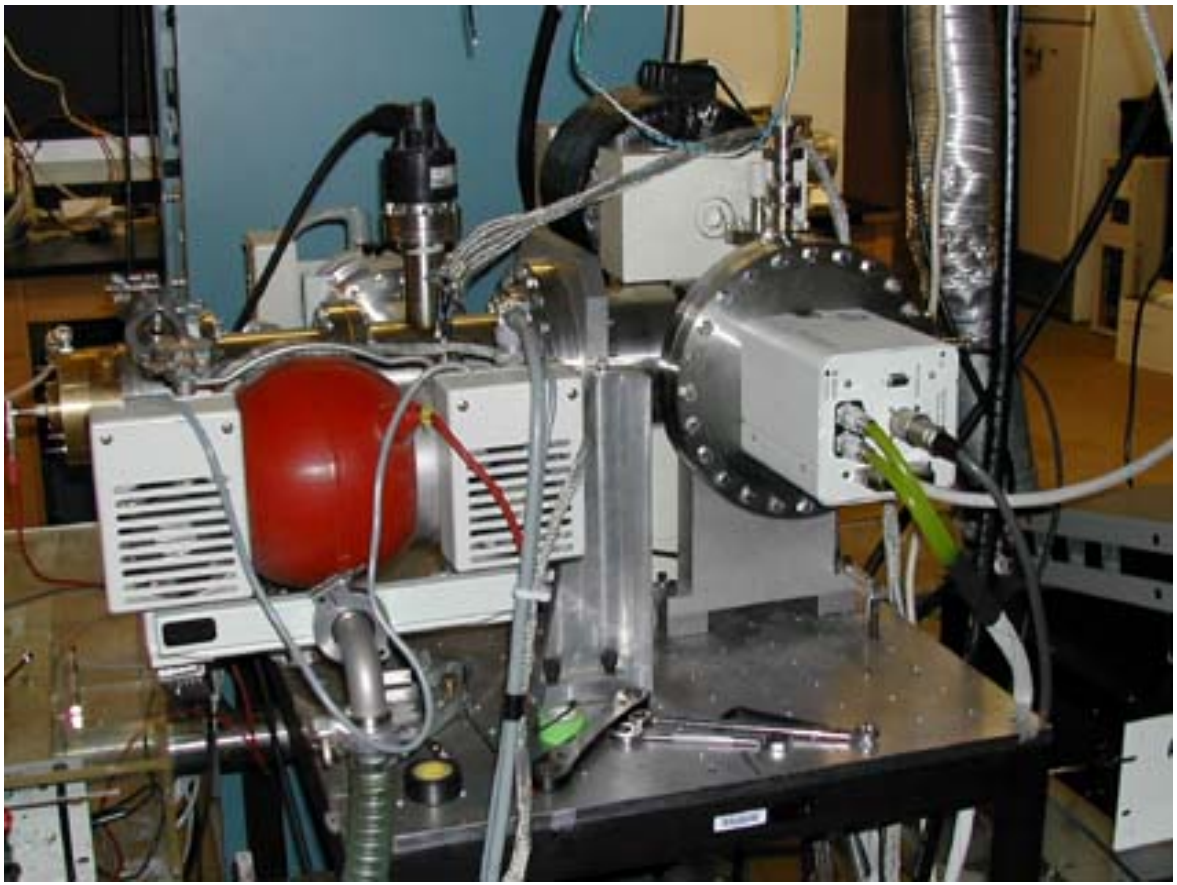
$\delta^{15}N$ from -2 to +2 ‰ = inorganic commercial fertilizers

$\delta^{15}N$ from +8 to +16 ‰ = animal manure

$\delta^{15}N$ from +2 to +8 ‰ = mix of manure and inorganic

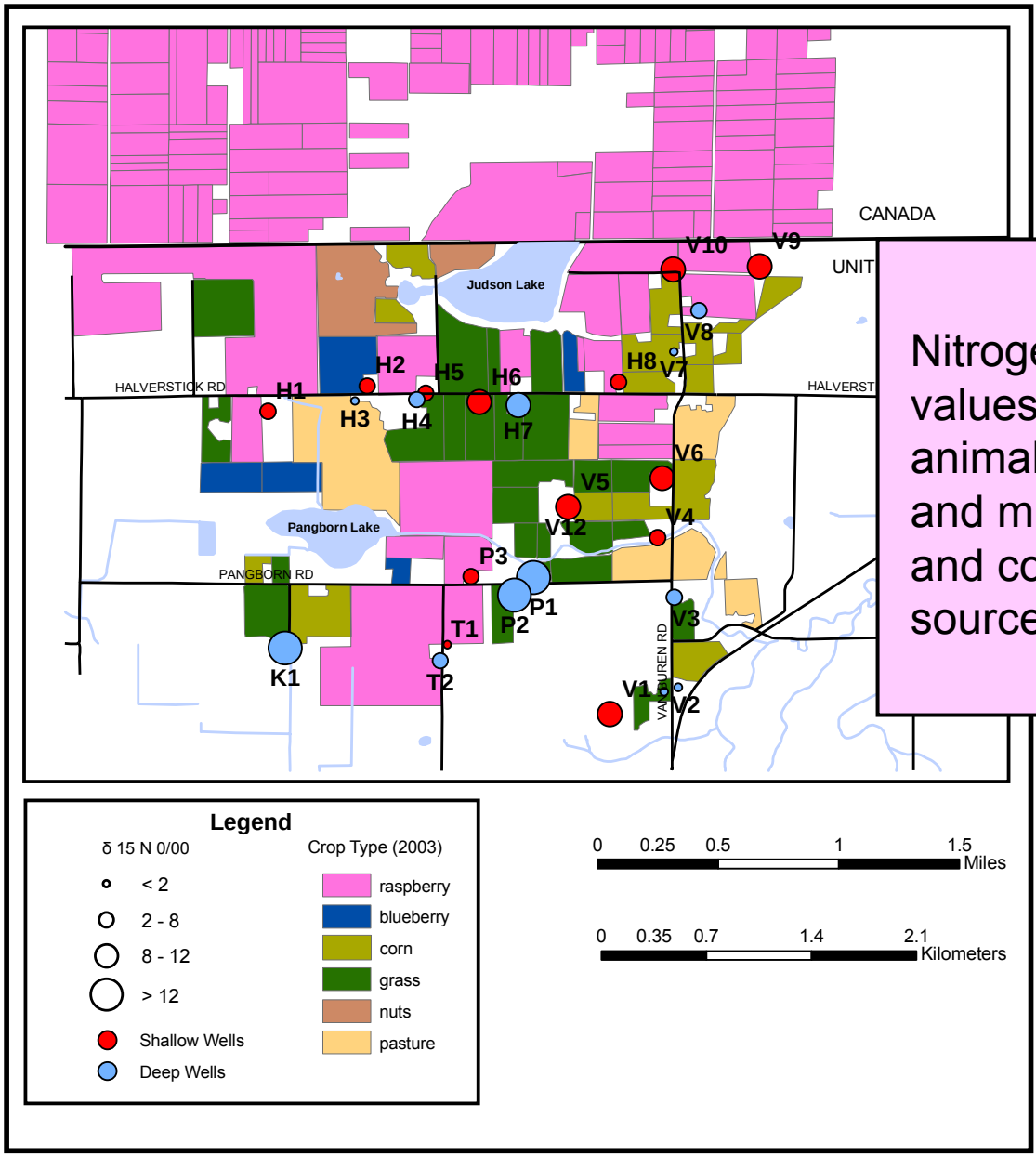
Nitrogen Isotopes samples were collected quarterly for 2 years

Nitrogen Isotopes were measured at the Colorado Plateau Stable Isotope Laboratory, Northern Arizona University

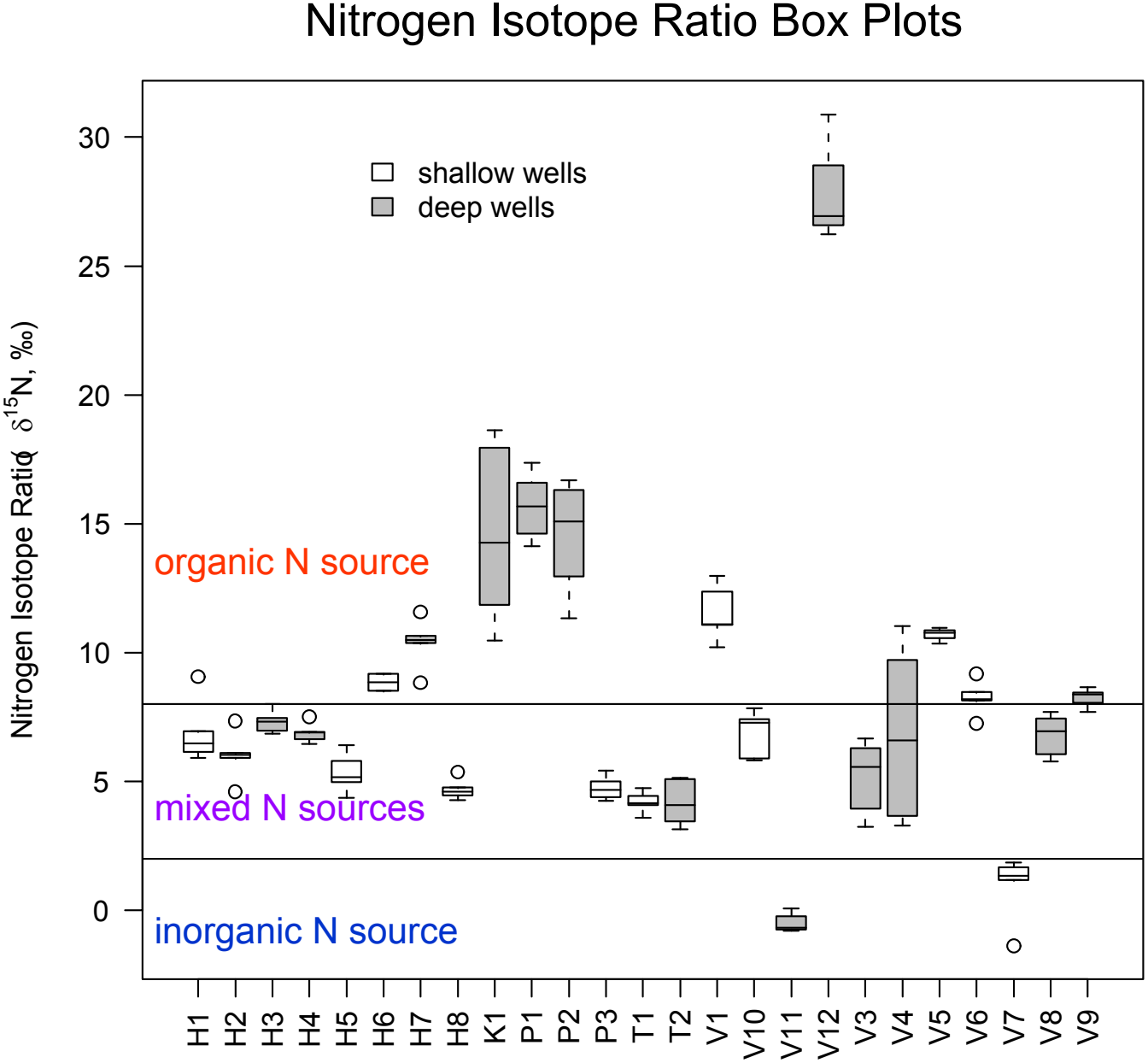


Isotope Ratio Mass Spectrometry (IRMS)

Groundwater Median Nitrogen Isotope Values

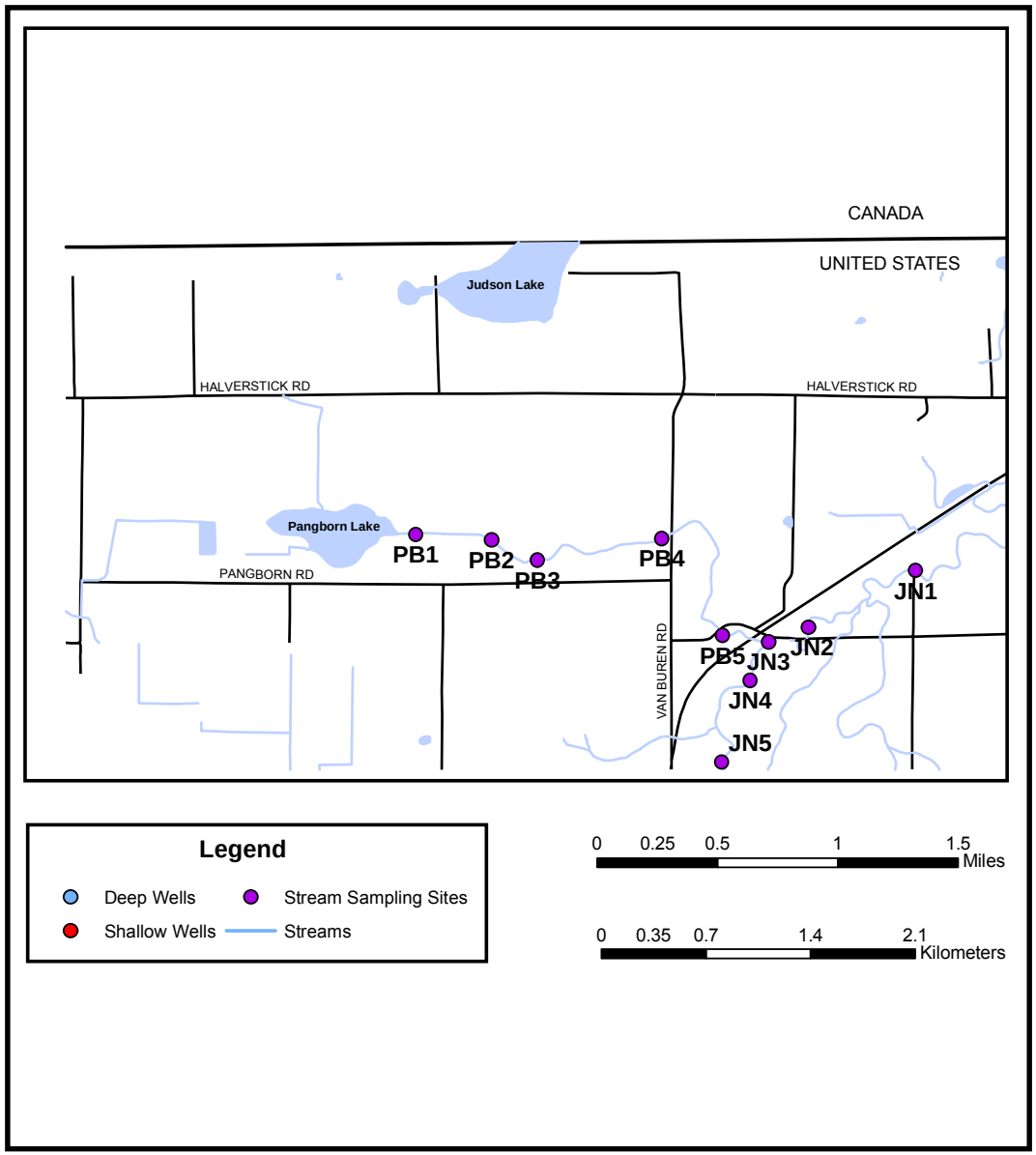


Nitrogen Isotope values ($\delta^{15}N$) indicate animal N sources and mixed animal and commercial N sources.

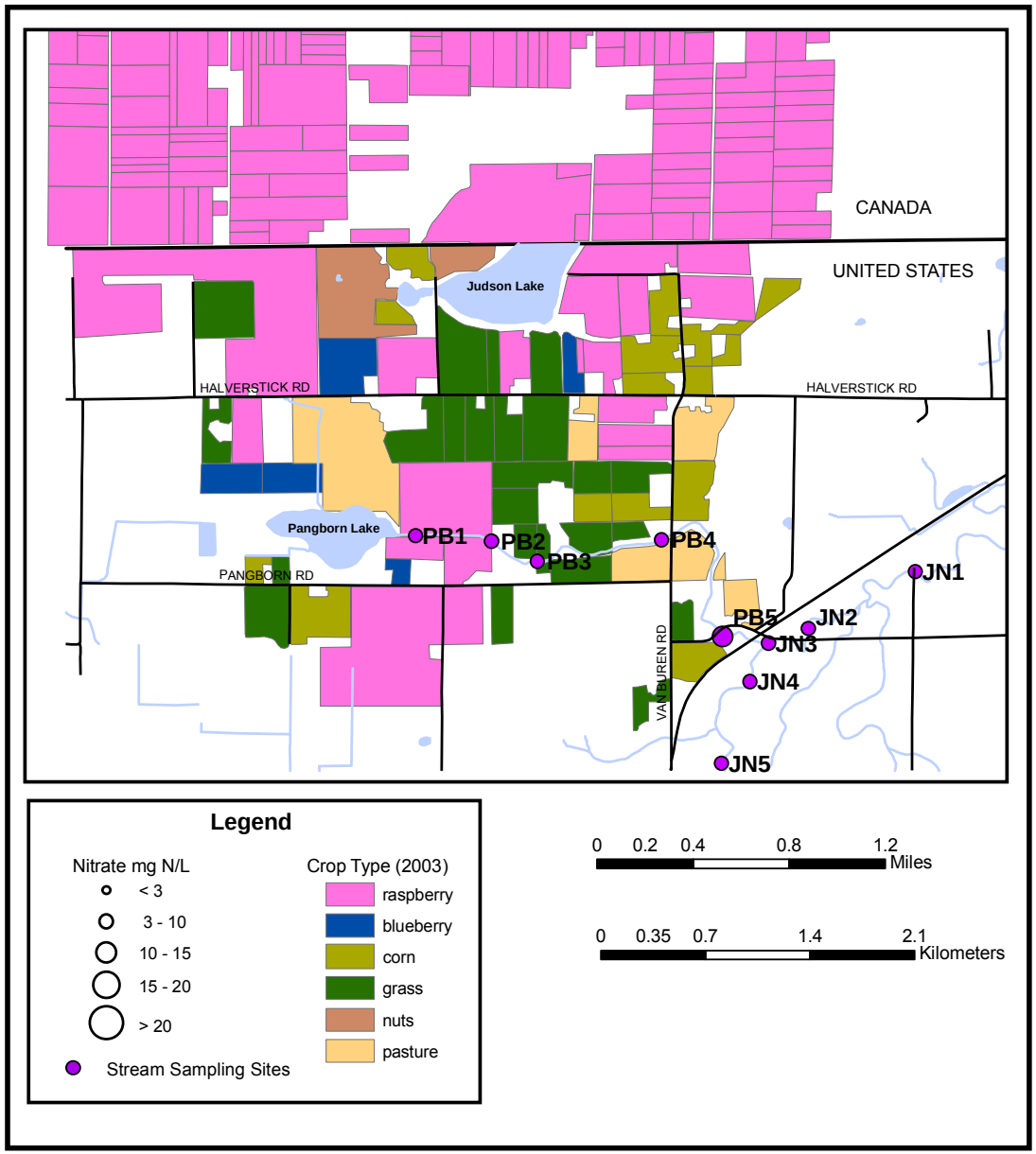

Nitrogen Isotope Ratio Box Plots
shallow wells
deep wells
organic N source
mixed N sources
inorganic N source
Nitrogen Isotope Ratio ($\delta^{15}N$, ‰)
30
25
20
15
10
5
0
H1
H2
H3
H4
H5
H6
H7
H8
K1
P1
P2
P3
T1
T2
V1
V10
V11
V12
V3
V4
V5
V6
V7
V8
V9

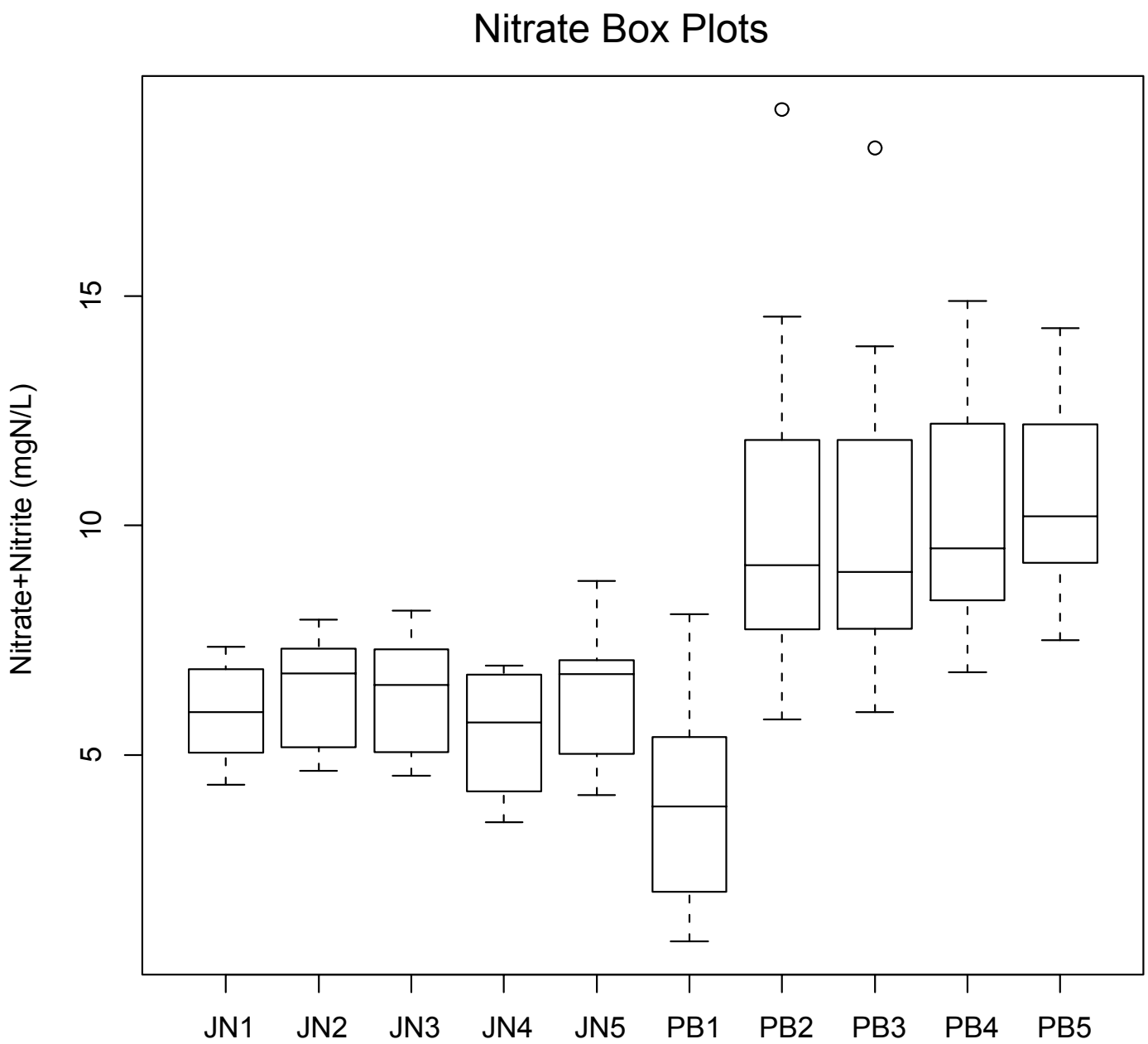
Surface Water was Sampled Bi-Monthly for 2 years

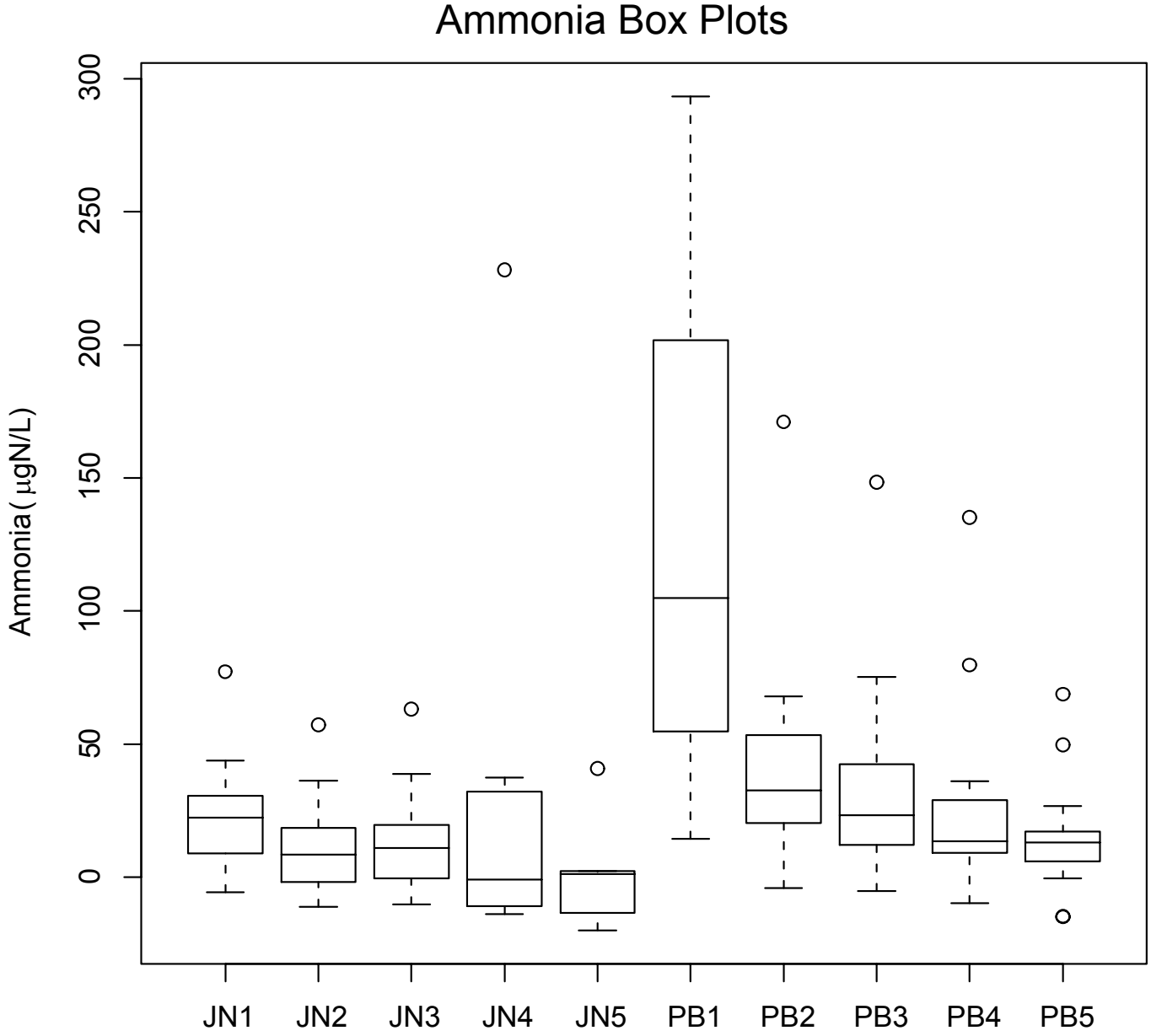
Stream Sampling Sites

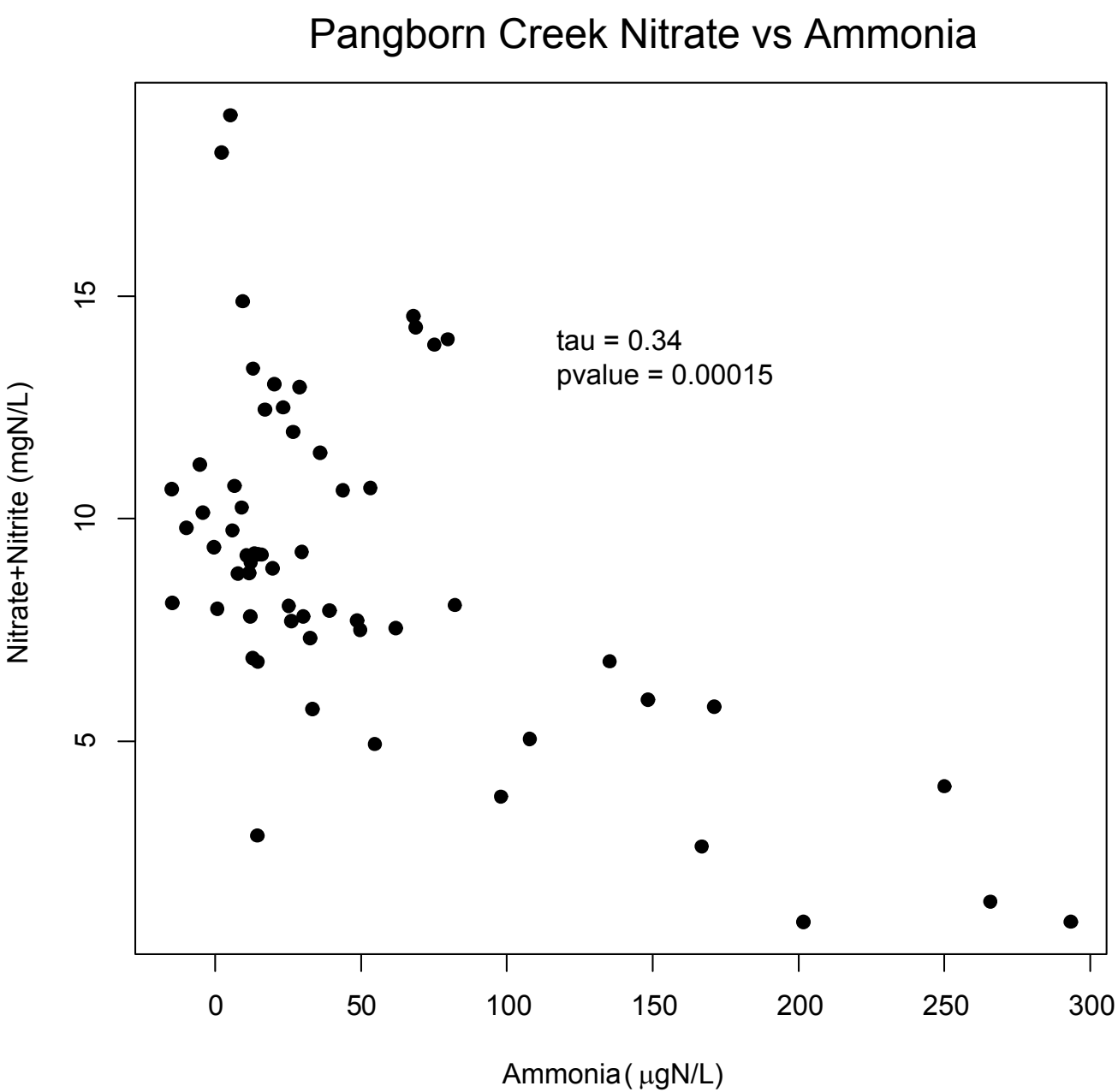


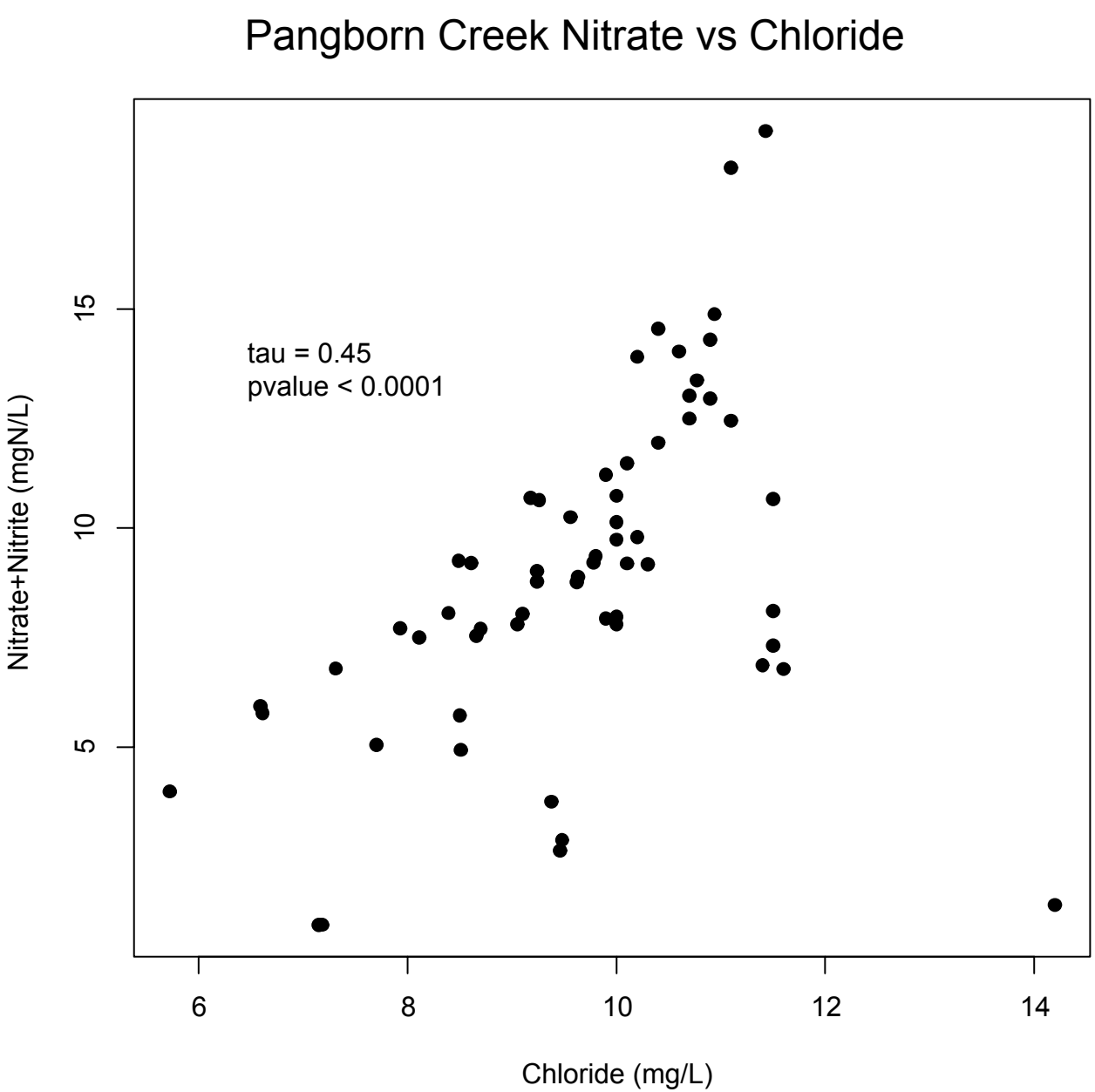
Stream Median Nitrate Values

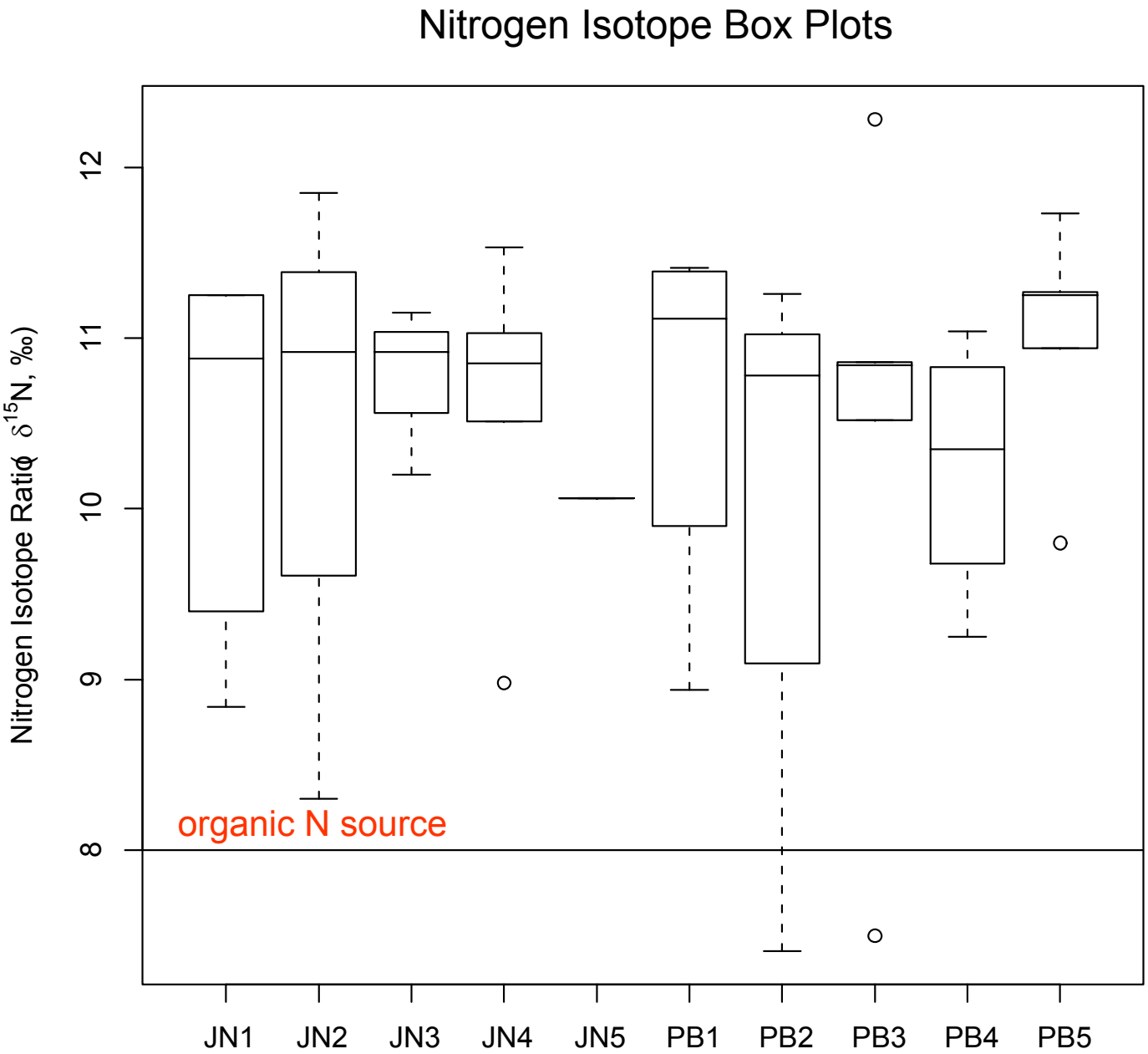



Nitrate Box Plots
Nitrate+Nitrite (mgN/L)
5
10
15
JN1
JN2
JN3
JN4
JN5
PB1
PB2
PB3
PB4
PB5

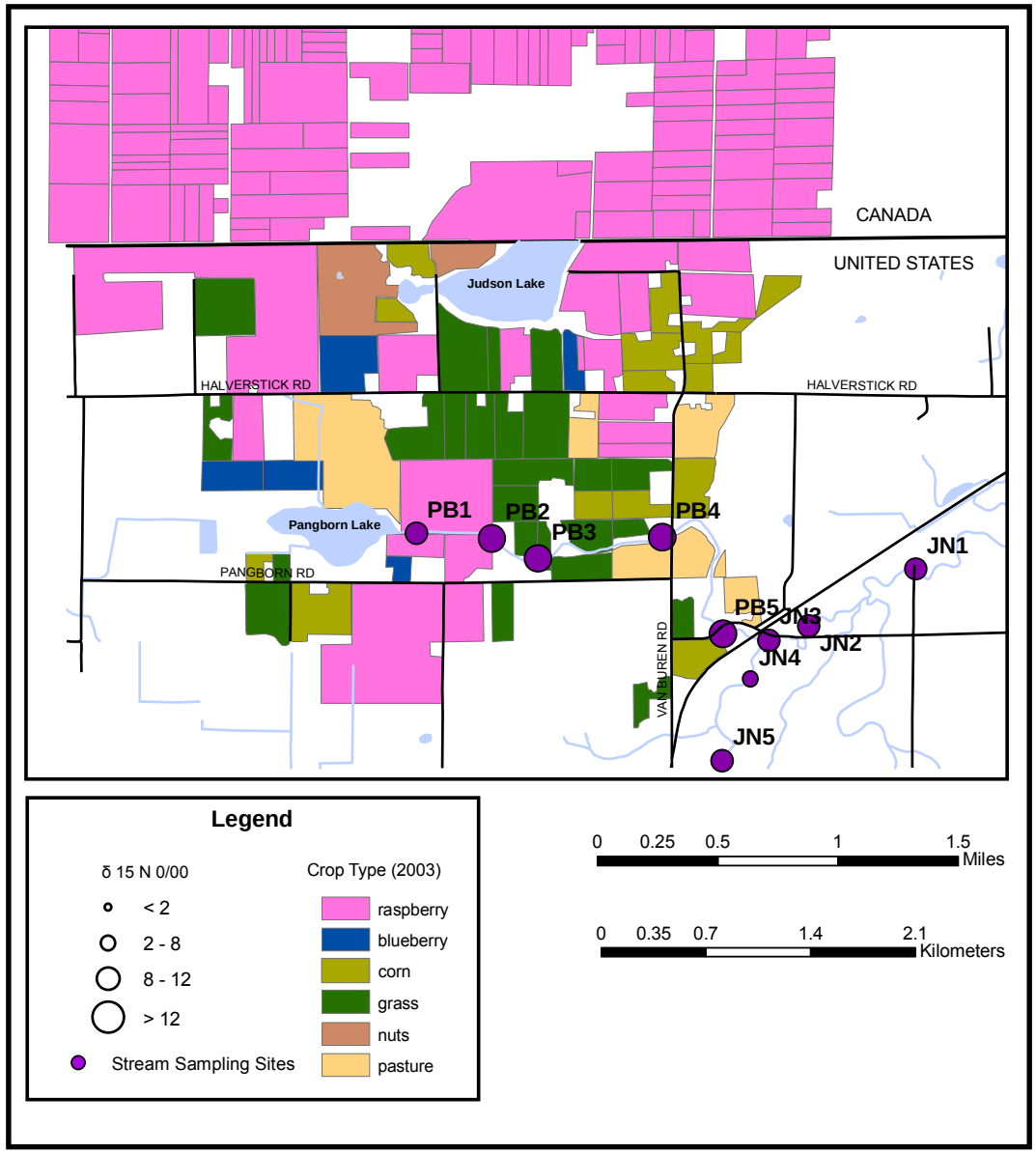

Ammonia Box Plots
Ammonia (µgN/L)
0
50
100
150
200
250
300
JN1
JN2
JN3
JN4
JN5
PB1
PB2
PB3
PB4
PB5


Pangborn Creek Nitrate vs Ammonia
tau = 0.34
pvalue = 0.00015
Nitrate+Nitrite (mgN/L)
5
10
15
0
50
100
150
200
250
300
Ammonia (μgN/L)

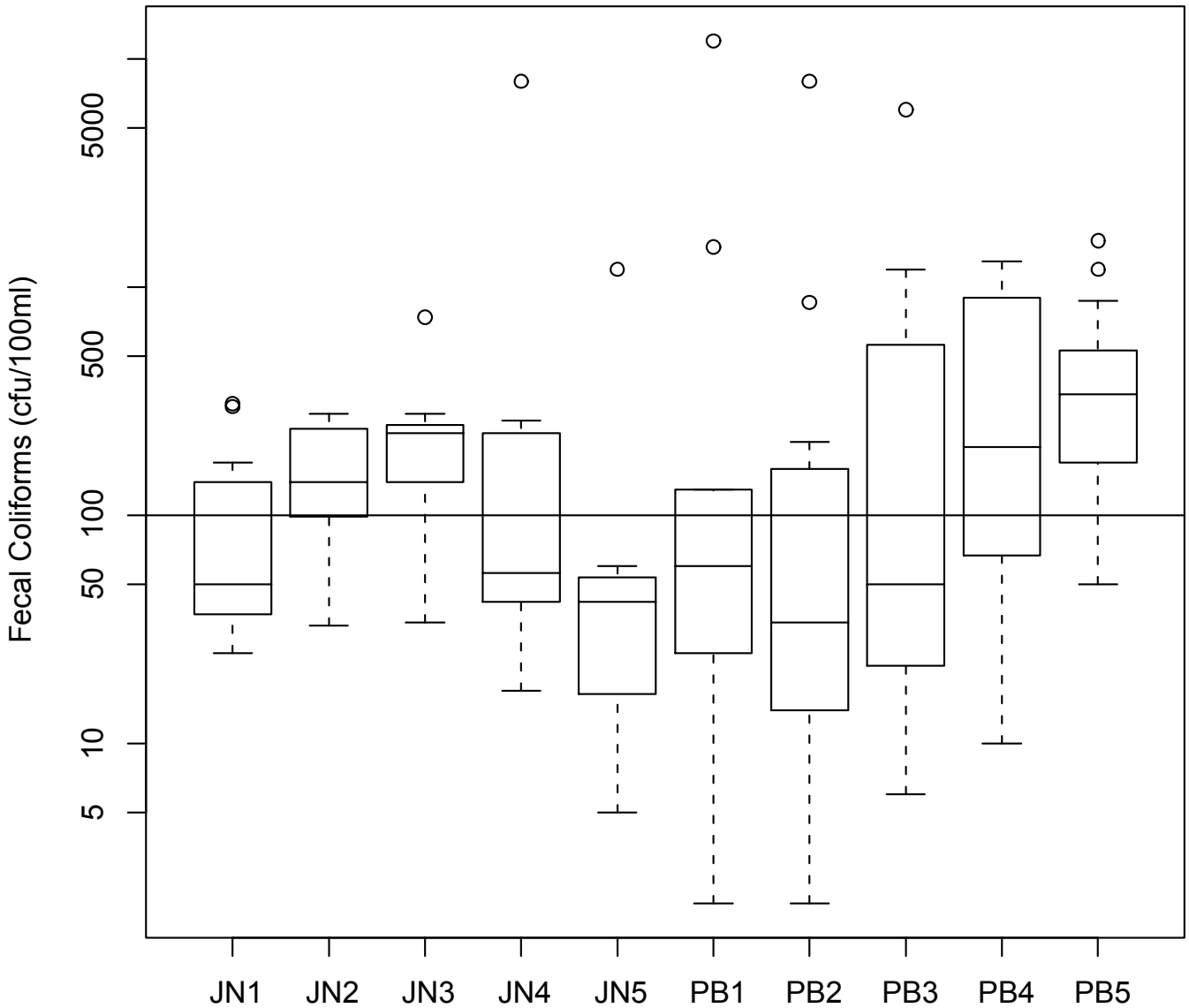

Pangborn Creek Nitrate vs Chloride
tau = 0.45
pvalue < 0.0001
Nitrate+Nitrite (mgN/L)
5
10
15
6
8
10
12
14
Chloride (mg/L)


Nitrogen Isotope Box Plots
Nitrogen Isotope Ratio ($\delta^{15}N$, ‰)
8
9
10
11
12
organic N source
JN1
JN2
JN3
JN4
JN5
PB1
PB2
PB3
PB4
PB5

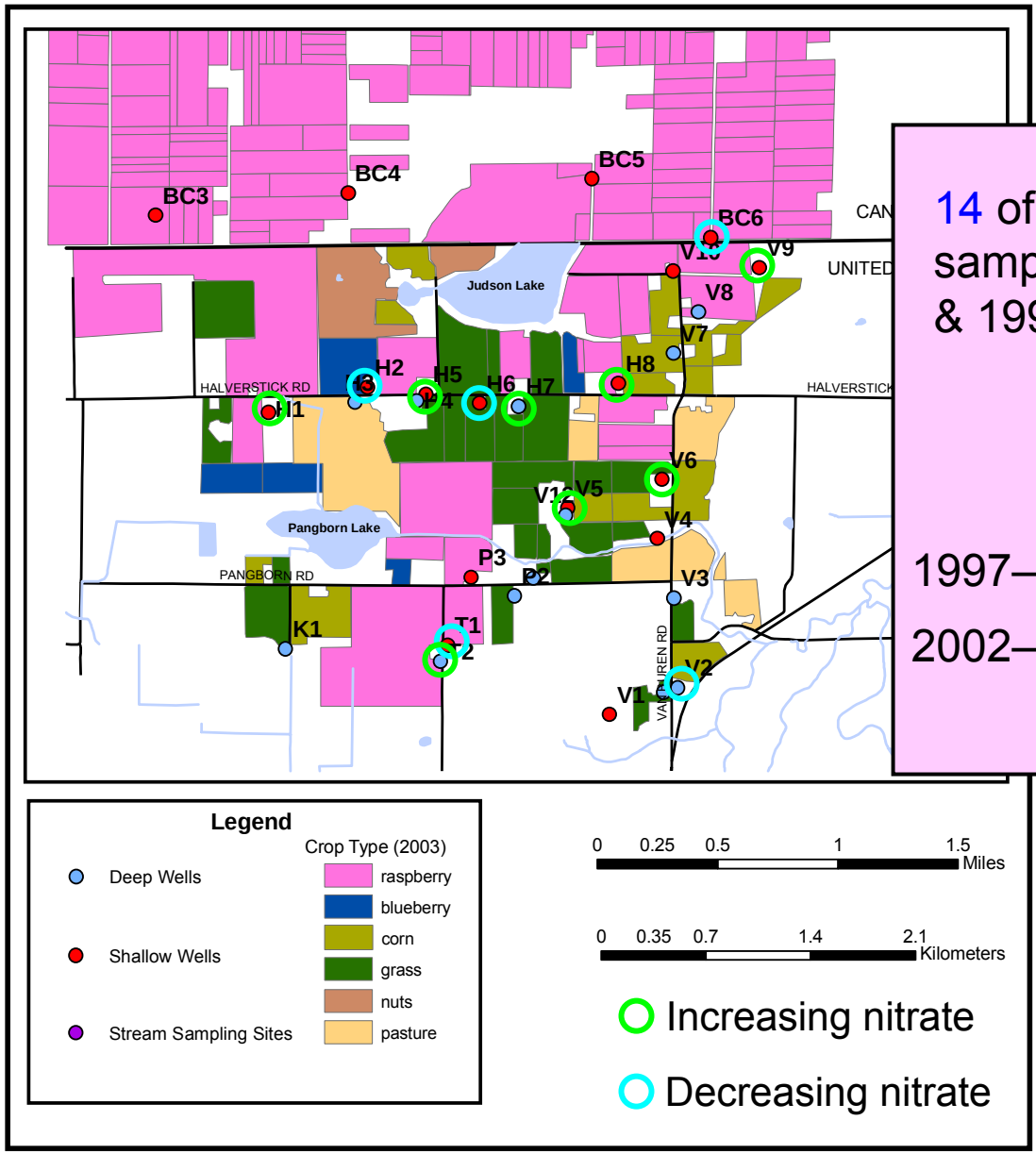
Stream Median Nitrogen Isotope Values



Fecal Coliform Bacteria Box Plots

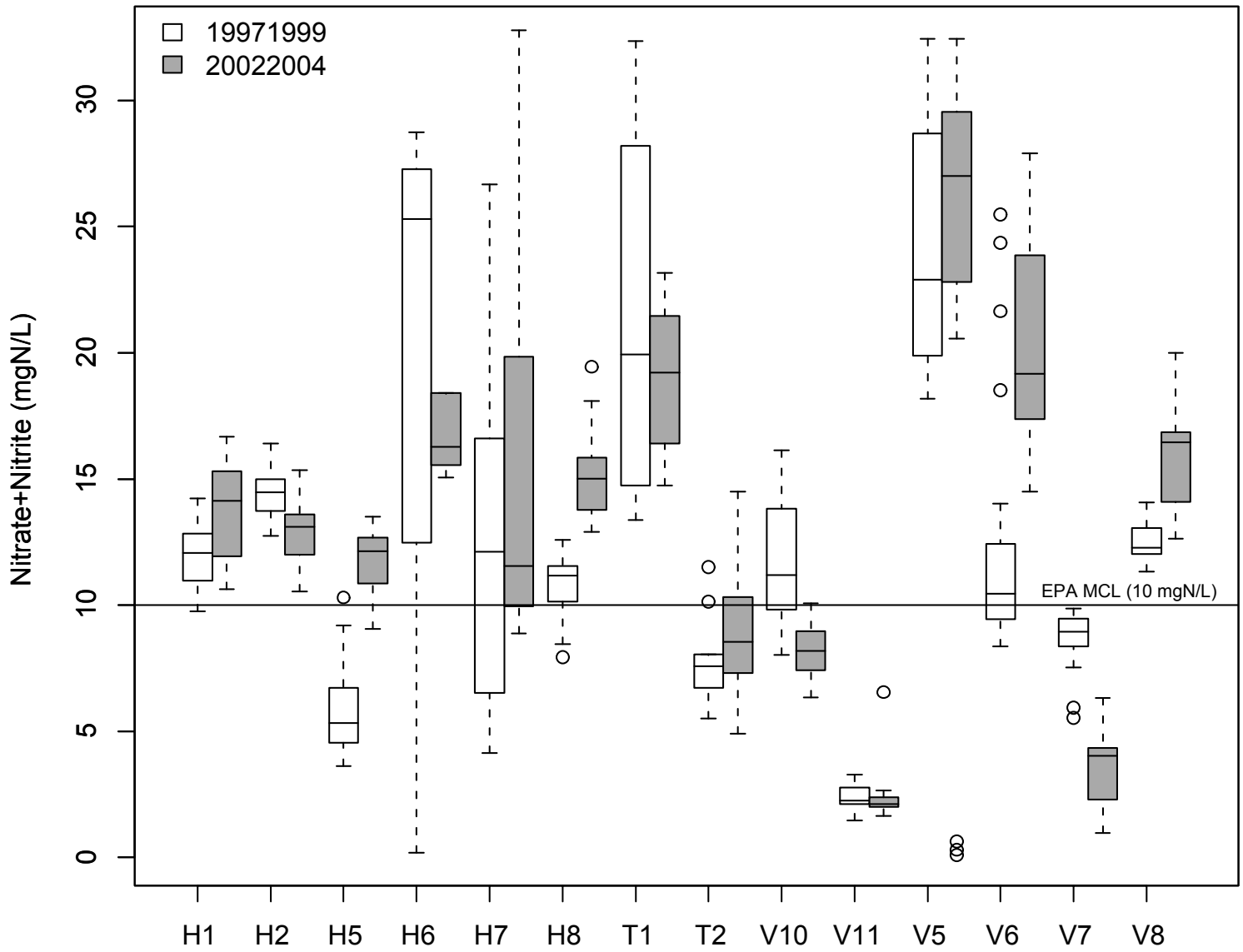


Nutrient Management Assessment



14 of the wells were also sampled between 1997 & 1999

	Site median nitrate
1997–1999	11.7 mg N/L
2002–2004	13.6 mg N/L


Nitrate+Nitrite from the 9799 and 0204 Studies by Site
19971999
20022004
Nitrate+Nitrite (mgN/L)
0
5
10
15
20
25
30
EPA MCL (10 mgN/L)
H1
H2
H5
H6
H7
H8
T1
T2
V10
V11
V5
V6
V7
V8

Conclusions

- Nitrate concentrations remain high in both surface water and groundwater in the study area.
- Nitrate concentrations transported across the border from BC range from about 10 to 25 mg-N/L and reflect a mix of manure and inorganic N sources.
- Nitrate concentrations in shallow wells in Washington range from about 15 to 35 mg-N/L and correlate to a combination of BC and local N sources.
- Denitrification is occurring in the peat in Pangborn Bog resulting in lower nitrate concentrations south of the bog.
- Denitrification is also occurring at other isolated locations.