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The role of irrigation runoff and winter rainfall on dissolved organic carbon loads in an agricultural watershed

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ABSTRACT

We investigated the role of land use/land cover and agriculture practices on stream dissolved organic carbon (DOC) dynamics in the Willow Slough watershed (WSW) from 2006 to 2008. The 415 km^2 watershed in the northern Central Valley, California is covered by 31% of native vegetation and the remaining 69% of agricultural fields (primarily alfalfa, tomatoes, and rice). Stream discharge and weekly DOC concentrations were measured at eight nested subwatersheds to estimate the DOC loads and yields (loads/area) using the USGS developed stream load estimation model, LOADEST. Stream DOC concentrations peaked at 18.9 $mg\,L^{-1}$ during summer irrigation in the subwatershed with the highest percentage of agricultural land use, demonstrating the strong influence of agricultural activities on summer DOC dynamics. These high concentrations contributed to DOC yields increasing up to 1.29 $g\,m^{-2}$ during the 6 month period of intensive agricultural activity. The high DOC yields from the most agricultural subwatershed during the summer irrigation period was similar throughout the study, suggesting that summer DOC loads from irrigation runoff would not change significantly in the absence of major changes in crops or irrigation practices. In contrast, annual DOC yields varied from 0.89 to 1.68 $g\,m^{-2}\,yr^{-1}$ for the most agricultural watershed due to differences in winter precipitation. This suggests that variability in the annual DOC yields will be largely determined by the winter precipitation, which can vary significantly from year to year. Changes in precipitation patterns and intensities as well as agricultural practices have potential to considerably alter the DOC dynamics.

1. Introduction

River water chemistry represents an integration of many terrestrial and aquatic biogeochemical processes in watersheds (Cole et al., 2007) and linkages among watershed hydrology, water quality, and human-driven changes in land use/land cover have been the focus of many studies (Raymond et al., 2008; Chen and Driscoll, 2009; Wilson and Xenopoulos, 2009). In particular, agricultural land use and associated practices such as irrigation, fertilization, liming, and crop rotations have the potential to greatly alter water budgets and surface water chemistry (Oh and Raymond, 2006; Royer et al., 2006; Raymond et al., 2008).

Riverine DOC concentrations and loads have been studied extensively due to the quantitative importance of DOC in regional and global carbon budgets (Cole et al., 2007; Raymond and Oh, 2007), in food web for aquatic biota (Stepanauskas et al., 2005), and in the transport of toxic metals (Ravichandran, 2004). In addition, DOC impacts drinking water quality due to the potential formation of carcinogenic by-products such as trihalomethanes (THMs) and haloacetic acids (HAAs) during water disinfection (Xie, 2004). Thus, the California state government recommended maximum DOC concentration of 3 $mg\,L^{-1}$ in order to more effectively manage associated disinfection byproduct (DBP) concentrations in surface water used for drinking water (CALFED, 2000; Chomycia et al., 2008). Although the newly formed THMs could be removed through coagulation, sedimentation, or filtration at later stages of water treatment (Xie, 2004), reducing the concentrations of DOC and DBP precursors from source water can be an improved

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management option. Therefore, understanding the riverine DOC dynamics and its sources in California is crucial to assess drinking water management scenarios given that water runoff from the upstream Sacramento and San Joaquin Rivers are the dominant sources to the Delta and drinking water intakes (Jassby and Cloern, 2000).

Many factors affect watershed DOC dynamics including hydrological flow paths (Lewis and Grant, 1979; McGlynn and McDonnell, 2003), storm events (Hinton et al., 1997; Saraceno et al., 2009), in-stream processes (Stepanauskas et al., 2005), wetland area (Eckhardt and Moore, 1990), and human land use/land cover (Sickman et al., 2007, 2010; Chen and Driscoll, 2009). In particular, agricultural land use has been recognized as a significant source of DOC and influences DOC characteristics such as chemical composition and lability (Dalzell et al., 2005; Hernes et al., 2008; Chen and Driscoll, 2009; Wilson and Xenopoulos, 2009; Sickman et al., 2010). However, the role of specific crop types and agricultural practices associated with the crop on stream DOC dynamics is not clear, particularly in watersheds in Mediterranean climates such as California's Central Valley where intensive irrigation practices ranging from drip to flood irrigation (Cooley et al., 2009) could significantly affect the production and transport of DOC to surface waters and downstream ecosystems. Agricultural land use in the Central Valley of California provides vital crop production in the U.S. and has received considerable attention for impacts of upstream agricultural land use on water quality in the Sacramento River/San Joaquin River Delta ecosystem (Stepanauskas et al., 2005; Krupa et al., 2012). We examined the impact of agricultural land use on DOC concentrations and loads from the Willow Slough watershed, a 415 km^2 agricultural watershed in the northern Central Valley, California. The objectives of this study were to (i) examine the temporal and spatial variability in DOC concentrations and loads from eight nested watersheds, (ii) assess the relative contribution of winter storm events on watershed DOC export, and (iii) infer from our study the potential role of agricultural watersheds on DOC dynamics of the large Sacramento River Basin. Given the reliance on surface water export from the Sacramento River/San Joaquin River Delta system for the drinking water needs of nearly 25 million people in California, understanding linkages between agricultural water use and water quality are critical to ecosystem and human health.

2. Methods

2.1. Site description

The Willow Slough Watershed (WSW) is located near Davis, California and the longitude and latitude of the mouth of WSW are 38.60° and −121.75° (Fig. 1a). The watershed includes the hilly inner Coast Range in the west and flat alluvial plains in the east (Florsheim et al., 2011). The inner Coast Range (mean slope = 25%) in the west covers about a third of the watershed area where relatively well-drained, coarse textured soils are developed with more poorly drained, fine textured soils in the alluvial fans and flood plains (mean slope = 1%) in the east (Florsheim et al., 2011). The soils data were extracted from the Soil Survey Geographic (SSURGO) database (http://soils.usda.gov/survey/geography/ssurgo/) and the gridded SSURGO database (http://soils.usda.gov/survey/geography/ssurgo/description_gssurgo.html) to identify the soil series and estimate the soil organic carbon content of the WSW. The soils of the WSW demonstrated a variety of weathering stage from relatively new entisols and inceptisols to advanced weathering stage of alfisols and vertisols. The most prevalent soil series occupying 20% of the watershed area was Capay series (*fine, smectitic, thermic Typic Haploxererts*) followed by Marvin (*Haploxeralfs*), Brentwood (*Haploxerepts*), and Tehama series (*Haploxeralfs*) that covered 8%, 7%, and 7% of the watershed, respectively. The soil organic carbon (SOC) content at 0–30 cm of depths was relatively large in the low lying agricultural part of the watershed (up to ∼6.5 kg m^{-2}) whereas the SOC content was low in the western hilly area (Fig. 2).

The mean annual precipitation of the entire WSW was 572 mm (median = 552 mm) per water year (from October to September) for 113 years (10/01/1895–09/30/2008) which was estimated using the PRISM data set (http://www.prism.oregonstate.edu/). Annual rainfall ranged from ∼450 mm in the eastern part of the watershed to ∼860 mm in the hilly Coast Range, with 95% of rainfall occurring between October and April. The rainfall in water years from 2006 to 2008 was 896, 311, and 503 mm per water year, respectively, which corresponded to 8th, 106th, and 66th wettest years among the 113 water years, thus providing an excellent opportunity to compare water and DOC budgets during extreme and average precipitation years.

Agricultural cropland is the dominant land use/land cover of the watershed (63%), followed by grassland (21%) and natural shrubland (8%; Table 1), which was quantified using GIS with National Land Cover Dataset 2001 (http://www.mrlc.gov/). Field observations were coupled with GIS data of crop types to quantify the distribution of individual crops in the watershed. Alfalfa (*Medicago sativa*) and tomato (*Lycopersicon esculentum*) were the two most prevalent crops, covering about 28% and 14% of the agricultural lands of WSW, respectively (Fig. 3). Other significant crops included grass for forage (13%), orchards (10%), and rice (*Oryza sativa*, 7%) (Fig. 3).

A total of eight gauging stations including the entire watershed (Fig. 1) were monitored for discharge at 15 min intervals and coupled with weekly and storm event discrete sampling for DOC concentrations (Table 1). The watersheds are nested such that the entire WSW includes two large subwatersheds, W2 and W3 (Fig. 1b and c), and W2 includes subwatersheds W6 (which includes subwatershed W4) and W8, whereas W3 includes W7 (which includes W5) (Fig. 1).

2.2. Sample collection and analysis

Water samples from the eight watersheds were collected weekly during baseflow, as well as more intensively during several high flow rainfall-runoff events. Stream DOC concentrations from the eight watersheds were monitored in 2006 while DOC concentrations from the entire watershed (W1) and the W8 subwatershed were also monitored in 2007 (Fig. 4). Discrete samples from storm events were collected at either 2 or 3 h time intervals, manually or by autosampler. Samples were returned to the laboratory and immediately filtered (pre-combusted 0.3 μm glass-fiber filters, Advantec MFS, Inc.), with DOC samples acidified to pH ∼2 and refrigerated until analysis (within 7 days). DOC concentrations were measured with a Shimadzu TOC-5000A high temperature catalytic oxidation analyzer measuring non-purgeable organic carbon. The mean of 3–5 injections of 100 μL is reported for every sample and precision, described as the coefficient of variance (C.V.) was <2% for the replicate injections. Reported values were corrected for the instrument blank, which was measured at the time of analysis.

2.3. Flow monitoring and DOC load calculations

Flow was also monitored at eight gauging stations within the watershed. Each station was located near a bridge and included a pressure transducer (In-Situ Inc., Fort Collins, CO) that recorded water levels at 15 min intervals, and a staff gauge. When water levels were sufficiently low, flow was