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Wetlands receiving water treated with coagulants improve water quality by removing dissolved organic carbon and disinfection byproduct precursors

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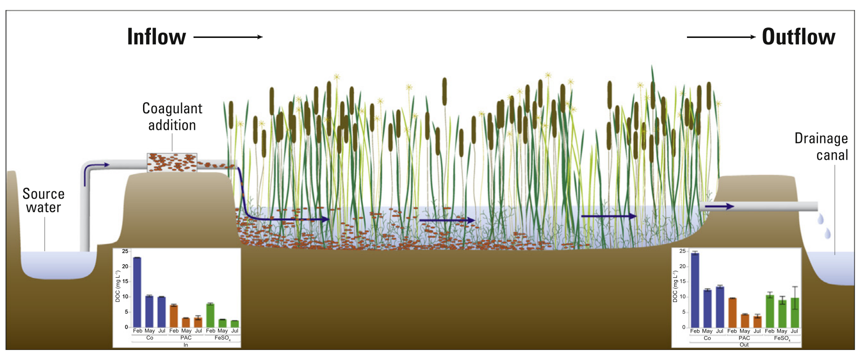
HIGHLIGHTS

- A novel application of a hybrid coagulation-wetland treatment system was evaluated.
- Hybrid coagulation-wetland systems can be net sinks for dissolved organic carbon and disinfection byproduct precursors.
- Optical properties indicate dissolved organic matter enters surface waters from underlying peat soil.

GRAPHICAL ABSTRACT



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ABSTRACT

Constructed wetlands are used worldwide to improve water quality while also providing critical wetland habitat. However, wetlands have the potential to negatively impact drinking water quality by exporting dissolved organic carbon (DOC) that upon disinfection can form disinfection byproducts (DBPs) like trihalomethanes (THMs) and haloacetic acids (HAAs). We used a replicated field-scale study located on organic rich soils in California's Sacramento-San Joaquin Delta to test whether constructed flow-through wetlands which receive water high in DOC that is treated with either iron- or aluminum-based coagulants can improve water quality with respect to DBP formation. Coagulation alone removed DOC (66–77%) and THM (67–70%) precursors, and was even more effective at removing HAA precursors (77–90%). Passage of water through the wetlands increased DOC concentrations (1.5–7.5 mg L^{-1}), particularly during the warmer summer months, thereby reversing some of the benefits from coagulant addition. Despite this addition, water exiting the wetlands treated with coagulants had lower DOC and DBP precursor concentrations relative to untreated source water. Benefits of the coagulation-wetland systems were greatest during the winter months (approx. 50–70% reduction in DOC and DBP precursor concentrations) when inflow water DOC concentrations were higher and wetland DOC production was lower. Optical properties suggest DOC in this system is predominantly comprised of high molecular weight, aromatic compounds, likely derived from degraded peat soils.

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1. Introduction

Wetland habitats are highly productive and biologically diverse environments that serve as critical interfaces between terrestrial and aquatic environments, modulating fluxes of material to receiving water bodies (Maynard et al., 2014). Wetlands can improve water quality by retaining or transforming constituents, and are used worldwide as a natural and economically favorable alternative to energy-intensive engineered treatment plant approaches to reduce export of pollutants like nutrients, metals, pesticides, and suspended sediments (Barber et al., 2001; Díaz et al., 2012; Haynes, 2015; O'Geen et al., 2010; Pinney et al., 2000; Reckhow et al., 2004). However, wetlands also can be sources of dissolved organic carbon (DOC) which may negatively impact drinking water quality (Engelage et al., 2009; Kraus et al., 2008; Rostad et al., 2000; Scholz et al., 2016). Net export of DOC is of particular concern when wetlands are located on organic-rich soils (Fleck et al., 2004).

DOC is a drinking water constituent of concern because during treatment a fraction of the DOC pool reacts to form disinfection byproducts (DBPs), and some of these compounds have been shown to be carcinogenic or mutagenic (Hrudey, 2009; Krasner et al., 2009). Although there are hundreds of DBPs, only the two most prevalent classes—trihalomethanes (THMs) and haloacetic acids (HAAs)—currently are regulated by the U.S. Environmental Protection Agency (EPA). Although at first approximation total DOC concentration is often a strong predictor of DBP formation, the composition of the dissolved organic matter (DOM) pool affects the amount and type of DBPs that form (Hua and Reckhow, 2007; Liang and Singer, 2003; Weishaar et al., 2003).

Coagulation with metal salts is an effective process used by drinking water treatment facilities for the removal of DOC, including DBP precursors, and is the preferred method to mitigate DBP formation (Matilainen et al., 2011). Metal-based coagulants such as those containing polyvalent cations like aluminum and iron, interact with DOM and transfer it to the colloidal or particulate form through two major processes: charge neutralization and adsorption (Duan and Gregory, 2003; Matilainen et al., 2010). These floc materials then can be removed from the water column through a combination of natural settling and filtration, thereby reducing DOC concentrations and reducing the potential for DBP formation. However using coagulation to treat large volumes of water at a treatment plant can be expensive. Removing DOC at its origin where it is more concentrated, prior to release and dilution in waterways that are sources for drinking water utilities, could improve drinking water quality and reduce costs incurred by the drinking water treatment plants (Diaz et al., 2009; Díaz et al., 2008; Kraus et al., 2010). Although numerous studies have examined how coagulation can be used to remove DOC and DBP precursors from water during drinking water treatment (e.g., Cheng and Chi, 2003; Hubel and Edzwald, 1987; Kavanaugh, 1978), we are not aware of any studies that have examined whether coagulation can be used in situ to reduce the export of DOC to receiving waters. Application of coagulants to natural environments have been widely studied to reduce nutrient export from wastewater treatment wetlands (Bachand et al., 2000; Haynes, 2015; Malecki-Brown et al., 2010; Malecki-Brown et al., 2007; Qualls et al., 2009), to reduce storm water run-off sediment and phosphorus inputs to receiving waters (Bachand et al., 2010; Lopus et al., 2009), and to reduce phosphorus availability and thus avoid formation of nuisance phytoplankton blooms in lakes and reservoirs (Boyer et al., 2011; Immers et al., 2015; Wang and Jiang, 2016).

Issues related to drinking water quality and watershed inputs of DOC are of concern in the Sacramento-San Joaquin River Delta (hereafter Delta) of California which provides drinking water to over 25 million people. Historically a vast wetland, drainage of Delta peat soils for agriculture and urbanization has resulted in land surface subsidence of up to 8 m below sea level, largely due to oxidation of organic matter (Deverel et al., 2016). To prevent these lands from flooding, drainage canals transport water to pumping stations that exports water high in DOC to adjacent Delta channels. DOC and DBP loads from these exported drainage waters have been identified as a significant contributor to high DOC concentrations entering downstream drinking water utilities (Chow et al., 2007; Fleck et al., 2004; Kraus et al., 2011; Kraus et al., 2008). Conversion of these subsided lands to managed wetlands has been proposed as an effective means to halt or even reverse subsidence (Deverel et al., 2016; Miller et al., 2008), however studies have shown that they have the potential to increase DOC and DBPs exported to receiving waters (Deverel et al., 2007; Fleck et al., 2007; Kraus et al., 2008).

As is the case in many regions that have lost wetland habitat, wetland restoration is an imminent priority for watershed management in the Delta. A recent California Natural Resources Agency (2017) initiative calls for restoration of 12,000 ha of tidal and sub-tidal wetland habitats, of which 1400 ha are targeted for specific projects including subsidence reversal, carbon sequestration, and levee improvement. In light of these large-scale wetland restoration plans, management actions should include strategies to mitigate elevated levels of DOC and DBP precursors exported from wetlands. Therefore, wetlands constructed on subsided lands of the central Delta provide an ideal location to test whether treating high DOC waters with coagulants prior to release into surrounding waterways can reduce export of DOC and DBP precursor concentrations and thereby improve downstream drinking water quality. Moreover, using constructed wetlands to naturally settle out and retain the resulting organo-metal floc along with wetland plant biomass may further polish the treated water and provide the added benefit of sequestering carbon, nutrients, and mercury while mitigating and even reversing subsidence (Ackerman et al., 2015; Henneberry et al., 2011; Stumpner et al., in press).

Here, we used a replicated field-scale study located on subsided organic-rich soils of the Delta to assess whether constructed flow-through wetlands which receive water treated with either iron- or aluminum-based coagulants can improve water quality with respect to DBP formation above that achievable using untreated wetlands. The coagulants remove DOC and DBP precursors from the water column and transfer it into the particulate pool which then settles out and is retained in the wetland, contributing to newly formed sediment material. This study included three main objectives: (i) determine whether passage of agricultural drainage waters through untreated (i.e., no coagulant added) constructed wetlands increases DOC and DBP precursor concentrations, (ii) examine how treatment of source water with coagulants effects DOC concentration, composition, and reactivity with respect to THM and HAA formation both immediately following coagulant addition and following passage through constructed wetlands, and (iii) gain insight into likely sources (e.g., peat soils, plants, algae) of DOC and DBP precursors added during wetland passage using optical measurements of UV–vis absorption and fluorescence spectroscopy. These findings build on previous work reporting the effects of these coagulation-wetland systems on other water quality constituents, plant growth, floc stability, and land surface accretion (Ackerman et al., 2015; Henneberry et al., 2016; Henneberry et al., 2011; Henneberry et al., 2012; Liang, 2016; Stumpner et al., 2015; Stumpner et al., in press).

2. Materials and methods

2.1. Study description

The information presented here is part of a larger study designed to assess the effectiveness of constructed wetlands treated with coagulants to reverse subsidence by accreting mineral material along with wetland biomass, while simultaneously improving water quality with respect to constituents of concern like DOC, DBP precursors, mercury, nutrients and suspended sediment. The replicated field experiment took place on Twitchell Island, CA, a subsided tract of land in the central Delta (Fig. 1). In the mid-1800s, the island was leveed and drained for