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Impact of land use patterns and agricultural practices on water quality in the Calapooia River Basin of western Oregon

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Abstract: Agricultural practices, including tillage, fertilization, and residue management, can affect surface runoff, soil erosion, and nutrient cycling. These processes, in turn, may adversely affect (1) quality of aquatic resources as habitat for amphibians, fish, and invertebrates, (2) costs of treating surface and ground water to meet drinking water standards, and (3) large-scale biogeochemistry. This study characterized the surface water sources of nitrogen (N) (total, nitrate [NO_3^-], ammonium [NH_4^+], and dissolved organic N) and sediment active within 40 subbasins of the Calapooia River Basin in western Oregon in monthly samples over three cropping years. The subbasins included both independent and nested drainages, with wide ranges in tree cover, agricultural practices, slopes, and soils. Sediment and N form concentrations were tested against weather and agricultural practice variables. Subbasin land use ranged from 96% forest to 100% agriculture. Average slopes varied from 1.3% to 18.9%, and surface water quality ranged from 0.5 to 43 mg L^{-1} (ppm) total N maxima and 29 to 249 mg L^{-1} suspended sediment maxima. Total N during the winter was positively related to percentage landcover of seven common agricultural crops (nongrass seed summer annuals, established seed crops of perennial ryegrass [*Lolium perenne* L.], tall fescue [*Schedonorus phoenix* {Scop.} Holub], orchardgrass [*Dactylis glomerata* L.], clover [*Trifolium* spp.], and newly planted stands of perennial ryegrass and clover) and negatively related to cover by trees and one seed crop, Italian (annual) ryegrass (*Lolium multiflorum*). Results for NO_3^- and total N were highly similar. Sediment concentrations were most strongly related to rainfall totals during periods of 4 and 14 days prior to sampling, with smaller effects of soil disturbance. Fourier analysis of total N over time identified four prominent groups of subbasins: those with (1) low, (2) medium, and (3) high impacts of N (up to 2, 8, and 21 mg L^{-1}, respectively) and a strong cyclical signal peaking in December and (4) those with very high impact of N (up to 43 mg L^{-1}) and a weak time series signal. Preponderance of N in streams draining agriculturally dominated subbasins was in the form of the NO_3^- ion, implying mineralization of N that had been incorporated within plant tissue following its initial application in the spring as urea-based fertilizer. Since mineralization is driven by seasonal rainfall and temperature patterns, changes in agronomic practices designed to reduce prompt runoff of fertilizer are unlikely to achieve to more than ~24% reduction in N export to streams.

Key words: ecosystem services—Fourier time series analysis—geographically weighted regression—water quality

Impacts of agricultural production practices on ecosystem processes across landscapes are varied and complex. Key concerns in agriculturally dominated landscapes include soil erosion, off-site movement of fertilizer nutrients (primarily nitrogen [N] and phosphorus [P]), altered hydrology, removal/impairment of critical habitat used by wildlife, and global climate change through production/sequestration of greenhouse gases, such as carbon dioxide (CO_2) and nitrogen oxides (NO_X) (USDA NRCS 2009; Mausbach and Dedrick 2004; Schnepf and Cox 2007). Mandated changes in tillage operations, fertilization practices, and crop rotations using a one-size-fits-all approach are likely to decrease production efficiency in the short-term, with little assurance that intended reductions in negative environmental effects will not be at least partially offset by unintended changes in other ecosystem services (Huang et al. 1996; Johnson et al. 1991; Whittaker 2005).

Nitrate nitrogen (NO_3^--N) was identified in the National Water Quality Assessment as a particular concern because concentrations in streams and shallow groundwater were found to often "exceed standards for protection of human health and/or aquatic life" and because detectable changes over recent periods were usually trends of increasing rather than decreasing concentration (Dubrovsky et al. 2010). Standards or levels of concern for N include 10 mg L^{-1} (ppm) NO_3^--N in drinking water (USEPA 2009), 25 mg L^{-1} ammonium nitrogen (NH_4^+-N) and 6,000 mg L^{-1} urea-N in surface water used by the Pacific treefrog (Schuytema and Nebeker 1999a, 1999b), and from 1 to 7 mg L^{-1} ammonia (NH_3) for chronic exposure by fish (USEPA 1999). Linkage between the export of NO_3^- from the entire Mississippi–Missouri River drainage basin and the severity of hypoxic conditions in large areas of the Gulf of Mexico near the river's mouth illustrates the vast geographic scope of issues regarding off-site movement of ecologically damaging levels of nutrients, nutrients that are nonetheless crucial for modern agricultural production (Turner and Rabalais 1994; Rabalais et al. 2002).

In line with their suggestion that "strategic integration of perennial plants in agricultural landscapes" should be "a fundamental strategy for restoring agroecosystem health and function," Schulte et al. (2006) encouraged research into the possibility of disproportionate benefits depending on specific locations of perennials within the landscape. In addi-

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tion to the issue of strategic locations, they also asked (but did not answer) how much of an annual-crop-dominated landscape would need to be converted back to perennials to significantly improve conditions. In a thorough review of ways to reduce NO_3^- export from tile-drained soils of the northern US Corn Belt, Dinnes et al. (2002) listed winter cover crops, riparian buffers, constructed wetlands, and diversified crop rotations, including perennial species, amongst a suite of altered crop management and land use practices that could be each expected to incrementally reduce NO_3^- export from midwestern farms.

Through its first five years, the Conservation Effects Assessment Project (CEAP) focused primarily on the water and soil quality impacts of conservation practices applied to cropland, with study sites comprising 14 long-term benchmark watersheds, 13 competitive grant watersheds, and 11 special emphasis watersheds (Duriancik et al. 2008). Central components of CEAP included measurements of NO_3^- and sediment loads in rivers draining study watersheds and modeling the effects of observed and potential land use changes on NO_3^- and sediment concentrations and exports, primarily through use of the Soil Water Assessment Tool (SWAT) (Nietsch et al. 2001a, 2001b) and data envelopment analysis with Pareto optimization (Confessor and Whittaker 2007; Whittaker et al. 2009). As an example of the interpretation that SWAT can bring to CEAP watersheds, conversion by farmers of 248 ha (613 ac) from Conservation Reserve Program grasslands to corn and soybean row crops in the Squaw Creek Watershed of southern Iowa increased the NO_3^- load of waters leaving the watershed in 2005 by an average of 30 kg NO_3^--N ha^{-1} (27 lb NO_3^--N ac^{-1}) of land converted, while restoration of native prairie and savanna on large areas of the nearby Walnut Creek Watershed decreased NO_3^- export (Schilling and Spooner 2006; Jha et al. 2010).

A common factor in most published research on relationships among soil and water quality parameters, agronomic practices, and land use patterns is heavy weighting toward production of annual crops under intensive management on highly disturbed landscapes. While such conditions are important to study due to their widespread geographic occurrence and the ongoing necessity of supplying food and fiber for humanity, ecological benefits of large-scale production of perennial grain or biofuel crops remain largely hypothetical due to the general dearth of landscape-scale studies of suitable proxies for these developing potential crops. In contrast to midwestern landscapes, nearly 50% of agriculturally cropped land in the Willamette River Basin of western Oregon is undisturbed by tillage in any given year, with over 81% retention from one year to the next of established perennial grasses and legumes (Mueller-Warrant et al. 2011). Additionally, the majority of land disturbed by tillage is fall-planted to the rapidly establishing species Italian (annual) ryegrass (*Lolium multiflorum* Lam.), further limiting opportunities for soil erosion and loss of nutrients. Two major water quality concerns previously reported for western Oregon agriculture were late fall through early winter peaks in NO_3^- in runoff from conventionally tilled fields and occasional detections of high concentrations of both NO_3^- and NH_4^+ ions in the first rainfall events following springtime fertilization of wheat (*Triticum aestivum* L.), with 120 to 140 kg ha^{-1} (107 to 125 lb ac^{-1}) N from ammonium nitrate (Harward et al. 1980). Even though NO_3^- concentrations exceeded 10 mg L^{-1} in only 2 out of 51 Willamette Basin streams sampled by United States Geological Service (USGS) in 1993, there was a strong positive relationship between percentage of agricultural land in drainages and NO_3^- concentrations in stream water (Wentz et al. 1998).

Study of an herbaceous riparian buffer located between a western Oregon grass seed field and a small stream found that high rates of denitrification occurred in groundwater within the buffer, leading to the presence of less than the detection limit of 0.05 mg L^{-1} NO_3^- by 6 m (19.69 ft) into the buffer from the edge of the grass seed field (Davis et al. 2007, 2008; Wigington et al. 2003). However, the research also showed that shallow groundwater passing through the buffer amounted to less the 1% of total streamflow during the winter, with the remaining 99% coming from overland flow paths originating in grass seed fields (Wigington et al. 2003). A study of five catchments in western Oregon found higher NO_3^- concentrations in winter than in spring (Wigington et al. 2005). The study also found that stream networks expanded in density by nearly two orders of magnitude between the perennial streams of summer and all drainages in the winter, with greatest expansion occurring in the catchment with the lowest relief, most slowly infiltrating soils, and highest proportion of grass seed crops. The authors expressed concern that "water moving from agricultural fields into expanded stream networks during large hydrologic events has the opportunity to bypass downstream riparian buffers along perennial streams and contribute nonpoint-source pollutants directly into perennial stream channels." Soil physical properties played a major role in effectiveness of western Oregon riparian buffers, and surface versus groundwater flows in a well-drained riparian forest were very different from those in a neighboring grass seed field situated on poorly drained soil (Davis et al. 2011).

Where new or modified agricultural production practices are needed to reduce contamination of surface waters by transported sediment, dissolved nutrients, and agrichemicals, careful discernment of the underlying issues is vital for the realization of cost-effective solutions. Are the sources of nutrients, sediment, and other pollutants transported in rivers and streams so ubiquitous that nearly all producers will need to modify their tillage, fertilization, and pest management practices to minimize negative effects on ecosystems? Alternately, are high concentrations of nutrients, sediment, and agrichemicals in aquatic environments primarily sporadic occurrences associated with specific, adverse combinations of weather events and crop management practices on individual fields and potentially amenable to focused implementation of improved best management practices? Given that there is always some flux of N in natural systems, the question is not whether agricultural losses of N can be reduced to zero, but whether the increased availability of N in ecosystems downstream from agricultural fields is high enough to impair their functioning (Pacific Fisheries Management Council 1999). Similar questions exist for P, sediment, and other pollutants.

Because interactions among agronomic practices (e.g., fertilizer application, tillage for seed-bed preparation, and residue management), rainfall patterns, soil temperatures, and crop canopy and root development collectively define an inherently complex availability of N for leaching (or exposed soil for erosion) that changes over time, it is a common practice to use sine and cosine of time as explanatory variables in regression models of water quality measurements (Mueller and Spahr 2005). When time is measured as a fraction of the calendar year, Fourier time series analysis conducted at progressively higher orders (sin[x] and cos[x], sin[2x] and cos[2x], sin[3x] and cos[3x] ... sin[Nx] and cos[Nx]) can achieve arbitrarily close fits to any temporal signal (Bliss 1958). When more than a single cycle's data are analyzed together, Fourier series analysis of sufficiently high order can match the average values on each day of the year but not the individual values, unless they happen to be identical for some particular calendar date. While rigorous treatment of the statistical properties of regression models incorporating Fourier series can become quite elaborate (Bliss 1958; Stolwijk 1999) and are beyond the scope of this paper, several relatively simple concepts are worth repeating. First, the general form for plotting simple periodic variables is what is referred to as a sinusoidal or sine curve:

$$Y = a_0 + A\cos(ct - \theta). \tag{1}$$

In this equation, a_0 is the mean response over the entire time cycle, A is the semiamplitude equal to half the range from minimum to maximum, c is $(2\pi) \div k$ where k is the number of equal subdivisions of the cycle period used in the analysis, t is time in integer values from 1 to k (or equivalently from 0 to k–1), and θ is the phase angle or time in radians when the function reaches its maximum. Second, because the time phase shift θ is an unknown value not easily computed directly from equation 1, the equation is usually rewritten in the following form where coefficients can be readily found using ordinary least squares regression:

$$Y = a_0 + a_1 \cos(ct) + b_1 \sin(ct). \tag{2}$$

In this equation, a_0, c, and t have the same definitions as in equation 1, while a_1 and b_1 are simply regression coefficients that can be used to derive A and θ of equation 1 by use of the following formulas:

$$A = \sqrt{a_1^2 + b_1^2} \tag{3}$$

$$\tan(\theta) = b_1 \div a_1$$

or

$$\theta = \arctan 2(a_1, b_1). \tag{4}$$

The general Fourier series approximation with order N pairs of sine and cosine terms can be written as

$$Y = a_0 + a_1 \cos(ct) + b_1 \sin(ct) + a_2 \cos(2ct) + b_2 \sin(2ct) + \ldots + a_N \cos(Nct) + b_N \sin(Nct)$$

or

$$Y = a_0 + \sum_{k=1}^{N} a_k \cos(kct) + b_k \sin(kct)$$

or

$$Y = a_0 + \sum_{k=1}^{N} A_k \cos(kct - \theta_k) \,. \tag{5}$$

The sine and cosine terms are typically viewed as joined pairs of variables with a combined two degrees of freedom when their significance is tested, as they are really both needed to determine the values of A and θ in equation 1 (or A_1 through A_N and θ_1 through θ_N in the Nth degree Fourier series version, equation 5). Omitting either the cosine or sine term from equation 2 is equivalent to testing a null hypothesis that the phase shift angle θ is either $\pi \div 2$ or $3\pi \div 2$ radians (e.g., 3 or 9 months) if the cosine term is dropped and either 0 or π radians (e.g., 0 or 6 months) if the sine term is dropped. While such tests can be meaningful if the start of the time period has been chosen to closely align with some typical date for applying fertilizer or the return of rainfall after a prolonged dry spell, in general a nonzero phase shift will be needed if calendar dates are used to measure time. Euler's formula (equation 6) is often used in Fourier transformation of known functions where the complex number notation simplifies the integration required to calculate the Nth series coefficients (equation 7) of the Fourier transformation of function $f(x)$ (Feynman 1977).

$$e^{2\pi i} = \cos(2\pi\theta) + i \sin(2\pi\theta) \tag{6}$$

$$c_n = \int_{-T/2}^{T/2} f(x) e^{-2\pi i (n/T) x} dx \,. \tag{7}$$

For modeling of complicated, noisy, cyclical phenomena such as NO_3^- concentration of water in streams draining agricultural landscapes, the exponential formulation using complex numbers has no real advantage over equation 5 since the underlying function itself is unknown and the Fourier series approximation can only be run up to some small number of degrees of freedom before losing significance for any additional higher order terms.

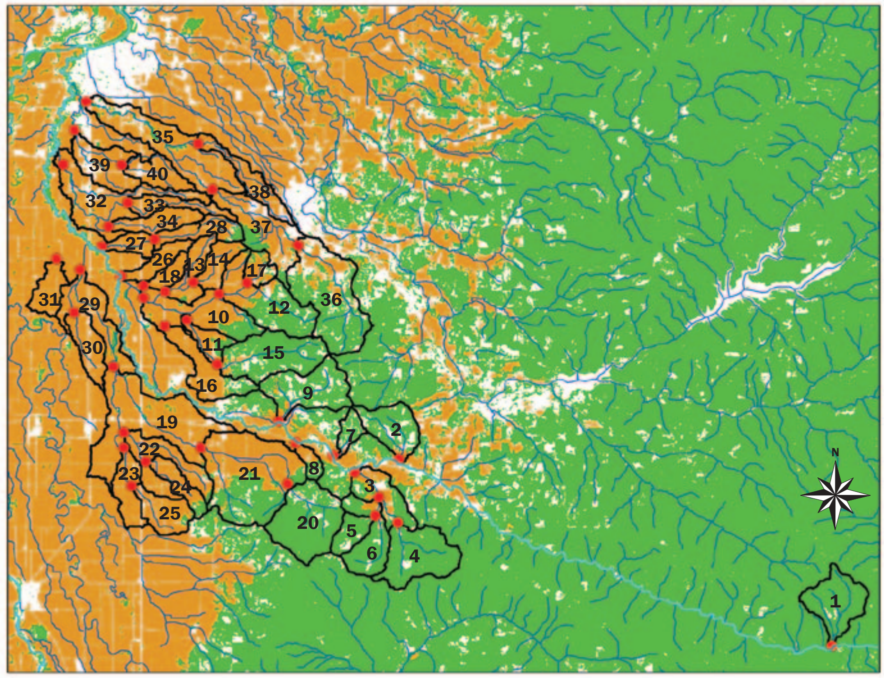
If Fourier series analysis is conducted separately within individual years (or at individual sites) as well as on data pooled over all years (or sites), it becomes possible to test for the existence of significant year (or site) effects, either in general or for semiamplitudes and phase shifts separately (Bliss 1958). Fourier analysis has several main advantages over other possible methods for analyzing time-varying responses such as NO_3^- concentrations of flowing streams. First, unlike polynomial regression, predicted values at the beginning and end of natural time period cycles such as days, months, or years are smoothly continuous with each other and, by definition, are identical after passage of a full cycle of time. Second, unlike analysis of variance methods that view discrete blocks of time (e.g., January 1 to 31, February 1 to 28…December 1 to 31) as independent levels of a time factor variable, Fourier analysis is not particularly disturbed by missing data or widely varying numbers of samples over time. Third, because Fourier analysis summarizes trends over the entire cycle period in a single regression with a relatively small number of terms, it is both possible and reasonably simple to divide a large collection of sites and/or years into groups of fairly homogeneous cases with statistically significant variation primarily among, rather than within, groups. In other words, it can try to answer the question of whether it really takes 120 separate models to adequately describe the patterns of NO_3^- or suspended sediment present at the outlets of 40 subbasins over three years. If many of the regressions are highly similar, using a far smaller number of models is not just good enough statistically, but actually better in the sense of being more easily understood by the human mind. Fourth, decomposing the signal into separate amplitude and phase angle components with Fourier analysis allows for the determination of whether sites and/or years differ solely in the magnitude of their responses, the timing of maxima and minima, or both.

Multiple sampling sites were established on tributaries to the Calapooia River in western Oregon for a CEAP competitive grants watershed project designed to evaluate impacts of agricultural practices on ecosystem services of interest. The subbasins analyzed included both independent and nested drainage types, with wide ranges in permanent tree cover, agricultural land use/cropping patterns, slopes, and soil types. Ecosystem services studied included abundance and diversity of biological indicator species along with the more traditional water quality measurements of nutrients and suspended sediment. Because none of the biological indicators exist within SWAT, it was necessary to develop original regression models of potential interactions among agricultural land use practices, water quality parameters, condition of biological indicator species, and watershed hydrology. The current manuscript describes relationships between water quality parameters as dependent variables and agricultural land use practices and hydrology as independent variables. One future manuscript will compare our current results with those from SWAT for water quality analyses, while several other future manuscripts will describe the complex relationships among biological indicators, agricultural land use practices, and water quality (as an independent variable influencing the biological indicators), elaborating on the earlier work by Floyd et al. (2009).

Our general hypothesis was that variability in agronomic practices among subbasins of the Calapooia River basin would be sufficient to associate land use patterns and agricultural practices with variation in water quality. The specific objectives of this paper were to identify and characterize the sources of N and sediment active within 40 subbasins of the Calapooia River basin in western Oregon in monthly samples collected over a 40-month period covering three cropping years.

Figure 1

Calapooia River Basin study site at 1:240,000 scale in UTM 10N NAD83 projection. Additional sample sites along the Calapooia mainstem have been omitted from this map. For reference, the city of Albany, Oregon, is the large white area in the upper lefthand (NW) corner of the map.



Legend

- Forests
- Agricultural land
- Rivers and streams
- Calapooia and Willamette River mainstems
- Water quality sample collection sites
- Subbasin boundaries

Notes: Numbers are subbasin ID numbers. Roads, cities, other development, reservoirs, or mostly bare land within upland forests are shown in white.

Materials and Methods

Hydrology. Total area of the Calapooia River Basin in Linn County, Oregon, was 965.7 km^2 (373.0 mi^2), of which 554.7 km^2 (214.3 mi^2) or 57.4% was covered by the independent footprints of the 40 subbasins we analyzed. Subbasin outlet pour-points and boundaries were defined using the ArcGIS Hydrology Toolset (ESRI 2010) and a 10 m (32.8 ft) digital elevation model raster, with minor modifications to match accessible locations for water sampling. Adjustments to subbasin boundaries were made in nearly flat areas where roads and ditches altered flow direction from that predicted by the digital elevation model. Subbasins chosen for analysis were those that were fully independent or simply nested to a low order (figure 1). For nested subbasins, separate, overlapping polygons were created to measure land use, physical properties, and rainfall totals. Properties of the uppermost subbasins in nested groups were also applied to the larger, downstream subbasin within which they were nested. This method of analysis was adopted rather than a subtractive model to avoid the need for assumptions of steady state conditions and identical rainfall patterns among nested subbasins. Slopes were derived from the digital elevation model, and areas within each subbasin by slope class (in increments of 0.1% slope) were summarized to provide average subbasin slopes.

Sampling Procedures. Samples were collected directly into acid-washed, 250 mL (15.3 in^3) bottles from midway through the water column after first rinsing them with surface water and were transported back to the laboratory at the end of each day. Sites were sampled approximately monthly during the period from October 5, 2003, through January 22, 2007. Rainfall occurred on most days throughout the winter months, and the only adjustment made for weather events during sample collection was avoidance of extremely high flows during the largest storms in the interest of safety of project personnel. Many of the smaller, ephemeral streams dried up by early summer and, therefore, could not be sampled until they began flowing again in midautumn. A few individual sites were inaccessible in winter during periods of very high water discharge. Duplicate samples were collected 10% of the time, and laboratory blanks were routinely transported to and from the field. Most samples were collected within single day, although scheduling conflicts occasionally extended the sampling period out to two or three days. Actual dates for the majority of samples were October 5, November 9, and December 12 in 2003; January 16, February 4, February 28, March 12, April 18, May 14, June 18, July 25, September 1, September 24, November 4, November 30, and December 16 in 2004;

January 11, January 25, February 10, March 10, March 31, April 14, April 28, May 26, June 30, July 26, August 25, September 26, October 25, November 30, and December 15 in 2005; January 10, February 7, March 7, April 6, May 4, June 8, July 8, August 15, and September 19 in 2006; and January 22 in 2007.

Laboratory Procedures. Water samples were filtered through 0.45 µm (1.8×10^{-8} in) polycarbonate filters. Filters were washed prior to use by soaking in a sequence of two double-deionized water baths for a minimum of 24 hours. The filter washing procedure was validated by comparison of analyses of sample blanks. Water samples were analyzed for dissolved organic C and total N using a Shimazu TOC-V/TNM-1 total organic carbon and total nitrogen analyzer (detection limit: 0.1 mg N L^{-1}). Using a flow injection colorimeter autoanalyzer (Lachat Instruments, Milwaukee, WI), NO_3^--N was determined using QuikChem method 10-107-04-1-A (detection limit: 0.05 mg N L^{-1}), NH_4^+-N using QuikChem method 10-107-06-2-A (detection limit: 0.05 mg N L^{-1}), total phosphorous using QuikChem 10-115-01-1-C (detection limit: 0.015 mg P L^{-1}), and orthophosphate (ortho-P) using QuikChem 10-115-01-1-A (detection limit: 0.03 mg P L^{-1}). Quality assurance measures included routine use of blanks, duplicate samples, and quality control check samples. Analyzing sample blanks validated the filter washing procedure. Suspended sediment concentration was quantified by weighing the dried sediment collected on 0.45 µm polycarbonate filters during the sample filtration process (Davis et al. 2007, 2008).

Land Use Determinations. A detailed description of the drive-by, ground-truth census and remote sensing classification of agricultural production practices in the Calapooia River Basin has been published elsewhere (Mueller-Warrant et al. 2011). We identified all crops grown on over 3,000 fields of the agricultural lowlands of the Calapooia River Basin, along with a stratified random survey of 1,800 fields in neighboring counties. Cropping years were viewed as running from August 1 of the previous calendar year through July 31 of the harvest year to match production cycles of grass seed crops, the dominant agriculture practiced in the Calapooia River Basin. From the entire list of crops, stand establishment conditions, and residue management practices used in western Oregon, we identified 16 specific cropping practices that represented approximately 96% of agricultural land use on the lowlands of the Calapooia River Basin. Cropping practices included established stands of perennial ryegrass (*Lolium perenne* L.); tall fescue (*Schedonorus phoenix* [Scop.] Holub); orchardgrass (*Dactylis glomerata* L.) and clover (*Trifolium* spp.) grown for seed; new fall plantings of perennial ryegrass, tall fescue, and clover grown for seed; new spring plantings of any grass seed crop; Italian ryegrass grown using either conventional tillage methods or volunteer stands under full-straw load management; pasture; hay crop; peppermint; cereals (primarily winter wheat); meadowfoam (*Limnanthes alba* L.); and bare ground in the fall planted to other (mostly annual) crops in the spring or summer. Remote sensing classification of these 16 major cropping practices was conducted at an average accuracy of 83% over a three-year period (harvest years 2005, 2006, and 2007) for nearly the entire Willamette River Basin using images from Landsat and MODIS satellites trained with the 16 cropping practices from the ground-truth GIS. Division of the agricultural landscape into disturbed ground versus permanent crops was done for each year by grouping established stands of perennial seed crops with pasture, hay crop, and peppermint as permanent cover. The remaining nine classes of the remote sensing classifications were viewed as disturbed ground. Division of the landscape into disturbed ground versus permanent crops had an average accuracy of 93% in our remote sensing classification. Permanent tree cover over the same spatial footprint was defined on the basis of late summer, normalized differential vegetation index for the period from 1992 through 2003 (unpublished data). Pixels neither classified as trees nor as one of the 16 cropping practices were assigned values based on an unpublished 56-category classification for 2008, which relied in large part on the 2001 National Land Cover Dataset (NLCD) (Homer et al. 2001). Our classification methods caused NLCD open water and wetland classes to be divided up among forested, agricultural, and urban land use categories. Because of the preponderance of forests and agriculture in the Calapooia River basin, regression models would generally only run with either percentage forest or agriculture in them, but not both, due to collinearity.

Weather Data. Daily weather observations were made at the nearby National Weather Service Cooperative Observer weather station at the Hyslop Crop Science Field Laboratory located 10 km (6 mi) northeast of Corvallis, Oregon. This station was 4.2 km (2.6 mi) NW of the nearest edge of the Calapooia River Basin boundary, 29 km (18 mi) from the center of the 40 subbasins, and 36 km (22 mi) from the center of the entire basin. Additional data were obtained using portable weather stations placed in multiple fields within the agricultural cropping area of the Calapooia River Basin. Most portable stations changed location from year to year and provided weather data over a total of 12 site-years for the period from January 2003 through January 2007. The portable stations recorded rainfall at 15- or 30-minute intervals, and these data were composited into 24-hour daily totals ending at 8 a.m. to match the official weather station methods. Based on the number of weather stations active any single day, rainfall was interpolated to the subbasin centroids using inverse distance weighting.

Statistical Procedures. Associations among variables were tested using simple linear correlation, ordinary least squares (OLS) regression, and analysis of variance. All land use classes were analyzed as areal percentages per subbasin rather than the raw, nonnormalized areas. Characterizations presented in the study include seasonal patterns quantified by Fourier time series analysis and regressions of individual sample N form (total, NO_3^-, NH_4^+, and dissolved organic N [DON]) and sediment concentrations versus subbasin tree cover, slope, and agricultural practice categories. Agricultural cropping practices (i.e., the 16 remote sensing classification categories) were analyzed individually and composited into groups using either of two different methods. The first method was the contrast of low and high physical disturbance levels over each cropping year previously described under the "land use determinations" section. The second method was grouping of agricultural cropping practices on the basis of similarity among their linear correlations for water quality parameters versus percentage of subbasin area devoted to each crop. Specific cropping practices grouped on this basis are listed below in the "Associations between Land Use Factors and Total Nitrogen" section.

Some analyses were conducted over the entire 40-month sampling period, while others were restricted to single cropping years. For total N, separate regressions were conducted across all available subbasins on each sampling date, along with regressions that pooled samples for high flow periods in which data from either 39 or all 40 sites were available. Missing sites in these cases either represented inaccessible conditions or sampling error rather than true absence of streamflow. In addition to the correlations and regressions explored for total N, we also tested relationships of sediment with total rainfall over periods of 1 to 14, 17, 21, 28, and 35 days prior to sampling. Regression over all sampling dates of sediment concentration against rainfall in 4- and 14-day periods prior to sampling and percentage area in disturbed agriculture required substitution of the 2004 to 2005 growing season disturbance data for missing land use data from the 2003 to 2004 growing season. Oregon Seed Extension totals in Linn County for acreage of various crops were highly similar in both the 2004 and 2005 harvest years, with changes of only +1%, +1%, +3%, and −2% in acreage of Italian ryegrass, perennial ryegrass, tall fescue, and orchardgrass, the four main grass seed crops.

A separate approach for identifying similarities among subbasins used Fourier time series analysis of the total N or sediment data at each site, followed by grouping of the sites on the basis of similar time series behavior. Within the general groups identified on the basis of Fourier analysis of total N at individual sites, we conducted Fourier analysis of the pooled data along with additional regression variables. After the best set of variables for OLS regression was identified, we conducted geographically weighted regression (GWR) (Fotheringham et al. 2002; Mitchell 2005) using ArcGIS Modeling Spatial Relationships Toolset (ESRI 2010) to test for the presence of spatial autocorrelation within our variables. GWR was conducted using the default neighborhood distance and the adaptive kernel option. GWR was used to calculate separate regressions in the neighborhoods of each point, either validating the results of OLS or showing that regression coefficients were not stable over space.

Results and Discussion

Precipitation and Streamflow Patterns. Rainfall in western Oregon typically peaks in December, with a monthly average of 181 mm (7.13 in), and then slowly declines to an average minimum of 9 mm in August (figure

Figure 2

Monthly rainfall totals at the official Hyslop weather station for time periods of interest. Solid line is second degree Fourier series approximation for the 116-year period from 1890 to 2005, calculated on average monthly totals and dates, with r^2 = 0.987. Line of open circles is second degree Fourier series approximation for the 40-month period of water quality sampling from October 2003 to January 2007, calculated on average monthly totals and dates, with r^2 = 0.923. Predicted values less than zero in August have been omitted from display in the 40-month graph. Each point on the Fourier curves represents the predicted rainfall totals for a period from 0.5 month before to 0.5 month after the date. Solid circles, small squares, triangles, diamonds, and large squares are observed monthly rainfall totals from 2003 (October to December only), 2004, 2005, 2006, and 2007 (January only).

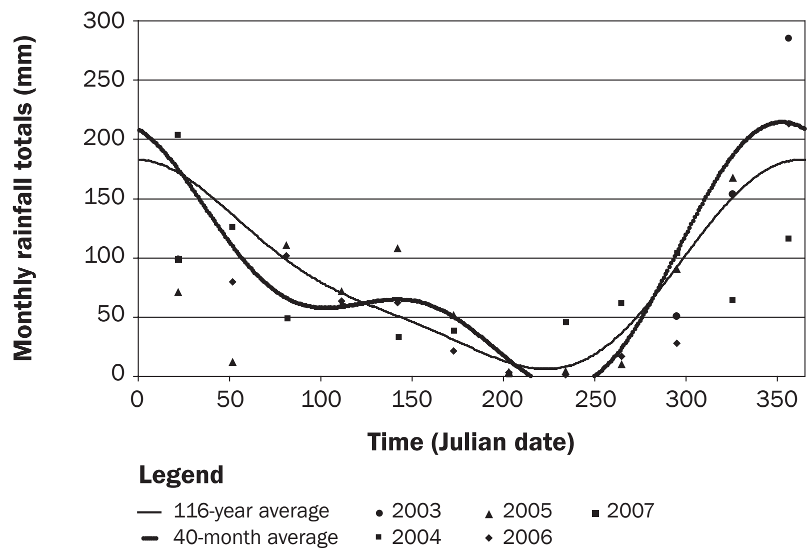


Figure 3

Monthly average discharge of the Calapooia River at Albany, Oregon, minus discharge at Holley, Oregon, for the period from January of 1971 through September of 1981. Solid line is third degree Fourier series approximation, calculated on monthly values averaged over the whole time period, with r^2 = 0.958. Triangles represent the observed monthly values. The gauge at Holley is upstream from the gauge at Albany and measures flow at the outlet of a heavily forested region comprising 38% of the total area of the Calapooia River Basin.

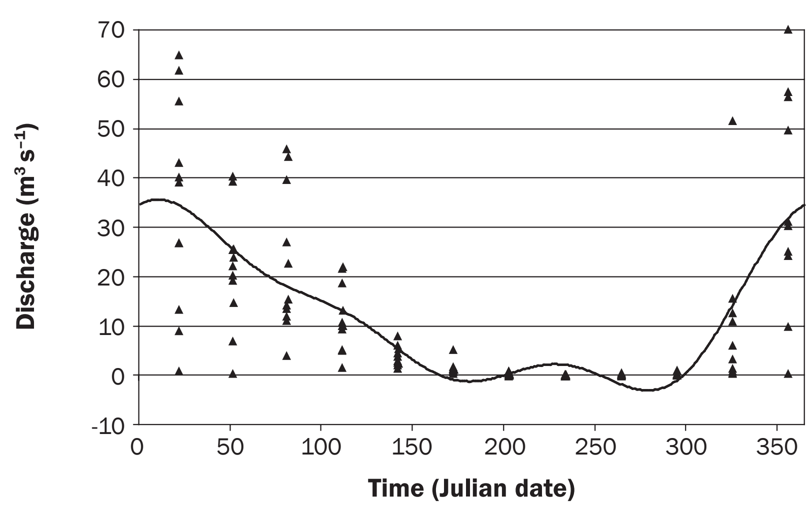
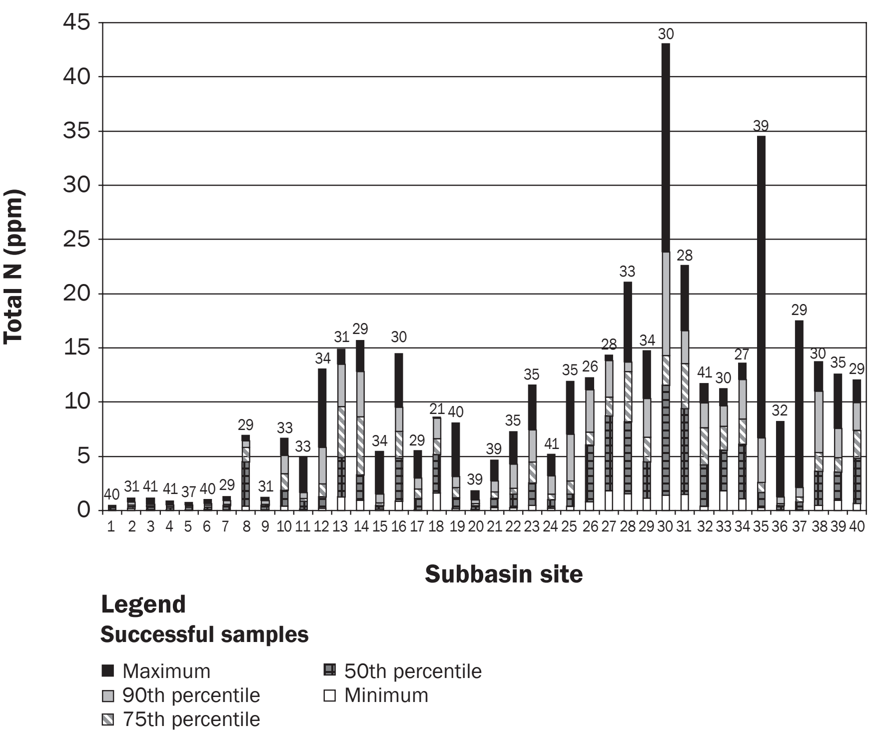


Figure 4

Total nitrogen (N) minima, maxima, and 50th, 75th, and 90th percentiles of the observed concentrations by subbasin, with count of successful sampling events above the bars. Minimum observed values are at the top of the open space at the bottom of each column while maximum observed values are at the top of the stacked bars in each column. Actual 50th, 75th, and 90th percentile values are at the top of each shaded region.



2). Over the sampling period from October of 2003 through January of 2007, precipitation averaged slightly above normal during late fall through early winter but near normal when viewed across the entire 40-month period. The 2004 through 2005 cropping year was drier than the preceding or following years, both of which experienced slightly above normal precipitation, especially during winter. The US Geological Survey operated two gauges on the Calapooia River until late 1981, and the difference in discharge between the downstream station at Albany and the upstream one at Holley illustrates typical streamflow patterns seen in the region (figure 3). The general curve for streamflow closely matches the average rainfall pattern, with a slight delay in winter caused by accumulating snowpack at higher elevations. The raw monthly streamflow data, however, showed extreme variation during winter and early spring, with flows approaching zero in some years and reaching twice normal in other years. Flow can be even more erratic in ephemeral streams whose headwaters lie in agricultural fields, and the number of successful water quality samples ranged from a low of 21 to a high of 41 over the 40-month period of our study (figure 4). Streams ran almost continuously at 10 of the sites, with an average of less than one sample missed, whereas an average of 10 samples were missed at the other 30 sites, most commonly those attempted in August, September, and October. The strong seasonality of streamflow in western Oregon imposes serious limits on our ability to interpret nutrient or sediment concentrations in our samples as implying total load exported from subbasins. However, if peaks in concentration occur nearly simultaneously with peaks in streamflow (using rainfall as a proxy), differences in concentration among subbasins in the winter can be reasonably interpreted as differences in load. A more rigorous treatment of this subject will await publication of results from using SWAT.

Variation among Subbasins. Subbasins ranged in area from 3.13 km^2 (1.21 mi^2) for site 8 (an unnamed ephemeral stream east of the city of Brownsville) to 167.1 km^2 (64.52 mi^2) for site 29 (Shedd Slough located on the west side of the Calapooia mainstem, including nested, upstream subbasins 19, 20, 21, 22, 23, 24, 25, and 30) (table 1). The average full area of subbasins was 28.48 km^2 (11 mi^2), while the average local area (after discounting overlapping of the nested, upstream subbasins) was 13.87 km^2 (5.35 mi^2). Average slopes within subbasins ranged from 19.3% for site 5 on West Brush Creek to 1.3% for site 23 on Spoon Creek, with an overall average of 6.1%. Area devoted to agriculture ranged from 100% for site 34 on Lake Creek to 4% at site 1 on the North Fork Calapooia near the eastern extent of the Calapooia River basin. The remaining 96% of area at site 1 was forested. Agriculture occupied an average of 63.7% of subbasin areas. Forests occupied an average of 35.5%, and urban development constituted the remaining 0.8% of subbasin areas. Some wetlands and open water occurred within all three broad land use classes. Disturbed agricultural land ranged from lows of 0% at certain subbasins to highs of 59%, 79%, and 83% in the 2005, 2006, and 2007 harvest years at sites 13, 18, and 40.

The number of successful sampling events ranged from highs of 41 at three sites to a low of 21 at site 17, with an average of 33 successes during the 40-month period (figure 4). Because results of most analyses using NO_3^--N were highly similar to those for total-N, the NO_3^--N results are not reported separately. Minimum and maximum concentrations of total N over all sites and sampling dates ranged from 0.1 to 43 mg L^{-1}, with average minima and average maxima of 0.6 and 10.4 mg L^{-1}, respectively. Twenty out of 40 sites were below 10 mg L^{-1} total N (the threshold concentration we used as an arbitrary indicator of possible N impact on ecosystems) on all sampling dates. On average, only 7.3% of all samples exceeded this concentration. The extreme site was 30, with 53% of samples exceeding 10 mg L^{-1}. Subbasin 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 (USEPA 1994).

Concentrations of suspended sediment over all sites and sampling dates ranged from 0 to 248.9 mg L^{-1}, with average minima and maxima of 1 and 120.6 mg L^{-1}, respectively (figure 5). Only 2 of the 40 sites had

Table 1

Subbasin physical properties, land use patterns, yearly variation in disturbed agricultural land, and nitrogen (N) impact groups.

Subbasin site	Sample location stream name	Subbasin outlet coordinates UTM 10N Easting (m)	Northing (m)	Subbasin area Entire (ha)	Local (ha) *	Upstream subbasins**	Average slope (%)	Land use areal extent Forest (%)	Agriculture (%)	Disturbed agricultural land by harvest year 2005 (%)	2006 (%)	2007 (%)
1†	North Fork Calapooia	546,705	4,898,270	1,536	1,536	none	18.91	95.8	4.2	1.1	1.1	1.1
2†	Johnson Creek	514,344	4,912,189	1,255	1,255	none	10.49	81.5	18.1	2.0	2.2	1.7
3†	Brush Creek	511,051	4,911,249	5,030	1,152	4, 6	8.30	83.5	16.1	0.9	0.5	0.1
4†	Brush Creek	514,282	4,907,478	1,947	1,947	none	13.54	95.4	4.6	0.4	0.0	0.0
5†	West Brush Creek	512,618	4,907,983	602	602	none	19.32	94.4	5.6	0.0	0.0	0.0
6†	West Brush Creek	512,850	4,909,352	1,931	1,330	5	14.35	90.4	9.5	0.5	0.2	0.0
7†	unnamed	509,461	4,912,513	412	412	none	12.34	91.7	8.3	4.5	4.5	4.5
8#	unnamed	506,661	4,913,431	313	313	none	8.33	44.8	55.2	16.3	31.7	27.1
9†	Warren Creek	505,369	4,915,020	1,836	1,836	none	12.11	81.7	18.1	2.4	2.4	2.4
10‡	Butte Creek	495,282	4,924,257	10,314	2,002	11, 12, 13, 16	4.45	37.0	62.6	29.0	27.2	29.3
11‡	Cochrane Creek	498,521	4,922,599	2,767	581	15	7.99	68.3	30.3	5.0	5.4	9.0
12§	Butte Creek	500,922	4,924,538	2,672	2,190	17	7.99	47.4	52.6	23.6	19.7	21.1
13§	Plainview Creek	496,911	4,924,715	1,540	845	14	2.47	1.9	98.1	58.7	49.3	45.3
14#	Plainview Creek	499,022	4,925,435	695	695	none	4.38	1.1	98.9	58.3	43.2	51.5
15#	Cochrane Creek	500,762	4,919,305	2,186	2,186	none	11.84	80.4	17.7	1.4	1.8	1.3
16§	unnamed	496,874	4,922,170	1,333	1,333	none	3.87	19.7	80.3	36.8	35.9	48.4
17‡	Butte Creek	503,042	4,925,393	482	482	none	8.08	17.4	82.6	6.5	16.6	14.5
18#	unnamed	495,279	4,925,146	432	432	none	1.55	0.5	99.5	57.2	78.9	41.8
19‡	Courtney Creek	493,043	4,919,118	14,235	3,795	21, 22, 23	1.71	27.8	71.7	36.4	27.1	34.4
20†	Courtney Creek	506,073	4,910,387	2,337	2,337	none	14.60	92.0	7.5	0.3	0.3	0.1
21‡	Courtney Creek	499,549	4,913,086	6,333	3,996	20	7.16	58.0	41.7	13.2	14.1	14.0
22‡	Spoon Creek	493,814	4,914,200	2,191	1,501	24	2.91	7.0	93.0	48.3	25.8	50.4
23§	Spoon Creek	493,821	4,913,069	1,916	922	25	1.31	2.7	97.2	58.3	38.6	48.2
24‡	Spoon Creek	495,432	4,912,013	689	689	none	5.19	15.6	84.4	43.0	33.5	42.3
25§	Spoon Creek	494,410	4,910,211	994	994	none	3.82	5.2	94.8	46.6	38.9	37.9
26#	unnamed	493,601	4,925,880	634	634	none	1.41	0.2	99.8	51.3	32.2	45.6
27#	unnamed	492,182	4,928,092	1,363	493	28	1.59	7.0	93.0	50.8	48.2	32.3
28§	unnamed	496,101	4,928,624	870	870	none	4.02	10.1	89.9	51.4	41.3	33.5
29§	Shedd Slough	490,545	4,926,347	16,710	1,540	19, 30	1.70	24.3	75.2	38.5	29.0	35.4
30#	unnamed	490,101	4,923,157	935	935	none	1.78	0.0	99.9	52.4	44.2	32.7
31#	unnamed	488,804	4,927,166	714	714	none	1.62	0.0	99.9	42.0	44.0	33.7
32§	Lake Creek	489,278	4,934,201	3,848	2,278	33, 34	1.72	1.8	96.5	44.5	33.2	40.0
33#	Lake Creek	494,097	4,931,339	720	720	none	1.41	0.2	99.8	53.4	51.7	33.2
34#	Lake Creek	492,659	4,929,573	851	851	none	1.57	0.0	100.0	38.1	21.8	27.2
35#	Oak Creek	491,012	4,938,891	8,978	2,820	37, 38	1.90	27.2	69.4	34.7	32.2	35.0
36#	Oak Creek	506,824	4,928,168	3,229	3,229	none	8.42	61.7	35.9	4.7	4.1	3.9
37§	Oak Creek	500,450	4,932,370	5,164	1,936	36	4.50	44.3	52.7	15.9	12.9	13.9
38§	Little Oak Creek	499,353	4,935,764	993	993	none	1.54	0.0	96.0	59.4	50.1	57.6
39§	unnamed	490,144	4,936,764	2,089	1,251	40	1.60	1.1	92.5	51.9	52.7	68.2
40§	unnamed	493,665	4,934,194	838	838	none	1.44	0.5	97.0	54.0	54.1	82.7
Mean				2,848	1,387		6.08	35.5	63.7	29.9	26.3	27.5

* Local area in nested subbasins is total area draining through subbasin outlet at sampling point minus area of any nested upstream subbasins also sampled.

† Low N impact with strong time series, type I.

‡ Medium N impact with strong time series, type II.

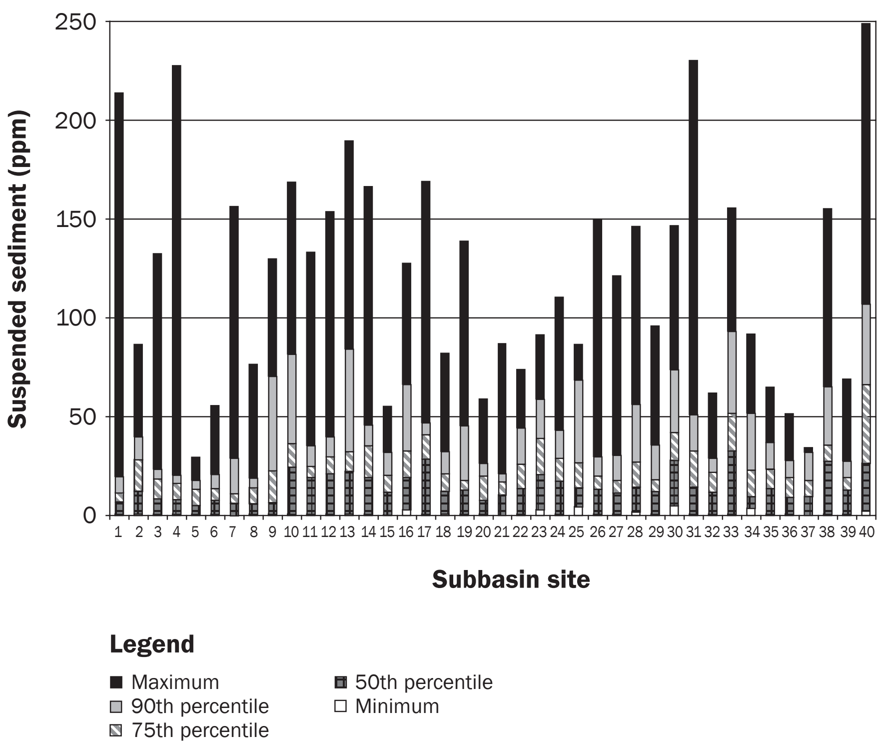
§ High N impact with strong time series, type III.

Very high N impact with weak time series, type IV.

** Identified by subbasin site number.

Figure 5

Suspended sediment minima, maxima, and 50th, 75th, and 90th percentiles of the observed concentrations by subbasin. Minimum observed values are at the top of the open space at the bottom of each column while maximum observed values are at the top of the stacked bars in each column. Actual 50th, 75th, and 90th percentile values are at the top of each shaded region.



suspended sediment concentrations below 50 mg L^{-1} (the upper end of the range among species reported by Newcombe and MacDonald [1991] for impact of sediment on salmonid behavior) 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 mg L^{-1}. The highest values of suspended sediment occurred on January 10, 2006, at 25 of the 40 sites. Heavy rainfall totaling 38.1 cm (15 in) at the official Hyslop weather station during the 23 days prior to this sampling date likely caused extensive stream bank failure.

Associations between Land Use Factors and Total Nitrogen. Regressions pooling late fall through late winter total N data achieved overall r^2 values of 0.740 and 0.811 in the 2004 to 2005 (six sampling dates) and 2005 to 2006 (five sampling dates) cropping years, respectively, when areal percentage of trees, seven pooled agricultural crops, and Italian ryegrass were used as explanatory variables (tables 2 and 3). These dates represented the only time periods in those two cropping years for which water was flowing at all sites. The seven pooled crops (i.e., disturbed ground planted to nongrass seed crops, established perennial ryegrass, established orchardgrass, established tall fescue, established clover, and fall-planted new stands of perennial ryegrass and clover) all had similar values for simple linear correlations of total N versus percentage subbasin area prior to being pooled (data not shown). All five of the grass seed crops in this pooled group would typically have received similar rates of spring-applied fertilizer, and the ground would be nearly bare of vegetation for all seven crops from late summer through midfall until rains arrived to either rejuvenate dormant oversummering perennial plants or germinate seeds.

When regressions were conducted at individual sampling dates, significance of the overall regression was lost for September 1 and September 24, 2004, August 25, 2005, and July 8, 2006, dates with many missing sites due to nonexistent streamflow. For regressions conducted at individual dates within the six and five sample collection dates pooled in the 2005 and 2006 harvest years, coefficients for trees were negative in all cases and significant at the $p \leq 0.05$ level in 9 of 11 cases. Coefficients for seven pooled agricultural crops were positive for all 11 sample dates and significant at the $p \leq 0.05$ level in 8 of 11 cases. Coefficients for Italian ryegrass were negative for 10 of 11 dates and significant at the $p \leq 0.05$ level in 6 of 11 cases. Sizes of the regression coefficients varied substantially between the two years, with the most stable values being the coefficients for the seven pooled agricultural crops. The positive sign of the coefficient for this variable indicates that higher percentage of land in these crops was linked to higher concentrations of total N in streams draining the subbasins. Similarly, the negative sign of the coefficients for the other two explanatory variables (trees and Italian ryegrass) indicates that higher percentages of land in these variables were linked to lower concentrations of total N in water.

Time Series Total Nitrogen Analysis. When Fourier time series analysis was conducted for total N at each site over all available sampling dates, several distinct patterns appeared. The overall Fourier analyses were significant at 28 of the 40 sites when conducted at third order, although significance could be also achieved for some of the remaining 12 sites if Fourier analysis was simplified down to second or first order (data not shown). Among the 28 sites with significant third order time series effects, peak total N values in the raw data reached up to 1.8 mg L^{-1} at the 9 sites we refer to as the low N impact, type I group (figure 6a). Peak total N values reached up to 8.1 mg L^{-1} at another 7 sites, which we refer to as the medium N impact, type II group (figure 6b). Peak total N values reached up to 21 mg L^{-1} at 12 sites, which we refer to as the high N impact, type III group (figure 6c). The 12 other sites (those with nonsignificant third order time series effects) also tended to have the largest total N concentrations, with values up to 43 mg L^{-1} in the type IV group (figure 6d). When pooled data for each of the four groups were subjected to Fourier analysis, the time series responses were significant at the $p \leq 0.001$ level for groups I, II, and III. The time series response of the pooled group IV sites was significant at the $p \leq 0.01$ level, despite the lack of significance in all 12 individual sample sites that made up this pooled group. Ratios of the predicted maxima to

Table 2

Regression across subbasins of total nitrogen (N) versus areal percentage of trees, seven pooled agricultural crops, and Italian ryegrass for 2004 to 2005 cropping year.

Sample collection dates	Overall regression statistics: Number of sites	r^2	*F* value	Coefficients and significance level: Intercept	Trees	Seven pooled agricultural crops*	Italian ryegrass
Nov. 30, 2004 through Mar. 10, 2005	40	0.740	34.1d	3.675c	−0.0388c	0.0856d	−0.0452a
Sept. 1, 2004	17	0.404	2.9 NS	0.892 NS	−0.0053 NS	0.0263 NS	−0.0017 NS
Sept. 24, 2004	19	0.264	1.8 NS	−0.440 NS	0.0135 NS	0.1405a	0.0107 NS
Nov. 4, 2004	35	0.376	6.2b	2.918 NS	−0.0244 NS	0.0814a	0.0236 NS
Nov. 30, 2004	39	0.412	8.2c	2.445a	−0.0226 NS	0.0347 NS	0.0138 NS
Dec. 16, 2004	39	0.697	26.8d	6.360c	−0.0712b	0.1621d	−0.0810 NS
Jan. 11, 2005	40	0.726	31.8d	4.760c	−0.0498b	0.1248d	−0.0656a
Jan. 25, 2005	40	0.723	31.3d	5.975d	−0.0665c	0.1121d	−0.0865b
Feb. 10, 2005	40	0.705	28.7d	4.536c	−0.0486c	0.0957d	−0.0663b
Mar. 10, 2005	39	0.476	10.6c	1.948 NS	−0.0165 NS	0.0675c	−0.0283 NS
Mar. 31, 2005	40	0.668	24.1d	4.612b	−0.0508a	0.1559d	−0.0612 NS
Apr. 14, 2005	40	0.567	15.7d	7.074c	−0.0816b	0.1071b	−0.0836 NS
Apr. 28, 2005	40	0.649	22.2d	4.321c	−0.0475b	0.0858d	−0.0812b
May 26, 2005	40	0.370	7.1b	2.345 NS	−0.0246 NS	0.2008c	−0.1125 NS
June 30, 2005	39	0.619	19.0d	0.895b	−0.0071 NS	0.0304d	−0.0120 NS
July 26, 2005	32	0.627	15.7d	−0.025 NS	0.0044 NS	0.0620d	0.0029 NS

Note: Letters represent significance levels: a is for $p \leq 0.1$, b is for $p \leq 0.05$, c is for $p \leq 0.01$, and d is for $p \leq 0.001$ for overall regressions and individual regression coefficients. NS denotes nonsignificance.

* Disturbed ground planted to nongrass seed crops, established perennial ryegrass, established orchardgrass, established tall fescue, established clover, and fall-planted new stands of perennial ryegrass and clover.

Table 3

Regression across subbasins of total nitrogen (N) versus areal percentage of trees, seven pooled agricultural crops, and Italian ryegrass for 2005 to 2006 cropping year.

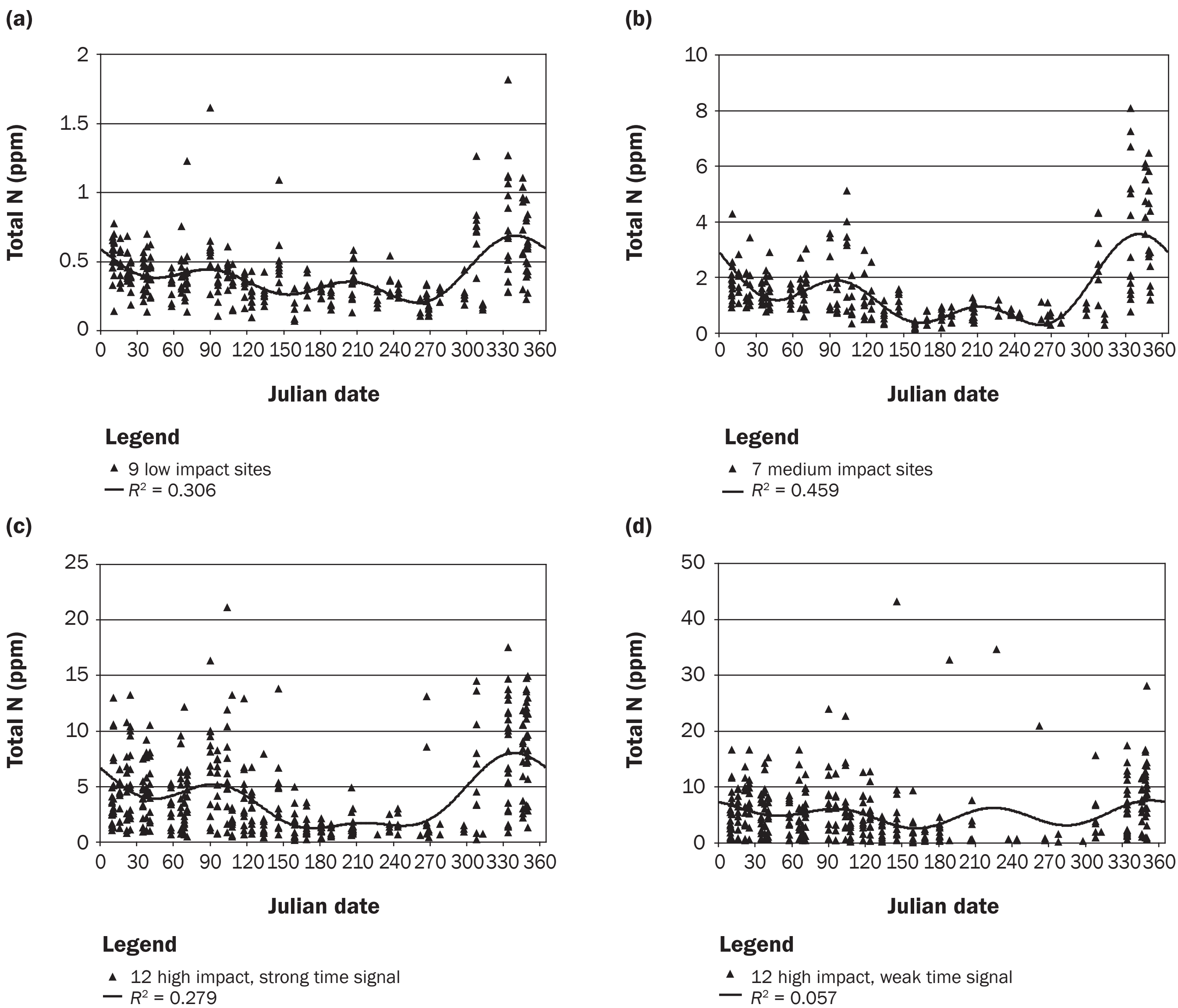
Sample collection dates	Overall regression statistics: Number sites	r^2	*F* value	Coefficients and significance level: Intercept	Trees	Seven pooled agricultural crops*	Italian ryegrass
Nov. 30, 2005 through Mar. 7, 2006	40	0.811	51.4d	7.988d	−0.0847d	0.0577c	−0.0806c
Aug. 25, 2005	16	0.282	1.6 NS	1.295 NS	−0.0089 NS	0.0036 NS	−0.0069 NS
Sept. 26, 2005	12	0.779	9.4c	1.822c	−0.0183b	−0.0301a	−0.0181a
Oct. 25, 2005	15	0.914	38.8d	1.087b	−0.0091b	−0.0015 NS	0.0026 NS
Nov. 30, 2005	39	0.725	30.7d	12.962d	−0.1327d	0.0356 NS	−0.0871b
Dec. 15, 2005	39	0.805	48.0d	12.251d	−0.1295d	0.0734c	−0.1145c
Jan. 10, 2006	40	0.633	20.7d	3.437d	−0.0330d	0.0194a	−0.0380c
Feb. 7, 2006	40	0.720	30.8d	3.702c	−0.0422b	0.1049d	−0.0403 NS
Mar. 7, 2006	39	0.661	22.8d	7.863d	−0.0898d	0.0627b	−0.1285d
Apr. 6, 2006	40	0.759	37.8d	3.990c	−0.0470c	0.0941d	−0.0369 NS
May 4, 2006	40	0.732	32.9d	1.952a	−0.0212 NS	0.1029d	−0.0388 NS
June 8, 2006	38	0.595	16.6d	1.239 NS	−0.0128 NS	0.0593d	−0.0461b
July 8, 2006	24	0.144	1.1 NS	13.152a	−0.1428 NS	−0.3670 NS	−0.1081 NS

Note: Letters represent significance levels: a is for $p \leq 0.1$, b is for $p \leq 0.05$, c is for $p \leq 0.01$, and d is for $p \leq 0.001$ for overall regressions and individual regression coefficients. NS denotes nonsignificance.

* Disturbed ground planted to nongrass seed crops, established perennial ryegrass, established orchardgrass, established tall fescue, established clover, and fall-planted new stands of perennial ryegrass and clover.

Figure 6

Total nitrogen (N) in mg L^{-1} (ppm) versus Julian date for (a) 9 low N impact sites, (b) 7 medium N impact sites, (c) 12 high N impact sites with strong time series signal, and (d) 12 high N impact sites with weak time series signal. Regression lines are from third degree Fourier series approximations of the four groups and are all significant at the $p \leq 0.001$ level, except for the high N impact weak time series group (d), which is significant at the $p \leq 0.01$ level. Predicted minima, maxima, and maximum:minimum ratios for regressions are (a) 0.2, 0.69, and 3.4; (b) 0.3, 3.56, and 11.84; (c) 1.24, 8.02, and 6.48; and (d) 2.62, 7.62, and 2.91. Minimum and maximum total N concentrations occurred on (a) September 17 and December 6, (b) September 18 and December 7, (c) June 23 and December 5, and (d) June 10 and December 19.

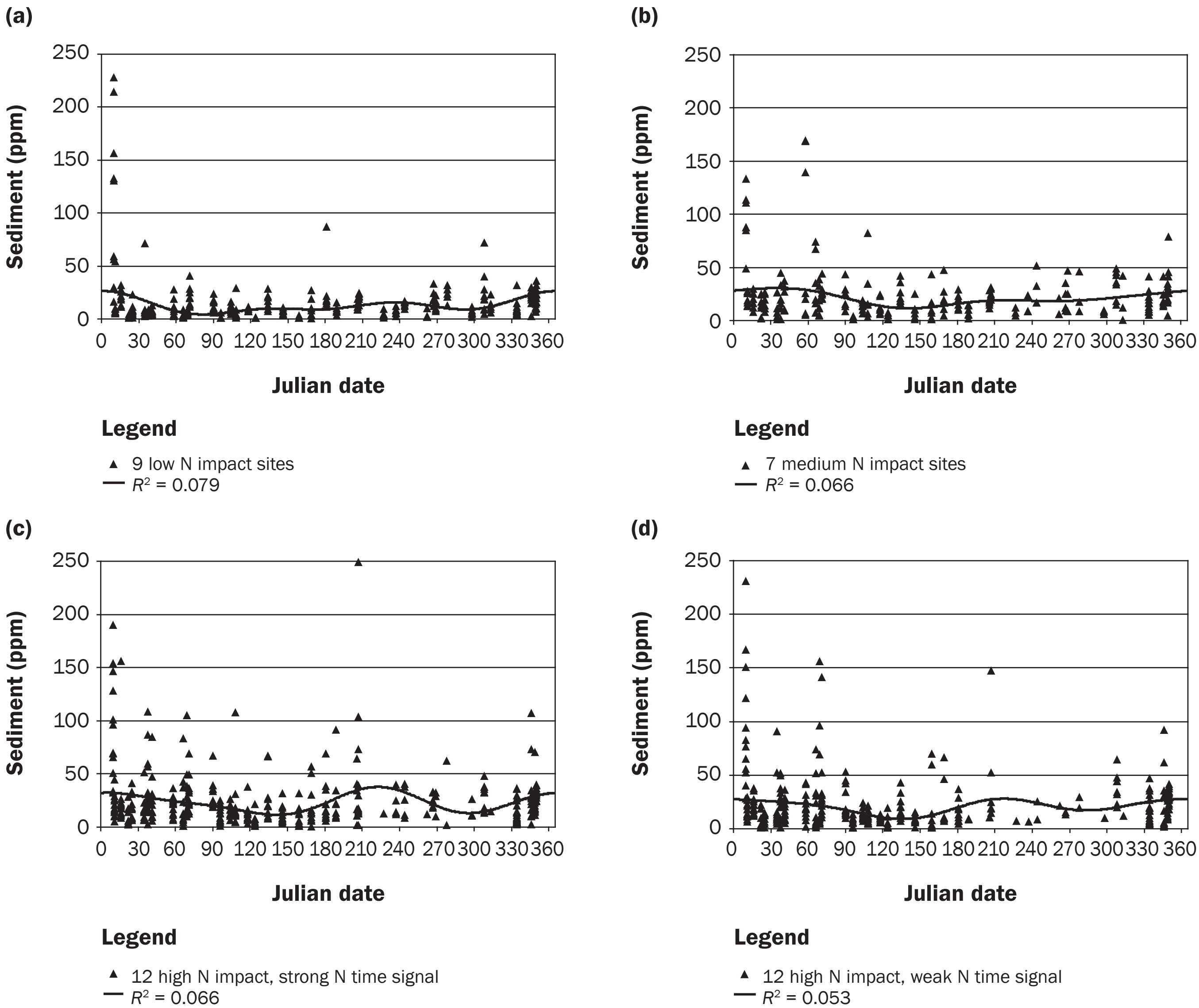


minima were 3.4, 11.84, 6.48, and 2.91 for Fourier analysis pattern types I, II, III, and IV. Predicted peak concentrations of total N occurred on December 6, December 7, December 5, and December 19 for types I, II, III, and IV. Predicted minimum concentrations of total N occurred on September 17, September 18, June 23, and June 10 for types I, II, III, and IV. Types I, II, and III possessed very similar temporal patterns, with major peaks in December followed by somewhat smaller peaks in early April and yearly minima in late summer.

The type I sites provide insight into the cyclical behavior of N in relatively natural ecosystems in western Oregon. Concentrations of total N were low, mostly below 0.5 mg L^{-1}, with a peak in very late fall representing the combined effects of mineralization of N during the late summer depletion of available (near-surface) soil moisture followed by a period of decreasing temperatures and increasing precipitation, which elevates the export of N from forests and grasslands. Timing of the NO_3^- concentration peak is the same as that reported on the Pudding River at Aurora, Oregon, in 1993 through 1995 (Wentz et al. 1998). After this N export peak, warming temperatures, increased plant growth and transpiration rates, and decreased rainfall intensity returned N losses to baseline levels for late winter and spring, and to even lower levels in summer

Figure 7

Sediment in mg L⁻¹ (ppm) versus Julian date for the same four groups of sites as categorized on the basis of total nitrogen (N) in figure 6. Regression lines are from third degree Fourier series approximations of the four groups and are significant at the $p \leq 0.001$ level for figures a and c, and at the $p \leq 0.01$ level for figures b and d. Predicted minima, maxima, and maximum:minimum ratios for regressions are (a) 4.3, 26.3, and 6.12; (b) 11.5, 30.5, and 2.66; (c) 11.6, 37.8, and 3.26; and (d) 9.1, 28, and 3.07. Minimum and maximum sediment concentrations occurred on (a) March 23 and January 1, (b) May 21 and February 5, (c) May 22 and August 11, and (d) May 16 and August.



when precipitation and streamflow diminished markedly.

The type II and type III sites differed from the type I sites mainly in the size of N fluxes. Vertical scales in figure 6b and figure 6c were increased by factors of 5-fold and 2.5-fold over those in figure 6a and figure 6b, respectively, in order to successfully display all the data. Predicted maxima increased from 0.7 mg L^{-1} for type I to 3.6 mg L^{-1} for type II and to 8 mg L^{-1} for type III, similar to the relative magnitude of y-axis scale changes needed for displaying data. One interpretation of the similarity in temporal patterns among types I, II, and III subbasins is that the major difference among them was simply how much extra N had been added to the system. Despite the substantially larger N fluxes in type II and III subbasins, the processes determining N retention or loss from the system presumably remained similar. Apparently this was not quite the case in the 12 subbasins showing type IV behavior. Even though there were smaller numbers of data points during the summer months than during the fall, winter, or spring months in figure 6d, all values exceeding 30 mg L^{-1} total N occurred between May and August. These large summer values were partially offset by the more numerous, lower values during the rest of the year, resulting in a very weak time series signal that described only 5.7% of the observed variation in total N in the type IV subbasins. The total N results for type III and IV subbasins were generally similar to findings from early studies of erosion and water quality in small, agriculturally dominated drainages in Polk County, Oregon, funded by the STEEP project (Harward et al. 1980). Those studies found highest concentrations of NO_3^- in runoff from wheat fields in late fall and early winter, declining concentrations in the spring, and occasional spikes in both NO_3^- and NH_4^+ ions during the first rainfall events following spring-time fertilization, with 120 to 140 kg ha^{-1} (107 to 125 lb ac^{-1}) N from ammonium nitrate.

Sediment Analyses. Simple linear correlations of suspended sediment concentrations vs. subbasin physical properties and land use patterns were lower than those calculated for total N (data not shown). The most promising relationship for sediment concentrations was a weak correlation with subbasin percentage of agricultural land disturbed within the current cropping year. Nevertheless, r^2 values for regressions of sediment concentrations from the six sampling dates pooled in the 2005 harvest year for total N and the five dates pooled in 2006 were only 0.232 and 0.125, respectively (data not shown). Because much of the variation in sediment concentration remained unexplained by the factors that were fairly strongly associated with total N, we considered other variables more likely to be associated with erosion of the soil surface and catastrophic failure of stream banks.

One such group of variables consisted of rainfall totals within defined numbers of days prior to the sampling dates. Simple linear correlation identified the strongest relationships with sediment for rainfall totals in periods of 4 and 14 days prior to sampling, although there were differences in the exact number of days for peak effect. Occurrence of these minor differences was based on whether we analyzed sediment over the full 40-month sampling period or conducted separate analyses for each growing season. Rainfall during the last day before sampling was poorly correlated in some years but strongly correlated in others, which may reflect whether the actual timing of rainfall events allowed runoff to reach the downstream sampling sites. Values of 4 and 14 days were optimal for peak correlations when the whole time period was used and were near the peaks when analyses were conducted within individual years. Such results were consistent with the findings of Harward et al. (1980) and Istok et al. (1985a and 1985b) that implicated saturated soil conditions during periods of prolonged rainfall events as the most important cause of soil erosion in western Oregon agricultural fields. They found that total rainfall during antecedent periods of 2 to 7 days possessed stronger relationships with sediment concentrations and total soil loss than precipitation amounts or intensity during the actual day of the runoff event.

As part of our attempts to understand variation in sediment concentrations, we conducted Fourier analysis of sediment over the entire 40-month sampling period for all individual sites and for pooled sites for each of the four N impact groups. Nearly all Fourier transformations for individual sites were nonsignificant (data not shown). When analyzed in the type I, II, III, and IV N impact groups, time series signals for sediment concentration were weak but significant in all four groups (figures 7a, 7b, 7c, and 7d). The range of values was similar for all groups, and so the y-axis scale was kept constant. All four groups displayed one peak in the winter, representing the primary peak for subbasin types I and II and a secondary peak for subbasin types III and IV. High rainfall, long-duration events common in western Oregon were the obvious cause for peaks during the winter, as reported previously by other researchers (Harward et al. 1980; Istok et al. 1985a and 1985b). Peaks that occurred in August for subbasin types III and IV likely had a different cause. One possibility is that they represent low flow conditions where sediment originated from physical disturbance of small stretches of stream channels (possibly by livestock) rather than surface erosion of soil across large field areas. The low N impact type I sites showed the strongest time series behavior in sediment concentrations, with predicted maxima and minima differing by a factor of 6.12-fold, nearly twice that found in the other three groups. The type I sites also showed the fastest decline in sediment concentrations, dropping from a peak on January 1 to a minimum on March 23. This limited duration of high sediment flows at the type I sites relative to the others is an example of the greater resiliency of a system less disturbed by tillage and other crop management practices.

OLS regression of sediment using independent variables of rainfall totals in 4- and 14-day periods prior to sampling along with percentages of agricultural land disturbed within each growing season provided higher r^2 values than those resulting from Fourier analysis (table 4 and figure 7). The coefficient for the 4-day prior rainfall total was 3.2 times the size of the 14-day prior rainfall coefficient, similar to the ratio of the number of days in the two periods (14:4 or 3.5 times). This similarity suggests that similar processes were at work over both time periods, presumably a mixture of surface erosion and stream bank failure. A GWR analysis using the same variables showed increased r^2 and decreased Akaike Information Criterion relative to OLS. When we changed from the default neighborhood method in ArcGIS to the adaptive kernel option, Akaike Information Criterion improved (i.e., it decreased). Compared to OLS, the average GWR intercept increased slightly (from 4.66 to 6.53), the average 4- and 14-day prior rainfall total coefficients remained nearly the same, and the disturbed agriculture coefficient increased by 3.2-fold (table 4). While many of the local GWR coefficients were similar to the global OLS coefficients, not all the local coefficients were significant. For the 4-day prior rainfall variable, none of the local coefficients had signs opposite to the OLS results, and 260, 326, and 694 of them were significant at the $p \leq 0.05$, 0.10, and 0.20 levels, respectively. For the 14-day prior rainfall variable, none of the local coefficients had signs opposite to the OLS results, and 376, 531, and 730 of them were significant at the $p \leq 0.05$, 0.10, and 0.20 levels, respectively. The somewhat higher numbers of significant coefficients for the 14-day prior rainfall variable suggests that it may be a slightly more reliable predictor of suspended sediment than the 4-day prior rainfall variable. In OLS regression, Student's t-test for the 14-day prior rainfall variable was a little higher than for the 4-day prior rainfall variable (5.37 vs. 4.73), although both were significant at $p \leq 0.001$. Results for the disturbed agriculture coefficient in GWR were less stable than those for the prior rainfall variables. The sign of the disturbed agriculture coefficient changed from positive in OLS regression to negative in GWR in 293 of the 1,368 cases, although none of the negative coefficients were significant at the $p \leq 0.05$ level. Positive coefficients were significant in 292, 292, and 395 cases at the $p \leq 0.05$, 0.10, and 0.20 levels, respectively. Negative coefficients were significant in 31 and 201 cases at the $p \leq 0.10$ and 0.20 levels, respectively. The spatial variability in the disturbed agriculture coefficients for GWR suggests that other (as yet unmeasured) variables might improve predictions of sediment

Table 4

Ordinary least squares and geographically weighted regression with adaptive kernel option across subbasins and time of suspended sediment versus rainfall totals 4 and 14 days prior to sampling and areal percentage of annually disturbed agricultural land.

	Overall regression statistics			Coefficients and significance level			
Method*	Akaike information criterion	r^2	*F* value	Intercept	4-day prior rainfall	14-day prior rainfall	Disturbed agriculture†
OLS	12,117.5	0.195	107.2c	4.661c	0.4552c	0.1419c	0.1998c
GWR_{mean}	12,069.7	0.292	182.1c	6.530	0.4782	0.1358	0.6363
$GWR_{0.05}$	—	—	—	382 (>0), 59 (<0)	260	376	292
$GWR_{0.1}$	—	—	—	450 (>0), 94 (<0)	326	531	292 (>0), 31 (<0)
$GWR_{0.2}$	—	—	—	623 (>0), 135 (<0)	694	730	395 (>0), 201 (<0)
Number of observations = 1,328							

Note: Letters represent significance levels: a is for $p \leq 0.05$, b is for $p \leq 0.01$, and c is for $p \leq 0.001$ for overall regressions and individual regression coefficients.

* GWR calculates separate regressions for all individual data points. The row labeled GWR_{mean} contains the global r^2 value and averages of all 1,328 local regression coefficients. The rows labeled $GWR_{0.05}$, $GWR_{0.1}$, and $GWR_{0.2}$ contain counts of the number of times the individual regression coefficients passed Student's *t*-tests for significance at the p = 0.05, 0.1, and 0.2 levels, respectively. In cases where some of the statistically significant local coefficients were negative (and of opposite sign to the GWR_{mean} and OLS coefficients), counts of those that were positive are followed by (>0) while counts of those that were negative are followed by (<0).

† Because we only possessed partial information on cropping practices in the first (2003 to 2004) growing season, we substituted subbasin averages for agricultural disturbance from the 2004 to 2005 growing season for the missing data.

Table 5

Regressions among the four nitrogen (N) impact subbasin types of total N versus Fourier transformation of Julian date, areal percentage of trees, seven pooled agricultural crops, Italian ryegrass, and rainfall totals for 4 days prior to sampling.

	Overall statistics			Regression coefficients and significance levels									
				Fourier series components									
N impact subbasin types	r^2	*F* value	Intercept	Semi-amplitude A_1	Phase angle θ_1 (days)	Semi-amplitude A_2	Phase angle θ_2 (days)	Semi-amplitude A_3	Phase angle θ_3 (days)	Trees	Seven pooled agricultural crops	Italian ryegrass	4-day prior rainfall total
All types	0.455	109.9e	3.757e	1.383e	−0.5 NS	0.297 NS	−72.0e	0.839c	−68.3e	−0.039e	0.082e	−0.043e	−0.019c
I	0.377	24.2e	1.130e	0.104e	−2.8a	0.071c	−44.1e	−0.085 NS	−91.8e	−0.008e	NA*	NA*	0.004e
II	0.531	27.1e	3.325e	0.946e	1.7a	0.524a	−59.5e	0.664 NS	−78.2e	−0.025e	−0.067e	−0.025e	0.010a
III	0.448	31.2e	2.785e	2.804e	10.6 NS	1.154 NS	−81.1e	1.151 NS	−83.2e	−0.024c	0.106e	−0.040e	−0.033c
IV	0.318	16.0e	9.071e	1.431b	−53.6e	0.990a	106.6 NS	1.544c	−46.2d	−0.106e	0.032b	−0.112e	−0.042b

Note: Letters represent significance levels: a is for $p \leq 0.2$, b is for $p \leq 0.1$, c is for $p \leq 0.05$, d is for $p \leq 0.01$, and e is for $p \leq 0.001$ for overall regressions and individual regression coefficients. NS denotes nonsignificance. *F*-test of full versus reduced regression models was 6.37, with 27 and 1,286 degrees of freedom, significant at the $p \leq 0.001$ level.

* NA indicates that variables were not included in regression due to absence of useful variation among the type I subbasins.

concentration as a response to land use and agricultural production practices.

Time Series Effects and AgronomicFactors on Nitrogen and Sediment. To better understand the roles of land use patterns and agronomic practices on N fluxes, we combined Fourier time series analysis with regression of factors that had influenced total N or sediment in analyses without temporal factors. In addition to areal percentage of trees, seven pooled agricultural crops, and Italian ryegrass, rainfall totals in the 4 days prior to sampling had a significant negative effect on total N when analyzed over all subbasins in combination with Fourier analysis (table 5). Addition of land use and agronomic practices changed values of the Fourier time series coefficients, but the Fourier amplitude and phase-angle factors with the greatest statistical significance showed the smallest changes. Coefficients for trees, seven pooled agricultural crops, and Italian ryegrass maintained the same arithmetic signs they possessed in the regressions without a Fourier component in all cases, except the seven pooled agronomic crops for the type II subbasins. We were unable to include the seven pooled crops or Italian ryegrass in analysis of the type I subbasins because of the total absence of Italian ryegrass and the near total absence of the seven pooled crops within those subbasins. Coefficients for trees, seven pooled agronomic crops, and Italian ryegrass from regressions over all subbasins and dates (table 5) were more similar to those from the continuous flow periods of the 2005 harvest year (table 2) than of the 2006 harvest year (table 3). The negative sign of coefficients for 4-day prior rainfall in regressions over

Table 6

Regressions among the four nitrogen (N) impact subbasin types of sediment versus Fourier transformation of Julian date, areal percentage of annually disturbed agricultural crops, and rainfall totals for 4 and 14 days prior to sampling.

	Overall statistics			Regression coefficients and significance levels								
				Fourier series components								
N impact subbasin types	r^2	*F* value	Intercept	Semi-amplitude A_1	Phase angle θ_1 (days)	Semi-amplitude A_2	Phase angle θ_2 (days)	Semi-amplitude A_3	Phase angle θ_3 (days)	4-day prior rainfall total	14-day prior rainfall total	Annual disturbance agriculture
All	0.224	42.2e	5.182e	5.577a	–132.8e	5.589b	71.1e	1.496 NS	–42.7 NS	0.531e	0.140e	0.214e
I	0.281	15.7e	3.121b	6.627a	–128.9e	3.199b	29.4 NS	3.230b	17.9 NS	0.501d	0.180e	Omit*
II	0.294	14.4e	13.289e	2.065 NS	–134.2 NS	4.586 NS	82.8c	1.512 NS	116.2 NS	1.176e	Omit*	Omit*
III	0.176	9.2e	2.678 NS	6.601 NS	–142.4c	9.723 NS	73.0e	4.455a	–48.6b	0.384b	0.140c	0.308d
IV	0.225	11.0e	3.882 NS	7.592 NS	–127.1b	6.178 NS	83.2d	1.896 NS	–100.1 NS	0.341b	0.179d	0.243e

Note: Letters represent significance levels: a is for $p \leq 0.2$, b is for $p \leq 0.1$, c is for $p \leq 0.05$, d is for $p \leq 0.01$, and e is for $p \leq 0.001$ for overall regressions and individual regression coefficients. NS denotes nonsignificance. *F*-test of full versus reduced regression models was 1.68, with 27 and 1,291 degrees of freedom, significant at the $p \leq 0.05$ level.

* Omit indicates that variables were not included in regression due to lack of significance when tested in regressions for type I or type II subbasins.

all subbasins and within just subbasin types III and IV can be interpreted as a signal of dilution of N by heavier rainfall. This effect was only apparent when the seasonal N pattern was already represented by Fourier time series. Rainfall totals in the 4 days prior to sampling affected sediment but not total N in simpler regressions conducted without the Fourier time-series factor.

The variables included in analyses for sediment that had been identified in regressions without a temporal factor (table 4) generally retained their significance when Fourier components were included (table 6). Rainfall totals in the period of 4 days prior to sampling were highly significant when analyzed over all subbasins and for subbasin types I and II, with marginal significance for subbasin types III and IV. The 14-day prior rainfall variable was significant in all cases except subbasin type II, and coefficients were generally close to their expected values of 28.6% of the 4-day coefficients. Effects of annually disturbed agriculture on sediment were significant in regressions over all subbasins and for subbasin types III and IV. Coefficients for annually disturbed agriculture were larger for subbasin types III and IV than they had been for regressions over all 40 subbasins.

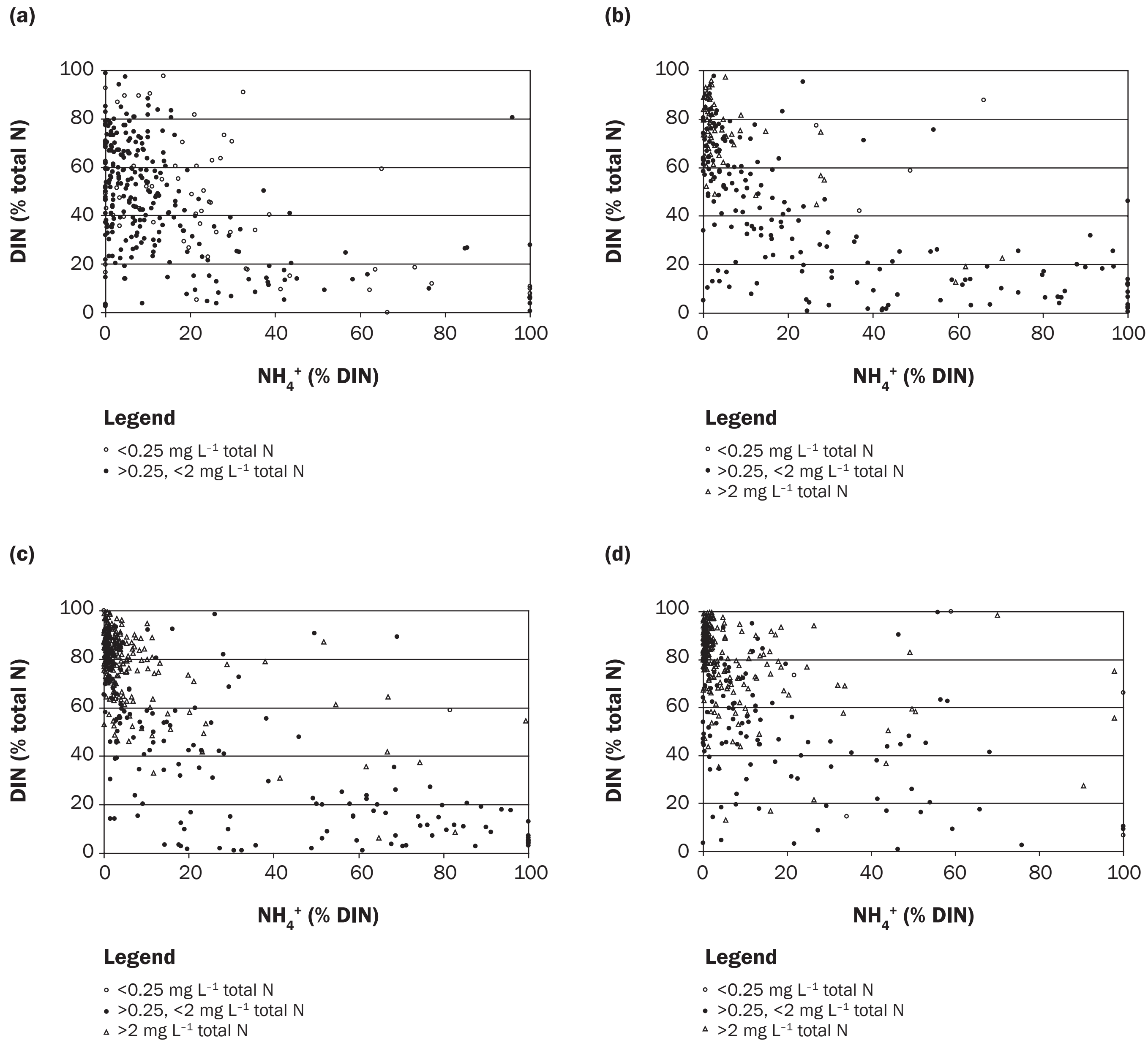
The temporal signal for DON as percentage of total N at type I sites was weak, with a minimum of 39% on December 31, a maximum of 69% on October 3, and r^2 of only 0.112 (data not shown). The temporal signal at Type II and III sites was strong, with predicted maxima near 92% on September 5 and August 19, predicted minima of 23% and 17% on December 22 and December 31, and r^2 values of 0.451 and 0.462 (data not shown). We interpret the strong temporal signal in DON at the type II and III sites as the combined result of two processes: (1) the dilution of biological sources of DON by high levels of NO_3^- in the winter and (2) the appearance of urea-based fertilizer sources of DON in the rest of the year, especially spring.

As a final method to identify and characterize the sources of N present in the Calapooia River basin, we graphed the relationship among N components as NH_4^+ percentage of dissolved inorganic N (DIN) on the x-axis versus DIN percentage of total N on the y-axis for each of the four subbasin types (figures 8a, 8b, 8c, 8d). For each of the figures, we identified points that fell within three broad classes of total N concentrations (i.e., <0.25, >0.25 and <2, and >2 mg N L^{-1}). For type I sites, the preponderance of samples fell between 20% and 80% DIN of total N and 0% to 20% NH_4^+ of DIN (figure 8a). By our definition of type I sites, none of the samples exceeded 2 mg total N L^{-1}. The major obvious change going from type I to type II sites was the increased prevalence of samples high in NO_3^- and low in NH_4^+ and DON (figure 8b). Many of the points clustering in the >60% DIN of total N and <10% NH_4^+ of DIN region of the graph represented samples with high total N concentrations. Comparing graphs for the type III versus type II sites, even more of the samples were clustered in the high NO_3^- and low NH_4^+ and DON region, with a preponderance of points exceeding 70% DIN in total N and less than 5% NH_4^+ in DIN (figure 8c). Individual high total N samples were scattered across most of the graph. The primary change going from type III to type IV sites consisted of an even greater concentration of points in the high NO_3^- and low NH_4^+ and DON region of the graph (figure 8d). Several of the >2 mg N L^{-1} total N samples from the type IV sites fell in the >90% NH_4^+ in DIN region of the graph, likely a result of livestock access to those streams during periods of low flow in the spring and summer. It is likely that these highest NH_4^+ concentration sites were not the highest exporters of NH_4^+ due to large seasonal variation in rainfall and streamflow.

Associations between Land Use Factors and Total Nitrogen. The lower concentrations of N associated with Italian ryegrass were likely due to agronomic practices commonly used to produce this crop. Most stands of Italian ryegrass are not fertilized in the fall and are often fertilized at only relatively low rates in the spring. Secondly, this crop produces relatively high yields of straw (despite low fertilization rates), which are usually left in the field due to lack of interest in using the straw as animal feed. As a consequence, it is either incorporated into the upper 10 to 15 cm (4 to 6 in) of soil through shallow disking, flail chopped onto the surface, or trampled into the soil by sheep that graze the dense stands of volunteer seedlings that develop in multiple-year Italian ryegrass seed fields. Thirdly, Italian ryegrass is commonly grown on poorly drained soils that experience anaerobic, reducing conditions throughout much of the winter, a situation favorable for denitrification. Rates of denitrification enzyme activity measured in a grass seed field were as high as those in a nearby riparian zone, implying substantial ability to remove excess NO_3^- when soils become saturated in

Figure 8

Dissolved inorganic nitrogen (DIN) as percentage of total nitrogen (N) versus ammonium (NH_4^+) as percentage of DIN for the same four groups of sites as categorized on the basis of total N in figure 6. (a) Type I site N forms, (b) Type II site N forms, (c) Type III site N forms, and (d) Type IV site N forms.



the winter (Davis et al. 2008). The association of Italian ryegrass crops with lower N in water at subbasin outlets is of special interest given the common practice of grazing Italian ryegrass fields with sheep. The frequent presence of sheep within waterways that drain the fields would be expected to contribute manure-derived N to adjacent waterways. Our explanation is that lower rates of fertilizer, immobilization of N by decaying straw, and denitrification in waterlogged soils more than compensate for the contribution of N from manure.

The association of greater concentrations of N from the seven pooled crops could be attributed to a number of factors. Crops that involve late summer tillage and fall planting of small-seeded species risk surface runoff loss of NO_3^--N during rainfall events in the fall and winter until the new crop finally achieves canopy closure and an extensive root system. In addition to NO_3^- produced by mineralization promoted by tillage during seedbed preparation, low rates of N-containing fertilizer (11 to 17 kg N ha^{-1}) (10 to 15 lb N ac^{-1}) are commonly applied in bands during fall planting, and larger amounts of urea are broadcast-applied in late winter through midspring. Due to mineralization that occurs from June through October, established fields of perennial grasses grown for seed, such as perennial ryegrass, orchardgrass, and tall fescue, accumulate NO_3^--N in the soil that may not be taken up because these crops are relatively dormant until rains arrive in midfall. This mineralized N can be a significant source of surface and shallow ground water NO_3^--N during the late fall and early winter months that are characterized by relatively high amounts of precipitation in western Oregon (unpublished data). In addition to this natural source of N, low rates of fertilizer (17 to 34 kg ha^{-1}) (15 to 30 lb ac^{-1}) may be applied in the fall, followed by applications of 110 to 170 kg ha^{-1} (98 to 152 lb ac^{-1}) N in late winter through midspring (Canode and Law 1978; Loeppky and Coulman 2002; Young et al. 2003, 2004).

Time Series Total Nitrogen Analysis. Combined with knowledge of agronomic practices employed by many grass seed farmers, the relative absence of temporal patterns in total N measurements in type IV subbasins becomes surprisingly informative. The high N sampling events at a given type IV site did not recur on or near the same Julian date in other years because if they had, there would have been a significant time series effect. The largest fertilizer applications to grass seed crops must be made during the period from late February through early April in order to maximize crop yield (Nelson et al. 2006; Young et al. 2003, 2004). Fertilizer is seldom applied during the period from early November through mid-February because soils are usually too wet to support application equipment and to avoid the risk of losing large quantities of N to surface runoff (Nelson 2005). Even though our knowledge of the specific agricultural management practices applied to individual production fields was inadequate to fully characterize actions responsible for the sporadic fluxes of high N concentrations in type IV subbasins, the year-to-year inconsistency in timing implies either poor implementation of recommended management practices or the failure of recommended management practices to deal with extreme weather events. In either case, once the specific management practices and weather events responsible for the unusually high concentration of N have been identified, there is reason to believe they can be mitigated, effectively changing these subbasins from type IV into type III with regards to N transport. This change could reduce the average total N export from the former type IV subbasins by 24% (based on the intercept coefficients of Fourier analysis of type III and type IV groups) and likely have greater impact on reducing the highest concentration events.

Likely sources for episodic release of high concentrations of N from single fields could include the following: (1) direct application of fertilizer to water flowing through seasonal drainage ditches within fields that are dry enough outside of the ditches to support application equipment, (2) occurrence of heavy rainfall within the first few days after application of fertilizer, (3) decomposition of livestock carcasses located near seasonal drainages, and (4) application of manure or wastewater effluent. Since these sources should have differing proportions of NH_4^+, NO_3^-, and DON within their total N pools, we examined the full set of laboratory measurements of N and P species, dissolved organic C, and suspended sediment in the set of samples that constituted the highest 2% of total N content, reporting these 26 cases in table 7. Several of the 26 highest total N events showed clear signals of either NO_3^--based fertilizers or high rates of NO_3^--mineralization in the soil, with high levels of NO_3^- and low levels of NH_4^+ and DON (event ranking numbers 3, 8, 12, 16, 20, and 24). NH_4^+ concentrations exceeded NO_3^- only for the event ranking number 1 case, the extremely high total N measurement on May 26, 2005, in subbasin 30, which, as previously mentioned, included the town of Shedd, Oregon. Livestock were frequently present at this sample site, and the levels of N species correspond to typical components of bovine manure. Moderately high DON levels (>20% of total N) can be a consequence of recent application of urea-based fertilizers, and such conditions occurred in many of the highest 26 total N events (event ranking numbers 2, 5, 6, 7, 9, 10, 13, 14, 21, and 23). Only 1 of the 26 cases (event ranking number 18 at subbasin 31) was highly similar to the ammonium nitrate-fertilizer runoff event of March 23, 1978, reported by Harward et al. (1980). Replacement of ammonium nitrate by urea as the primary N fertilizer used in western Oregon explains the shift from the ammonium nitrate fertilizer signal occasionally found in water samples 40 years ago to the urea signal sometimes seen today.

Conclusions

The positive correlation between loss of total N from subbasins and production of seven common (mostly grass seed) crops suggests that farmers ultimately lose substantial fractions of their applied N. However, the preponderance of N in streams draining agriculturally dominated subbasins was in the form of NO_3^-, implying mineralization of N that had been cycled through plant growth in crop production systems. Sporadic occurrence of high total N and low NO_3^- surface water samples (especially within the subbasins most strongly impacted by N) suggests that urea-based fertilizers may sometimes be applied too closely in time to heavy rainfall or too closely in space to flowing water. Given recent increases in fertilizer prices, economic incentives to reduce N losses clearly exist. Because N use efficiency of western Oregon grass seed production (in cases where both straw and seed are harvested) already exceeds the worldwide average efficiency of 33% (and the developed-nations average efficiency of 42%) for cereal production (Raun and Johnson 1999), large gains in efficiency in grass seed may be challenging to achieve. Wide variation in total N concentrations, even among subbasins with over 90% of their land in agriculture, suggests that practices which avoid the highest N losses must exist locally. While the N impact patterns we defined as types II, III, and IV were all present in subbasins fully dominated by agriculture (from 93% to 100% of land in crops or pasture), type IV behavior was also seen in a subbasin with less than 18% agricultural land use. Even though livestock production was a relatively minor component of Calapooia River basin agriculture, some of the most dramatic reductions in N concentrations of surface water may well come from improvements in livestock management practices. Improved N management of crops will likely achieve small, incremental decreases in N export to streams, although more dramatic benefits may occur in a small number of cases.

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Table 7

Total nitrogen (N) ranking, subbasin site, N impact group, sample acquisition date, total N, ammonium nitrogen (NH_4^+-N), nitrate nitrogen (NO_3^--N), dissolved organic N (DON), dissolved organic carbon (DOC), ortho-phosporus (ortho-P), and total P for the highest 2% of samples in total N.

Total N rank	Subbasin site	N impact group	Date of sampling	Total N (mg L^{-1})	NH_4^+ (mg L^{-1})	NO_3^- (mg L^{-1})	DON (mg L^{-1})	DOC (mg L^{-1})	Ortho-P (mg L^{-1})	Total P (mg L^{-1})
1	30	IV	5/26/05	43.04	29.70	12.7	0.64	21.2	0.80	0.96
2	35	IV	8/15/06	34.50	0.02	21.7	12.78	28.5	0.01	0.37
3	35	IV	7/8/06	32.70	0.29	31.8	0.61	30.1	0.26	0.43
4	30	IV	12/16/04	28.03	3.70	19.7	4.63	28.9	0.79	0.97
5	30	IV	3/31/05	23.85	1.59	15.0	7.26	18.3	0.14	0.24
6	31	IV	4/14/05	22.60	6.65	6.5	9.43	29.9	0.06	0.17
7	28	III	4/14/05	21.06	1.84	13.8	5.42	13.2	0.04	0.07
8	35	IV	9/19/06	20.83	0.00	19.0	1.83	10.4	0.16	0.58
9	37	III	11/30/05	17.48	0.04	12.7	4.74	12.4	0.01	0.04
10	31	IV	11/30/05	17.37	0.12	13.1	4.15	16.5	0.12	0.16
11	30	IV	1/11/05	16.64	2.48	12.8	1.36	24.8	0.53	0.64
12	31	IV	12/15/05	16.63	0.06	15.5	1.07	16.8	0.09	0.14
13	31	IV	3/7/06	16.63	0.25	11.8	4.58	19.8	0.04	0.07
14	30	IV	1/25/05	16.56	1.95	10.3	4.31	30.5	0.61	0.98
15	28	III	3/31/05	16.27	0.09	13.1	3.08	9.5	0.04	0.11
16	30	IV	12/15/05	16.26	0.31	15.8	0.15	24.4	0.38	0.55
17	14	IV	11/4/04	15.64	0.01	12.8	2.83	10.7	0.16	0.17
18	30	IV	2/10/05	15.16	6.19	6.4	2.57	51.0	1.02	12.00
19	13	III	12/16/04	14.89	0.14	12.5	2.25	11.3	0.14	0.11
20	29	III	12/15/05	14.72	0.06	13.2	1.46	16.9	0.14	0.20
21	13	III	11/30/05	14.62	0.09	11.6	2.93	13.1	0.13	0.18
22	16	III	11/4/04	14.47	0.01	11.8	2.66	8.5	0.04	0.04
23	27	IV	4/14/05	14.30	0.61	10.2	3.49	14.4	0.03	0.06
24	30	IV	11/30/05	14.30	0.29	13.0	1.01	11.1	0.23	0.31
25	31	IV	12/16/04	14.28	0.02	12.0	2.26	14.9	0.07	0.11
26	31	IV	2/7/06	14.19	0.13	11.5	2.56	16.8	0.06	0.11

Notes: I = low N impact with strong time series. II = medium N impact with strong time series. III = high N impact with strong time series. IV = high N impact with weak time series based on Fourier transform analysis. DON = dissolved organic N; calculated by subtracting NH_4^+-N and NO_3^- -N from total N.

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