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# Dissolved carbon transport in a river-lake continuum: A case study in a subtropical watershed, USA

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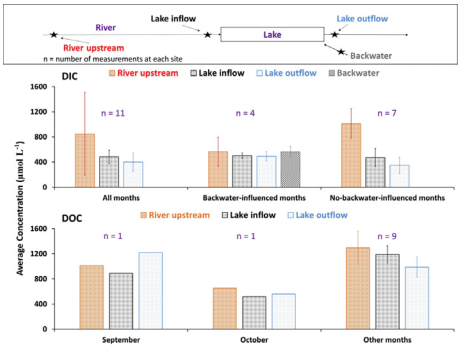
## HIGHLIGHTS

- In 9 out of 11 months the lake was a sink for DOC sustained by terrigenous sources.
- The lake changed to a DOC source during months with extended water residence time.
- DIC in the river-lake continuum originated mainly from $^{13}$C depleted sources.
- $CO_2$ outgassing made the lake a sink for the down-network DIC transport.
- Backwater containing high-level DIC could offset the sink function of the lake.

## GRAPHICAL ABSTRACT



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## ABSTRACT

Rivers and lakes have been traditionally studied as separate entities for carbon transport. However, there is a gap in our knowledge of the connectivity of dissolved carbon in a river-lake continuum. In this study, we analyzed dissolved carbon along the Little River-Catahoula Lake in subtropical Louisiana, United States to assess carbon biogeochemistry in such a river-lake continuum. Monthly in-situ measurements and water sample collections were made at four locations during April 2015 to February 2016 to determine riverine carbon transport into and out of the lake. Results show that much of the dissolved inorganic carbon (DIC) in the river-lake continuum originated from $^{13}$C depleted sources with an average $\delta^{13}C_{DIC}$ of −18.5‰. Significant decreases in DIC were found after the river passed through the lake (from 482 to 399 μmol $L^{-1}$), which was most prevalent when the lake was not affected by backwater flow from the downstream river. $CO_2$ outgassing could be mainly responsible for the sink behavior of the lake for DIC. Dissolved organic carbon (DOC) in the studied watershed were mostly terrigenous with low $\delta^{13}C_{DOC}$ averaged at −29.2‰. Significant, consistent decreases in DOC concentrations were found from the river to the lake inflow and then to the lake outflow. During the majority of the year, the lake reduced DOC concentrations from the river inflow water, but switched to functioning as a source of DOC during warmer, dryer conditions in September and October due to increased water residence time. Therefore, the lake functioned both as a sink and as a source for DOC.

## 1. Introduction

Studying the biogeochemical connectivity between rivers and lakes can help us understand their ecological and environmental impacts

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within a drainage basin. Rivers are the principal linkages from the land to the ocean carrying suspended and dissolved materials, the transfer of which are key components of the carbon balance at the decadal to centennial scale, the sediment balance, the nutrient balance of surface waters, and control the coastal zone functioning to a great extent (Milliman et al., 1987; Wafar et al., 1989; Caddy and Bakun, 1994; Meybeck, 2003; Gong et al., 2015). In a river-lake network, lakes have been found to remove nitrogen (Harrison et al., 2009) and carbon substantially (Cole et al., 2007; Bastviken et al., 2011). Nowadays lakes are increasingly being studied in the context of biogeochemical connectivity across waterscapes (Winter, 1999; Jones, 2010; Lottig et al., 2011; Lottig et al., 2013), which remains an emerging research frontier (Powers et al., 2014).

Carbon, required by all aquatic organisms, is one of the most concerned elements in aquatic geochemistry studies. Dissolved inorganic carbon (DIC) and dissolved organic carbon (DOC) together constitute the major carbon reservoir in rivers and lakes, which have been recognized as important components of the global carbon cycle interacting with atmospheric, terrestrial and oceanic carbon (Brunet et al., 2005; Shin et al., 2015). DIC is often the most abundant inorganic carbon phase in rivers and streams in aquatic ecosystems (Marx et al., 2017), while DOC plays an important role in affecting the transport of metals and organic pollutants, influencing photo-chemistry of natural waters and nutrient availability and serving as an important source of microbial substrate (Hope et al., 1997; Battin et al., 2009). Previous studies have recognized the importance of identifying the source and fate of DIC and DOC in surface water transport to elucidate carbon cycling through atmosphere–land–ocean systems (Volk et al., 1997; Maurice and Leff, 2002; Mayorga et al., 2005; Miller, 2011). The species and magnitude of dissolved carbon exchanges within these systems can be determined through the concentration and carbon isotopic composition of DIC ($\delta^{13}C_{DIC}$) and DOC ($\delta^{13}C_{DOC}$) in waters (Telmer and Veizer, 1999; Ye et al., 2015).

Lakes and rivers have traditionally been studied as separate entities for dissolved carbon transport, and a knowledge gap still exists in the dissolved carbon transport in a river-lake continuum. Rivers are considered as either a single channel of flowing water or as a larger system including the river channel floodplain network (Bouwman et al., 2013). Consequently, riverine carbon transport is mostly studied as a continuous system from headwaters to the river mouth without considering in-network lakes within rivers' passageways (Dubois et al., 2010; Iwata et al., 2013). Several studies have noted that rivers and lakes should be considered as a combined conduit and reactor for terrestrial carbon transport across waterscapes (Cole et al., 2007; Tranvik et al., 2009), and the retention process within in-network lakes need to be included for quantifying the biogeochemical filtering of a river-lake continuum (Bouwman et al., 2013). Specifically, existing studies focusing on riverine DIC have reported that partial pressure of carbon dioxide ($pCO_2$) in rivers and streams can decrease downstream because of $CO_2$ evasion as water travels away from high $CO_2$ inputs (Brunet et al., 2009). Some studies have also shown that $pCO_2$ may also increase downstream if originates in large lakes (Buhl et al., 1991; Flintrop et al., 1996). However, very few studies have looked into how DIC dynamics change in a fluvial system before and after passing through a lake. For DOC, while extended residence times in lakes could result in lakes functioning as DOC sinks, results to date have been inconsistent indicating that lakes can function as both sources (Kalinin et al., 2016) or sinks (Kang et al., 2016) of DOC. In addition, most studies for dissolved carbon dynamics have been undertaken in Nordic or temperate regions (Pacheco et al., 2014; Chow et al., 2017), but their results may not necessarily reflect the same as a subtropical watershed study.

To assess the influence of an in-network lake on DIC and DOC transport, this study was conducted along the Little River-Catahoula Lake continuum in central Louisiana, USA to discern the dynamics of concentrations and $\delta^{13}C$ isotopic signatures of DIC and DOC across waterscapes. The ultimate goal is to determine the major sources and corresponding biogeochemical processes controlling DIC and DOC dynamics, and to explore whether the subtropical lake function as a carbon sink or carbon source for dissolved carbon transport in the river-lake continuum.

## 2. Methods

### 2.1. Little River – Catahoula Lake continuum

This study was conducted in the lower Little River Basin in subtropical Louisiana, United States, from April 2015 to February 2016 (Fig. 1). The Little River is formed by the confluence of the Dugdemona River and Castor Creek at a geographical location of 92°21′46″W and 31°47′48″N, the headwaters of which are predominantly forested (DaSilva et al., 2013). The river flows initially southeastwards in north-central Louisiana, and then turns east-northeastwards into Catahoula Lake (Fig. 1). Catahoula Lake is the largest natural inland freshwater lake in Louisiana with a surface area of approximately 119 $km^2$. It is a principal stopover and wintering area for hundreds of thousands of migratory waterfowl and shorebirds. In 1972, a check dam (a.k.a. Little River Closure Dam) and an outflow canal were built at the lake to control water level for creating optimal habitats for migratory birds (Doyle et al., 2002). The check dam is built across the natural outflow channel at French Fork (Fig. 1) to prevent outflow from the lake. Previous studies have reported backwater flows to the lake through the dam (Dugué, 2015). Since the French Fork of the Little River is connected to the Black River which flows into the Atchafalaya River, the Catahoula Lake water stage is affected by Atchafalaya River's stage. When the Atchafalaya River stage is <7.3 m, excess water drains to the east to the Black River through the check dam on the French Fork of the Little River. When the Atchafalaya River stage is >7.3 m, the lake receives backwater from Atchafalaya-Red-Mississippi rivers through the Balck River and the check dam on the French Fork (Dugué, 2015; Latuso et al., 2017). The outflow canal is a straight channel of approximately 30 m in width and the outflow is controlled by a sluice gate by the US Army Corp of Engineers. The lake water level is normally maintained high during the winter-spring period and low during the summer–fall period with maximum and average water depth at around 16 and 11 m, respectively (Dugué, 2015).

Climate in the region can be classified as humid subtropical with long hot summers and short mild winters. The long term annual precipitation is about 1470 mm (Gaydos et al., 1973). Headwaters of the Little River are mostly covered by pine forests, and the uppermost part of the river above Catahoula Lake flows through a mixed oak-gum bottomland forest interspersed with stands of bald cypress (Gaydos et al., 1973). The variably-inundated lakebed of Catahoula Lake is occupied by herbaceous plants and woody plants at slightly higher elevations on the lake margins including water-elm (*Planera aquatic* J.F. Gmel.), swamp-privet (*Forestiera acuminate* (Michx.) Poir.) and bald cypress (*Taxodium distichum* (L.) Rich.) (Latuso et al., 2017). The surface geology of the river drainage area is dominated by a series of clays, sands, and gravels which unconformably overlie Tertiary deposits (also known as Citronelle and Port Hudson formations) (Fisk, 1939). The Little River was developed by upon Pleistocene deltaic plains during one or another stage of Pleistocene rejuvenation (Fisk, 1939), and high calcium limestones are distributed in catchments of its headwaters (MWKL, 1972). The dominant soil series in the catchment are the Smithdale and Ruston series. Other important soil series include Ouachita, Jena, Libuse, Gore and Fausse series (NRCS, 2017).

### 2.2. Sampling design

Four sites were chosen to represent the Little River-Catahoula Lake continuum (Fig. 1). They include 1) a Little River upstream site (LIL) that was close to the confluence point of the Dugdemona River and