Spatial Data and Synoptic Protocols: LINX-2

Assessment of Nitrate Concentration Patterns in River Networks

Revision 2.2: July 31, 2004

Landscape Analysis Contact Info:

M.S. Student: (Primary contact)	Ashley Helton (amhelton@uga.edu) Institute of Ecology University of Georgia Athens, GA 30602-2202 Voice: (706) 542-5881
Landscape PIs:	Geoff Poole (gpoole@eco-metrics.com) Eco-metrics, Inc. 4051 Wildflower Lane Tucker GA 30084 Voice: (770) 621-0266
	Judy Meyer (jlmeyer@uga.edu) Institute of Ecology University of Georgia Athens, GA 30602-2202 Voice: (706) 542-3363

Revision History

The following represents a list of changes in these protocols:

Version 2.2:

1) Updated contact information on title page. Ashley Helton (a new M.S. student who will be coordinating the synoptic and spatial data and working on the landscape analysis for her thesis) replaces Sue Herbert as the primary technical contact
2) Judy Meyer's e-mail changed and the new address was added to the contact list.

Version 2.1:

3) Changed requirements for analyses of grab samples. Required analyses are now NO_3, NH_4, TDN, and field measurement of conductivity and temperature.
4) Water samples sufficient for TN, TP, SRP, and Cl analysis must be collected and appropriately preserved, although analysis for these parameters is not required.
5) Synoptic sampling can be dropped in the third year if first two years of synoptic data collection occur without major problems.

Version 2.0:

1) ~~Required analyses for grab samples are now NO_3, NH_4, DON, and Cl. Optional parameters include P04 and TP.~~
2) Conductivity measurements are required at each synoptic sampling site.
3) Site selection now requires a longitudinal profile of mainstem (in both 1,000 l/s and 10,000 l/s basins in biomes that have 10,000 l/s basins)
4) Summary "Crib Sheet" has been added in order to provide condensed overview of protocols.
5) Descriptions of required GIS data have been refined and clarified.
6) Web links have been updated.

Summary Crib Sheet: Spatial Data Compilation and Synoptic Sampling

Site Identification

1. **Identify synoptic sampling catchment.**
   a. Discharge should be ~1000 l/s (or 10,000 l/s) discharge during ^{15}N releases.
   b. Basins should be free of major dams
   c. Basins should have a variety of land cover types.
   d. Basins should be free of major water withdrawals or point sources of N. If these are unavoidable, data on withdrawal rates and NO_3, NH_4, TDN, TN, TP, SRP, and Cl discharges from point sources will be required.
2. **Divide 1000 l/s catchment into ~5 to 7 logical sub-catchments** (Figure 1).
3. **Identify synoptic sampling points and discharge measurement points.**
   a. Points at mouth of catchment and at mouth of each sub-catchment will have grab samples, temperature, conductivity, <u>and discharge measurements</u>.
   b. Distribute approximately 40 or 50 sampling points evenly amongst sub-catchments.
   c. Within each sub-catchment, choose locations with reasonable access and which capture the diversity of land use combinations within the catchment (Table 2).
   d. Choose additional synoptic points along the mainstem stream to create downstream profile of concentrations. Mainstem points directly upstream of major tributaries are especially helpful. Beware of sampling the mainstem directly downstream of major tributaries. Lateral mixing of tributary water can, under some circumstances, require a kilometer or more. If you have a 10,000 l/s basin, don't forget to do a downstream profile in the 1,000 l/s basin, too!
4. **Identify 15N release sites.** Ideally, many of the 15N release sites will fall within the 1000 l/s catchment.
5. ***Where required:* Identify 10,000 l/s catchment**. Each of the above steps will be completed for the 10,000 l/s catchment. The 1000 l/s catchment should be used as a sub-catchment of the 10,000 l/s catchment. You may want to have more than 40-50 synoptic sampling points. Half of the synoptic sampling points (to a maximum of 40) should be in the 1,000 l/s catchment. The other half should be distributed throughout the 10,000 l/s catchment. This will mean that the density of synoptic points in the 1000 l/s catchment is higher than in the remainder of the 10,000 l/s catchment. This is important so that the density of points in the 1,000 l/s catchment is similar to that in other biomes where there is no 10,000 l/s catchment.
6. **Obtain GPS coordinates for each synoptic sampling site and each 15N release site.** When you collect your points, <u>be sure your GPS is set to use NAD 1927, not NAD 1983.</u> If your GPS is set for NAD 1983, your points will not line up on the 1:24000 USGS maps correctly!!

Maps

1. **Obtain topographic USGS maps of the 1000 l/s catchment (and 10,000 l/s catchment).** Mark synoptic sampling sites, discharge sites, and 15N release sites on maps and mail to Sue. The maps will facilitate communication about compilation of all subsequent data.

Compile Spatial Data Sets

1. **Obtain Digital Elevation Model, Landcover Classification, 1:24000 Hydrography Layer, and Road Layer for the 1000 l/s catchment (and 10,000 l/s catchment).**
2. **For any 15N release site outside of the 1000 l/s or 10,000 l/s catchment, Land Cover and Hydrography Layer must be provided for the catchment defined at the downstream end of the 15N release site.**
3. **USGS DRG (Digital Raster Graphics) files.** Required for each 15N release site.
4. **Create shape files (GIS layers) that contain sampling site information.** All points should include attribute tables with the stream name and any site ID number you use to reference the point.
   a. Point theme with 15N release sites. Two points per site; one at the top of the reach and one at the bottom.
   b. Point theme with all synoptic sampling sites. One point per site. Discharge measurement sites should be flagged in the attribute table. Any USGS gages should have their gauge number in the attribute table.
   c. Polygons with watershed boundaries. Watershed boundaries should be traced from the DRGs for each 15N site. Watershed boundaries for the 1000 l/s and 10,000 l/s sites can be derived from the DEM.
   d. Point theme with significant point sources of N and water withdrawals (if any).

Synoptic sampling

1. **Synoptic sampling must be accomplished <u>in years 1 and 2</u> (year 3 will be required if sampling fails in either year 1 or 2). Synoptic samples consist of:**
   a. Conductivity and temperature readings at each synoptic sampling location.
   b. Grab samples at every synoptic sampling site. Analyze for NO_3, NH_4, TDN. Either analyze for TN, TP, SRP, and Cl, or store samples for subsequent analysis of these parameters.
   c. Discharge measurements at the mouth of each sub-catchment within the 1000 l/s catchment, at the mouth of the 1000 l/s catchment. For 10,000 l/s basins, discharge is also required at the mouth of each sub-catchment within the 10,000 l/s catchment, and at the mouth of the 10,000 l/s catchment (USGS gage recommended for the mouth of the 10,000 l/s catchment).
2. **Grab samples and discharge measurements must be collected:**
   a. as close in time as possible to the 15N experiments;
   b. in as short a period as possible
   c. during a period of no significant rainfall, preferably after at least a week of dry weather.
   d. before noon (for discharge) to avoid time of peak ET influence.

Supplemental data during synoptic sampling

1. Where significant, the following data must be gathered for the period of synoptic sampling:
   a. discharge rates for major point sources of NO_3, NH_4, TDN, TN, TP, SRP, and Cl;
   b. withdrawal rates for major water withdrawals.

Background (from the proposal):

"The recent analysis of N flux in the Mississippi basin by Alexander et al. (2000) suggested that nitrate retention in headwater streams accounts for the majority of N removal during transit through the river system. This result was derived indirectly by integrating monitoring data from a range of stream sizes into a mass-balance model. We intend to expand on and test this hypothesis by using a simple NO_3 dynamics model to scale our experimental results from study reaches of small streams up to entire stream networks draining 5^{th} or 6^{th} order watersheds.

In their analysis, Alexander et al. included all streams of approximately 1^{st} to 4^{th} order as headwater streams. We hypothesize that it is the smaller streams in this category (1^{st} to 3^{rd} order) that account for the majority of Alexander's headwater nitrate storage. We further hypothesize that the structural complexity of 4^{th} through 6^{th} order streams is an important determinant of nitrate retention in these larger systems, although at lower rates than in smaller streams. To test these hypotheses, we will develop a GIS-based water and N routing model for application to larger watersheds and apply it to a 5^{th} or 6^{th} order river basin at each of our 8 study sites."

Objective:

Determine if patterns of in-stream NO_3 concentration measured across ~5^{th}-6^{th} order stream catchments are best explained by a model of NO_3 processing/storage/transport that assumes the rate of NO_3 processing in stream channels is inversely related to stream size.

General Approach:

Model the mass-balance of NO_3 in the stream network assuming several different scenarios, each representing a different assumed relationship between NO_3 processing and stream order. Compare predicted and observed patterns of NO_3 concentration across the catchment to determine which scenario is best at describing the measured pattern of NO_3 across the catchment.

Flow accumulation modeling approach

A simple "flow accumulation" model of stream discharge should be sufficient for this study. In such a model, the stream flow at any location (cell) in the stream network is estimated by multiplying the catchment area times the water yield for the catchment. The water yield for a catchment can be estimated from stream gauging data by dividing discharge by catchment area. A flow accumulation model should work well so long as stream discharge is relatively constant over the course of collecting synoptic NO_3 measurements.

The concentration of NO_3 for any point (p) in the model can be determined using the following equation which uses "p-1" as notation to represent the stream cell upstream of cell "p":

$$[NO_3]_{\{p\}} = (([NO_3]_{\{p-1\}} \cdot Q_{\{p-1\}}) + NO_3Lateral_{\{p\}} + NO_3Release_{\{p\}} - NO_3Uptake_{\{p\}}) / Q_{\{p\}}$$

Where:

[NO_3] = concentration of NO_3 in the stream
Q = stream discharge
NO_3Lateral = mass of NO_3 received by the stream cell from lateral sources
NO_3Release = mass of NO_3 released to the water column due to instream processing
NO_3Uptake = mass of NO_3 removed from the water column by instream processing

NO_3Release and NO_3Uptake will be calculated according to the "biome independent" model of in-stream NO_3 processing developed from our field experiments and parameterized to represent processing rates in the particular catchment being modeled. NO_3Uptake is the gross rate of nitrate uptake determined from the results of the N15 addition experiments in individual streams. NO_3Release is essentially the total nitrification rate that we also will be determining from results of the N15 addition experiments. Since Q will be derived based on flow accumulation, NO_3Lateral is the only unknown in the model.

Addressing Lateral NO_3 Influx

In the proposal, we stated that we would attempt to estimate lateral influx of NO_3 by measuring NO_3 concentration in streamside wells, relating groundwater NO_3 concentrations to surrounding land use, and extrapolating lateral NO_3 influxes across the catchment based on land use. This assumption was based on findings suggesting that land-use and landscape metrics are strong predictors of lateral loading rates (e.g. Jones et al. 2001).

This approach, however, may be quite problematic. First, even where groundwater is the primary means of delivery, concentrations of NO_3 in groundwater can vary widely across small spatial scales – especially in areas where hyporheic water influences the groundwater system. An accurate estimate of mean NO_3 concentration may require large sample sizes, yet our budget for wells and groundwater sampling is limited. Second, groundwater is only one of several means by which NO_3 may be delivered to a stream. Other mechanisms include atmospheric deposition, lateral erosion, overland run-off, or anthropogenic means of delivery (such as agricultural drainage tiles). Third, even if lateral NO_3 delivery rates are related to land use, there is no guarantee that site-to-site variation in groundwater concentration will correlate with loading rates since there are multiple pathways of NO_3 delivery. Finally, ground- and surface-water exchange is a two-way process. Where the hyporheic zone is a NO_3 source, hyporheic exchange could result in significant NO_3 delivery to the channel via back-and-fourth exchange even if there is no *net* groundwater gain. Thus, given potentially inaccurate estimates of mean NO_3 groundwater concentrations, an oversimplified conceptual model of one-way groundwater flow, and failure to consider other potentially important delivery pathways, estimates of lateral NO_3 inputs based on groundwater concentrations may be highly inaccurate.

An alternative approach can be developed by testing our landscape-scale hypotheses by deriving different, but equally compelling predictions from the hypotheses.

Hypothesis Tests

As discussed in the section describing the model equation, if we assume various rates for NO_3 uptake and release, the pattern of NO_3 delivery to streams across the landscape will be the only unknown in the model equation. Therefore, if we assume a variety of scenarios representing different hypotheses regarding in-stream processing at the catchment scale, we can use the model to back-calculate the landscape-scale pattern of NO3 loading necessary to create the measured pattern of [NO_3] across the stream network if the hypothesis were true. If, under any of the scenarios, the predicted pattern of landscape loading can be explained by land use patterns, our experiment will support the hypothesis represented by the modeling scenario.

Using this approach, there are at least three potential competing hypotheses regarding in-stream processing of NO_3 at the landscape scale (plus a null hypothesis) that can be tested:

Hypothesis 1: At the landscape scale, in-stream processing of NO_3 is inconsequential in determining the concentration of NO_3 in stream water. The influence of land-use overwhelms the effects of in-stream processing. Resulting modeling scenario: implement the model assuming no biological uptake or release (e.g., in equation 1, NO_3release = 0 and NO_3uptake = 0).

Hypothesis 2: At the landscape scale, in-stream processes are important determinants of NO_3 concentration, but all streams process NO3 similarly regardless of stream size (e.g., stream order). Resulting model scenario: implement the model assuming that biological uptake and release rates are independent of stream order and uptake and release rates we measure at our headwater study sites are assumed to be representative streams throughout the entire catchment.

Hypothesis 3: At the landscape scale, in-stream processes are important determinants of NO_3 concentration, but processing rates are related to stream size (e.g., stream order). Resulting model scenario: implement the model assuming that biological uptake and release rates will change consistently with stream order. Uptake and release rates we measure in our headwater study sites are assumed to represent the highest rate of in-stream processing in the catchment with processing rates decreasing as stream size increases**.** *(Comment by Mulholland: exponential decrease in processing rates with increasing stream size?)*

If Hypothesis 1 is correct, a simple landscape mass balance of NO_3 delivery to the stream will be sufficient to explain spatial variation of NO_3 in the stream. If Hypothesis 2 is correct, applying the instream rates of NO_3 processing from our tracer experiments to the entire watershed will create a model where the predictive power of the model is improved over that resulting from testing Hypothesis 1, *and* model error (residuals) have no significant relationship with steam size. If model error (residuals) are significantly correlated with stream size, Hypothesis 3 will be supported. In this case, the analysis of residuals will provide us with estimates of the change in processing rates associated with increasing stream size in each of the study basins. Inter-biome comparison of the relationship between stream order and model residuals should provide the basis for new hypotheses regarding catchment-scale NO_3 processing.

Just as in the approach we described in the proposal, this approach assumes that patterns of NO_3 loading across the catchment are related to patterns of land use. If this assumption is false, we are apt to erroneously accept the null hypothesis. However, available evidence suggests that NO_3 loading is largely predictable based on land use (de Wit 2001; Jones et al. 2001). Further, this approach allows us to test hypotheses about variation in stream processing/transient storage across the landscape without attempting to determine ahead-of-time the relationship between land-use and NO_3 loading rates.

Data collection protocols

Beyond those data being collected during our tracer experiments, the field data required for the landscape model are measurements of NO_3 and NH_4 concentration and stream discharge for a synoptic sampling of strategic locations across the catchment. Landscape data requirements are shown on Table 1. Ideally, we would repeat the synoptic sampling each of the 3 years of experimental work to permit 3 independent analyses for each catchment.

Catchment Selection

Within each biome, one large catchment must be selected for landscape-scale modeling. In addition, in three biomes (North Carolina, Michiana, and Oregon) a second even larger catchment will be analyzed. There are several important considerations for selecting catchments.

Size: In the proposal, we had identified catchment order as 5^{th} or 6^{th} order. However, stream order can be tricky. Depending on climate, drainage density, branching pattern, and the definition of a first order streams (e.g., from 1:24,000 USGS maps, perennial channels on the ground, etc.), the size of a 5^{th} or 6^{th} order stream (and its catchment) can vary remarkably. Basin area is another possibility for measuring basin size, although variation in climate across biome may result in sampling substantially different sized streams that drain similar sized catchments. Because of these compounding circumstances, base-flow discharge may be the best statistic upon which to standardize our streams. Since the relative importance of streambed dynamics in a stream is influenced by the ratio of discharge to streambed area, comparing basins with approximately the same base flow discharge may provide the most uniform comparison across basins. Since we are targeting streams of 5 to 50 l/s for our N15 experiments, and considering the availability of catchments across our biomes, we will target streams with discharge of about 1000 to 3000 l/s at the time when N15 experiments are conducted (~2 orders of magnitude larger than study steam). This stream flow will not be too difficult to gauge at this size and should provide manageable basins for gathering landscape data. Additionally, in North Carolina, Michiana, and Oregon, we will target additional basins of 10,000 to 30,000 l/s. Rather than attempt to gauge the mainstems of these largest streams, we will use USGS gauge information.

Land Cover: The catchment should have a variety of land covers/uses – preferably well-distributed spatially.

Tracer Sites: Ideally, some of the tracer sites will be in the catchment.

Point Sources: If there are large point sources of Nitrogen in the catchment, site coordinators will have to obtain the discharge records and provide estimates of point-source loads at the time the synoptic sampling is conducted. From a work-reduction point of view, catchments without large point sources are preferable. Also, discharge records are not necessarily reliable.

Water Withdrawals: Catchments without substantial water withdrawals are preferred. If substantial withdrawals are unavoidable, again, site coordinators will have to obtain the records that show the amount of each withdrawal during the synoptic survey.

Dams: Each catchment should be free of major mainstem dams.

Stream Gauges: Any catchment well-outfitted with USGS or other stream gauges would minimize the need to collect stream flow data.

Synoptic Sampling Site Selection

In order to effectively estimate water yield across the catchment, each catchment should be divided into a small number (say 4 to 6 – the actual number will vary depending on stream network configuration) sub-catchments (Figure 1). A total of 40-50 synoptic sampling sites should be distributed throughout the catchment, with one located at the mouth of the catchment, one each at the mouth the sub-catchments, and the remainder in representative streams of several different stream orders within the sub-catchments. Since a one-time stream discharge measurement must be sampled for each sub-catchment, dividing the catchment into sub-catchments based on the location of permanent stream gauges will reduce field effort.

Care should be taken that synoptic sampling sites are well-distributed among adjacent land-use types, across stream orders, and between sub-catchments. Since small streams account for the majority of stream miles in a catchment, sampling should be weighted somewhat toward smaller streams. Creating a cross-tabulation of site counts (e.g., Table 2) will help. Mapping stream order and cover type with a GIS can be useful in helping to select an array of sampling sites that fills out the cross tabulation properly.

Synoptic Sampling

As close in time to the tracer experiments as possible, synoptic grab samples and conductivity reading should be taken at each synoptic sampling location. If suitable permanent gauges are not available, a discharge measurement must be taken at the catchment outlet and at each sub-catchment outlet each year (Hauer and Lamberti, *Methods in Stream Ecology*, is a good reference for basic instructions on measuring discharge is streams). It is critical that sampling occur after a period of no (or little) precipitation. Lags between precipitation and stream discharge and/or uneven precipitation across the catchment could affect estimates of water yield in the catchment and ultimately influence model results substantially. Especially in dry climates, discharge measurement should be taken before noon to avoid the time of peak influence of ET on discharge. So long as there is no precipitation, the synoptic sampling can occur across several days, but synoptic sampling should occur in as short a time and as close to the tracer release experiments as possible.

Synoptic samples consist of:

a. Conductivity and temperature readings at each synoptic sampling location.
b. Grab samples at every synoptic sampling site. Analyze for NO_3, NH_4, TDN. Either analyze for TN, TP, SRP, and Cl, or store samples for subsequent analysis of these parameters.
c. Discharge measurements ONLY at the mouth of each sub-catchment within the 1000 l/s catchment, at the mouth of the 1000 l/s catchment. For 10,000 l/s basins, discharge is also required at the mouth of each sub-catchment within the 10,000 l/s catchment, and at the mouth of the 10,000 l/s catchment (USGS gage recommended for the mouth of the 10,000 l/s catchment).

Equipment needed and methods

Level and stadia rod
Flow meter
50 m measuring tape
Rebar and hand sledge-hammer
Meter stick
GPS
Conductivity meter
Water sample bottles and labels
Cooler and Ice
Clipboard and data sheets

Compiling Spatial Data Sets

Compilation of spatial data for catchments should proceed according to two steps: Catchment-wide coverages, and sampling site coverages. Below, the word "catchment" refers to the 10,000 l/s catchment at sites where one exists. Otherwise, it refers to the 1,000 l/s catchment.

Catchment-wide coverages: Target basins were identified preliminarily at the Sevilleta workshop for all Biomes except the Southwest. Table 3 shows the basins and some characteristics. Once basins are finalized, the following information should be compiled for each catchment: (NOTE: It you don't already have in-house GIS resources that cover your selected catchment, I have provided links to where the required data can be found, however, many states have "data clearinghouses" often maintained by the state library. Data obtained from state sponsored clearinghouses will often be more refined and more easily accessible. I encourage you to spend the time necessary to determine if such a facility exists for your study site.) Please provide all digital data to Sue as either

ArcView coverages or ArcInfo export files. Please provide all vector and raster data in the same projection used by the DRGs that cover the N15 release sites (Typically, UTM 1927 using same zone as DRG).

1. USGS Topographic Maps: Order topographic maps from the USGS that provide coverage of the catchment. Buy the most detailed scale (e.g., 1:24000, 1:100000, or 1:250,000) that allows the catchment to fit on ~4 maps or fewer (e.g., don't buy 15 1:24000 maps if you have a large catchment – just get 3 or 4 maps at 1:100000). Send the maps to Sue Herbert. The maps will facilitate Sue's work with people on the ground in each biome. You may wish to order maps for yourself, too.

   http://mcmcweb.er.usgs.gov/topomaps/ordering_maps.html

2. Digital Elevation Model and Land Cover Data: Please provide a seamless 30 m DEM and Landcover classification of the study catchment (1,000 l/s or 10,000 l/s as applicable). The Landcover classification should be from the National Land Cover Dataset. Either an in-house seamless 30 m DEM or the National Elevation Dataset DEM is acceptable. NLCD and NED data can be ordered interactively at:

   http://seamless.usgs.gov

3. Hydrography and road layers: Hopefully, each of you will have a source for hydrography and road layers. We need 1:24000 scale data to address the small streams we are studying and no such pre-processed data exists nationwide. You will need to hunt around for hydrography and road layers (state data clearinghouses, etc.). If you can't find 1:24000 hydrography layers anywhere else, you will have to download the raw DLG (Digital Line Graph) files for each 1:24000 quad that covers your catchment and then process the hydrography layer. However, these DLG data are pretty raw and will need quite a bit of post processing (which is why the state-run data warehouses are generally a better source). Rather than spell out how to do that here, Sue will work with sites individually. Again, hopefully there will be an existing hydrography and road layer for each catchment. Just in case, however, DLGs can be found at:

   http://edc.usgs.gov/geodata/

4. Watershed Boundary: A shapefile with one polygon representing the entire watershed boundary and one additional polygon for each subbasin identified in the watershed (e.g., Figure 1) (10,000 l/s site will need to digitize sub-basins of the 10,000 l/s catchment. One of those sub-basins should be the 1,000 l/s catchment. The 1,000 l/s catchment will have to be further subdivided into its own sub-basins). You can either derive these polygons from the digital elevation model or digitize the watershed boundaries from DRGs (Digital Raster Graphics).

5. Gauge sites: A single shape file with points representing all USGS gauge sites in the catchment as well as those sites where you will be measuring stream flow (e.g.,

outflow of each subbasin) during synoptic sampling. For points that represent USGS gauge sites, please include the USGS gauge number in the attribute table. (Points where you are measuring flow can have a null value in this attribute field.).

6. Point sources and withdrawals (if any): A single shape file with all point sources and withdrawals located and described.

Synoptic site coverage: Only one coverage is necessary for synoptic sampling. This shapefile should contain the locations of the synoptic sampling sites determined using a GPS in whatever projection used by the DRG files (typically UTM 1927).

15N release site coverages: As sample sites are identified the following GIS coverages must be compiled:

For 15N sites located within the synoptic catchment:

1. Sampling site locations: A shapefile with two points for each sampling site that demarcate the top and bottom of the study reach. A GPS should be used to determine Latitude and longitude of the top and bottom of each study reach.
2. USGS Digital Raster Graphic (DRG) files: Because 15N release sites are on small streams, UGSG 1:24,000 DRGs should be used to locate the sites and digitize the catchment of the 15N release sites. Therefore, all of the DRGs necessary to document the 15N should be provided to Sue.
3. Catchment areas: A shapefile with one polygon for each sampling site that delineates the catchment for the sampling site. These should NOT be derived from digital elevation models but should, instead, be delineated by hand DRGs. DEMs are notoriously inaccurate for delineating very small basins.

15N release sites located outside of the larger experimental catchment require the same information as those within the larger catchment *in addition* to the following:

4. Land Cover Data: Please provide a 30 m landcover classification for each 15N release site located outside of the large experimental catchment. As with the data for the large experimental catchment, the Landcover classification should be from the National Land Cover Dataset. See above for instructions to retrieve NLCD data.
5. Hydrography and road layers: As for the larger experimental catchment, hydrography and road layers are needed for 15N release site. Some sites, of course, will be too small to have any hydrography or road information. See the description of hydrography and road layers for the larger experimental catchment (above) for details.

Literature Cited

Alexander, R.B., R.A. Smith, and G.E. Schwarz. 2000. Effect of stream channel size on the delivery of nitrogen to the Gulf of Mexico. Nature 403: 758-761.

de Wit, M. J. M. 2001. Nutrient fluxes at the river basin scale. I: the PolFlow model. *Hydrological Processes* 15: 743-759.

Jones, K. B., A. C. Neale, S. N. Maliha, R. D. Van Remortel, J. D. Wickham, K. H. Riitters, and R. V. O'Neill. 2001. Predicting nutrient and sediment loading to streams from landscape metrics: a multiple watershed study from the United States Mid-Atlantic Region. *Landscape Ecology* 16: 301-312.

Table 1. Catchment-scale (GIS) data necessary to model catchment NO_3 dynamics. (Each site will be required to provide these data to Sue Herbert. However, Sue will be happy to coordinate directly with GIS technicians or database managers at each site in order to facilitate the data transfer.)

Data Type	Coverage	Source	Purpose
DRG (Digital Raster Graphics)	Each Tracer Experiment study sites	USGS	Estimate of catchment area for tracer study sites (DEMs are inaccurate for small catchments)
DEM (Digital Elevation Model)	Entire Catchment	USGS NED database	Analyze catchment topography
Land Cover	Entire Catchment	USGS NLCD database	Determine cover types across the catchment
Road Layer	Entire Catchment	DOT, Forest Service, BLM, etc.	Determine road density (to help differentiate management intensity in vegetated areas)
Hydrography Layer	Entire Catchment	USGS	Estimate stream order, locate sampling sites, base-map for figures
GPS (Global Positioning System) Data	Tracer Experiment sites within modeled catchment, Synoptic sampling sites, Water withdrawals, Point sources		Determine location of sampling sites.

Table 2. Idealized cross-tabulation of synoptic sampling site counts by cover type and stream order in a catchment where Urban, Agriculture, Forestry, and Wilderness were all important cover types. Additionally, a longitudinal profile of the mainstem is required. For each catchment, the categories and distribution of sampling site should be altered to reflect the specific character of the catchment. Each catchment should target 40 to 50 sampling sites. Catchment and sub-catchment outflow sites will require both a discharge measurement and grab sample; the remaining sites will require only a grab sample.

% of Total Catchment Discharge	**Sample Site Counts**			
	Urban	Ag	Forestry	Wilderns
1% - 10%	3	3	3	3
10% - 20%	3	3	3	3
20% - 40%	2	2	2	2
40% - 70%	1	1	1	1
Mainstem	5-10 sites distributed along mainstem			

Table 3: Large-basins preliminarily identified for modeling NO_3 dynamics. Subject to change…

Biome	**Stream**	**Catchment Area (km^2)**	**Mean discharge during season of N15 Release (L/s)**	**USGS Gauge #**
Massachusetts	Ipswitch/Parker Rivers	370	1700	01102000/ 01101000
Wyoming	Flat Creek	290	2000	13018350
Kansas	Mill Creek	750	1000	06888500
Puerto Rico	Rio Piedras	45	1000	50049100
North Carolina	Headwaters Upper Little TN	?	?	?
	Upper Little Tennessee (?)	366	10,000	03500000
Oregon	Tualatin River (?)	1700	3,000	14207500
	Willamette River	?	>10,000	
Michiana	Rabbit River (?)	170	1800	04105500
	Kalamazoo River	?	>10,000	

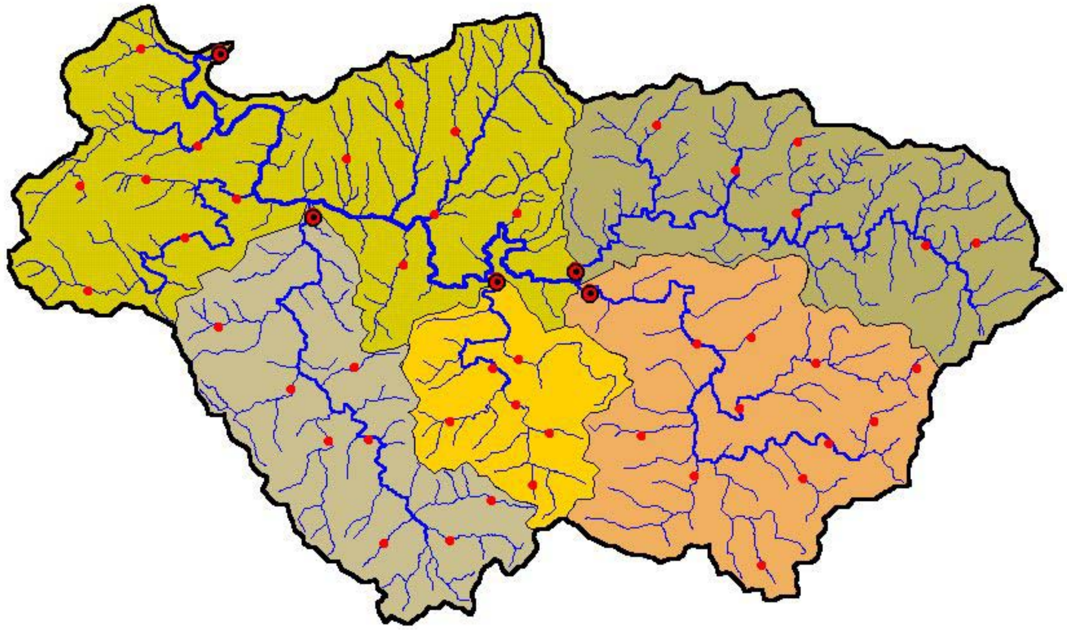

Figure 1: Example of a 5th order catchment divided into 5 primary sub-basins. Red dots represent synoptic sampling locations where grab samples will be taken. Larger red dots with black centers show show places where a single discharge measurement will be taken each year along with a grab sample.