TIEE

Teaching Issues and Experiments in Ecology - Volume 7, July 2011

ISSUES : DATA SET

Nitrogen biogeochemistry of headwater catchments underlain by discontinuous permafrost

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Black spruce forest covers a north-facing hillslope. Note the thick organic layer that covers the forest floor. Photo by Tamara Harms.

THE ECOLOGICAL QUESTION:
What influences flux of nitrogen from catchments underlain by discontinuous permafrost?

ECOLOGICAL CONTENT:
Catchment biogeochemistry, boreal forest, discontinuous permafrost, nitrogen (N)

WHAT STUDENTS DO:
Students work with a large dataset describing nitrogen dynamics in the Caribou-Poker Creeks Research Watersheds, small watersheds in the boreal forest that are underlain with various extents of permafrost cover. Students use spreadsheet and graphics software to investigate responses of N cycling to permafrost, seasonal patterns, and inter-annual variation by 1) making observations concerning long (inter-annual) and short-term (seasonal) patterns in nutrient concentrations in streams, 2) hypothesizing about physical and biological conditions influencing nitrogen chemistry, and 3) testing predictions using graphical analyses. The first activity provides a guided approach to addressing a research question with the available data. Supplemental activities are inquiry-based and instructors can either specify analyses to perform or choose to allow students to gain experience with exploratory data analysis in more advanced courses.

STUDENT-ACTIVE APPROACHES:
Skills developed include investigating causal relationships, calculations, preparation of graphs, and interpretation of data. Communication activities include think-pair-share, class discussion, and presentation of findings with the class or in written reports.

SKILLS:
Drawing observations from graphical data, hypothesizing, calculations and preparation of figures from large datasets, graphical analyses, facilitated group learning, written presentation of results

ASSESSABLE OUTCOMES:
Formative assessment via small-group and class discussion; display-quality figures; written and verbal presentation of observations, analyses, and interpretation

SOURCES:
http://www.lter.uaf.edu/
Bonanza Creek Long-Term Ecological Research Program

ACKNOWLEDGEMENTS:
We thank contributors to the Bonanza Creek LTER program for assistance with data collection.

OVERVIEW OF THE ECOLOGICAL BACKGROUND

Catchment biogeochemistry addresses reaction and transport processes that deliver and transform water and other materials. A catchment (also referred to as a watershed) includes the land area that is drained by a particular body of water. In catchments drained by small streams, the amount of water, dissolved, and suspended materials in stream flow at the catchment outlet provide information about the hydrologic, biological, and geochemical processes that have occurred within the catchment. These hydrologic and biogeochemical processes may respond to climate, disturbance events, and atmospheric or biological inputs of materials.

Water enters catchments as precipitation. Once in the catchment, water moves over the ground surface as overland flow, or percolates through soils. Some of this water is stored in catchments as soil water, or within deeper groundwater aquifers. The relative importance of each of these processes is determined by characteristics of storms including duration and intensity; the amount of water previously stored in the catchment; and attributes of the catchment including soils, vegetation, size, and slope. Water leaves catchments due to evaporation, transpiration by plants, and stream flow. While moving through the catchment, water collects dissolved materials, including nutrients. The relative amounts of dissolved materials depend on soil and vegetation types, and amount of time water spends in contact with each type. Following the movement of water through catchments is therefore important for understanding nutrient cycles, and streamflow can serve as an integrator of catchment processes.

In some high-latitude catchments, frozen ground further influences the flow of water through catchments. Ground that remains frozen for >2 years is termed permafrost, and the presence of permafrost restricts the amount of water that flows belowground. Shallow soils thaw each season, and these shallow soils are termed the active layer, because they allow water to flow through them. Early in summer, flow of water is restricted to upper, organic soil horizons, and the thaw depth can increase to include mineral soils later in the season, but infiltration to deeper layers and connection to deep aquifers are restricted by permafrost.

Although numerous dissolved materials are transported by water through catchments to streams, nitrogen (N) is of interest to researchers in boreal regions because its availability limits primary productivity. Nitrogen enters catchments primarily by biological fixation of atmospheric N_2, which converts N into organic forms. Plant materials, including living tissues and litter on the forest floor, contain organic N that can be leached by water to form dissolved organic N (DON). DON can be converted to inorganic forms (ammonium [NH_4^+], and nitrate [NO_3^-]) by soil micro-organisms. Both plants and micro-organisms can take up inorganic and organic N and assimilate it into their tissues; some micro-organisms can additionally use inorganic forms of N to obtain energy. Inorganic N tends to be found in deeper, mineral soil horizons, whereas organic N is concentrated in the forest floor and in shallow soils.

Nitrogen dynamics may be changing in high latitude catchments. Evidence for changes include high concentrations of inorganic N in streams (Jones et al. 2005, Petrone et al. 2006), export of inorganic N in streamflow that exceeds inputs to catchments (Jones et al. 2005), and increasing fluxes of inorganic N in an arctic river (McClelland et al. 2007). These patterns may be related to climate warming by thawing permafrost, increasing depth of seasonal thaw, changes to plant species composition, or physical disturbance of soils.

References:

McClelland, J.W., M. Stieglitz, F. Pan, R.M. Holmes, B.J. Peterson. 2007. Recent changes in nitrate and dissolved organic carbon export from the upper Kuparuk River, North Slope, Alaska. Journal of Geophysical Research-Biogeosciences 112:G04S60.

Jones, J.B., K.C. Petrone, J.C. Finlay, L.D. Hinzman, W.R. Bolton. 2005. Nitrogen loss from watersheds of interior Alaska underlain with discontinuous permafrost. Geophysical Research Letters 32:L02401.

Petrone, K.C., J.B. Jones, L.D. Hinzman, R.D. Boone. 2006. Seasonal export of carbon, nitrogen, and major solutes from Alaskan catchments with discontinuous permafrost. Journal of Geophysical Research-Biogeosciences 111:G02020.

Resources:

http://earthon.iab.uaf.edu/J_Jones/GoogleEarthCPCRW.html

A file for viewing in Google Earth contains maps of CPCRW, including catchment boundaries, permafrost distribution, topography, and vegetative cover.

http://www.lter.uaf.edu/bnz_cpcrw.cfm

The CPCRW are part of the Bonanza Creek Long-Term Ecological Research site and a detailed site description is located on the BNZ LTER website.

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STUDENT INSTRUCTIONS

Site description

Datasets used in this activity are drawn from the Caribou-Poker Creeks Research Watersheds (CPCRW), which are part of the Bonanza Creek Long-Term Ecological Research Program established for ecological studies of the boreal forest. The boreal forest biome accounts for nearly a third of the total forest area on Earth. Boreal forest includes spruce forests, bogs and fens, hardwood forests, and tundra vegetation. CPCRW (104 km^2) contain several headwater watersheds that vary in permafrost extent. Permafrost, defined as ground that remains at or below 0^oC for two or more years, is distributed in valley bottoms, and on north- and east-facing slopes due to colder average temperatures in these locations. Snowmelt at CPCRW occurs approximately between early May and June each year. Mean annual air temperature is -2.5^oC and mean annual precipitation totals 400 mm, with approximately 1/3 as snow.

A small stream draining a headwater catchment at CPCRW. A flume and autosampler are located on this stream, and used to monitor discharge and water chemistry. Photo by Tamara Harms.

Stream discharge has been monitored at CPCRW for over 40 years and we will use a subset of those data in concert with chemistry of stream water to investigate patterns of nitrogen (N) biogeochemistry at CPCRW. To measure discharge, streams are routed through small flumes of known cross-sectional area, and water level in each flume is monitored as pressure. These pressure data are converted to stream discharge (L/s) using calibration relationships between water level in the flumes and measured stream discharge. Water samples are collected by automated samplers several times each day. These samples are analyzed in the laboratory for a suite of elements in dissolved form. We will focus on nitrate (NO_3^-), the predominant inorganic form of N in the catchments, and dissolved organic nitrogen (DON). For these exercises, N concentrations are reported as daily mean values for each stream.

Table 1. Characteristics of headwater catchments at CPCRW.

	Catchment area (ha)	Permafrost cover (%)
C2	520	3
C3	570	53
C4	1000	18

ACTIVITY 1: Contrasting catchments

Observations and hypotheses

You will use Microsoft Excel to create two graphs summarizing observations of NO_3^- and DON concentrations for 3 watersheds during summer 2007. Using these graphs and the summary data presented in Table 1, you will record observations regarding differences between the catchments and develop hypotheses and potential tests to explain the differences.

1. Open the Excel file "student data" and click on the "Activity 1" worksheet.
   - 1.1. First plot concentration of NO_3^- against date for watershed C2 by selecting data in columns "Sample Date" (X values) and "Nitrate (μM)" (Y values).
   - 1.2. Choose XY (Scatter) as the plot type, with points connected by a straight line.
   - 1.3. Label the X and Y axes and title your graph.
   - 1.4. Add data from watersheds C3 and C4 to the same plot. Right-click the plot and select "Source data". Then add a new series named C3, with corresponding sample date and NO_3^- data as the X and Y values. Repeat for C4.
   - 1.5. Create the same plot for DON data by following steps 1-1.4.

2. Adjust the scale of the axes of your two plots for easy comparison by double-clicking an axis, choose the "Scale" tab and enter minimum and maximum values. Be sure to save your results.

3. In your lab notebook, record at least 3 similarities and differences you observe between DON and NO_3^- concentrations between catchments C2, C3, and C4. Consider average differences as well as temporal trends.

4. Discuss your findings with your lab group. Did your observations match those of your group? If not, how were they different? Record any new observations contributed from your lab group.

5. Appoint a presenter to briefly describe your observations for the class.

6. What could be causing the observed differences among catchments? Choose one observation from the list generated by the class and pose 3 hypotheses that could explain that observation. Record your hypotheses in your lab notebook. You may want to review the information presented in the "Overview" and "Site description" sections to help generate your hypotheses. Write a brief description of a potential experiment or test of one hypothesis. What type of data or further observations would you need to collect to test the

hypothesis? What would you predict if the hypothesis is correct? Predictions may be stated in words, but it is often useful to draw a graph describing the predicted outcome.

7. Share your hypothesis and potential test with other members of your group. Discuss the reasoning underlying your hypothesis and test. You may be asked to present this to the class.

Testing hypotheses

Using the available data, we can test the hypothesis that permafrost extent causes differences in N concentrations among the catchments by determining the relative amount of flow through shallow and deep soils. We can test this hypothesis by comparing patterns of DON and NO_3^- among the catchments, because most DON is contributed by the forest floor and shallow soil horizons, whereas NO_3^- is produced in deeper, mineral soils. Permafrost cover differs substantially among the 3 catchments, and we can use contrasts between the catchments to test our hypothesis.

8. If permafrost extent determines N concentrations by influencing the amount of flow through shallow and deep soils, what do you *predict* regarding concentrations of NO_3^- and DON in streams draining each of the 3 catchments? Record this prediction.

9. We will characterize patterns of DON and NO_3^- for the catchments in 2 ways: using average concentration, and average flux. First, calculate average concentration of DON and NO_3^- in each stream (C2, C3, and C4) using the AVERAGE function in Excel. The calculation should include all dates sampled in 2007. Construct a table to compare these average values. Include the catchment name, and permafrost extent for each catchment.

10. Another way to compare chemistry of catchments is to consider the amount of material leaving the catchment in streamflow, referred to as *flux*. Flux is calculated by converting concentration to mass of material leaving the catchment by dividing N concentration by streamflow. The mass of N leaving the catchment is specific to a unit of time that is determined by the period of observation. Here we are using daily mean discharge and concentration values, so our flux is in units of per day. Finally, we can standardize the flux to the catchment area, to account for differences in the sizes of the catchments. The Activity 1 worksheet contains values of N flux in g N ha^{-1} d^{-1}. Summarize these data for each catchment by calculating the average flux over the summer season. Add these estimates of NO_3^- and DON flux for each catchment to the table containing concentrations.

11. Using the summary table you have constructed, do the results match the prediction? What can you conclude from these data regarding potential effects of permafrost extent and N dynamics? Are there exceptions to the expected patterns? What could explain these exceptions?

Activity 1 Synthesis report- Contrasting catchments

Prepare a report that summarizes the observations, questions addressed, and suite of hypotheses generated in Activity 1.

Report checklist:

Initial observations and hypotheses

-Graphs of DON and NO_3^- concentration

-List of observed differences among catchments

-Hypotheses potentially explaining differences among catchments

-Proposed test of 1 hypothesis, including data required

-Prediction resulting from proposed test (the prediction could be in the form of a graphic)

Test of permafrost hypothesis

-State the hypothesis

-Describe the approach used to test the hypothesis

-List the predictions

-Summary table

-Interpretation of results

Include answers to the following questions:

1) What different information do concentration and flux provide about N dynamics in catchments?
2) Why might catchments of different sizes export different amounts of N?

ACTIVITY 2: Intra-annual (within year) variation

Observations and hypotheses

In this activity you will use the graphs you produced in step 1 and precipitation data found in the “Activity 2” worksheet to examine temporal patterns that occur within a year.

1. Observe the graphs of nutrient concentrations that you made in Activity 1 for patterns that occur within the year. Record at least 3 of these observations in your notebook.

2. What factors or processes could generate temporal patterns in N concentration within a year? Pose 3 hypotheses explaining the observed patterns and list them in your lab notebook. Write a description of a potential

experiment or test of each hypothesis. What data or observations would be needed to test each hypothesis? Identify the predicted patterns resulting from each test if the corresponding hypothesis is correct.

3. Share your observations, hypotheses and potential tests with other members of your group. Discuss the reasoning underlying your hypotheses and tests.

Testing hypotheses

4. What processes could link temporal patterns of precipitation and N? Pose a hypothesis stating a causal relationship that links precipitation and N in streamflow. To test the hypothesis, you will use a comparison of the time series of precipitation and of N concentrations for 2007. Record the prediction that follows from the test if your hypothesis is correct. This prediction may be in the form of a sketch of a graph.

5. Open the "Activity 2" worksheet. This worksheet contains data describing precipitation in the research watersheds. Precipitation is similar for all 3 catchments, and we will use these data to explore responses of N dynamics to precipitation inputs.
    5.1. Add a plot of precipitation to your graphs of DON and NO_3^- concentration. This provides a clear way of comparing temporal trends in concentration and precipitation. To accommodate all of the data on the same graph, add precipitation as a new series. Right click the graph of concentration, choose "Source data", and add precipitation data from the Activity 2 worksheet in the Excel file. Be sure to save your work.
    5.2. Precipitation in cm is beyond the range of concentration values, so add a second y-axis for the precipitation data. Right-click the precipitation data series on the graph and choose "Format data series." Click the Axis tab and select "Secondary axis".
    5.3. To reduce overlap in the precipitation and concentration datasets, plot the precipitation data at the top of the graph. Double-click the precipitation axis, select the Scale tab, and select "Values in reverse order". Adjust the data range to minimize overlap between the concentration and precipitation data points. Precipitation is now plotted from the top of the graph, so points further from the top represent greater precipitation.

6. What do you observe regarding the patterns in N concentration and precipitation? Do the patterns match your prediction? If not, what may explain the discrepancy? Record these observations in your lab notebook.

Activity 2 Synthesis report- Intra-annual (within year) variation
Prepare a report that summarizes the approaches and findings from the activities you have performed. Include the observations, questions addressed, and suite of hypotheses you recorded. Describe the tests and predictions for each hypothesis. The report should include the graphs you have prepared, interpretation of the results, and answers to the final questions listed below.

Report checklist:
Initial observations and hypotheses
-List of 3 observed temporal patterns
-3 hypotheses potentially explaining observed temporal patterns
-Proposed test of each hypothesis (3), including data required for the test
-Prediction resulting from each proposed test (the prediction could be in the form of a graphic)

Test of precipitation influences on intra-annual patterns in N concentration
-State the hypothesis linking temporal patterns in N concentration with precipitation
-Briefly describe the approach used to test the hypothesis
-List the prediction following from the hypothesis
-Graphs of DON and NO_3^- concentration with precipitation
-Interpretation of results

Include answers to the following questions:
1) Why might temporal patterns differ for inorganic and organic forms of N?
2) How do the temporal patterns and N responses to precipitation differ among catchments and what could explain these differences?

ACTIVITY 3: Inter-annual (between years) variation
Some ecological patterns are not apparent within a single year, or may change over longer time periods. In this activity, you will describe relationships between N concentrations and precipitation collected over 7 years.

Observations and hypotheses
1. Using the data contained in the Activity 3 worksheet, plot NO_3^- and DON concentration for all years (2002-2007). You should produce a plot for each year that is similar to plots of the 2007 data generated in Activity 1.
   1.1. To produce multiple graphs of a similar layout, copy and paste an existing graph. Right-click the new graph and choose “Source data.” Select the Series tab and change the cell references to include data for the correct year.

2. In your lab book, briefly describe the inter-annual patterns in N concentrations. Look for similarities and differences in temporal trends across all years, the

magnitude of DON and NO_3^- concentrations, and similarites and differences among the 3 catchments.

3. What could be causing the differences among years? Choose one observation and pose at least 2 hypotheses that could explain the observed pattern and record them in your lab notebook. Describe a test of each hypothesis and record the predictions for each test if the hypothesis is correct. It may help to include a sketch of a graph describing each predicted result.

4. Share your observations, hypotheses and potential tests with other members of your group. Discuss the reasoning underlying your hypothesis and tests.

Testing hypotheses

5. You have several datasets available to test your hypotheses explaining differences in catchment N patterns among years. These datasets include: DON and NO_3^- concentrations and fluxes, stream discharge, and precipitation. Identify and carry out a test of one of your hypotheses using any of these datsets. It may be helpful to compare annual means, or total precipitation or N flux across each catchment/year combination. As a starting point, first calculate total precipitation for each year.

6. Next, compare the total precipitation for each year to mean stream N concentrations.

Activity 3 Synthesis

Prepare a report that summarizes your approach to investigating inter-annual variation and your findings. Include the observations, questions addressed, and suite of hypotheses. Describe the tests and predictions for each test and hypothesis. The report should include the graphs you have prepared and include interpretation of the results.

Report checklist:

Initial observations and hypotheses

-A graph of DON concentration and a graph of NO_3^- for each year in the dataset

-At least 3 observations describing inter-annual patterns

-2 hypotheses explaining observed inter-annual patterns

-Description of a test of each hypothesis

-Predictions from each test if the hypothesis is correct

Testing hypotheses

-State the hypothesis you chose to test

-Describe the test

-List the predicted results for the test
-Include tables and figures generated as part of the test
-Describe your conclusions from the test. Did results match predictions and therefore provide support for the hypothesis?

Include answers to the following questions:

1) Why might inter-annual patterns differ for inorganic and organic forms of N?
2) Why do the inter-annual patterns in N concentration differ among catchments in some years but not in others?

NOTES TO FACULTY

Description of Excel Files:

- Student Dataset: This file contains contains 3 Microsoft Excel worksheets, organized by activity. The first, labeled "Activity 1" contains NO_3^- and DON concentrations (μmol/L), mean daily stream discharge (L/s), and DON and NO_3^- flux (g N ha^{-1} d^{-1}) for 3 headwater catchments at CPCRW in 2007. The catchments contrast in their permafrost extent and catchment size (Table 1). The second worksheet labeled "Activity 2" contains data from Activity 1 alongside precipitation data (cm). The third worksheet labeled "Activity 3" contains precipitation, discharge, and NO_3^- and DON concentrations for each catchment for 2002-2007. [xls]
- Faculty Dataset: This file contains the student data, amended with example graphs and calculations. [xls]

These activities use hands-on experience with real data to introduce students to concepts and data analysis techniques used in catchment biogeochemistry. Exercises are intended for students in an introductory ecology course, but may also be appropriate for specialized courses. Concepts demonstrated include the relationships between precipitation, stream discharge, and nutrient availability and flux. The activities address the differences between organic and inorganic forms of nutrients, and emphasize temporal variation at seasonal and inter-annual scales. Finally, the activities introduce the role of permafrost in ecosystem processes, an important issue for students to be aware of given observed effects of climate change occurring in high-latitude ecosystems. These activities (particularly Activity 3) emphasize the role of long-term data in understanding ecological problems. If you do not choose to assign Activity 3, it will be important to emphasize to students that data used in this lab session are available through the Long-Term Ecological Research Network, which addresses ecological issues over the course of decades.

These activities require extensive use of Microsoft Excel. We provide some tips for generating graphs in Microsoft Excel. However, different versions and operating systems may alter these procedures slightly, and you may need to adjust instructions according to software available in the classroom. Depending on previous use of Excel in the course, a review may be necessary prior to beginning the exercises.

Depending on previous coverage of water and nutrient cycles in the course, it may be useful to ask students to diagram the movement of water and materials through a catchment prior to beginning the exercises. This could be done individually, with a group discussion to synthesize a final diagram. The information in the "Overview" section provides a starting point.

Activities are divided into three sections: 1) catchment characteristics, 2) intra-annual variation, and 3) inter-annual variation. Activity 1 walks students through the scientific method from observations to hypothesis testing, including instruction with data manipulation. This activity is suited to a three-hour laboratory period with the synthesis report completed as a take-home assignment. Activities 2 and 3 are extensions of the work done in Activity 1 and are more inquiry-based than Activity 1, with Activity 3 being the most open-ended. One or both of these activities could be assigned as out-of-class work for more advanced classes. Where group discussion occurs in these activities, this discussion could be held at the start of the next lab session, allowing students to incorporate feedback from their peers into their final reports. In all activities, final reports may be presented as written lab reports, or collaborative oral presentations.

Each activity includes hypothesis generation regarding the factors causing observed patterns. Students are then asked to specify tests of those hypotheses. It will be critical to include a discussion of alternative hypotheses, and the data or tests necessary to assess them. In the activities we provide data and instructions for testing a subset of potential hypotheses that can potentially explain the observed patterns. This provides an opportunity to emphasize to students that science proceeds in an iterative fashion. We find patterns, and as we collect new datasets to test the causes of those patterns, we identify additional potential mechanisms that require further tests. The table below summarizes patterns present in the datasets and potential factors students may hypothesize have caused observed differences in N concentrations among catchments.

Notes on calculations

Nitrogen flux is provided to students in the student dataset, and the procedure for calculation of N flux is given in the instructions to Activity 1. For more advanced classes, you can ask students to calculate flux on their own, or work through the dimensional analysis for the calculation as a group prior to completing the activity.

Nitrogen flux [g N/ha/d] = Q[L/s] * (1/catchment area [ha]) * NO_3^- concentration [µmol/L] * 14 ug N/µmol NO_3^- * 86400 s/d * 10^{-6} µg/g, where Q is the mean daily discharge in liters per second.

Nitrogen flux for DON can be calculated using the formula above by replacing NO_3^- concentration with DON concentration.

Below in Table 2 is a list of observations that students may generate, along with potential causes of the patterns. We cannot provide data required to test all possible hypotheses that may explain observed patterns. However, students should generate multiple hypotheses at the start of each activity. Some observations and potential causes (hypotheses) are provided in the table below. Hypothesis generation by students will depend in part on previous exposure to related concepts. You may want to use some of these examples to guide group discussion or individual students' work at the initial stages of each activity.

Table 2. The hypothesis generation portions of each activity.

Observation	**Potential cause**
Greater NO_3^- concentration in C2 and C4 than C3	Geology -contribution of rock-derived NO_3^-
	Vegetation -differences in N fixation -differences in plant N requirements
	Permafrost -change in routing of water through the catchment -release of NO_3^- from thawed permafrost -deeper flowpaths in contact with mineral soils
Greater DON concentration in C3 than C2 and C4	Vegetation -variation in production of organic matter by primary producers
	Permafrost -Shallow flowpaths in contact with organic soil horizons
	Topography -contributions of organic N from bogs or other low-lying areas
Increase in NO_3^- concentration from spring to summer	Hydrology -deepening of flowpaths as soils thaw results in export of inorganic N from mineral soils
	Temperature -stimulation of decomposition
Decrease in DON concentration from spring to	Hydrology

summer	-deepening of flowpaths as soils thaw results in decreased contact with plant litter and organic soils
	Snowmelt -dilution of organic N by snowmelt
Peaks and valleys in N concentrations within a year	Precipitation -flushing of solutes stored in the catchment during storms -dilution of stream N concentration by precipitation
	Temperature -stimulation of decomposition -evapo-concentration of solutes -biological uptake of N in streams
Greater variability in concentrations in some years compared to others	Precipitation -variation in the distribution of storms throughout the thaw season influences hydrologic flushing of solutes -variation in the total amount of precipitation determines rates of biological activity or hydrologic connection of the stream with the catchment
Differences in mean N concentrations between years	Primary productivity -influences demand for nutrients by plants
	Insect outbreaks -reduce plant uptake of N
Variation in relative abundance of NO_3^- compared to DON among years	Thaw depth -influences the distribution of flowpaths through organic and mineral soils

GENERIC DISCLAIMER

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