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The effects of land use on stream nitrate dynamics

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Summary The effects of land use and land use change on stream nitrate are poorly understood. While case studies have been presented, most process work has been done in areas with one land use (minimally disturbed or agricultural) and areas with substantial atmospheric deposition. In this paper we present results from three neighboring headwater catchments in western Oregon with similar (low) atmospheric deposition, size, and geology but with different, spatially consistent land use expressions: forest, agriculture, and residential. The climate in western Oregon has a distinct pattern of a three-month rainless period in the summer, a wetting up with many storms in the fall and winter, and a decrease of storms in the spring. We investigate how human activity alters the export of nitrate, whether the input of nitrate changes throughout the year which may affect storm response (i.e., depletion of soil water nitrate, addition of fertilizer, etc.), and how the changing contribution of source waters throughout the year affects streamflow concentrations. Our results showed marked differences in export rates between the three catchments. The forested catchment showed minimal export for three monitored storms (fall, winter, spring) through the seasonal wetting up of the catchments, and the residential catchment showed high export for all three storms. While the agricultural catchment displayed elevated export in the fall (similar to the residential catchment), exports decreased progressively throughout the rainy period (following late summer manure and green bean application). Overall, our results of storm event nitrate concentrations suggest that varying nitrate inputs have a large affect on nitrate dynamics. While within-storm nitrate concentration response patterns in the residential catchment were the same as the patterns in the reference forested catchment (a ''concentration'' pattern throughout the year), a ''dilution'' pattern was observed in the fall and winter and a ''concentration'' pattern was observed in the spring in the agricultural catchment.

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Introduction

Increases in nitrogen inputs in the last 50 years have caused great concern for the health of stream ecosystems (Pimentel, 1993; Howarth et al., 2002). Nitrogen inputs from human activity have doubled in the United States from 1961 to 1997 (Howarth et al., 2002). In general, approximately one-third of nitrogen inputs to catchments are exported, with the majority exported to surface waters (Howarth et al., 2002). This increase in export to surface waters has been shown to cause algal blooms, which in turn cause hypoxia and ''dead'' zones for fish (National Science and Technology Council, 2000; Rabalais et al., 2002; National Research Council, 2000). Episodic acidification of streams has also resulted from increased nitrate levels (Wigington et al., 1996a,b; Wellington and Driscoll, 2004).

Not surprisingly, land use has been found to have a large effect on the amount of nitrogen exported to the stream (Salvia-Castellvi et al., 2005; Schilling, 2002; Jordan et al., 1997; Owens et al., 1991; Howarth et al., 2002; Jordan and Weller, 1996; Johnson et al., 1997; Herlihy et al., 1998; Wernick et al., 1998; Arheimer and Liden, 2000; Jones et al., 2001; Wayland et al., 2003; Donner et al., 2004; Woli et al., 2004; Buck et al., 2004; Lattin et al., 2004; Little et al., 2003). Since a significant portion of nitrogen export from catchments is due to non-point source fertilizer runoff, the proportion of agricultural land in a catchment is often correlated to stream nitrate export (Howarth et al., 2002). Nitrogen export is generally greater in rivers draining more densely populated catchments (Jordan and Weller, 1996). This may be due to sewage inputs or deposition and subsequent runoff of NO_x emissions. The majority of the work on land use effects has focused on baseflow or a small number of sampling events correlating land use and nitrate (Johnson et al., 1997; Herlihy et al., 1998; Wernick et al., 1998; Arheimer and Liden, 2000; Jones et al., 2001; Wayland et al., 2003; Donner et al., 2004; Woli et al., 2004; Buck et al., 2004; Lattin et al., 2004; Little et al., 2003; Schilling, 2002). While it is clear that land use affects the magnitude of nitrate and other nutrients exported from catchments, it is not clear how it affects nutrient dynamics or the nutrient concentration pattern during storm events.

A few studies have been conducted in catchments with mixed land use during storm events; however, much of the work has been concerned with monthly exports, and little is shown of nitrate concentrations varying with discharge dynamics (Jordan et al., 1997; Owens et al., 1991; Bolstad and Swank, 1997; Salvia-Castellvi et al., 2005). Results are shown as a baseflow index or monthly averages (Jordan et al., 1997; Owens et al., 1991; Salvia-Castellvi et al., 2005). Alternatively, one event or the ''typical'' response for a catchment is shown (Salvia-Castellvi et al., 2005; Bolstad and Swank, 1997). These studies, in addition to studies conducted in forested or agricultural catchments, either show a ''concentration'' pattern, where nitrate concentrations increase with increasing flow rates and essentially mimic the storm hydrograph, or a ''dilution'' pattern, where nitrate concentrations decrease with increasing flow rates as a mirror image of the hydrograph (Salvia-Castellvi et al., 2005; Bolstad and Swank, 1997; Webb and Walling, 1985; Petry et al., 2002; Vanni et al., 2001; Inamdar et al., 2004; McHale et al., 2002; Burns et al., 1998). During storm events, nitrate may be quickly mobilized to the stream (Creed et al., 1996; Creed and Band, 1998; McHale et al., 2002). The magnitude of nitrate concentrations undoubtedly vary throughout the year due to the ''wetting-up'' and ''drying-down'' of the catchment, but how do these storm patterns change with season? While the strong links between hydrology and nitrate are well established, most studies to date have been conducted predominantly in either minimally disturbed environments or agricultural areas.

We argue that further investigation of the seasonality of nitrate dynamics during storm events should occur in catchments with varying land uses. In order to understand the behavior of solutes during storm events, studies need to be conducted in areas with major disturbances (Burns, 2005). Here, we present a study that examines the seasonality of nitrate dynamics in three catchments with similar physical characteristics (area, geographic proximity, geology, soils, topography, elevation) but different land uses. Storm events were monitored in this Mediterranean climate from the end of a 3-month rainless period through a clear progression of wet-up and potential flushing events. We explore how human activity alters the export of nitrate. In addition, we determine whether or not the input of nitrate changes throughout the year, which may affect storm response (i.e., depletion of soil water nitrate, addition of fertilizer, etc.), and how the changing contribution of source waters throughout the year affects streamflow concentrations.

Site description

The three study catchments are each on the order of 50 ha and are sub-basins of the 33 km^2 Oak Creek Watershed, located near Corvallis, Oregon, USA (Fig. 1). This area is located in the Pacific Northwest of the United States in a region virtually devoid of atmospheric nitrogen deposition (annual rate of approximately 1.52 kg/ha/year, http://nadp.sws.uiuc.edu/nadpdata/annualReq.asp?site=OR97). The climate in the Pacific Northwest is relatively mild and often described as a mediterranean climate, with dry summers and wet winters. Average temperature in the Oak Creek Watershed is 11.5 °C, and mean annual precipitation is approximately 111 cm/year (Oregon Climate Service, www.ocs.oregonstate.edu). The majority of the precipitation falls during the rainy season (November–June). Minimal snowfall occurs in the catchment, with snowmelt occurring 1–2 days after the event. The Oak Creek Watershed has clear and well-defined land uses expressed within its subcatchments. The upper portion of the watershed is a minimally disturbed, second growth Douglas Fir forest. The mid-portion of the watershed is primarily agricultural (sheep and cattle grazing, growth of clover, wheat, and fescue) with small inholdings of residential areas. Land use in the lower portion of the watershed consists of urban residential and the Oregon State University campus. Each study catchment has a clean expression of land use (forested, agricultural, residential) and shares approximately the same headwater divide.