Seasonal Variations in River Flow and Nutrient Concentrations in a Northwestern USA Watershed

Anne Sigleo, Walter Frick

Abstract

Dissolved nutrient concentrations were measured in the Yaquina River, Oregon from 1998 through 2001 to determine nutrient loading from the watershed as part of a larger agency program for evaluating nutrient sources. The effects of storms on dissolved nutrient transport were investigated relative to stream discharge for three storm events, including one in a high rainfall-discharge year, and two in average years, one of which followed a drought year. During the drought year (no flows >25 m^3s^{-1}), total dissolved nitrate input was considerably less than in wetter years. However, dissolved nitrate concentrations were unusually high in the first winter storm runoff after the drought. In the November 2001 storm, dissolved nitrate increased rapidly (to nearly 200 µM) but decreased by 20 to 30 percent as the storm progressed. The dissolved nitrate nitrogen loads varied from 17,400 kg day^{-1} during high-flow storm events to less than 2.25 kg day^{-1} during late summer, low flow conditions. Dissolved silica dynamics were quite different and during storm events silica concentrations in the Yaquina River decreased to near zero at the storm height, probably due to dilution by rapid, shallow flow, and then recovered after 48 hours. During the time interval studied, over 94% of the dissolved nitrate and silica were transported during the winter months of greater rainfall indicating that seasonality and river flow are important determinants when considering nutrient loadings.

Keywords: nitrogen, silica, orthophosphate, river flow, Oregon

Introduction

The capability of rivers to export nutrients is controlled by water discharge, which in turn is a function of climate, topographic relief, water retention properties of the soils, and geologic structure of the basin. The hydrologic cycle controls the timing and volume of freshwater delivery to coastal ecosystems. Hydrographic input to Pacific Northwest rivers is related to seasonal variations in precipitation with mild wet winters and cool dry summers (Peterson et al. 1984). To estimate the effects of storms on nutrient mobility, the dissolved nutrients and suspended sediment loads were measured and compared with stream discharge in the Yaquina River, OR. This study comprises the watershed portion of a larger nutrient budget project for Yaquina estuary.

The specific objectives of this work were to determine the watershed input of dissolved nitrate, ammonium, phosphate, and silica, along with suspended and resuspended sediments in the Yaquina River. We were specifically interested in the variation of nutrient fluxes with respect to inter-annual variations in precipitation, along with the variation of dissolved nitrate, ammonium, phosphate and silica fluxes with water discharge. We were further interested in distinguishing between seasonal effects as compared to the effects due to variations in annual discharge.

Methods

Yaquina River and watershed

The Yaquina watershed (Figure 1) rises from sea level at Newport, Oregon to an elevation of 1249 m. The

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Sigleo is a Research Environmental Scientist, U.S. Environmental Protection Agency, Western Ecology Division, Newport, OR 97365. E-mail: sigleo.anne@epa.gov. Frick is a Research Oceanographer, U.S. Environmental Protection Agency, Ecosystems Research Division, Athens, GA 30605.

watershed has a surface area of 655 km^2 and an average elevation of 166 m. The primary land use is silviculture. The forests are dominated by conifers, although disturbed sites are frequently occupied by pioneer broad-leaved trees (Ohmann and Gregory 2002). Broad-leaved trees, predominantly red alder and broad-leaf maple, also occur in riparian areas along streams. The Yaquina River flow at Chitwood gage averages 6.2 m^3 sec^{-1}, although it can vary from 0.28 m^{3}sec^{-1} during late summer low flow conditions to >78 m^3 sec^{-1} during storm events. Typically discharge from rainfall is high in late fall and winter (November to March) and low to moderate the remainder of the year. The Yaquina River flows through the Tyee, Yamhill, Yaquina and Alsea Formations, as well as Quaternary alluvial deposits. The rocks of these formations contain massive to thinly bedded tuffaceous siltstones, sandstones, basalt breccias, and augite-rich tuff that are sources for silica and suspended sediment (Snavely and Wagner 1963). The soils generally are well drained with poorly developed horizons (Ohmann and Gregory 2002).

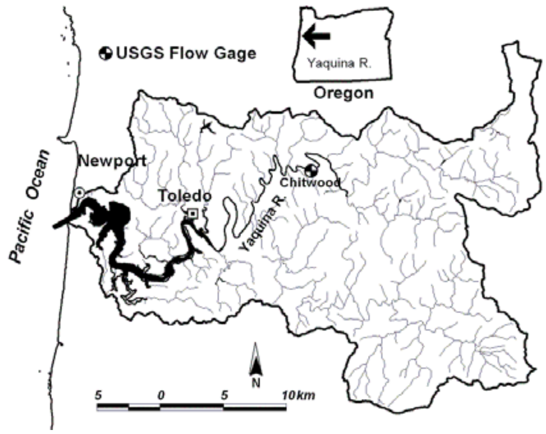

Figure 9. The Yaquina River watershed.

Sampling Methods

Water samples were collected weekly at USGS stream gage 14306030 (presently operated by Oregon Water Resources Department) near Chitwood, OR (Lat 44 39 29 N, Long 123 50 15 S) from September 1998 through December 2001. There were no high flows >25 m^{3}s^{-1} in the winter of 2000-2001 during a drought. In 2001, the first flood event of the fall-winter season was intensely sampled November 21-28. For suspended sediment determinations water samples (250 to 100 ml) were filtered through precombusted, preweighed glass fiber filters. Duplicate samples were analyzed gravimetrically for suspended sediment concentration and the results mathematically averaged. Filtered (Whatman 25 mm GF/F filters in a Gelman nylon filter holder) water samples (20 ml) were collected for dissolved nutrient analysis and frozen within an hour. Dissolved nutrients were analyzed by a contract laboratory (MSI Analytical Laboratory, U.C. Santa Barbara, CA) using a Latchet Autosampler for simultaneous determination of nitrite, nitrate + nitrite, ammonium, phosphate and silicate. Because nitrite comprised less than 1% of the nitrogen species at this site, it is not discussed further, and nitrate + nitrite will be treated as nitrate.

Specific conductance and temperature were measured with a YSI 30 conductivity temperature probe suspended in the water at the time the samples were collected. Dissolved organic carbon (DOC) was analyzed with an OI Model 700 TOC analyzer. Chlorophyll *a* was measured on a Turner 10-AU fluorometer.

Nutrient load calculations

The nutrient data were combined with hydrographic data to calculate suspended sediment and nutrient loadings from the surrounding watershed. Nutrient loads are a product of a nutrient concentration and the mass water flow. To calculate the amount of nutrient transported by the Yaquina River in a specified time period the following formula was used:

$$M = \sum_{i=\text{begin hour}}^{i=\text{end hour}} [\mathrm{x}]_i \, f_i \, \Delta t \qquad (1)$$

where *M* is the total mass of nutrient or suspended sediment transported at Chitwood in some specified time period beginning at begin hour and ending at end hour, the term X in brackets is the nutrient or suspended sediment concentration at hour *i*, f_i is the corresponding river flow rate, and Δt is the time interval (e.g., 3600 s) under consideration.

Results

River discharge during flood events of WY99 (water year October 1, 1998 to September 31, 1999) and WY02 (water year October 1, 2001 to September 31, 2002) peaked sharply followed by a gradual recession for seven to 10 days (Figure 2). The December 1998 and November 1999 storms were the largest storms for their respective water years. The second major storm of WY00 (December 1999) followed a major 50-year storm by approximately three weeks. In addition, this

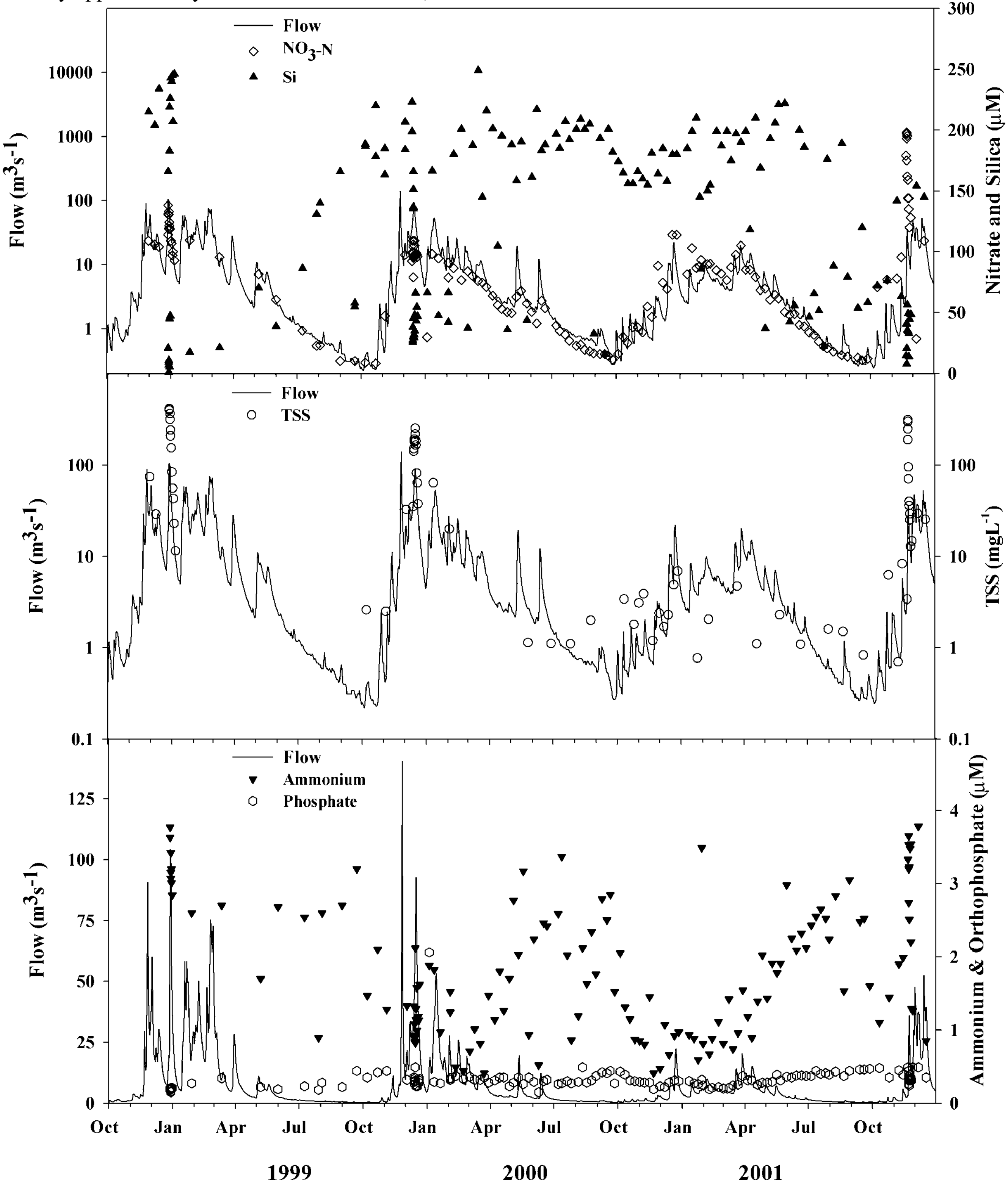

Figure 10. Nitrate, silica, TSS, ammonium, orthophosphate, and streamflow as functions of time, October 1999 – December 2001. Nitrate and TSS, on linear scales, may be compared to streamflow plotted logarithmically (top and middle panels) to emphasize potential functional relationships. In the bottom panel streamflow is plotted on a linear scale to illustrate the range in water flow.

storm contained two episodes of peak flow, the second being slightly larger than the first. There were no flood events in WY01.

Total suspended solids (TSS) ranged from 425 mg l^{-1} during the December 1998 storm to less than 1 mg l^{-1} during low flow summer conditions (Figure 2). The water temperature varied from 7.5 C in December to 20.3 C in July and August. Specific conductance varied from 69 to 114 □S, a range indicative of freshwater.

In the Yaquina River, dissolved silica concentrations increased from 120 □M (pre-storm) to over 270 □M in freshwater portions of the river during the rising hydrograph, decreased to near zero at the storm height and then recovered (Figure 2). During the late summers of 1999 and 2001, silica decreased by a factor of 4 suggesting biological utilization of that nutrient. During the summer of 2000, there was no apparent decrease in silica concentrations suggesting a surplus of dissolved silica relative to nitrate.

Overall the concentration of nitrate nitrogen varied by a factor of 20, with the lowest values coinciding with low river flow during September and early October (Figure 2). Dissolved nitrate increased rapidly during high flow events and then decreased by 20 to 30 percent as the storm progressed. During the drought year WY2001, total dissolved nitrate input was considerably less than in wetter years. Dissolved nitrate concentrations were unusually high (up to 195 □M) in the first winter storm runoff after the drought. After winter high flow events, nitrate decreased smoothly indicating biological utilization until the concentrations were reduced to 10 □M in late summer and early October.

Ammonium concentrations varied from 0.8 to 3.8 □M with the higher values occurring during winter storm events and late summer when heterotrophic activity is at its maximum. Phosphate ranged from 0.16 to 0.49 □M with the higher values tending to occur during winter, although high values also occurred in August and September of 2000 and 2001. The low phosphate variation suggests that phosphate is tightly cycled within the system (Molinero and Burke 2003). Dissolved organic carbon (DOC) values were generally between 1.5 and 3 mg l^{-1} with the highest values occurring in September and October during the fall phytoplankton bloom. Chlorophyll *a* varied from below the detection limit during December and January to over 6 □g l^{-1} in August.

Discussion

Silica

Dissolved silica concentrations were greatly decreased during storm events (Figure 3). Examination of Figure 3 indicates that the silica concentration decreased with the first rainfall, and decreased further still with the first storm of WY 02. When the storm effect subsided, silica increased to pre-storm concentrations. The apparent decline in silica concentrations is caused by dilution from rapid, shallow flow (Kennedy 1971). Generally rapid flow is minimal in forested systems. However, if surface soils are saturated, during intense rainfall near surface flow will become important. It is the rapid, shallow flow that is thought to dilute the older, base flow concentrations of silica (Kennedy 1971). This dilution effect at maximum flood also is observed in the California, Sacramento-San Joaquin system (Smith et al. 1985, Schemel and Hager 1986). Careful inspection of Figure 2 suggests that there was more silica draw down during the late summer after the drought.

Nitrate

Nitrate is highly soluble relative to silica, for example. As a result, the concentration of nitrate simply increases as water flow increases, and there is no apparent dilution (Hill et al. 1999). The source of nitrate appears to be from the surrounding watershed as suggested by the low conductivity water (average < 70 □S). Within the watershed, over 20% of the regional vegetation is classified as broad-leaf hardwood, and of that 20%, 90% consists of alder (Ohmann and Gregory 2002). Alder (*Alnus* spp.*)* forms a symbiotic relationship with the actinomycete *Frankia* spp. and together they are able to fix nitrogen from the atmosphere (Vogel and Gower 1998). In comparative studies of conifer forests with and without alder, the C and N content of the over story biomass, total vegetation, and forest soil were greater in conifer forests with alder than those without alder (Vogel and Gower 1998). In other words, the added nitrate from the presence of alder increased the overall productivity of the system. In addition, ^{15}N natural abundance studies further supported the premise that alder had increased the nitrogen budget by symbiotic diazotrophic nitrogen fixation (Vogel and Gower 1998). Other scientists also reported greater litter fall

N inputs in conifer stands with alder relative to those without alder (Binkley et al. 1992). Because there is a substantial amount of alder in the Yaquina watershed (Ohmann and Gregory 2002), it seems reasonable that decaying alder leaf litter provides a source of nitrate in this forested watershed.

Nutrient load calculations indicate that the annual nitrate load is directly related to river flow. Thus in high rainfall years, more nitrate is transported into the river from the watershed than in low rainfall years. During dry years, nitrate tends to build up in soils, largely as a result of reduced plant uptake, and is washed into streams at larger rates during subsequent wet years (Goolsby et al. 1999). This relationship is clearly seen for the WY02 flood in November 2001 (Figures 2 and 3).

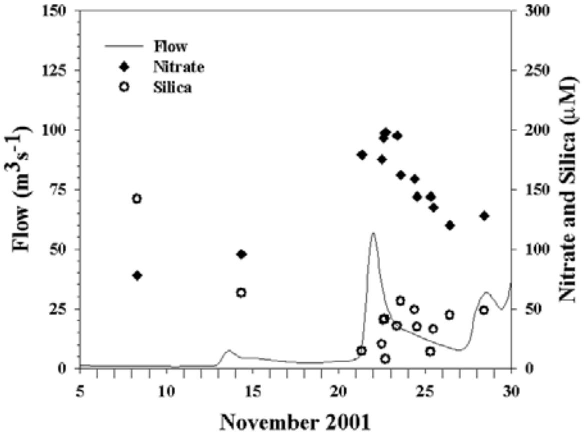

Figure 11. November 2001 storm nitrate and silica.

An empirical nitrate model

The semi-logarithmic relationship suggested between nitrate concentrations and stream flow shown in Figure 2 may be modeled by the following equation:

$$\text{nitrate} = 19.79 \ln(\text{stream flow}) + 35 \qquad (2)$$

A comparison of the nitrate model predictions and observed nitrate values is shown in Figure 4. The bulk of the three-year samples are represented by open triangles, labeled “Normal,” whereas the solid triangles correspond to the transition period ending the drought year 2001, beginning with the first significant, but comparatively minor, fall storm on October 11th and followed by the major storm beginning on November 21st and peaking two days later. The cluster of three points near 75 µM observed corresponds to data collected on October 11th and 25th and November 8th. The thirteen highest observed nitrate values in this group correspond to storm samples taken between November 21st and 28th. The highest outlying value above the line of agreement (106.7 µM) corresponds to the first sampling event, December 6th, after the storm. The point immediately below it is an unrelated outlying point corresponding to the sample taken on January 4, 2000. The r-square value for all points is 0.65 whereas the r-square value excluding the events represented by the solid triangles is 0.86.

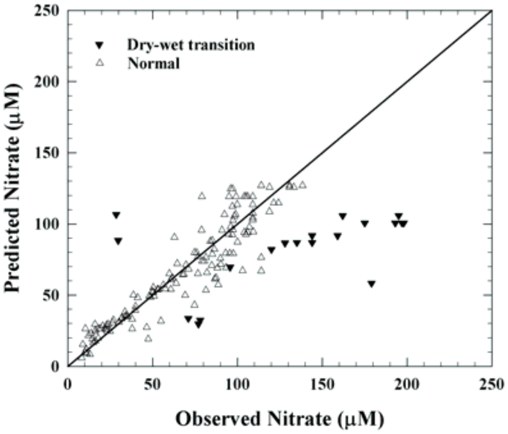

Figure 12. Nitrate model: Predicted versus observed concentrations. Conversion factor: 72 µM nitrate N equals 1 mg l^{-1} nitrate nitrogen.

It is clear from Figure 4 that the highest nitrate values are significantly underpredicted. Manipulation of the logarithmic model expressed by the equation above shows that, if the model were accurate at all times, the highest nitrate value would correspond to a stream flow of almost 3000 m^3s^{-1}, more than an order of magnitude greater than the actual maximum daily stream flow at the time. However these instances are associated with highly transient conditions as indicated by Figure 2. In other words, they are associated with rapid changes in the hydrograph and almost hourly nitrate samples.

Based on the November 2001 storm, it seems clear that long dry spells lead to a buildup of nitrate in soils that contributes to subsequent high nitrate concentrations in the Yaquina River associated with the first significant storms. The model appears to apply to conditions not affected by major transitions from dry to wet weather.

According to the empirical nitrate model, the dissolved nitrate nitrogen loads varied from 22586 kg day^{-1} during a high-flow storm event (11/26/99) to 1.34 kg day^{-1} during late summer. For comparison, the computed maximum and minimum based on high (12/28/99) and low flows and corresponding discrete nitrate samples yield approximately 17440 and 2.25 kg day^{-1} respectively. The daily maximum for the drought was 2588 kg day^{-1}, almost an order of magnitude smaller than that of the previous year (22586 kg day^{-1}). The annual dissolved nitrogen loads varied from 480 t yr^{-1} to 112 t yr^{-1} during the drought year. For the period of November 1, 1999 to April 30, 2000, the nitrate-nitrogen load was 459 t, whereas for the following summer-fall period of May 1 to October 31, 2000, 23.6 t is predicted to have been carried down the Yaquina River. The results indicate that for the time interval studied, about 94% of the annual dissolved nitrate was transported during the winter months of higher rainfall during the wet years compared to about 84.5% during the winter months of the drought year.

Conclusion

The results indicate that winters of higher rainfall will increase the annual nutrient load to the river relative to low rainfall winters. Silica is carried downstream from the upland watershed. During periods of high river discharge, the dissolved silica load tends to increase until “flood stage.” During highest flows, dilution from rapid, near-surface flow becomes important. Ammonium and phosphorus concentrations increase only slightly during storm events indicating that the total load is tied directly to river discharge. Increased dissolved nitrate concentrations during storm events supports the hypothesis that the majority of nitrate-N may enter the estuary during storm pulses. A simple model relating nitrate concentration to the natural logarithm of stream flow predicts reasonably well, attaining an r-square value of 0.86 for events not preceded by drought.

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