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Fate of nitrate in seepage from a restored wetland receiving agricultural tailwater

Neil Brauer [a], Jonathan J. Maynard [b], Randy A. Dahlgren [a], Anthony T. O'Geen [a,*]

[a] Department of Land, Air and Water Resources, University of California, One Shields Avenue, Davis, CA 95616, USA
[b] USDA ARS, Jornada Experimental Range, New Mexico State University, P.O. Box 30003, MSC 3JER, Las Cruces, NM 88003-8003, USA

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ABSTRACT

Constructed and restored wetlands are a common practice to filter agricultural runoff, which often contains high levels of pollutants, including nitrate. Seepage waters from wetlands have potential to contaminate groundwater. This study used soil and water monitoring and hydrologic and nitrogen mass balances to document the fate and transport of nitrate in seepage and surface waters from a restored flow-through wetland adjacent to the San Joaquin River, California. A 39% reduction in NO_3-N concentration was observed between wetland surface water inflows ($12.87 \pm 6.43\,mg\,L^{-1}$; mean $\pm$ SD) and outflows ($7.87 \pm 4.69\,mg\,L^{-1}$). Redox potentials were consistently below the nitrate reduction threshold ($\sim$250 mV) at most sites throughout the irrigation season. In the upper 10 cm of the main flowpath, denitrification potential (DNP) for soil incubations significantly increased from 151 to 2437 mg NO_3-N $m^{-2}\,d^{-1}$ when nitrate was added, but showed no response to carbon additions indicating that denitrification was primarily limited by nitrate. Approximately 72% of the water entering the wetland became deep seepage, water that percolated beyond 1-m depth. The wetland was highly effective at removing nitrate (3866 kg NO_3-N) with an estimated 75% NO_3-N removal efficiency calculated from a combined water and nitrate mass balance. The mass balance results were consistent with estimates of NO_3-N removed (5085 kg NO_3-N) via denitrification potential. Results indicate that allowing seepage from wetlands does not necessarily pose an appreciable risk for groundwater nitrate contamination and seepage can facilitate greater nitrate removal via denitrification in soil compared to surface water transport alone.

1. Introduction

There have been many efforts across the world to mitigate wetland habitat lost over the past century. This movement is echoed in California's Central Valley where stakeholders have established the goal of creating and protecting over 60,000 ha of new wetland habitat in the state (Central Valley Joint Venture, 2006). Many of these wetlands are, or will be, ephemeral, flow-through wetlands receiving irrigation return flows during the growing season (April–September). Most wetlands in CA are restored with the primary objective of enhancing waterfowl habitat, however, these systems also have the potential to retain and remove nutrient loads that would otherwise be exported directly into major waterways (Fisher and Acreman, 2004). Therefore, wetland treatment of agricultural return flows is being considered as a beneficial management practice to reduce algal and nutrient loads that contribute to seasonally low dissolved oxygen in the lower San Joaquin River, California (Lehman et al., 2004; Diaz et al., 2012).

Many studies have demonstrated that natural and constructed wetlands are generally effective at removing nitrogen from municipal and agricultural wastewaters (Brodie, 1989; Phipps and Crumpton, 1994; Kadlec and Knight, 1996; Woltemade, 2000; Jordon et al., 2003; Zedler, 2003; Beutel et al., 2009; Diaz et al., 2012). Removal efficiencies as high as 98% have been reported, though other studies report significantly lower N removal rates typically between 35 and 55% (Watson et al., 1989; Phipps and Crumpton, 1994; Comin et al., 1997; Kovacic et al., 2000; Mitsch et al., 2000; Tanner et al., 2002). A study of three wetlands used to treat subsurface tile drainage water in the Midwestern, USA demonstrated NO_3 removal rates of 28% (Kovacic et al., 2000). Similarly, high but variable NO_3 removal rates (35–100%) have been documented from water seeping through side berms of a constructed wetland in Illinois (Larson et al., 2000). Variation in

* Corresponding author. Tel.: +1 530 752 2155.
E-mail address: atogeen@ucdavis.edu (A.T. O'Geen).

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nitrate removal is a result of many factors such as hydraulic residence time, soil properties, vegetation characteristics, variability in input loads, N loading, temperature, dissolved oxygen concentration, climate and nitrogen form (nitrate, ammonium or organic) in input waters (Phipps and Crumpton, 1994; Beutel et al., 2009; O'Geen et al., 2010).

Using wetlands as a beneficial management practice to reduce non-point source pollution from agricultural drainage waters may introduce a problem as these wetlands could leach contaminants such as nitrate directly into the groundwater. This could compound an existing problem in California where groundwater NO_3-N loading rates of 200 Gg per year have been reported in areas of intensive agriculture such as the Salinas Valley and Tulare Lake Basin (Viers et al., 2012). Several studies of dairy lagoons summarized in Harter et al. (2002) document high seepage rates (up to 1 cm d^{-1}), and elevated groundwater N concentrations beneath lagoons. Similarly, Huffman (2004) found NO_3-N concentrations exceeding the EPA drinking water standard (10 mg NO_3-N L^{-1}) beneath two thirds of 34 swine lagoons in North Carolina. More studies of nitrogen fate and transport in wetlands receiving tailwater from cropland are needed because the existing literature base for this topic encompasses a wide range of environmental characteristics that govern nitrogen transformations (e.g., differences in nitrogen form, N concentration, hydrology, soil characteristics and climate).

The primary objectives of this study were to determine the fate of nitrogen in seepage waters of a restored surface-flow through wetland and to determine the importance of hydrologic- as well as soil- and biogeochemical-factors that regulate nitrate removal. We addressed these objectives by: (i) monitoring nitrogen concentration in nested piezometers (10, 50, and 100 cm) throughout the wetland and comparing them to surface water; (ii) measuring spatial patterns in selected soil and hydrological characteristics; and, (iii) developing wetland hydrologic and nitrogen mass balances to evaluate the fate of nitrate. The results from this study provide information relevant to the optimization, design, and management of restored wetlands for nitrate removal. Moreover, these findings expand upon the limited number of published studies that document nitrate removal by constructed wetlands receiving nitrate runoff from irrigated agriculture (Beutel et al., 2009).

2. Materials and methods

2.1. Site description

The restored flow-through wetland (8.7 ha) is located in the Central Valley of California adjacent to the San Joaquin River (Fig. 1). The two-year-old wetland intercepts irrigation return flows from about 420 ha of farmland before discharging into the river. Tailwaters originate from both furrow and flood irrigated crops primarily of tomatoes, melons, stone fruits, nuts, and alfalfa.

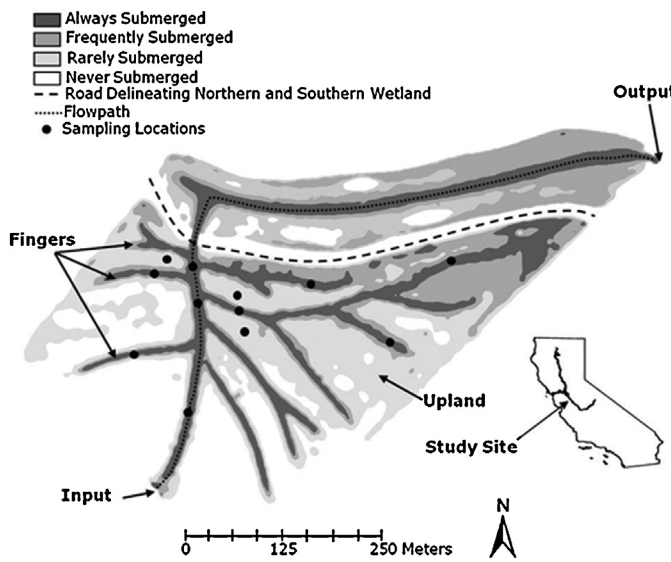

Fig. 1. Schematic showing site location, wetland morphology, sampling locations and areas of submersion. Dashed line represents a road. Dotted line is the main flowpath hydrologic zone. The upland hydrologic zone represents landscape positions that are rarely submerged.

The climate is Mediterranean, having hot and dry growing seasons and cool, wet winters. No precipitation occurred during the irrigation season.

The wetland has a dendritic form with three distinct hydrologic zones (Fig. 1): (i) the main flowpath, characterized by deep water (~0.75 m), measurable flow velocity, high sedimentation rates (~10–35 kg m^{-2} yr^{-1}) and minimal vegetation; (ii) the fingers, shallow (~0.1–0.5 m) areas with no measurable flow velocity, low sedimentation rates (~0.5–5 kg m^{-2} yr^{-1}), and partially vegetated with *Polygonum lapathifolium* (smartweed); and (iii) upland zones that experienced intermittent flooding, but had saturated conditions that extend within 25 cm of the soil surface and densely vegetated with smartweed, grasses and riparian trees such as willow and cottonwood (Table 1 and Fig. 1).

2.2. Hydrologic characterization

The wetland received agricultural return flows during the irrigation season from April to September, with no rainfall occurring during this time. Surface water inflow and outflow volumes were measured at 30-min intervals using v-notch weirs and barometric pressure compensated water level loggers (Solonist, Georgetown, ON). A digital elevation model (DEM) was created using a Trimble RTK GPS (Trimble, Sunnyvale, CA) with ±3 cm accuracy. The DEM was used to relate water depth measured at two locations (30-min intervals) with water depth throughout

Table 1
Wetland physical and hydrologic characteristics.

Wetland attributes	
Total area (ha)	8.7
Flowpath	1.8
Fingers	2.2
Upland	4.7
Vegetation	*Typha latifolia*, *Polygonum lapathifolium*
Depth range (m)	0–1.3
Average temperature flowpath (°C)	22.3
Average temperature fingers (°C)	21.5
Hydraulic residence time-modeled (days)	0.9