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Diel patterns of algae and water quality constituents in the San Joaquin River, California, USA

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ABSTRACT

The San Joaquin River (SJR) is a hypereutrophic river that contributes to hypoxia in the downstream Stockton Deep Water Ship Channel. Oxidizable materials, in the form of algal biomass from upstream sources, contribute to the hypoxic conditions, especially from July to October. Our earlier work demonstrated the existence of strong chlorophyll-*a* diel cycles which complicated the calculation of algal loads for the watershed-scale monitoring program, necessary to address the total maximum daily load (TMDL) for dissolved oxygen (DO). The purpose of this study was to determine if diel patterns existed for other water quality constituents, and to determine the role of algal growth dynamics in driving these diel changes. Studies conducted between 30 June and 15 October 2004 evaluated temporal changes for several water quality constituents over four, 48 h studies at two sites along the mainstem of the SJR. Strong diel (24 h) patterns were observed for chlorophyll-*a* and pheophytin-*a* (algal pigments), temperature, DO, pH, dissolved inorganic nitrogen (DIN, NH_4^+-N + NO_3^--N), soluble reactive phosphorus (SRP), and volatile suspended solids (VSS). Patterns of DIN and SRP were inverse of those observed for algal pigments, temperature, DO, pH, and VSS. The observed diel patterns of algal pigments and temperature were greater in the beginning of the summer (June/July) and diminished by the end of summer (September/October) due to the decreased photoperiod. Within a 24 h period the fluctuations observed in algal pigments and nutrients suggest that growth of algae during daylight hours and depletion at night are largely responsible for the observed diel patterns. Due to the observed diel variability in these water quality constituents, the samples collected for TMDL programs may not be representative unless samples are collected at the daily mean for a system.

1. Introduction

Temporal water quality dynamics have been shown to occur on the inter-annual, seasonal, storm event, and diel time scales (Dahlgren et al., 2005). This variability provides large challenges for designing effective monitoring programs, such as those required by the total maximum daily load (TMDL) program for quantifying concentrations and fluxes of nonpoint source pollutants. In the absence of ability to monitor constituents continuously (e.g., turbidity, electrical conductivity), monthly to twice monthly sampling is often employed as the standard sampling frequency. However, for dynamic water quality constituents (e.g., temperature, dissolved oxygen, algae, metals), this frequency of sampling may greatly hinder accurate quantification of pollutant loads. Furthermore, monitoring programs are often limited by financial constraints, which prevent the collection of samples at the frequency needed to accurately assess multiple water quality constituents.

Temporal variability in water quality constituents is controlled by a number of factors. Traditionally discharge was considered the master variable controlling stream hydrochemistry with increased flow typically causing a dilution of constituent concentrations (Durum, 1953; Hem, 1948). However, recent studies have demonstrated more complex regulation of stream hydrochemistry by an integration of factors such as biogeochemical processes (Soulsby et al., 2002; Harrison et al, 2005; Parker et al., 2007; Pellerin et al., 2009), preferential flow paths and source area dynamics in contributing watersheds (Creed and Band, 1998; Harriman et al., 1990; Mulholland et al., 1990; Van Verseveld et al., 2009), irrigation patterns (Brauer et al., 2009), and transport processes (Lucas et al., 2006; Volkmar et al., 2011-this issue). As an example, Nagorski et al. (2003) examined differences between monthly, daily, and bi-hourly (2 h) sampling over a 12-month period in Western Montana. Monthly sampling detected a wide range of climatic, hydrologic, and geochemical conditions in each watershed. Daily sampling showed that post-rain surges in some

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solute and particulate concentrations were similar to those of early spring runoff flushing characteristics on the monthly scale. In contrast, bi-hourly monitoring showed diel patterns in dissolved oxygen (DO), pH, and water temperature.

Within the San Joaquin River (SJR) watershed, water quality monitoring generally occurs on a monthly to twice monthly sampling schedule to identify factors contributing to low DO levels that occur in the Stockton Deep Water Ship Channel (http://www.sjrdotmdl.org/background.html). Basin wide identification of oxygen demanding sources and transformations was necessary to develop the DO TMDL. Our previous work identified algal biomass from upstream sources as a major contributor to the hypoxic conditions in the lower SJR, especially from July to October (Volkmar and Dahlgren, 2006). In addition, this research identified large variability in the concentrations of constituents depending on the time of day the sample was collected, particularly during the summer months. This variability led us to question if diel patterns were significant in water quality constituents in the SJR, what were the driver(s) of these diel patterns, and how do diel patterns impact monitoring strategies.

Diel patterns for a number of water quality constituents in riverine systems have been reported and several explanations have been used to describe the driving force for these diel patterns. It is generally accepted that photosynthesis and respiration of aquatic plants and microbes is the controlling factor of diel patterns for pH, DO, and dissolved inorganic carbon (Kaplan and Bott, 1982; Sabater et al., 2000; Nagorski et al., 2003; Kent et al., 2005; Parker et al., 2005, 2007; Poulson and Sullivan, 2010). Other mechanisms to explain diel patterns in riverine environments are attributed to water temperature and/or incident radiation (Scholefield et al., 2005), pH and temperature (Jones et al., 2004; Laursen and Seitzinger, 2004), aquatic uptake (Hessen et al., 1997; Volkmar et al., 2011-this issue), groundwater flow (Wilcock and Chapra, 2005), snowmelt (Sullivan et al., 1998; Ahearn et al., 2004), and photochemistry and in-stream vegetation (Sullivan et al., 1998; Spencer et al., 2007).

This study examined diel variability in several water quality constituents in the hypereutrophic SJR in central California. The purpose of this study was to i) examine the existence and magnitude of diel changes in water quality constituents during the summer months, ii) determine the role of algal growth in driving the diel changes in water quality parameters, and iii) correlate the uptake of available nitrogen and phosphorous with algal biomass production. This study is important for devising water quality monitoring strategies to assist the DO TMDL, as well as providing process-level and rate data for simulation modeling of aquatic ecosystems in the lower SJR and other eutrophic rivers worldwide.

2. Materials and methods

2.1. Site description

The San Joaquin Basin has a perennial drainage area of 19,158 km^2 in California's Central Valley including portions of the Sierra Nevada (11,192 km^2), Coast Ranges (2078 km^2) and Valley Basin (2273 km^2) (Kratzer et al., 2004) (Fig. 1). The Valley Basin is among the most productive agricultural regions of California, in large part due to the availability of irrigation water. The climate of the valley basin is arid-to-semi arid receiving 254 to 305 mm of annual precipitation almost exclusively during the winter months. Most of the snowmelt runoff from the Sierra Nevada is stored in reservoirs and utilized for irrigation and remote urban uses. Approximately 79% of the average stream-flow in the SJR comes from east-side river basins originating in the Sierra Nevada: Merced River (17%), Tuolumne River (28%) and Stanislaus River (34%). The remainder originates as surface and subsurface drainage from irrigated agriculture. Agricultural diversions and drains cycle water along the entire length of the lower SJR. Agricultural drains are estimated to contribute up to 90, 83 and 92% of the annual NO_3^-, total phosphorus (TP), and total suspended solids (TSS), respectively (Saleh et al., 2003). A detailed description of

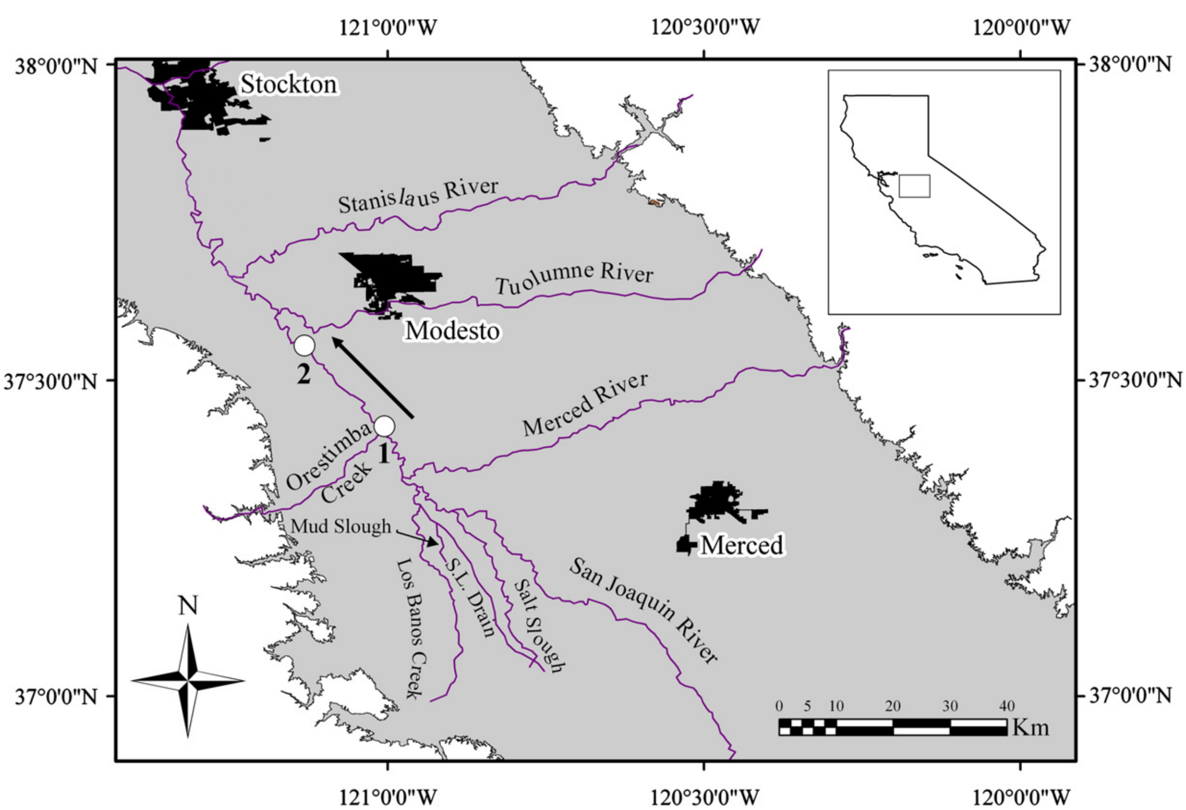

Fig. 1. Sampling locations for the 48 h studies along the mainstem of the San Joaquin River (1 — Crows Landing; 2 — Grayson). The arrow between the two sampling locations indicates flow direction.