

EPA Regional Priority AFO Science Question
Synthesis Document

Nitrogen Source Tracking

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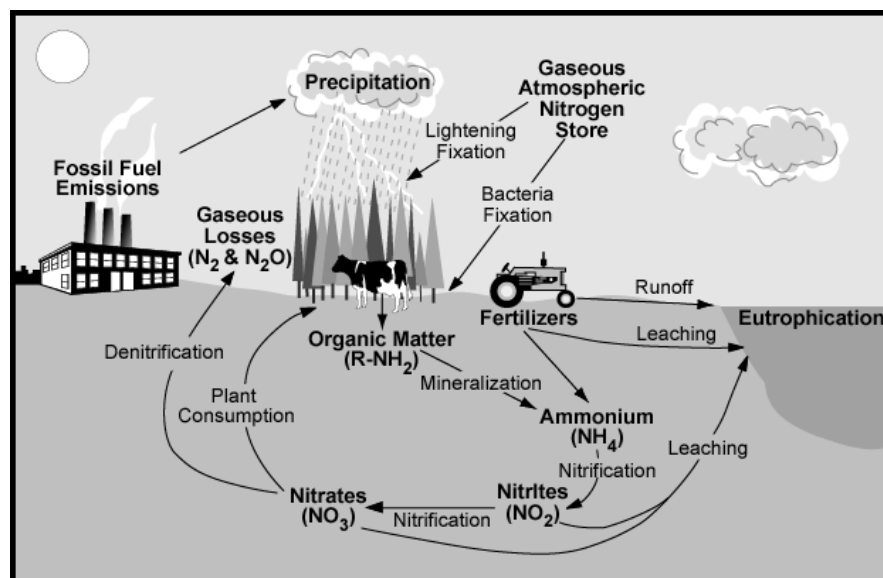
SECTION 3: NITROGEN SOURCE TRACKING

3.1 Nitrogen Forms in the Environment

In 1992, EPA established drinking water standards for nitrate and nitrite (measured as nitrogen) at 10 mg/L and 1 mg/L, respectively. Levels exceeding these standards can cause serious illness and death to infants in the short-term. Long-term effects include diuresis, increased starchy deposits, and hemorrhaging of the spleen. Nitrogen and other nutrients also are the source of algal blooms in surface waters, which can deplete dissolved oxygen and kill aquatic life. Nitrogen is the most prominent element in the Earth's atmosphere and a key element to all forms of life. It can be found in many forms in the environment. Some anthropogenic sources of nitrogen include: commercial fertilizers applied to lawns, golf courses, and agricultural fields; septic fields; waste water treatment facilities; manure from animal feeding operations; and manure applied to agricultural fields.

Nitrogen is necessary for plant life and is utilized in soils. Natural processes of nitrogen in the environment include mineralization, nitrification, and denitrification (see Section 2.1.2.2). Nitrogen also enters soil systems via acid rain deposition. Although nitrogen is abundant in the atmosphere it is often the limiting factor in terrestrial and aquatic systems. There are microbes present in soils that can convert nitrogen gas into forms of nitrogen useable by plants. This process is called mineralization. Nitrification occurs in oxic environments and involves microbes converting organic nitrogen (N) to inorganic forms useable by plants. Cultivation adds oxygen to the soil and increases microbial activity. Cultivation is beneficial to plant growth, but if microbes break down more nitrogen than can be utilized by plants, the remaining nitrogen will either be lost via leaching or stored in deeper soil horizons, sometimes for many years (Kreitler and Jones, 1975). In anoxic environments, microbes will utilize nitrogenous compounds in order to make use of the attached oxygen atoms. The result is the release of nitrogen in a gaseous form. Figure 3.1 displays the basic nitrogen cycle.

Figure 3.1 - The Nitrogen Cycle (Pidwerny, 2004)



These different natural processes produce nitrogen that is utilized by plants, generally in the form of ammonium (NH_4^+) and nitrate (NO_3^-). Due to the positive electron charge of ammonium, it will generally bind to negatively charged soil particles (clay and organic matter) and aquifer matrices to become fixed in the environment until utilized by plants or other processes (Karr, *et al.*, 2002). However, the negative electron charge of nitrate and its solubility in water allows for rapid movement through soils into ground and surface waters via rain and snow melt. “Macropore (cracks, root channels, etc.) flow appears to contribute significantly to the recharge of ground water and therefore the transport of nitrate” (Wells and Krothe, 1989). Different soil types, land uses, climates, and weather patterns influence the rate of nitrogen movement.

Nitrogen found in surface and ground water is often from undetermined or nonpoint sources. Tracing an inorganic compound to its original source is a difficult task. The development and implementation of technology and the understanding of geochemical processes which influence the flow of nitrogen through ecosystems has made this task easier. Tracing nitrogen compounds is not an exact science and no single methodology is able to differentiate the many sources of nitrogen in the environment. However, a number of studies have reported success using stable isotope tracking. This method has been in use since the mid-1970's and although there are some limitations, mainly due to the many variables in nitrogen form and natural conditions, it is one of the only ways to track an inorganic substance such as nitrogen.

3.2 Nitrogen Isotope Tracking

An isotope is a naturally occurring mass variation of a single element in the environment. If an element such as nitrogen has extra neutrons, it will not affect the charge of the atom, but it will affect its atomic mass. An atom of nitrogen that contains an extra neutron is referred to as ^{15}N . Stable isotopes refer to isotopes that are found naturally and are not radioactive. Several elements contain stable isotopes including oxygen and nitrogen. Stable isotopes have been used in archaeology to determine the sources of ancient human diets and now these principles are being modified for application in ecological studies (Peterson and Fry, 1987). Due to the small amounts of these isotopes, they can be a useful fingerprint to track the path of nutrients through the environment.

Nitrogen found in the atmosphere is comprised of 99.637% ^{14}N with the remaining 0.363% represented as ^{15}N . This ratio of ^{15}N to ^{14}N is referred to as the atmospheric standard. Most ecological studies express nitrogen isotopic compositions in terms of $\delta^{15}\text{N}$, which are parts per thousand differences from the atmospheric standard or ‰ (Peterson and Fry, 1987). Mass spectrometers can be utilized to differentiate the variations of nitrogen masses in a water or soil sample. Another method more convenient to field collection of fresh water involves passing the samples through anion exchanging resin columns in the field (Silva, *et al.*, 2000). Once the ratios are determined, the following equation can be utilized to determine the $\delta^{15}\text{N}$ (‰):

$$\delta^{15}\text{N} (\text{‰}) = \left[\frac{(^{15}\text{N}/^{14}\text{N})_{\text{sample}} - (^{15}\text{N}/^{14}\text{N})_{\text{standard}}}{(^{15}\text{N}/^{14}\text{N})_{\text{standard}}} \right] * 1000$$

If $^{15}\text{N}/^{14}\text{N}$ in the sample has a greater ratio than the atmospheric standard, then the $\delta^{15}\text{N}$ will be positive (e.g. +10.1 ‰). If the ^{15}N in the sample is less than the ratio found in the atmosphere, then the $\delta^{15}\text{N}$ will be negative (e.g. -2.5 ‰) (Karr, *et al.*, 2002).

In 1975, nitrogen ratios were used by Kreitler and Jones to delineate unique isotopic ranges for nitrate from different soil environments. They compared the nitrogen isotopic range of soil nitrate to isotopic ranges of ground water nitrate to determine the source of nitrate contamination in drinking water. Based on land use in the area, they determined the probable sources of contamination were from animal sources or the oxidation of organic N from cultivation (nitrification). In cultivated fields that had been grazed by cattle for the past 10-20 years, nitrate levels in the soils were constant with depth, however, the ^{15}N concentration was higher in the shallow portions of the soil profile; the portion of the profile that was influenced by grazing. The decreased ^{15}N concentrations in the deeper soils were within the range of natural soil nitrogen. These findings illustrated a change in nitrogen source over time. By studying isotope concentrations in septic fields, cultivated fields with no grazing, cultivated fields with grazing, and turnrows (no plant materials), Kreitler and Jones determined that nitrogen sources from human and animal waste on average had >10.0 ‰ ^{15}N and cultivated fields on average contained < 10.0 ‰ ^{15}N based on natural sources of nitrogen (nitrification). The testing of nitrogen contaminated ground water yielded isotopic ranges < 10.0 ‰ ^{15}N leading to the finding that natural sources were the cause of the contamination. This study was performed in an area comprised of mollisol soils (prairie soils with high organic matter). Cultivation since 1900 had added oxygen to the soil, creating more nitrate (from nitrification) in the already nitrogen enriched mollisols. Nitrate accumulated just below the root zone for many years until the 1950's. Dry conditions during the 1950s led to extensive terracing in the agricultural region in order to bring the water table higher for crop use. Some farmers interviewed by Kreitler reported a six meter rise in the water table. This increase in ground water levels allowed leaching of the accumulated nitrate. This study was integral to the isotopic tracking methods used today and showed the importance of combining scientific evidence with land use history. It also showed that ^{15}N concentrations can be used to differentiate human/animal waste and natural nitrogen sources (Kreitler and Jones, 1975).

A few years later, in 1979, Gormly and Spalding compared eight different commercial fertilizers in different forms (NH_3 , NH_4NO_3 , urea, etc.) and determined the $\delta^{15}\text{N}$ values in commercial fertilizers were approximately the same regardless of country or region of origin.

In 1985, Flipse and Bonner published a study proving $^{15}\text{N}/^{14}\text{N}$ ratios in synthetic fertilizers applied to golf courses and potato farms increase when they travel through the soil from natural processes (denitrification/ammonia volatilization). The study also noted that ratios still did not approach the $^{15}\text{N}/^{14}\text{N}$ ratios of human/animal nutrient enriched waters ($> +10$ ‰). The study concluded that fertilizers could be distinguished from human/animal sources, but not from naturally occurring nitrate.

Many studies have shown the correlation of high concentrations $\delta^{15}\text{N}$ to animal waste in surface and ground waters (Karr, *et al.*, 2001; Karr, *et al.*, 2003; Komor and Anderson, 1993; Curt, *et al.*, 2004). However, it is still difficult to differentiate animal and human sources via nitrogen isotopes (Curt, *et al.*, 2004). Table 3-1 illustrates the similarity of $\delta^{15}\text{N}$ between human and animal wastes and the wastes from different animal species. Other methods are proving

helpful in distinguishing human and animal source contamination via bacterial source tracking (See Section 4.3). Further research may provide interesting results from the combination of bacterial source tracking and isotope tracking.

Table 3-1. Sample $\delta^{15}\text{N}$ from Different Animal Sources (Curt, *et al.*, 2004)

Nitrogen Source	Mean
Animal waste:	
Swine manure	13.82 \pm 7.03
Swine slurry	29.68 \pm 9.98
Poultry manure	10.98 \pm 4.44
Dairy cattle manure	12.19 \pm 2.69
Beef cattle manure	16.21 \pm 0.25
Sheep manure	17.14
Products from waste water treatment plants:	
Sludge	11.42 \pm 7.21
Effluent	11.61 \pm 2.71

3.2.1 Nitrogen and Oxygen Isotopes in Combination

Since 1975, researchers have identified limitations of using nitrogen isotopes to trace sources (See Section 3.3), but also have added parameters (^{18}O , chlorides, sodium, etc.) to more thoroughly determine and document nitrogen sources. Komor and Anderson (1993) report the following $\delta^{15}\text{N}$ (‰) values:

- Animal/Human Waste: +10 to +20 ‰
- Natural Organic Material: +4 to +9 ‰
- Commercial Fertilizers: -4 to +4 ‰

Although the above $\delta^{15}\text{N}$ are not rigidly defined and vary slightly by author and study, they can correctly classify the sources of $\delta^{15}\text{N}$ values (Komor and Anderson, 1993). Isotopes of oxygen (^{18}O) have been used in combination with ^{15}N for tracing contaminated ground water. ^{18}O has proven a useful tracer in differentiating a contaminant plume originating from a single septic system. However, ^{18}O has proven more effective at showing processes involved in nitrogen cycling rather than source tracing (Aravena, *et al.*, 1993). $\delta^{18}\text{O}_{\text{NO}_3}$ varies regionally when produced by nitrification because one atom of oxygen comes from O_2 (gas) and two oxygen atoms come from soil or ground water (Bliefuss, *et al.*, 2000). Bliefuss states there is a “large isotopic contrast between nitrate produced in the atmosphere and nitrate produced by microbial nitrification in the soil. The oxygen isotopes in nitrate are useful for identification of nitrate

from fertilizer and atmospheric nitrate” (Bliefuss, *et al.*, 2000). Table 3-2 presents the USGS reported typical $\delta^{15}\text{N}$ and $\delta^{18}\text{O}$ isotope ranges.

A study conducted at a swine facility employed the combination of ^{15}N and ^{18}O to determine nitrate sources. A nitrate plume beneath fields where swine manure was applied as fertilizer was discovered to be the source of domestic well contamination. ^{18}O from NO_3 was used together with ^{15}N to determine the extent of denitrification (the rate of NO_3 removal from the nitrogen pool) occurring in soils at the site. The study also found that as long as “the rate of nitrogen loading through waste application has been sufficient to dominate the nitrate content of ground water and denitrification in soils and ground water has not removed a large fraction of the nitrate pool” that $\delta^{15}\text{N}$ can trace a nitrate signal (Karr, *et al.*, 2002).

Table 3-2. Ranges Reported by USGS (Chamberlain, 2001)

Typical ranges of $\delta^{15}\text{N}$ and $\delta^{18}\text{O}$ of types of NO_3		
$\delta^{15}\text{N}$	$\delta^{18}\text{O}$	Description
0	+23	Fertilizer manufactured from atmospheric gas
20	-5 to +15	Animal waste
+15 \pm 5	-5 to +15	Soil Nitrate
0	+23	Air
up to +40	up to +20	NO_3 produced by denitrification
–	+5 to +20	Ground water

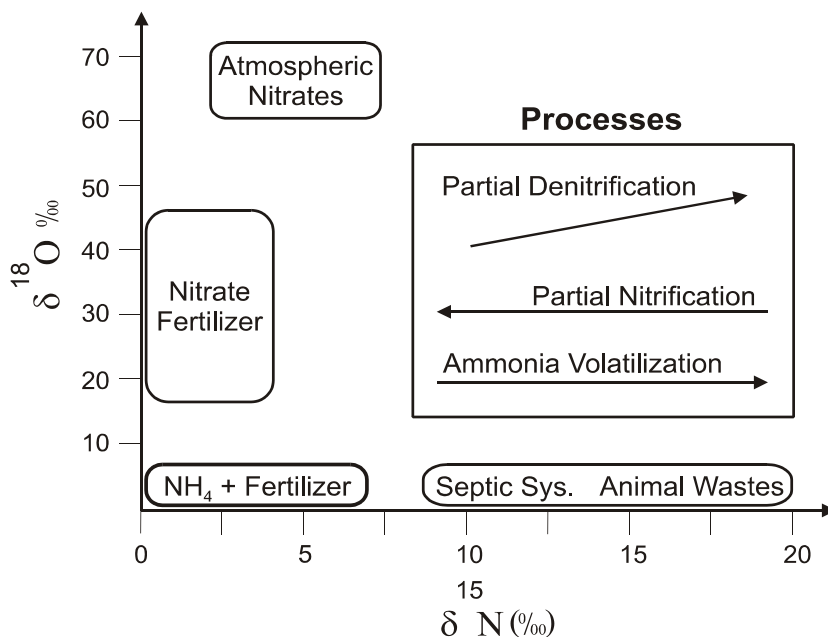
In another study “water samples from 10 relatively large karst (limestone, CaCO_3) springs were collected during four different seasons and analyzed for inorganic constituents, dissolved organic carbon, atrazine, $\delta^{15}\text{N}$, and $\delta^{18}\text{O}$ of nitrate ions. The isotopic data were the most definitive and suggested that the sources of nitrate in spring water are dominated by N–fertilizer with some possible influence of atmospheric nitrate, and, to a much lesser extent, human and/or animal waste. The trend of $\delta^{15}\text{N}$ and $\delta^{18}\text{O}$ data for nitrate also indicated that a significant degree of denitrification is occurring in the shallow karst hydrologic system (within the soil zone, the epikarst, and the shallow karst aquifer) prior to discharging to springs” (Panno, *et al.*, 2001).

3.2.2 Stable Isotopes Combined with Geochemical Data

Studies also have combined geochemical data with isotopic tracers to distinguish agricultural and residential land uses. In 2000, Bleifuss, *et al.* studied an area where shallow public wells were closed due to nitrate contamination. The area studied was once agricultural land that was developed into residences. Nitrate sources from residential areas are expected to be from lawn fertilizers and septic system wastes. As stated earlier, nitrate associated with cultivation would be from fertilizers or nitrification. The researchers determined dissolved oxygen levels were sufficient to exclude denitrification as a source of nitrate removal and therefore isotopic methods could be applied. “The $\delta^{18}\text{O}_{\text{NO}_3}$ values of the public supply wells indicate that the nitrate is primarily derived from nitrification of ammonium in the soil. The $\delta^{15}\text{N}_{\text{NO}_3}$ values suggest cultivation sources predominate; however, the influence of septic system wastes can be seen in the elevated $\delta^{15}\text{N}_{\text{NO}_3}$ values of some of the shallower well fields in the area” (Bleifuss, 2000).

Since both land uses could indicate fertilizers and since manure application could create elevated $\delta^{15}\text{N}_{\text{NO}_3}$ values similar to septic waste, additional geochemical criteria were employed to delineate the source of contamination. Calcium is generally found in higher concentrations in agricultural soils due to liming of soils and application of fertilizers. Water leached from agricultural fields also can have traces of pesticides. Residential land is generally higher in sodium, chlorides, or bicarbonate. The sodium and chloride originate from road salts and septic tanks in populated areas. It also is important to note that septic plumes add organic carbon to systems which lowers dissolved oxygen as microbes consume the organic material. Cultivation adds oxygen to the soil system. The researchers knew the public wells contained low dissolved oxygen, high $\delta^{15}\text{N}_{\text{NO}_3}$, and considerable sodium. Therefore, the combination of isotopic tracers and geochemical data indicated residential sources of nitrate caused the contamination and eventual closing of the public drinking water wells. An interesting side note of the study was that wells down gradient from golf courses, where intensive cultivation takes place, showed calcium and magnesium levels which resembled agriculture fields. This study’s findings distinguished nitrate sources from residential and agriculture sources, but found similarities between agriculture fields and golf courses (Bleifuss, 2000). Figure 3-2 displays the nitrogen and oxygen isotopic composition of nitrate as reported by Bleifuss (2000).

Figure 3-2. Nitrogen and Oxygen Isotopic Composition of Nitrate Sources Based on the Work of Previous Researchers (Bleifuss, 2000)



3.2.3 Stable Isotopes in Marine Environments

In 1983, Mako conducted a study in Massachusetts showing the “usefulness of nitrogen and carbon isotopes to determine whether sediments in estuarine and coastal areas derive organic matter from terrestrial or marine sources.” Terrestrial sources included discharges from wastewater treatment facilities. Marine sources included solid waste ocean dumping. This study may be helpful to those studying estuarine environments where the source of pollution is unknown. Once sources are recognized, isotope tracing ratios may help further narrow the sources of pollution (Mako, 1983). Likewise, a 1998 study “used nitrogen and sulfur stable isotopes ($\delta^{15}\text{N}$, $\delta^{34}\text{S}$) to distinguish between sewage inputs of these elements to sediments, particulate organic matter, algae, and animals. The isotope data revealed widespread presence of sewage-derived inputs while changes towards more typical marine values over time indicated a lessening of sewage inputs. The incorporation of sewage particulates into blue mussels as revealed by $\delta^{15}\text{N}$ and $\delta^{34}\text{S}$ values in their tissues was evident and suggested the importance of sewage-derived nutrients to the local food web” (Tucker, *et al.*, 1998). Tucker’s study supported previous research published in 1981 on a study conducted in California on Dover sole and Ridgeback prawn muscle (Rau, *et al.*, 1981). In 1997, McClelland and Valiela linked “nitrate from ground water-borne wastewater/anthropogenically derived nitrogen from watersheds to nitrogen in estuarine plants and animals using nitrogen isotope tracers. This suggests that wastewater nitrogen may be detectable in estuarine biota at relatively low loading rates, before eutrophication leads to major changes in species composition and abundance within estuarine food webs” (McClelland and Valiela, 1997).

3.3 Evaluation of Isotope Source Tracking

Even though many studies have reported success in determining nonpoint sources through the use of isotope tracking, there are some known flaws of isotope tracking. The many variances of soil type, climate, weather patterns, land use, etc. make it difficult for a single method to determine a single source of nitrate contamination. The idea of combining several different isotope tracking methods however, is gaining momentum. The following subsections provide information on evaluations critical of using stable isotopes, namely $\delta^{15}\text{N}$ and $\delta^{18}\text{O}$, to determine the source of nitrate contamination. Although these criticisms are valid, there are sometimes simple field tests that may be performed (determining oxic and anoxic soil and ground water conditions) to eliminate these concerns.

3.3.1 Temporal Changes

As seasons or temperatures change, the level of microbiological activity shifts as well. This change in activity can cause an increase or decrease in soil nitrate concentration. These changes in concentration are due to the processes of nitrification and denitrification. Panno, *et al.* observed “differences in isotopic composition of NO_3^- and some of the chemical characteristics were observed during the four consecutive seasons in which spring water samples were collected. Isotopic values for $\delta^{15}\text{N}$ ranged from 3.2 ‰ to 19.1 ‰ and $\delta^{18}\text{O}$ ranged from 7.2 ‰ to 18.7 ‰” (Panno, *et al.*, 2001). Komor and Anderson, 2001 also identified temporal and depth variations in $\delta^{15}\text{N}_{\text{NO}_3}$ values.

3.3.2 Isotopic Fractionation

Although the application of manure to agricultural soils does not necessarily produce isotopically heavy nitrate (Bleifuss, *et al.*, 2000), isotopic fractionation can take place during denitrification and also during the volatile loss of ammonia. In one study this fractionation caused a higher concentration of ^{15}N in ground water than in the fertilizer placed on a field (Flipse, 1985). “Nitrogen isotopes can be fractionated during transport through the unsaturated soil zone or aquifer e.g. denitrification and dissimilatory nitrate reduction may increase $\delta^{15}\text{N}$ values of residual nitrate” (Komor and Anderson, 2001).

McClelland and Valiela, 1997 state that isotopic fractionations “mask the effect of the original nitrate source or the isotopic fingerprint of soil nitrate” and “the mineralization-immobilization turnover of nitrate has not been taken into account in field studies.” Their study states “the dual isotope approach may be of limited use for agricultural soils because microbial processes can change isotopic fingerprints of fertilizer nitrate and mask original source. Kellman and Hillarie-Marcel support that statement and further say “attempts to use nitrogen isotopes of nitrate to identify contaminant sources has rarely been attempted and not adequately tested to ensure isotopic fractionations do not alter $\delta^{15}\text{N}$ values during transport. Furthermore, ground water studies have often failed to illustrate the measuring of fractionation to ensure it is not altering the source signature” (Kellman and Hillaire-Marcel, 2002).

3.3.3 Soil Properties

Soil properties also affect the validity of using isotopes as environmental tracers. Soil type and texture can increase rates of denitrification, therefore isotopic fractionation, in heavily cultivated and fertilized areas. Fine textured soils and areas of extremely shallow ground water make source identification difficult (Gormly and Spalding, 1979). Kellman and Hillarie-Marcel also state, “Soil texture may exert a major control on the extent to which denitrification alters $\delta^{15}\text{N}_{\text{NO}_3}$ source sign. The use of $\delta^{15}\text{N}_{\text{NO}_3}$ stable isotopes to identify NO_3^- sources may be site dependent” (Kellman and Hillaire-Marcel, 2002).

Jordan, *et al.*, 1997 found that plants within a nitrogen saturated system will discriminate against ^{15}N uptake. Although this is not likely in a nitrogen limited system, researchers should still be cautious when applying the nitrogen isotope methodology and make sure site conditions are optimal.

3.3.4 Similar $\delta^{15}\text{N}$ Values

It is still very difficult to use isotopic tracers to identify certain contaminate sources. Human waste water is very difficult to differentiate from animal waste using $\delta^{15}\text{N}$ (Curt, *et al.*, 2004). Intensive turf cultivation from golf courses can resemble $\delta^{15}\text{N}$ values of agricultural cultivation (Bleifuss, *et al.*, 2000). However, other geochemical tracers and technologies are making this task less complicated.

3.3.5 Watershed Variables

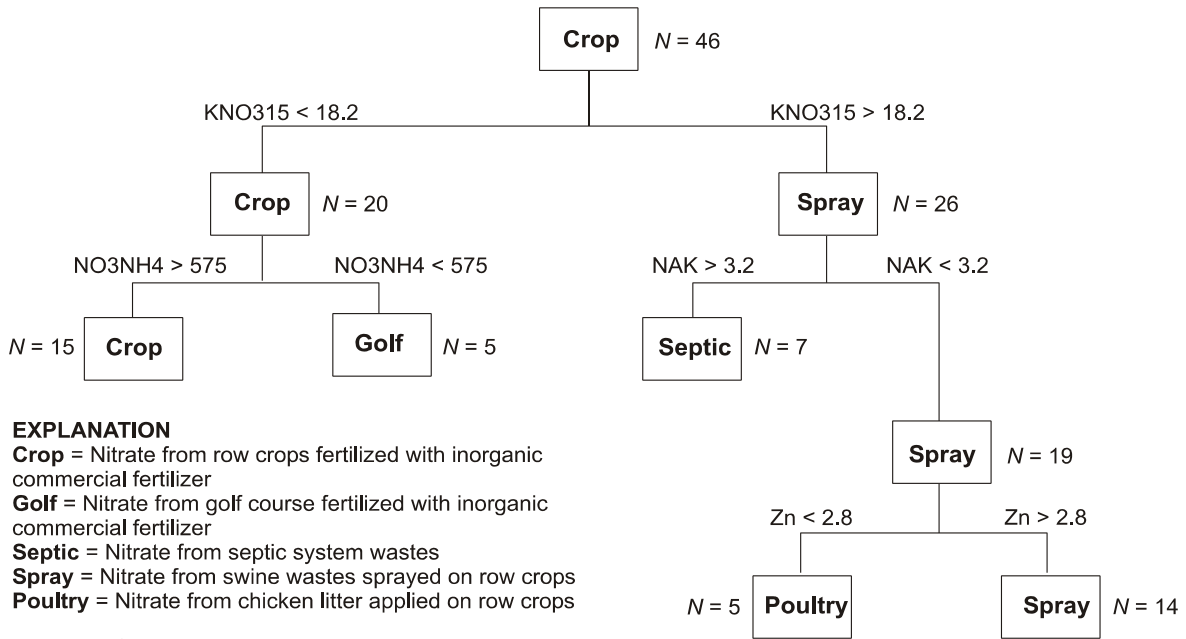
Kellman and Hillarie-Marcel suggest “that using $\delta^{15}\text{N}$ for nitrate source identification in stream sampling of water draining progressively larger areas would produce increasingly uncertain results” (Kellman and Hillaire-Marcel, 2002). This implies that the farther downstream from the source the sample is taken, the more difficult it will be to trace the $\delta^{15}\text{N}$ signal.

3.4 Classification-Tree Method

Many modern statistical computer packages contain classification-tree models that may be useful in determining nitrate sources utilizing $\delta^{15}\text{N}$ with other geochemical parameters. In 2002, Spruill, *et al.* utilized these computer applications to create two tree models devised from 48 water samples containing nitrate from five different sources (classes). Both of these models distinguished all five source categories with greater than 80% success.

“The basic idea behind classification-tree models is to create a hierarchical tree of key variables and values based on a sample of objects of known classes; the resulting tree is then used to predict classes from another independently obtained sample having the same variables, but unknown classes” (Spruill, *et al.*, 2002). Figure 3-3 illustrates the first classification tree Model 1. Model 2, although not pictured, would be very similar utilizing slightly different variables.

Figure 3-3. Classification tree Model 1 using the predictor variables potassium plus $\delta^{15}\text{N}$ of nitrate (KNO_3/NH_4) nitrate to ammonia ratio (NO_3/NH_4), sodium to potassium ratio



EXPLANATION

- Crop** = Nitrate from row crops fertilized with inorganic commercial fertilizer
- Golf** = Nitrate from golf course fertilized with inorganic commercial fertilizer
- Septic** = Nitrate from septic system wastes
- Spray** = Nitrate from swine wastes sprayed on row crops
- Poultry** = Nitrate from chicken litter applied on row crops

Zn < 2.8 Split variable and split value selected by program to allocate observations from parent node into one of two resulting child nodes.

Crop N = 46

Tree node showing the dominant class in the node. The node at the top of the tree (the root node) has the most classes (all observations), whereas the terminal nodes at the bottom of the tree have only one class if the model is perfectly successful. N indicates the number of observations at the node.

Model 1 used four predictor variables ($\delta^{15}\text{N}$, nitrate to ammonia ratio, sodium to potassium ratio, and zinc) to predict nitrate sources. Model 2 utilized all the variables utilized in Model 1 except $\delta^{15}\text{N}$ and added two other variables (sodium plus potassium and calcium to magnesium ratio). Model 2 was effective at predicting nitrogen source without using $\delta^{15}\text{N}$. The author notes that “ $\delta^{15}\text{N}$ appears to be a reliable indicator under conditions where other chemical indicators would not be as effective. Therefore, inclusion of $\delta^{15}\text{N}$ in analyses is almost always advantageous for identification of sources and establishing model plausibility” (Spruill, *et al.*, 2002).

The classification-tree model is a promising method of using statistical models to determine the principle source of high nitrate where multiple sources are contributing. The models used in this study were effective in shallow aquifers in the North Carolina Coastal Plain where there is low specific conductance. The methods and parameters would likely have to be modified for different geographic regions or specific source contaminants.

3.5 Ongoing Research

Research is being conducted that may further benefit the field of nitrogen source tracking. The ongoing studies described below are listed with the study title, agency conducting research, and a summary of the pertinent information.

Title: Fate & Transport of Nutrients in Agricultural Systems As Affected by Soil and Nutrient Management

Agency: USDA ARS

End Date: April 2006

McCarty, USDA ARS is utilizing nuclear magnetic resonance spectroscopy to precisely measure the forms and transformations of phosphorus and nitrogen in soils and wastes. This study plans to quantify basic nutrient transformation and transport processes and their controlling factors in agricultural systems. This study may provide information that will be useful in future attempts to determine the source of nitrogen.

Title: Comprehensive Systems for Managing Nutrient Flows and Gaseous Emissions in Relation to Dairy Manure

Agency: USDA ARS

End Date: April 2005

Meisinger, USDA ARS is developing rapid methods of analysis for both inorganic and organic nitrogen in manure. The study will identify major loss pathways of nutrients, and aid future stable isotope tracking researchers in addressing isotopic fractionation that occur during denitrification and volatile ammonia loss.

Title: Model Prediction of Soil Carbon and Nitrogen Transformations in the Soil/Plant/Air Biosystem

Agency: USDA ARS

End Date: August 2004

Clapp, USDA ARS is using in situ carbon dioxide concentrations in soil to model and improve predictability of carbon and nitrogen dynamics in the soil.

Title: Tracing Sediment Sources in Eastern Iowa by Using Stable Carbon and Nitrogen Isotopes: An Exploratory Research

Agency: USGS

End Date: February 2005

Papanicolaou, USGS is working on a technique to determine the origins of runoff sediment by examining the nature of chemicals, hydrological effect, and the ratios of stable carbon and nitrogen isotopes that compose the sediment. Two factors must be met for this procedure to be successful; variations between sources must be greater than internal variations, and any possible anthropogenic and/or biogenic alterations be taken into account.

Title: Nitrogen Cycling in Alabama Rivers: Effects of Nutrient Addition on the Composition of Functional Microbial Communities

Agency: USGS

End Date: February 2005

Olson, USGS has begun an experiment using the microbial communities located around a watershed and wastewater treatment plant to compare the levels of biodiversity. Differences in the levels of microorganisms that assist in nitrogen transformation could be an indicator that water quality is not maintained. If the study proves correct, the methods could be used to effectively monitor soil and water quality.

Title: Development of a New Technique for the use of Dissolved Helium as an Environmental Ground water Tracer

Agency: USGS

End Date: February 2005

El-kadi, USGS has begun a study using helium to trace surface water and ground water. Helium has the advantages of being non-toxic, inert, occurring in low levels naturally, and allowing for automated monitoring.

Title: Sequestration of Phosphorus with Iron Mine Tailings

Agency: USGS

End Date: February 2005

Brown, USGS is sequestering phosphorus with iron mine tailings in surface water to prevent eutrophication. "Anerobic re-oxidation of iron is facilitatied by oxidants with a more positive redox potential than ferric/ferrous couple such as the nitrate/N₂ couple. When this occurs, iron oxidation also helps resolve nitrate stimulated eutrophication."

Title: Rapid Solar Transformation of Nutrients in Natural Waters

Agency: USGS

End Date: February 2005

Peyton, USGS is measuring the photogeneration rates of ammonia and phototransformations of other nitrogen species that are induced by sunlight in surface waters. Solar driven photochemical processes could be significant in the transformation of nitrogen species and Peyton is exploring whether these processes need to be included in current water quality models.

Title: Study of Denitrification in the Karlsruhe Aquifer Using Stable Isotopes of N and O in Nitrate

Agency: USGS

End Date: August 2004

Korom, USGS is utilizing stable nitrogen and oxygen isotopes to determine whether denitrification is the result of lower nitrate concentrations in an aquifer.

Title: Development of Smoke Tracer Instrumentation for Groundwater Recharge Investigations in the Edwards Aquifer Region

Agency: USGS

End Date: February 2005

Taucer, USGS is experimenting with a smoke tracer system, which will use smoke instead of dyes to trace ground water flow. The tracer is designed to identify ground water routes for tracking. The unit is designed to be mobile and non-invasive.

Title: Modification of Management of Animal Waste for Continued Safe Disposal on Lands

Agency: USDA ARS

End Date: May 2005

Rowe, USDA ARS is attempting to determine “the effects of storage, time and other environmental factors on concentrations and forms of nitrogen and phosphorus in poultry litter stacks.” Understanding the forms of nitrogen used in land applied manure may help future researchers to determine sources of nitrogen.

Title: Using Marine Derived Nitrogen in Tree Rings to Assess Nutrient Flux and Salmon Escapement

Agency: USGS

End Date: February 2005

Johnson, USGS is utilizing stable nitrogen isotope ratios from tree ring samples collected from live trees to correlate historical salmon abundance with nutrient abundance. The researcher’s predicted outcome is that fluctuations in tree growth and nitrogen isotope ratios should correlate with records of salmon escapement. While this study has obvious applicability to wildlife managers, it also provides nitrogen isotope researchers with an option for determining nitrogen fluctuations in areas that have unknown previous land use.

Title: Brief Overview of BST

Agency: Virginia Tech

End Date: Unknown

Bacterial Source Tracking (BST) is being developed to track fecal bacteria to its source. Molecular and biochemical BST methods are being researched as a quick, inexpensive means for determining a bacteria source more generalized than a point source, but more specific than a non point source. Currently, BST can be used to determine if the source is from human or animal sources, and to a lesser extent, if the animal is livestock or wildlife.

3.6 Conclusions

Determining the source of an inorganic element, such as nitrogen, in surface and ground water is challenging. The science of utilizing stable isotopes is becoming a valued technology that continues to evolve. Ratios of stable nitrogen isotopes can not differentiate between every possible source of nitrogen by themselves, but by combining this knowledge with other geochemical and statistical principles more confidence in the validity of source identification will occur.

Ongoing research is providing more insight into not only the study of nitrogen isotopes, but also natural transformations of nitrogen in the environment. Pinpointing the source of a nitrogen atom may not be possible, but more research in the areas of nitrogenous compounds and transformations is needed to further develop the potential of nitrogen source tracking. Hydrogeological principles are needed to further understand the flow of ground water, surface water, and runoff when determining how nitrates enter water systems. All of these factors change depending on climate, terrain, and other variables. No one method of tracing nitrogen may ever be valid for every site or scenario, but further research into the presented areas may yield exciting and meaningful results.

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