MAKING SENSE OF NITROGEN FLUX PATTERNS IN THE CALAPOOIA RIVER BASIN

G.W. Mueller-Warrant, S.M. Griffith, G.W. Whittaker, G.M. Banowetz, W.F. Pfender, T.S. Garcia and G.R. Giannico

Nitrogen is a key nutrient limiting productivity of many biological systems, including grasses grown for seed in western Oregon. Application of adequate amounts of nitrogen in fertilizer is a vital component in profitable production of nearly all non-leguminous crops, including cereals, pasture, and grass seed. Crops in differing stages of growth vary greatly in their ability to take up nitrogen (in forms such as nitrate and ammonia) from the soil. Newly seeded stands have extremely limited root systems, and nitrate losses by surface runoff and deep infiltration in new seedings may be almost as high as in fallow. On the other extreme, the extensive root system present in well established perennial grasses, whether grown for seed production, pasture, or hay, is extremely efficient in scavenging nitrogen from the soil. Nitrogen applied to crops can be removed from the field through a variety of mechanisms, including the desired one of crop harvest and a variety of undesirable ones, including denitrification, gaseous emissions of ammonia and nitrous oxide, and surface runoff or deep leaching of nitrate or ammonia dissolved in water. Impact of nitrogen movement away from the fertilized field varies with the nature of what's downstream. If the water is simply being reused to irrigate other crops, losses are merely an economic concern for the farmer who applied fertilizer upstream. If downstream levels of nitrate, nitrite, or ammonia exceed drinking water standards or physiological tolerances of fish or amphibians, a variety of legal mechanisms may be triggered, especially for surface waters that supply drinking water for municipalities or harbor populations of fish or amphibians listed as threatened/endangered. Since nitrous oxide is a potent greenhouse gas, losses in that form may impact the capability of agricultural systems to meet present or future standards for greenhouse gas emissions.

To better understand the opportunities for more efficient use of nitrogen fertilizer by western Oregon agriculture, we sampled streams draining 40 sub-basins of the Calapooia River basin on a monthly basis from October 2003 through January 2007 (Fig. 1). Streams originating in the nearly level areas of agriculturally-dominated lowlands were intermittent, only flowing reliably from November through April, whereas streams originating in the hilly terrain to the east dominated by forests often ran year round. Summer flow rates generally were lower than winter rates. Nitrate, ammonia, dissolved organic nitrogen (DON), and suspended sediment levels were measured in all samples. Since most of the nitrogen was in the form of nitrate, total N will generally be reported rather than separate nitrate, ammonia, and DON except when the specific forms are of interest. Landuse/landcover within the sub-basins was measured by ground-truth field survey and remote sensing classification using Landsat and MODIS imagery. Many of the 40 sub-basins were nested inside of larger ones, and quality of water exiting any particular sub-basin would be obviously dependent on practices occurring within that sub-basin and the quality of water flowing into it from upstream sub-basins.

We averaged 33 successful samples per site during the 39-month period, providing a total of 1320 unique measurements of nitrate, ammonia, DON, and sediment levels. One of the simplest ways to summarize this large amount of data was to calculate how many of these samples exceeded arbitrary levels, such as the 10 ppm drinking water standard for nitrate, the 7 ppm chronic ammonia water quality standard for fish, or a general 50 ppm standard for behavioral effects of sediment on fish. Minimum and maximum concentrations of total N over all sites and sampling dates ranged from 0.07 to 43.04 ppm, with average minima and average maxima of 0.57 and 10.43 ppm, respectively. Twenty out of 40 sites were below 10 ppm total N on all sampling dates. On average, only 7.3% of all samples exceeded this concentration. The extreme site was 30, with 53% of sampling dates exceeding 10 ppm. Sub-basin site 30 includes the town of Shedd, Oregon. The persistently high levels of total N at this site may include effects of livestock grazing or an urban contribution similar to that commonly found in storm and sewer runoff from larger cities.

The concentrations of suspended sediment over all sites and sampling dates ranged from 0.0 to 248.9 ppm, with average minima and maxima of 1.0 and 120.6 ppm, respectively. Only 2 of the 40 sites had suspended sediment concentrations below 50 ppm on all sampling dates. An average of 6.6% of all samples exceeded this concentration. The extreme site was 40, with 27% of sampling dates exceeding 50 ppm. The highest values of suspended sediment occurred on Jan. 10, 2006, at 25 of the 40 sites. Heavy rainfall totaling 15 inches at the official Hyslop weather station occurred during the 23 days prior to this sampling date and likely caused extensive stream bank failure in addition to surface erosion of fields.

A somewhat more sophisticated method of summarizing the data was regression of nitrogen and sediment data against physical properties and landuse characteristics of the 40 sub-basins. Regressions of average total N concentrations during the late fall through late winter period produced r^2 values of 0.740 and 0.811 in the 2004–05 (six sampling dates) and 2005–06 (five sampling dates) cropping years, respectively, when N concentration was analyzed as a function of the percentage of tree cover, seven pooled agricultural crops, and Italian ryegrass. Coefficients for trees and Italian ryegrass were negative, indicating that the higher the percentage of land in trees and Italian ryegrass, the lower the concentrations of total N in water draining out of the sub-basins. The seven pooled crops were disturbed ground planted to non-grass seed crops, established perennial ryegrass, established orchardgrass, established tall fescue, established clover, fall-planted new perennial ryegrass, and fall-planted new clover. Coefficients for these crops as a group were positive, indicating that the higher the percentage of land in them, the higher the concentrations of total N in water leaving the sub-basins. When separate regressions were conducted at each sampling date, non-significant results often occurred in late summer samples when many of the intermittent streams were not flowing. Regression of sediment concentration against the variables that had partially explained total N was much less successful, indicating that other processes, primarily rainfall totals in the period from 4 to 14 days prior to sampling, were more important in determining sediment levels in the water.

Because there were large differences over time in stream flow rates and concentrations of total N and sediment, we used Fourier transformation to help understand the general behavior of total N and sediment over yearly calendar dates. First, we conducted Fourier analysis separately for each of the 40 sampling sites. Then we grouped sub-basins together based on similarity in maximum total N and Fourier transformation coefficients. The first group of 9 sites had maximum total N concentrations less than 1.8 ppm, and Fourier transformation described 30.6% of the variation in total N over dates and sites. We refer to this group as the “low N impact (Type I) sites.” The second group of 7 sites had maximum total N concentrations greater than 1.8 ppm but less than 8.1 ppm, and Fourier transformation described 45.9% of the variation in total N over dates and sites. We refer to this group as the “medium N impact (Type II) sites.” The third group of 12 sites had maximum total N concentrations greater than 8.1 ppm but less than 21 ppm, and Fourier transformation described 27.9% of the variation in total N over dates and sites. We refer to this group as the “high N impact, strong time signal (Type III) sites.” The fourth group of 12 sites had maximum total N concentrations greater than 21 ppm but less than 43 ppm, and Fourier transformation described only 5.7% of the variation in total N over dates and sites. We refer to this group as the “high N impact, weak time signal (Type IV) sites.”

There were strong similarities in the time series patterns for the first three groups. Their peaks in total N occurred on Dec. 6, 7, and 5 after a sharp rise from minimums in late summer. The Type I low N impact group of sub-basins was 90% forest, 10% agriculture, with an average slope of 14% (Fig. 2a). The most likely explanation for the total N pattern seen at these low N impact sampling sites was nitrification of decaying organic matter (leaves and roots) on and near the soil surface during the normal late summer dry spell, followed by flushing out of the nitrate when heavy rains returned in late fall/early winter. Concentrations of total N were 3.4 times higher at the peak than at the minimum. This temporal pattern was similar to that found by researchers looking only in western Oregon forests, and is a natural consequence of the climate and growth habits of plants. The Type II medium N impact group of sub-basins was 33% forest, 67% agriculture, with an average slope of 5% (Fig 2b). Concentrations of total N were 11.84 times higher at the peak than at the minimum for this group. The Type III high N impact, strong time signal group was 13% forest, 85% agriculture, 2% urban development, with an average slope of 3% (Fig 2c). Concentrations of total N were 6.48 times higher at the peak than at the minimum for this group. Comparing these three groups of sites, an obvious effect of increasing agriculture was increasing levels of total N. While N fluxes increased at all dates throughout the year as percentage of land in agriculture increased, the largest concentrations still occurred at the same early December time. Since most fertilizer for grass seed crops is applied in March, it is clear that the majority of fertilizer N must be successfully taken up by crops in late winter/early spring, contributing to their growth on through crop maturity in early summer. The N is then released back into the soil in late summer and early fall as soils dry out and leaves and roots die back. Agricultural production is obviously conducted under higher levels of N than forestry, but the same interplay of climate and plant growth cycles still determines when the N moves from soils into streams and rivers.

The Type IV group comprised the high N impact, weak time signal sites, averaging 19% forest, 81% agriculture, and 4% slope (Fig. 2d). Maximum N concentrations in this group were twice those found in any other group, and seasonal patterns in total N were very weak. Concentrations in December were similar to those in March, and wild fluctuations occurred among samples collected during late spring and summer. The contrast between this group of 12 sub-basins and the 28 others strongly suggests an opportunity to improve N management in these 12. Several concerns stand out. First, the high N levels at some of the sites in some of the years during late spring and summer included several cases where low flow was combined with the physical presence of livestock in the water. The sample with the very highest concentration of total N also had the highest concentration of ammonia, and was obviously impacted by livestock manure. Because stream flows were very low when this sample was taken on May 26, 2005, it is likely that downstream impacts were minor despite the high levels of ammonia. The second serious concern was the existence of sampling events with high concentrations of total N of which more than 20% was in the form of DON, likely indicating that urea-based fertilizers made it into flowing surface water, either immediately during application or soon enough afterward that crops had not yet had the opportunity to take up all the ammonia produced during hydrolysis of urea or all the nitrate produced subsequently by soil microorganisms metabolizing the ammonia. Our preliminary estimate was that no more 24% of the total N exported from all 40 sub-basins could have been the result of poor timing between application of fertilizer and occurrence of heavy enough rainfall to generate surface runoff from agricultural fields. More detailed mass balance analysis using SWAT will be conducted to define the prompt losses of fertilizer N that might be reduced using improved management practices, but it is clear from our initial analysis that the vast majority of N exported from the Calapooia was an inevitable consequence of growing high yielding crops under the climatic conditions of western Oregon. The negative relationship between nitrogen runoff and production of Italian ryegrass presumably represents the combined effects of the poorly drained soils usually used to grow this crop, the higher straw loads left on Italian ryegrass fields, and lower fertilization rates compared with other crops. The first two factors should act to promote immobilization and denitrification of nitrate.

Several major conclusions can be drawn from this research. The good news is that a large majority of fertilizer N is indeed taken up by grass seed crops. The mixed news is that a substantial fraction of the N present in crops at harvest is subsequently released back into the soil in late summer/early fall and converted to nitrate, which is then vulnerable to leaching and runoff in the heavy rains of late fall/early winter. The bad news is that sporadic events occur where undesirably high percentages of spring-applied fertilizer N escape from the fields to which it was applied. Obvious ways to reduce the frequency and severity of such events include: (1) avoiding direct application of fertilizer to drainage ditches and areas with standing or flowing water, (2) limiting fertilizer application when there is a high probability of heavy rainfall within the next few days, and (3) applying no more than maximum recommended rates of fertilizer for the crops being grown.

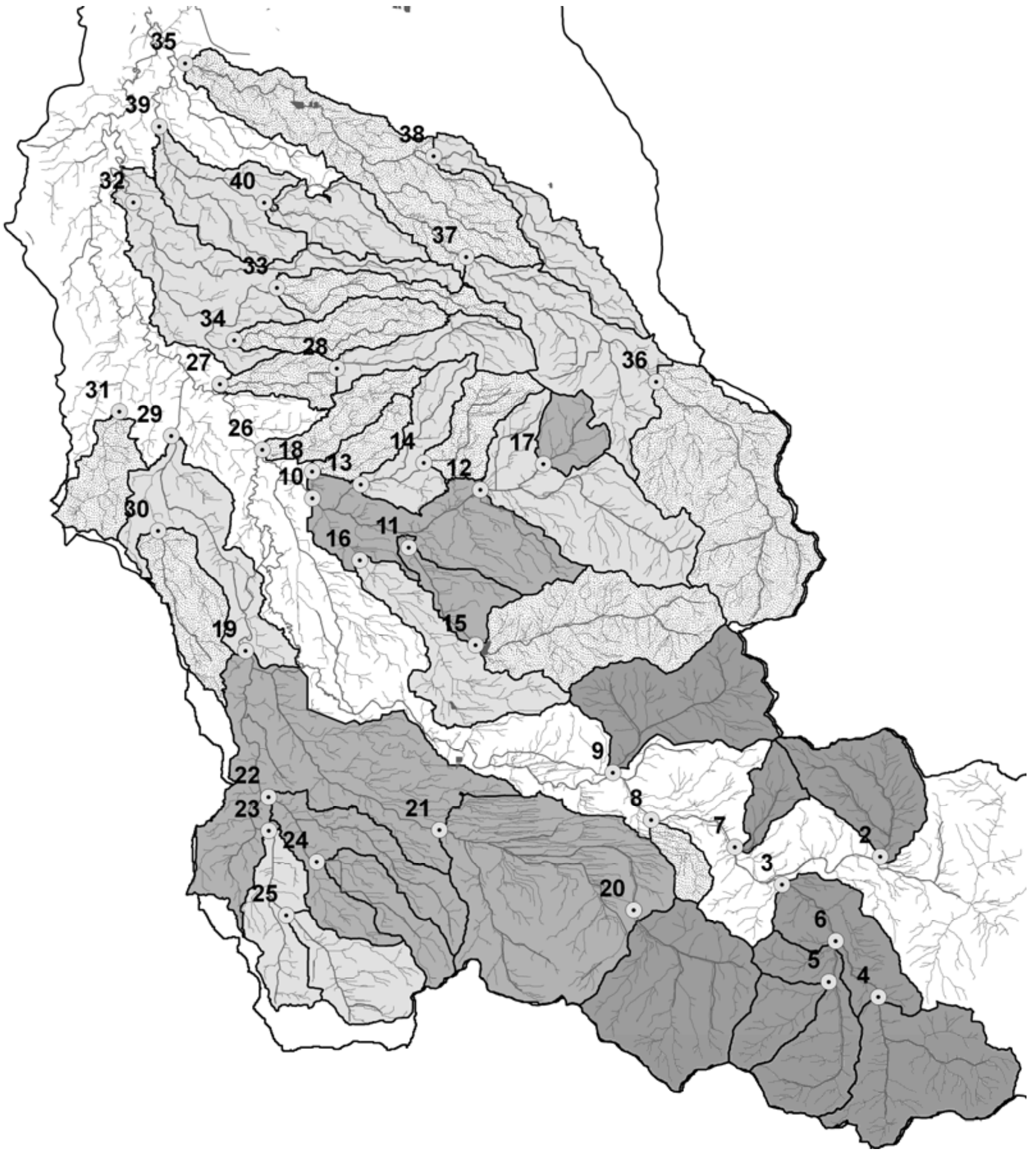

Figure 1. Calapooia River sub-basins at 1:90,000 scale. N-impact sub-basin Types I, II, III, and IV are shown as dark gray, medium gray, light gray, and speckled. Circles mark sampling points, with ID numbers to their NW. Sub-basins boundaries are heavier and darker than rivers and streams. Sub-basin 1 located 22 miles further east is omitted.

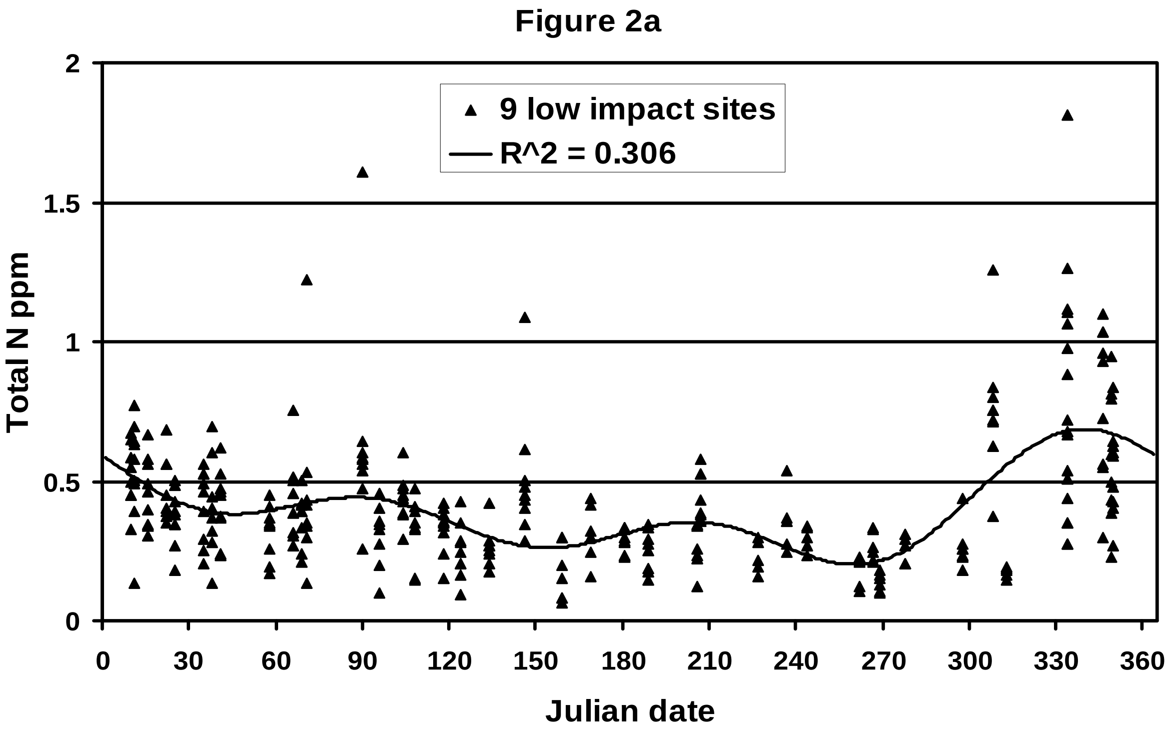

Figure 2a. Total N concentrations in 9 low impact Type I sub-basins averaging 14% slope, 90% forest, 10% agriculture, Dec. 6 peak.

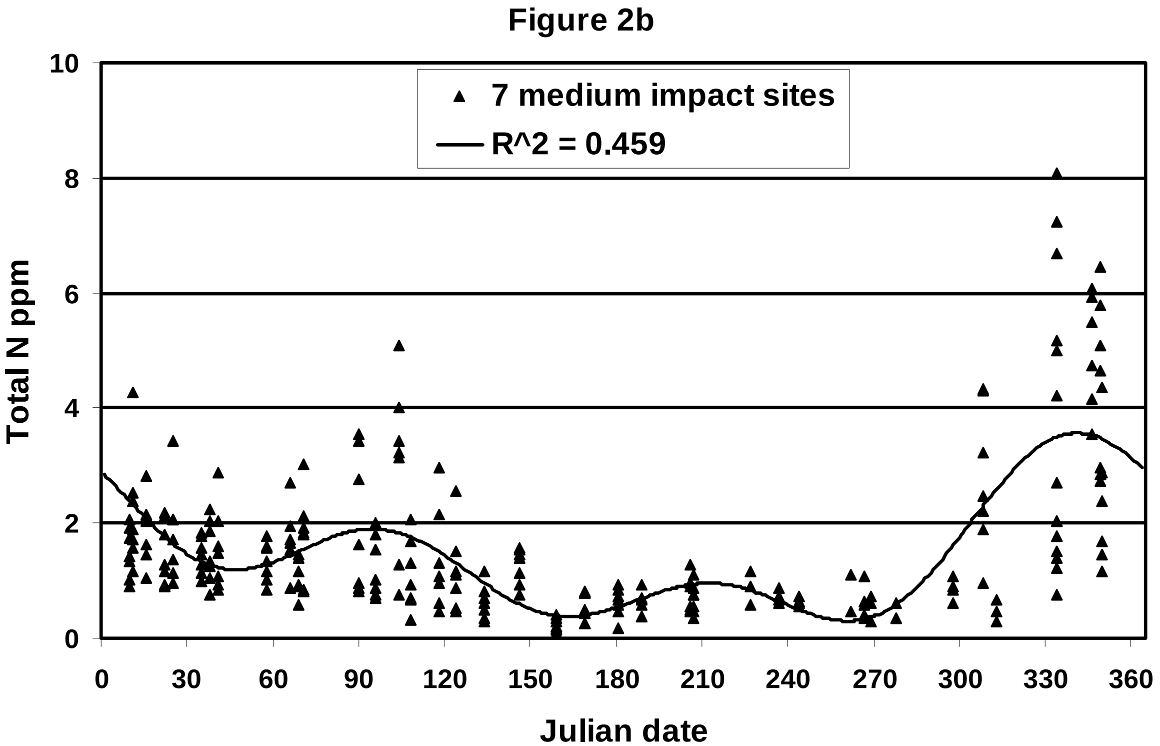

Figure 2b. Total N concentrations in 7 medium impact Type II sub-basins averaging 5% slope, 33% forest, 67% agriculture, Dec. 7 peak.

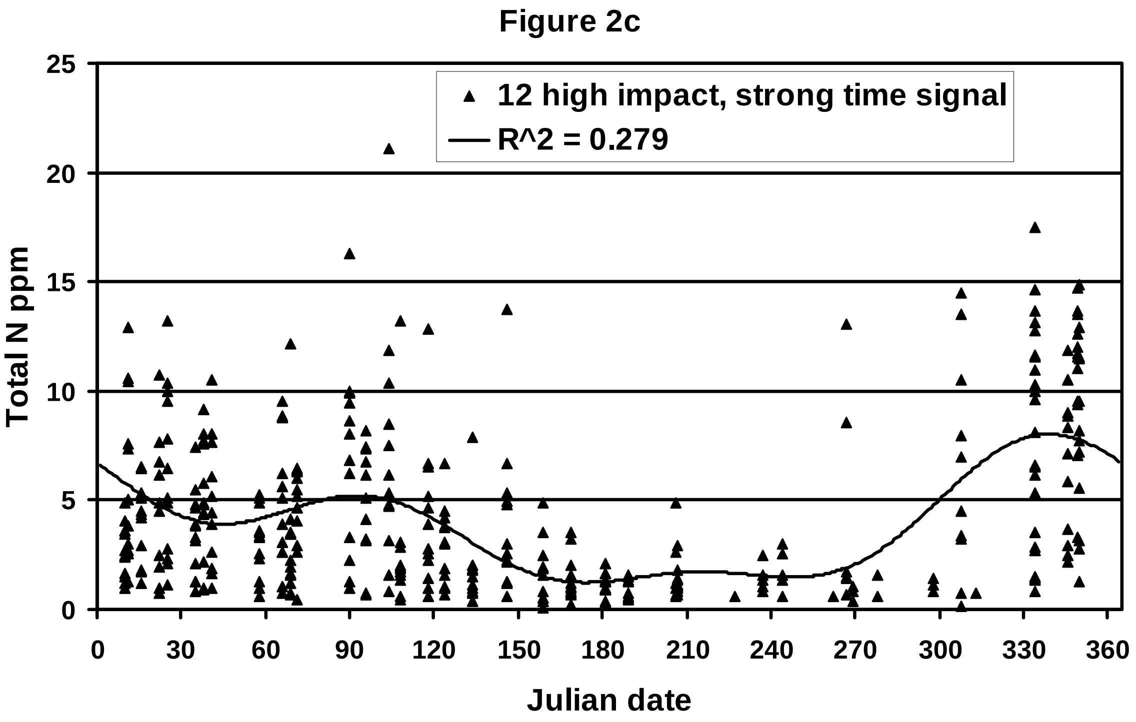

Figure 2c. Total N concentrations in 12 high impact Type III sub-basins averaging 3% slope, 13% forest, 85% agriculture, Dec. 5 peak.

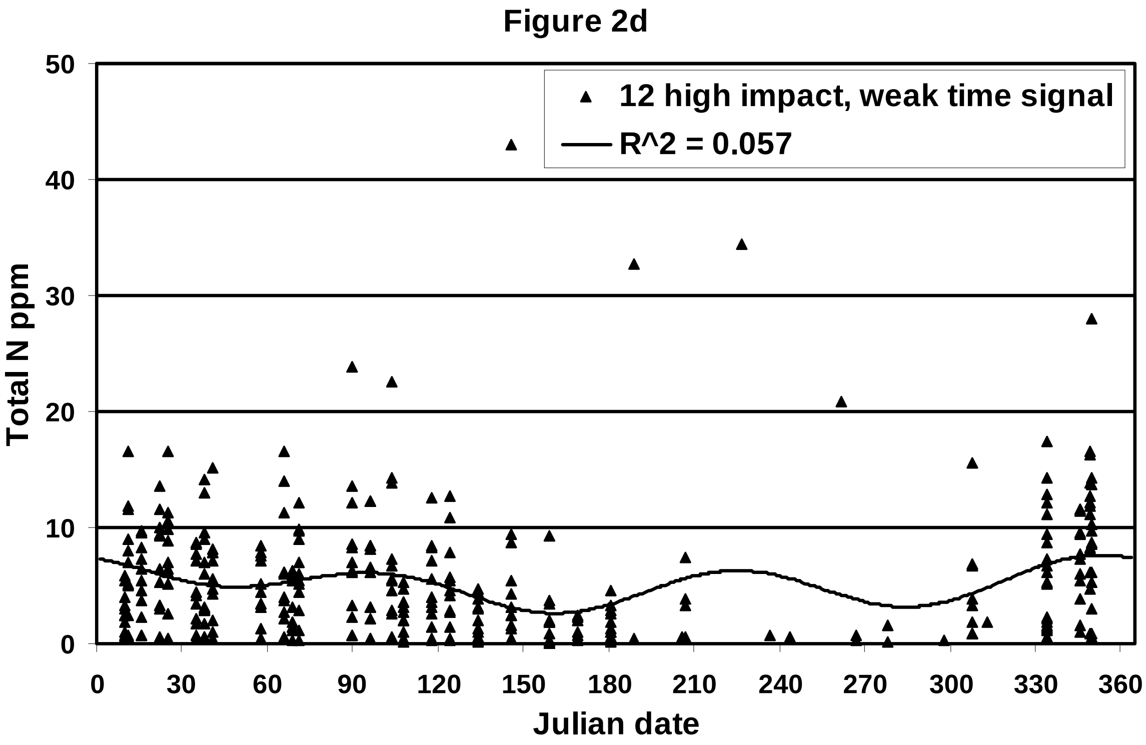

Figure 2d. Total N concentrations in 12 high impact Type IVsub-basins averaging 4% slope, 19% forest, 81% agriculture, Dec. 19 peak.