

Coupling Nitrogen Transport and Transformation Model with Land Surface Scheme SABAE-HW: Application to the Canadian Prairies

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Hydrology and Nutrient Cycling

- Interested in developing models for coupled hydrology and nutrient cycling, in prairie environments. Supports DRI collaboration with CWN work.
- This work will provide a new direction in *advancing understanding of emerging water issues.*

Overall Objectives and Approach

Develop coupled hydrologic models to help understand the interactions between climate, hydrology, vegetation, and nutrient cycling over diverse scales.

Apply the models to understand and solve problems relevant to water quality and supply.

Motivation and Specific Objectives

- Motivations:
 - Climate and land use changes are (or will) occur in over the prairies
 - Nutrient transport under winter conditions not well understood
 - What are the local and regional impacts of these changes on water quality and the environment?

Motivation

- Technical Objectives:
 - Enhance modeling capabilities of SABAE, gCLASS, or CHRM for regional scale water, nutrient and thermal fluxes
 - Incorporate realistic mechanisms under freeze and thaw cycles
 - Develop ability to understand and predict the effects of climate, drought and land-use changes

Motivation

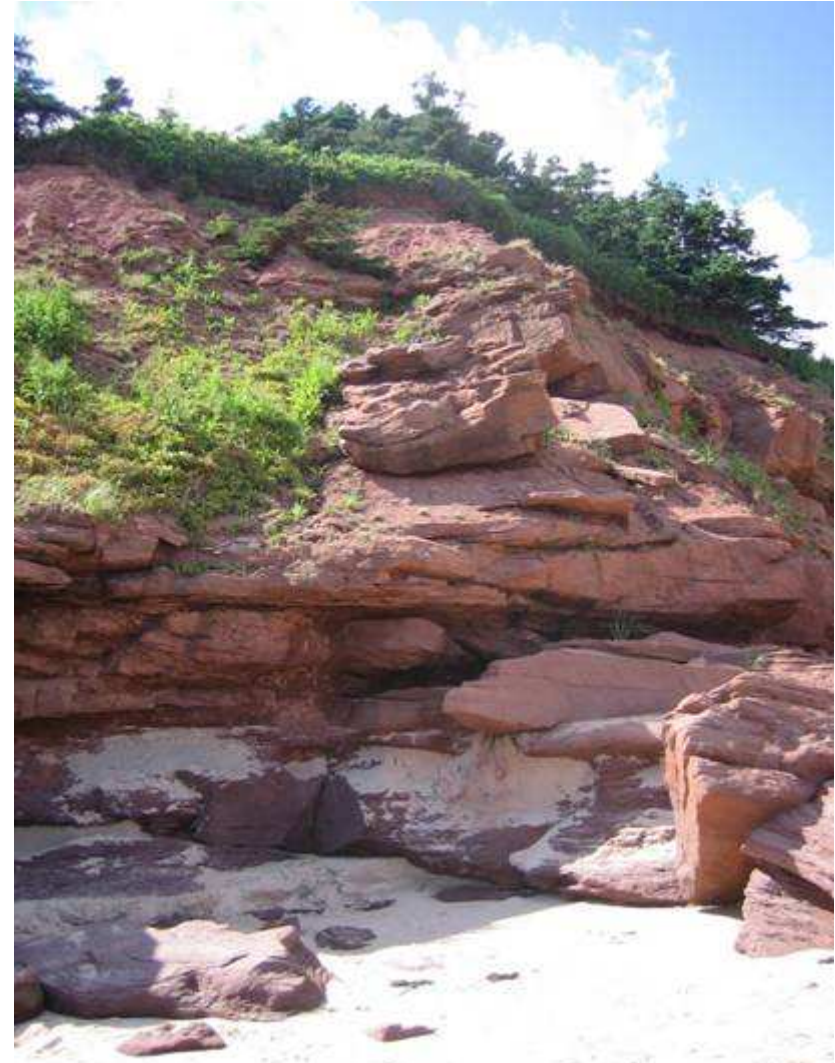
- Other Objectives
 - Build stronger ties between UM and Water Stewardship, other interested partners



Coastline on PEI



- ❖ 20% of land in potato production rotation
- ❖ Dependent on pesticide/fertilizer use

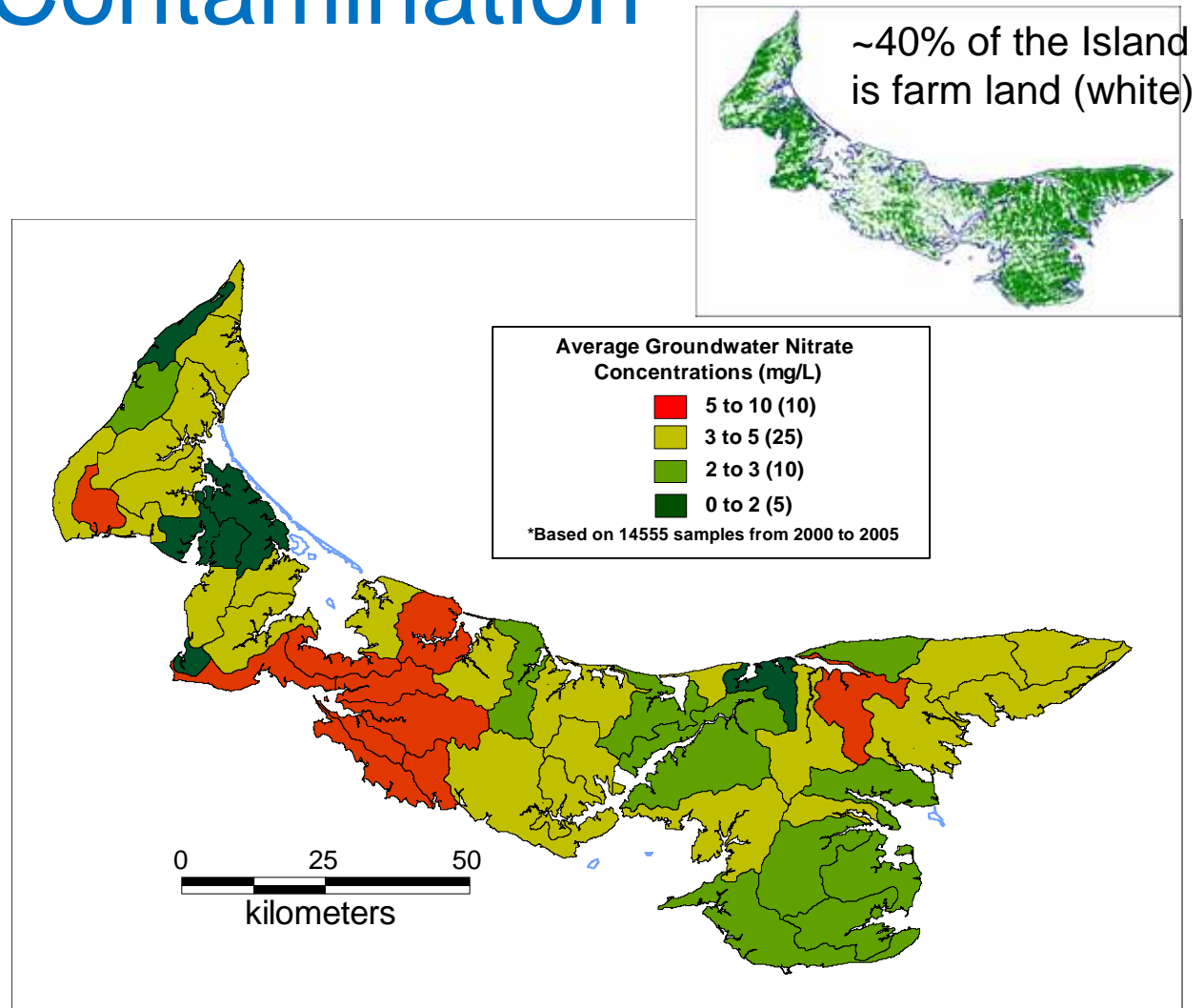


Permeable till/"Redbed" sandstone (0-200 m) forms a porous-fractured aquifer

Groundwater Nitrate (NO_3) Contamination

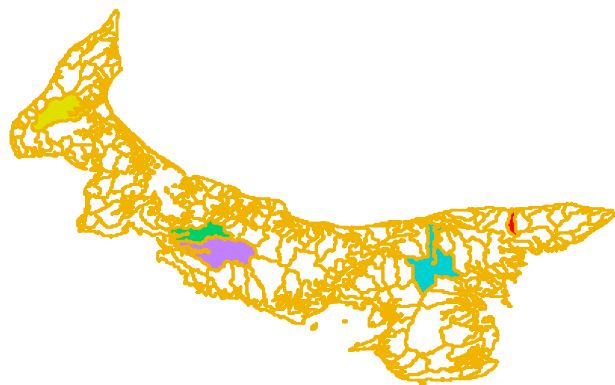
HW-9

- Many watersheds with higher average concentrations and in some cases, nitrate levels exceed health threshold of 10 mg/l.
- Areas associated with greater agricultural intensity.
- 90% have elevated levels beyond background.
- Both mean nitrate levels from tested wells and the # of wells with nitrate >10 mg/l increased over time.

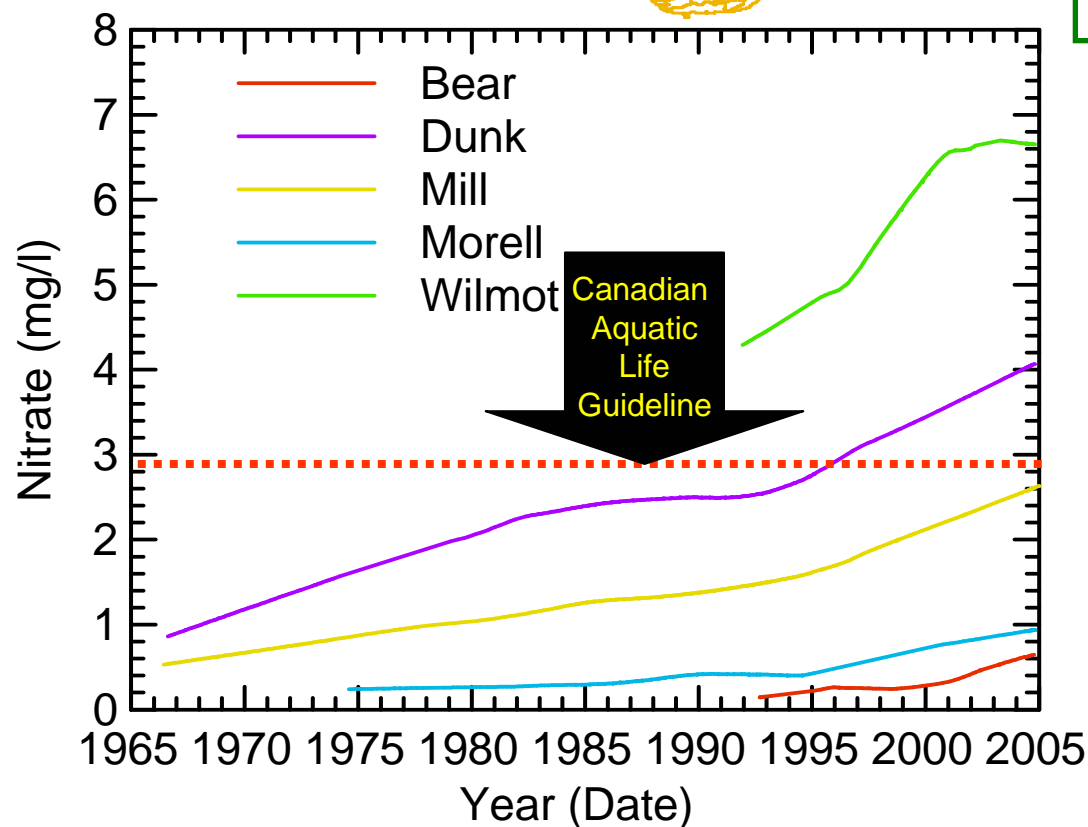


Courtesy of Yefang Jiang, and Jim Young, PEI Provincial sources

Surface Water Nitrate Contamination

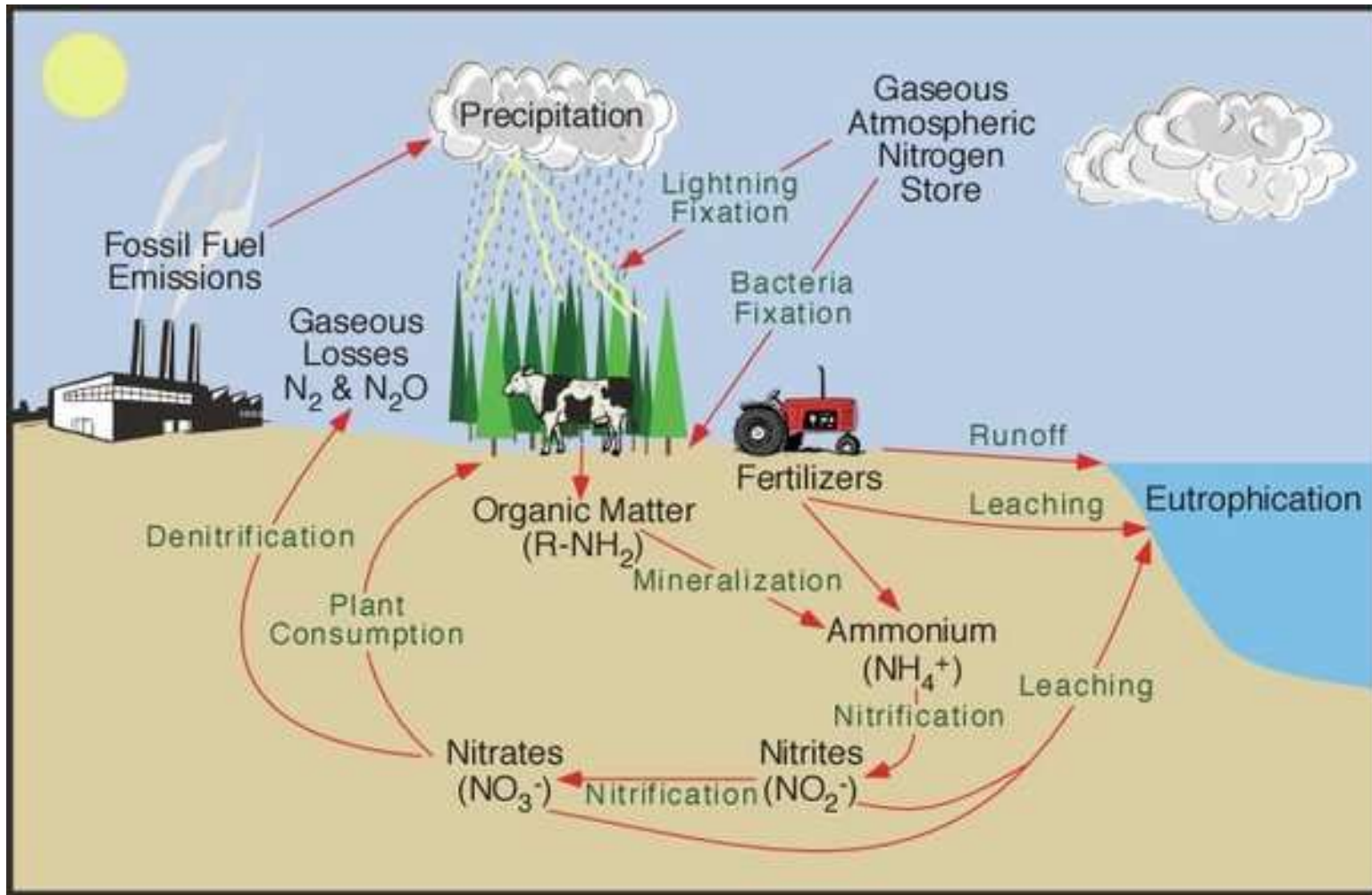


- SW nitrate levels increased over time and exceeded the Canadian aquatic life guideline in some cases.
- Excessive nitrate contributed to eutrophication in some estuaries.



Courtesy of Yefang Jiang, and Jim Young, PEI Provincial sources

Nitrogen Cycle



Background

Most of the studies confirm the increase of N fluxes during the freeze and thaw. N_2O fluxes were also increased in this period.

Depth and **duration** of the snow pack are the important parameters to control **soil temperature** and **soil moisture** and **N cycling** during the melting period.

It has been reported that N **net mineralization** is not negligible in winter time. Some researchers have stated that nitrogen net mineralization **increases** after thawing period while there have been other studies indicating that there is **no change** in the N mineralization after soil frost .

The cumulative effects of **multiple freeze/thaw cycles** must be known to estimate soil nitrogen losses over winter.

Available Models: Solute Transport and Transformations

European nitrogen dynamics model:

- ANIMO
- DAISY
- SUNDIAL
- SOIL/SOILN (COUP)

Solute transport model:

- SHAW
- HYDRUS

U.S. nitrogen dynamics model:

- NLEAP
- GLEAMS
- LEACHM
- RZWQM

SABAE Model

(Soil Atmosphere Boundary, Accurate Evaluations of Heat and Water)

Is a soil-multilayer version of the Canadian Land Surface Scheme (CLASS)

It allows a user to specify depth and number of soil layers.

It extends the CLASS model to perform computations over refined discretization of any unsaturated soil column

Input data (Atmospheric , soil properties and vegetation cover)

Out put (Snow Pack, Soil temperature and soil moisture)

Benchmarking Field Comparisons

- A. Compare the results of SABAE-HW with Observation data
- B. Compare the results of SABAE-HW with SHAW model

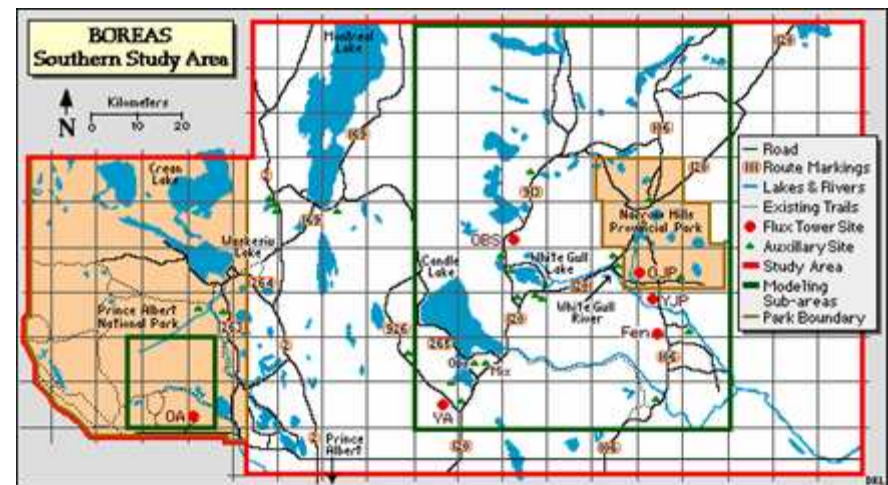
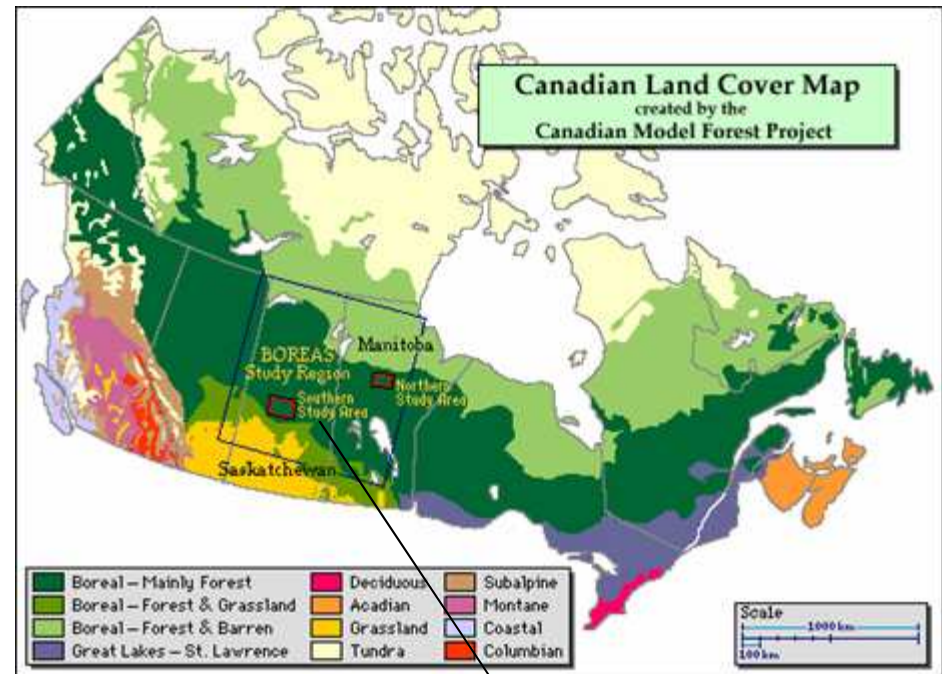
Two Boundary Conditions:

- Water table
- Unit Gradient

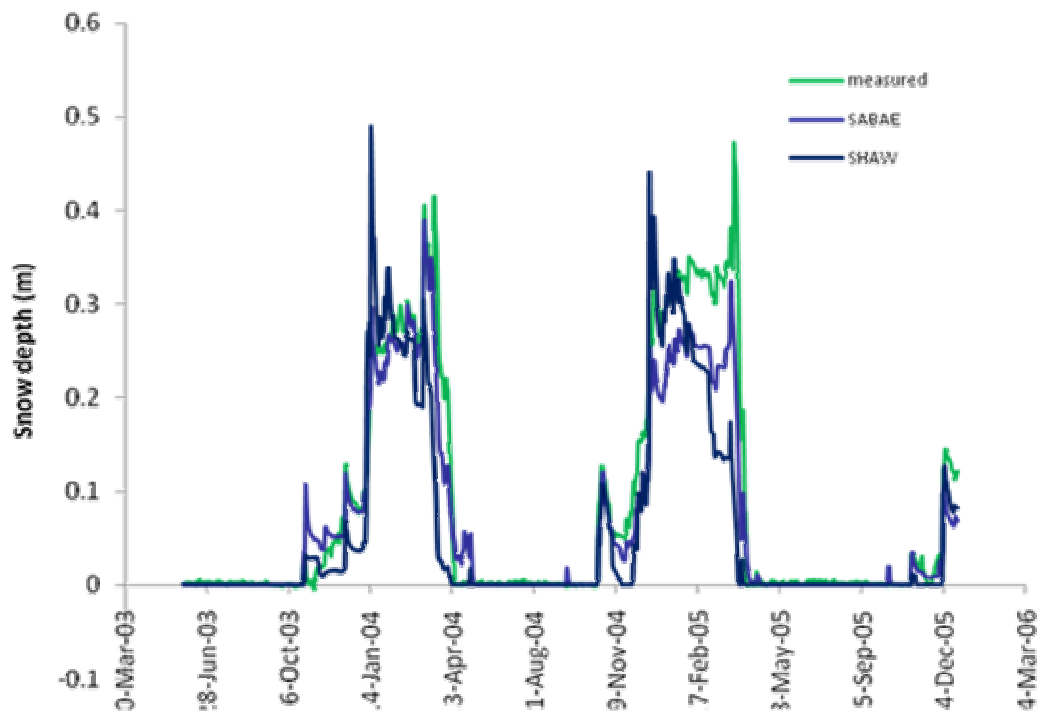
Soil Column was extended to:

- 3 meters (11 layers)
- 7meters (19 layers)

- ❑ Elevation 579.27 m
- Mean Annual Air Temp. 0.4° C
- ❑ Mean Total Annual Precipitation 467.2 mm
- ❑ Soil type is sand and sandy loam
- ❑ Cover Type mature jack pine, very sparse green alder



Snow Depth

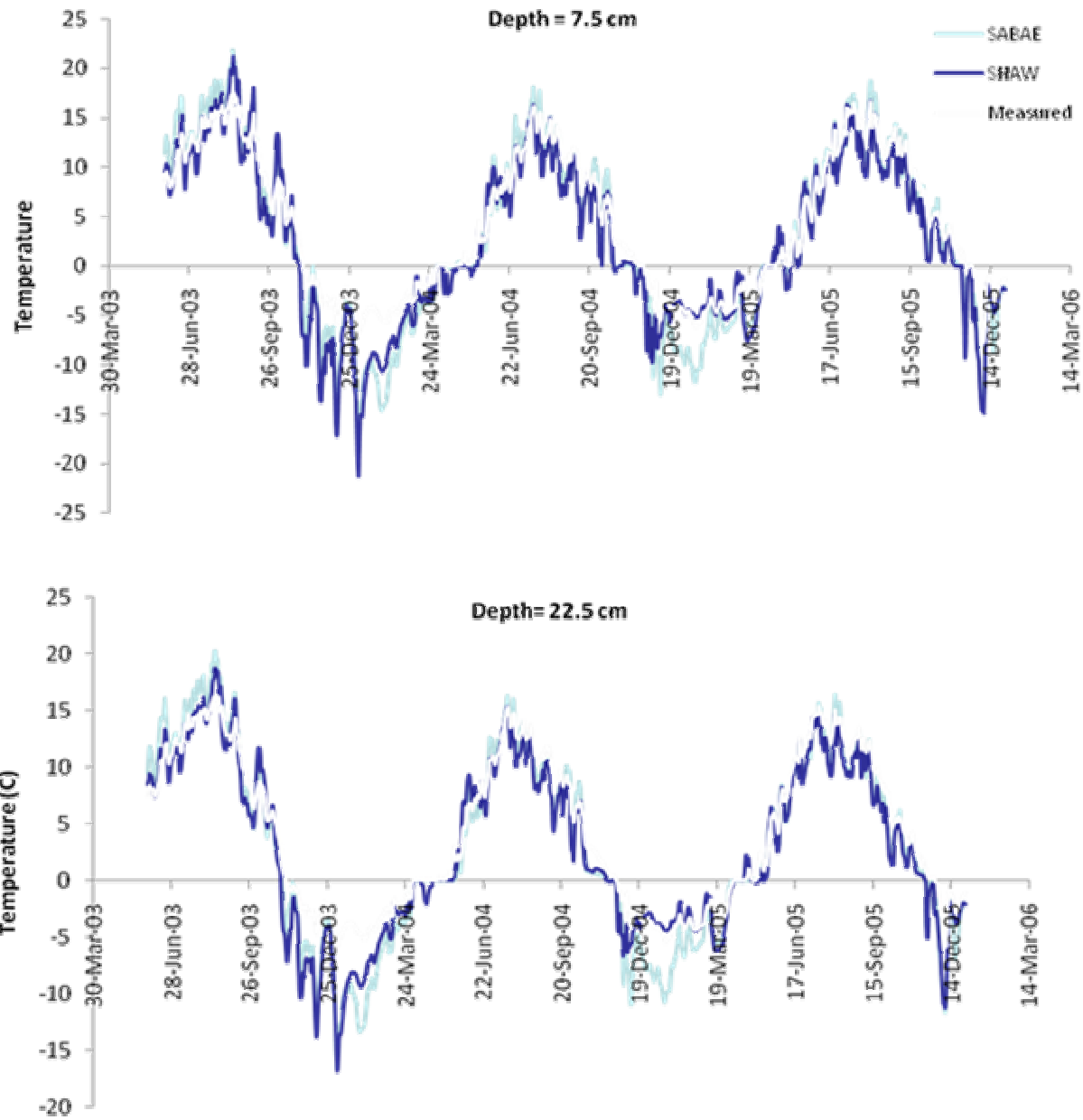


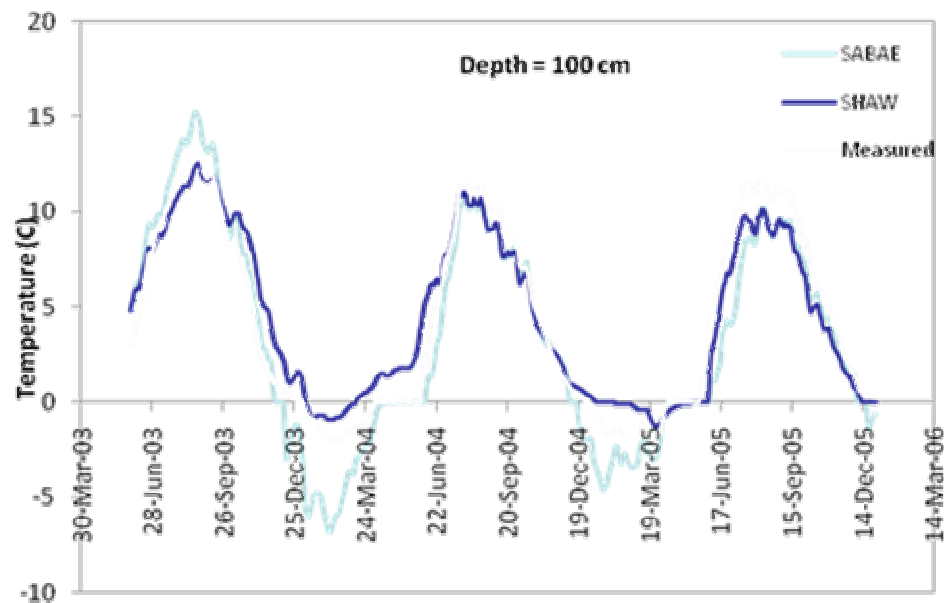
Simulated and measured snow depths from June 2003 to Dec. 2005

Measured data versus SABAE			Measured data versus SHAW		
Average err	RMSE	Correlation	Average err	RMSE	Correlation
-0.01	0.03	0.97	-0.02	0.06	0.86

Average Error, Root Mean Square Error and Correlation values for simulated and measured snow depth within Old Jack Pine site from June 2003 to Dec. 2005

Soil Temperature





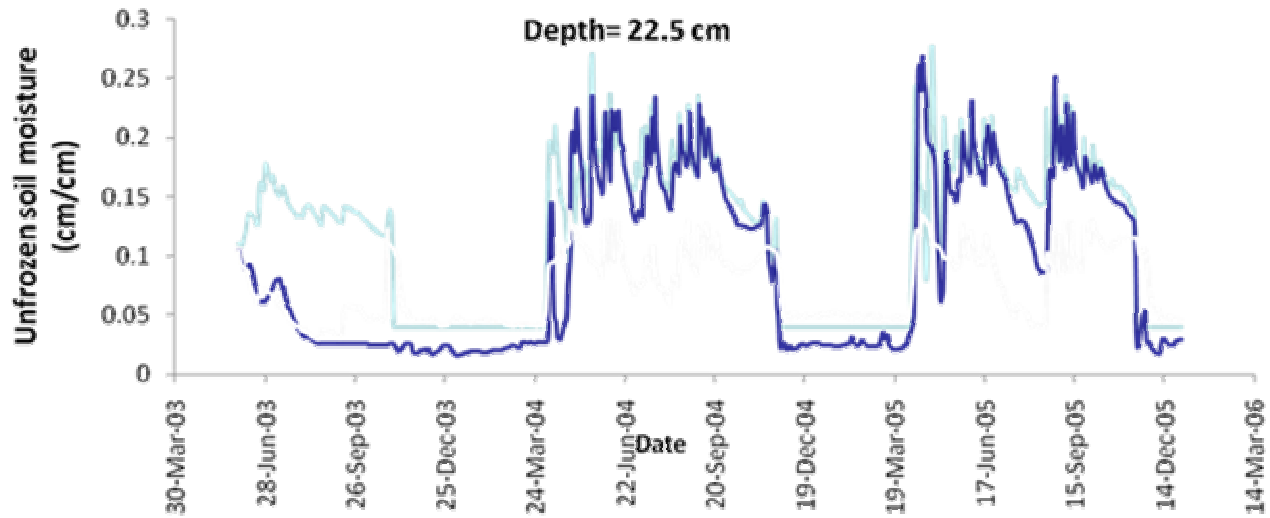
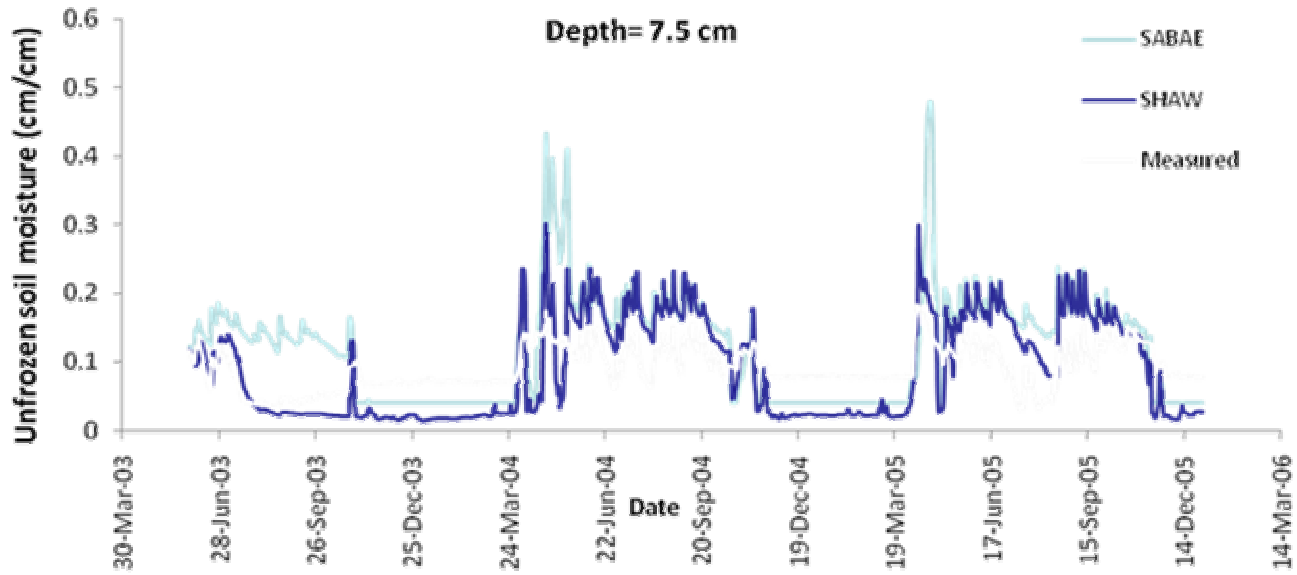
Average Error, Root Mean Square Error and Correlation values for simulated and measured soil temperatures at various soil depths within Old Jack Pine site from Nov. 2004 to Feb. 2005

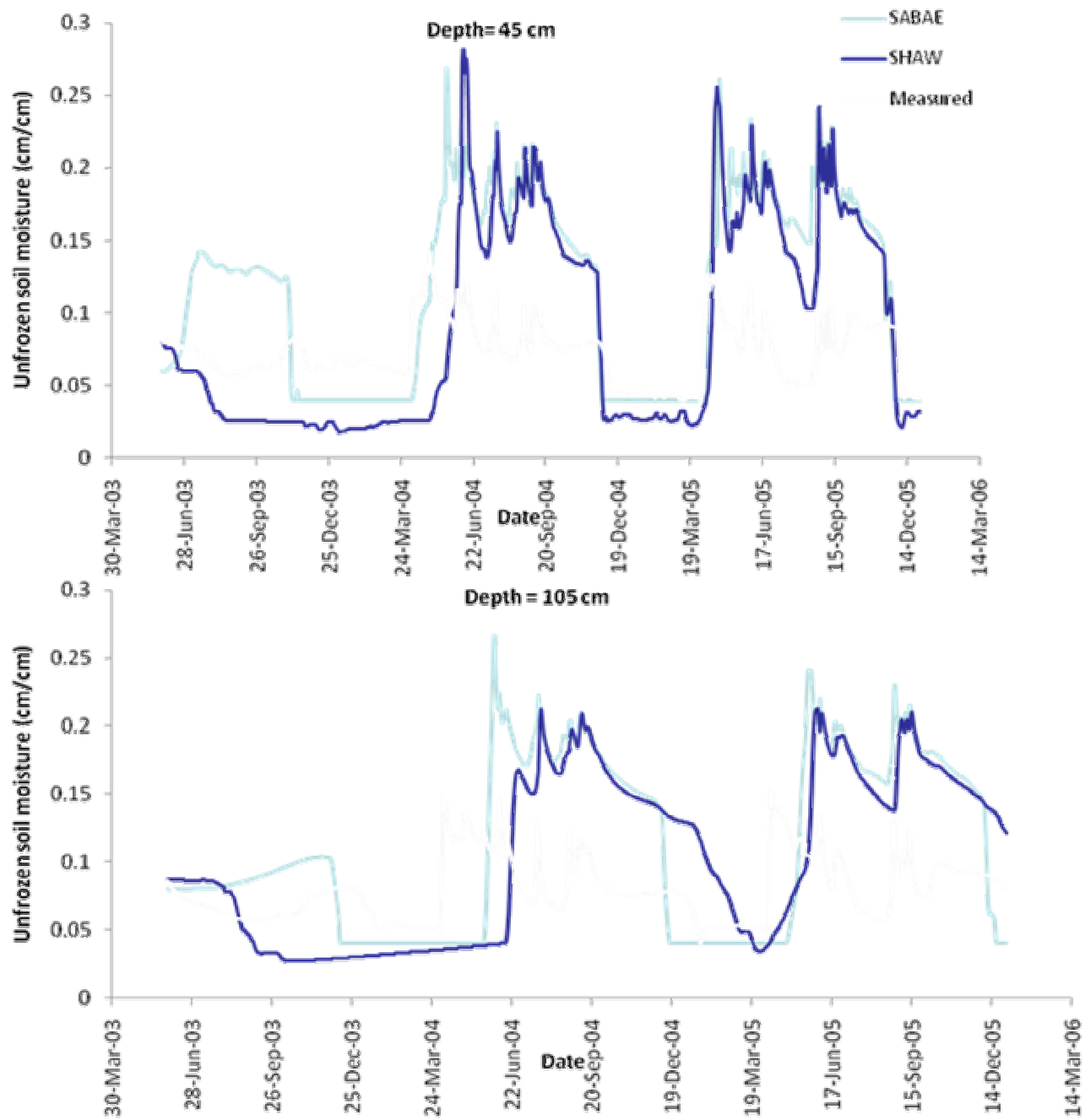
depth	Measured data versus SABAE			Measured data versus SHAW		
	Average err	RMSE	Correlation	Average err	RMSE	Correlation
7.5	-2.11	2.60	0.90	-0.7	1.84	0.66
22.5	-1.34	1.82	0.90	-0.33	1.31	0.79
50	0.47	0.91	0.89	-0.2	0.91	0.89
100	-1.23	1.66	0.94	0.7	0.94	0.97

June to Oct, 2005

depth	Measured data versus SABAE			Measured data versus SHAW		
	Average err	RMSE	Correlation	Average err	RMSE	Correlation
7.5	-0.58	1.43	0.95	-1.52	1.52	0.96
22.5	-0.86	1.26	0.96	-1.54	1.54	0.97
50	-1.17	1.33	0.97	-1.49	1.49	0.97
100	-2.39	2.7	0.87	-1.77	1.77	0.99

Soil Moisture





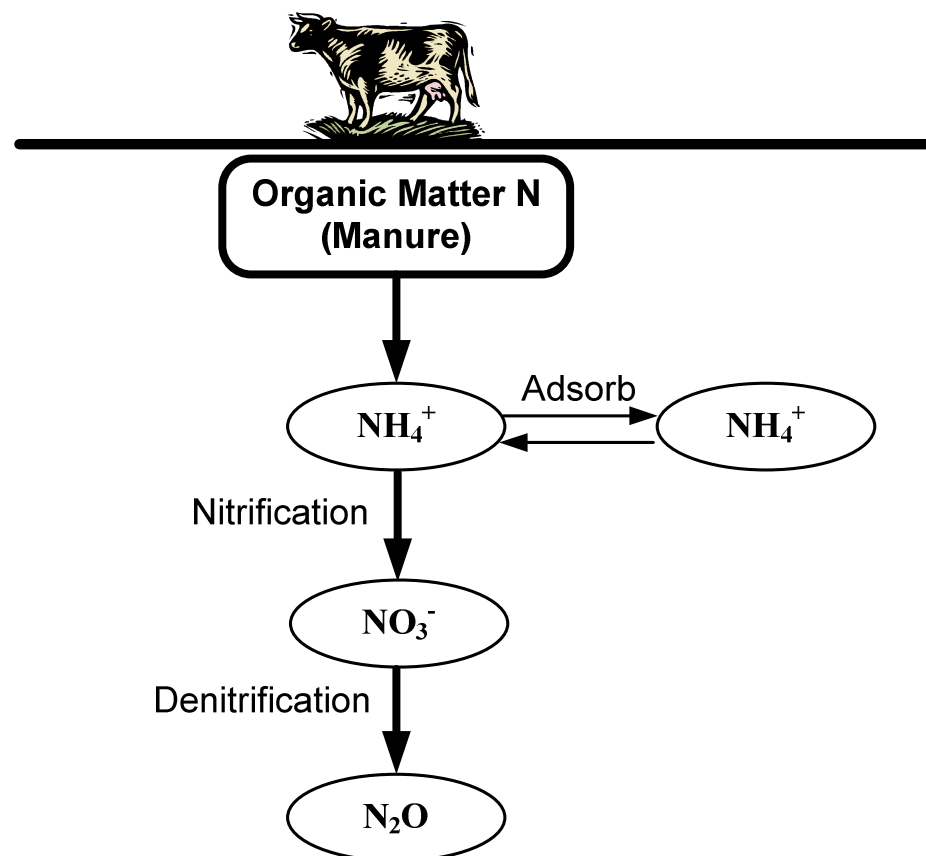
Nitrogen Transport and Transformations Model

Assume here that manure is the only source of organic matter

Single pool nitrogen transformation

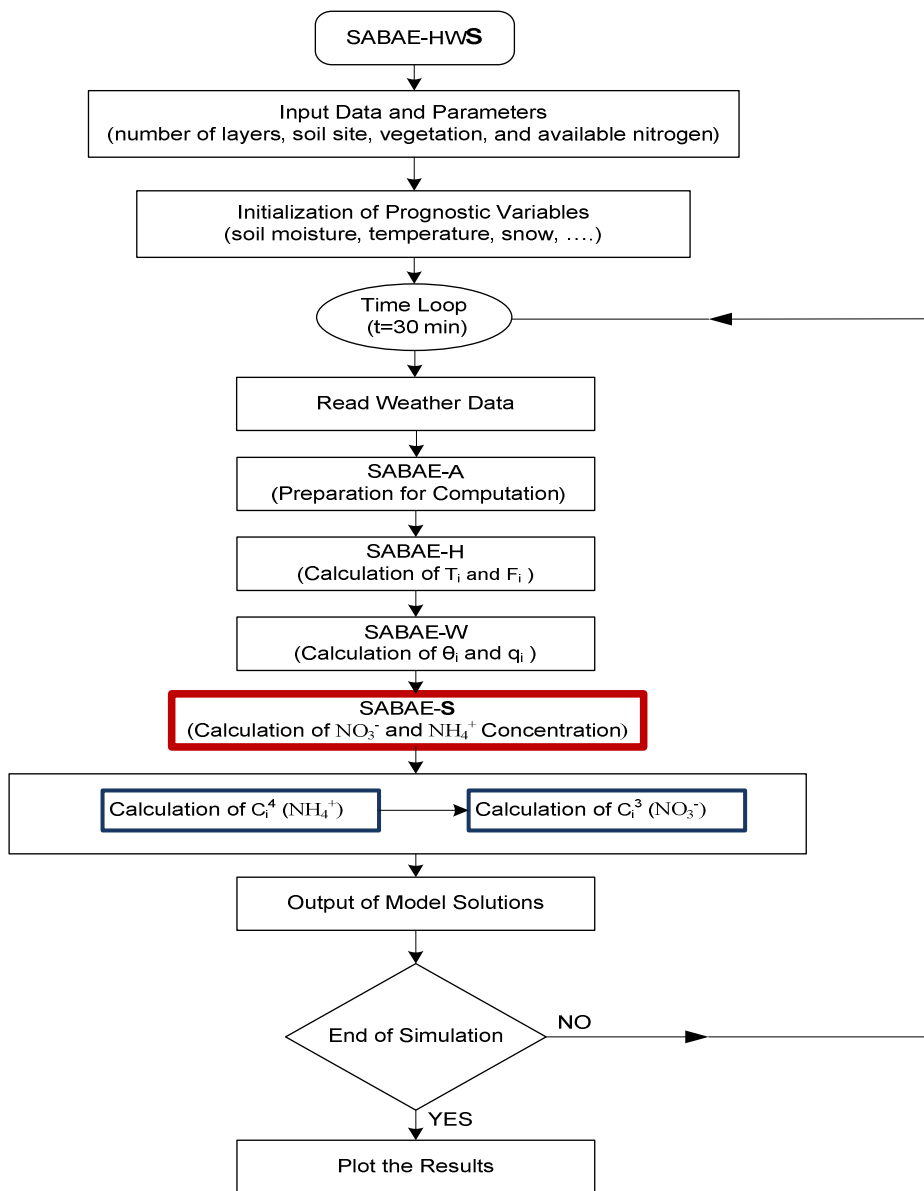
NH_4^+ is strongly adsorbed by soil particles

A majority of the leachate nitrogen is in the NO_3^- form



Processes

- Advection-dispersion, reaction and retardation
- Mass input from land-surface, atmosphere and not some average recharge
- Heat transport, energy fluxes
- Advective fluxes at flow sources/sinks, constant head and river boundaries
- $\text{NO}_3\text{-N}$ from all sources
- Freeze-Thaw mechanisms



Descriptive Algorithm for SABAE-HWS Model

Manure Application

Manure as a source of nutrients:

- Improves the physical condition of the soil
- Increases the organic matter content of the soil
- affects the changes of runoff and soil erosion

The main concerns of regulators, agriculture:

- The rate of nitrate and nitrogen
- Over fertilizing (mineralizable form)

Winter Manure Application

Manure is only applied in winter if there is a lack of storage capacity or inflexibility in spreading manure due to limited storage.

- Limited manure storage structures
- Availability of time for manure spreading
- Reduced soil compaction

It should be studied under two conditions:

1. Hydrological process
 - a. Infiltration
 - b. runoff
2. Nutrient transport

Future Work

- Currently running SABAE-HW over the drought period of 10 years (1997-2006) and compare the results with OJP measured data and SHAW model
- A detailed discretization of ammonium and nitrate equations including nitrogen transformation processes should be completed soon
- Solute transport model will be compared to analytical solutions developed by Carlier, 2008 and Kumar et al., 2009 subjected to their boundary conditions, and also SHAW model
- Nitrogen transport and transformation model will be coupled with SABAE-HW at the time step level (SABAE-HWS). First order coefficients need to be optimized
- The field data will be applied for calibration and validation of SABAE-HWS. Winter manure application needs to be validated

Conclusions

- **Outcome:** coupled CHRM or SABAE with nitrogen biogeochemistry
 - a. Study effects of climate on N-cycling
 - b. Scale on process model results
 - c. Sensitivities to various properties/parameters.
- **Significance:** Hydrologic synthesis is needed to inform policy makers to deal with challenges of water quality and supply.