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Short communication

# Estimation of shallow groundwater discharge and nutrient load into a river

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ABSTRACT

Pollution of rivers with excess nutrients due to groundwater discharge, storm water runoff, surface loading, and atmospheric deposition is an increasing environmental concern worldwide. While the storm water runoff and surface loading of nutrients into many rivers have been explored in great detailed, the groundwater discharge of nutrients into the rivers has not yet been thoroughly quantified. This study ascertained the shallow groundwater discharges and nutrient loads into the Lower St. Johns River (LSJR), FL, USA. The groundwater discharges were obtained using Darcy's law along with field measured hydrological parameters, whereas the groundwater nutrient loads were calculated based on the groundwater discharges and the field measured nutrient concentrations. The average rate of groundwater discharge per unit cross-section area over the four selected sites along the LSJR was about $1.2 \times 10^{-2}$ m$^3$ m$^{-2}$ d$^{-1}$. The average loads of groundwater nutrients into the adjacent LSJR were 10.6 and 5.6 mg m$^{-2}$ d$^{-1}$, respectively, for nitrate- and nitrite-nitrogen ($NO_x$-N) and total phosphorus (TP). In general, seasonal variations of the groundwater levels were larger than the river stages, whereas site variations of groundwater nutrient concentrations were larger than seasonal variations of groundwater nutrient concentrations. Results from this study are useful for estimation of groundwater contamination and river eutrophication.

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## 1. Introduction

Eutrophication of surface waters with excess nutrients due to groundwater discharge, storm water runoff, surface loading, and atmospheric deposition is an environmental concern worldwide. This is also true for the Lower St. Johns River (LSJR), Florida. Excessive nutrients entering the LSJR come mainly from surface runoff generated from urban, rural, and agricultural lands; discharges from ditches serving agricultural croplands; contaminated groundwater seepage from malfunctioning septic tank systems; aquatic weed control and naturally occurring organic inputs; and atmospheric deposition (Campbell et al., 1993; Ouyang et al., 2011). The degradation of water quality due to nitrogen and other nutrients has resulted in altered species composition and decreased overall health of aquatic communities within the area. High levels of these constituents in surface water bodies have contributed to conditions of severe algal blooms, elevated bacterial levels, and increased biochemical oxygen demand (BOD). Increased BOD levels can lower oxygen concentrations to the point where fish kills occur (Campbell et al., 1993). Despite a need to understand nutrient dynamics in the LSJR and its potential adverse environmental impacts upon river water quality, little effort has been devoted to comprehensively summarizing shallow groundwater nutrient status and its potential discharge into the LSJR.

Groundwater discharge associated with nutrient load into estuaries and rivers can be significant across a wide range of temporal and spatial scales. Evidence of such discharges and loadings as well as their impacts upon hydrological and biological conditions in estuarine and river systems has been documented in the past decades (Cable et al., 2004; Kim, 2010; Santos et al., 2010; Markku et al., 2011; Shukla et al., 2011). Cable et al. (2004) studied the use of multiple techniques, including seepage meters, natural tracers and numerical modeling, to determine the volume of total groundwater discharge into the Indian River Lagoons in Florida. They found that groundwater discharge rates ranged from 4 to 9 cm d$^{-1}$ using seepage meters, 3–20 cm d$^{-1}$ using tracers $^{222}$Rn and $^{226}$Ra, and 0.05–0.15 cm d$^{-1}$ using groundwater flow model. These authors attributed the discrepancy in groundwater discharge rates to the sources of water being measured and not the techniques themselves. Sigua and Tweedale (2003) reported that on average, the Indian River Lagoon is receiving the annual external loads of 832,645 and 94,467 kg of TN and TP, respectively. Of which, about 8 and 19% of TN and TP, respectively, were from the groundwater discharges. Although these studies have provided good insights into the groundwater discharges and nutrient loads into the surface waters, the potential adverse environmental impacts of the groundwater nutrients upon river water quality are still poorly understood.

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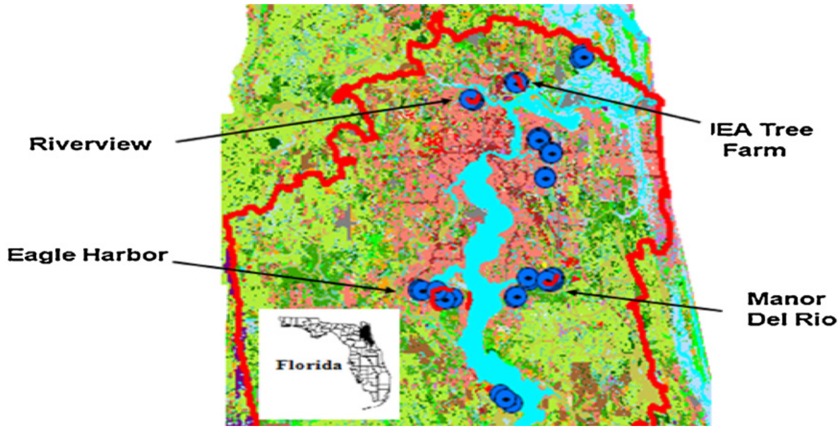


**Fig. 1.** Location of the shallow groundwater monitoring sites used in this study.

The objective of this study was to investigate shallow groundwater discharge and nutrient load from the four selected sites, namely Eagle Harbor, JEA Tree Farm, Manor Del Rio, and Riverview from the Duval and Clay Counties, into the adjacent LSJR using field measurements and Darcy law. The specific motivations were to estimate: (i) seasonal variations of river and groundwater levels and nutrient concentrations; and (ii) average groundwater discharges and nutrients (i.e., $NO_x$-N and TP) load into the LSJR.

## 2. Materials and methods

The LSJR basin is located in northeast Florida, between 29° and 30°N and between 81.13° and 82.13°W. It is an area of about 7192 km$^2$ and represents about 22% of the area within the St. Johns River Water Management District (SJRWMD), Florida. Land uses within the basin largely consist of residential, commercial, industrial, mining, ranching, row crop, forest, and surface water. A series of water-quality problems including point and non-point source pollutants such as nutrients, hydrocarbons, pesticides, and heavy metals have been identified and addressed since the 1950s (Campbell et al., 1993).

Twelve shallow groundwater wells from four sites (Fig. 1) were installed in 2003 for the purpose of monitoring groundwater quality in the LSJR basin. Well casing depths range from 4 to 7 m, which are considered shallow groundwater wells in Florida. The groundwater samples were collected quarterly for a 1-year period by the contractor and chemically analyzed by the SJRWMD. The four sites selected in this study are from Eagle Harbor, JEA Tree Farm, Manor Del Rio, and Riverview areas. These sites were identified to have highest groundwater nutrient contamination.

Groundwater sampling includes the collection of groundwater sample and water level data as well as the measurement of hydraulic conductivity data from 12 wells. Prior to sample collection, each well was purged with a minimum of 3 well volumes or 1 well volume and 2 equipment volumes (for well with very low recharge rates). All wells were purged and sampled using a peristaltic pump and dedicated tubing using low flow quiescent procedures. Water level data was measured in each sampling event. The hydraulic conductivity was measured with slug test. All sampling and analysis activities were conducted in accordance with the SJRWMD Standard Operating Procedures for the collection and analysis of water quality samples and field data, which is in compliance with US EPA's standard methods.

The rate of groundwater discharge from the shallow groundwater into the adjacent LSJR can be calculated by using the Darcy's law, whereas the groundwater nutrient load into the adjacent LSJR can be estimated using the following equation:

$$R_{Nut} = 10^3 Q C_{Nut} \quad (1)$$

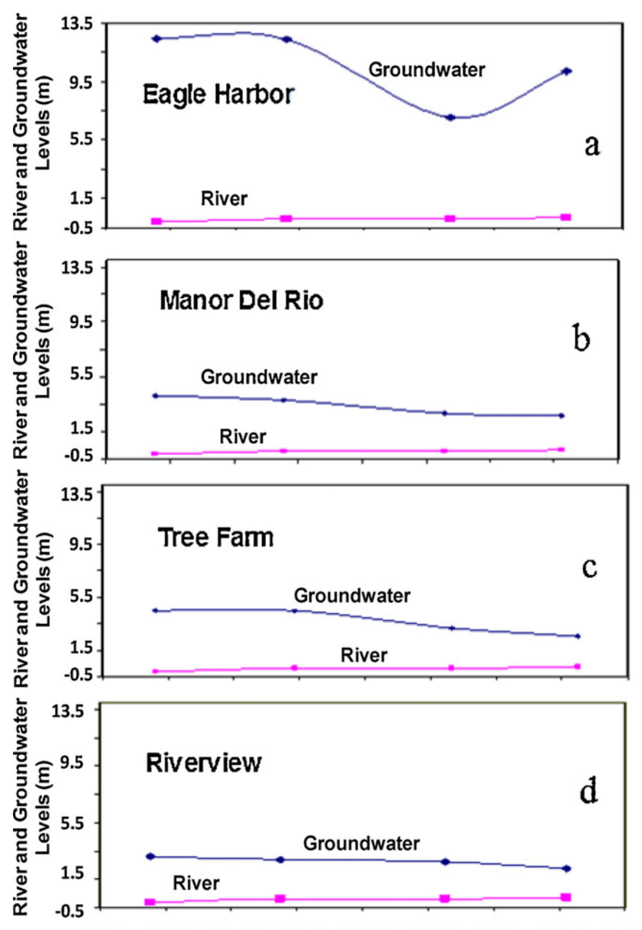


**Fig. 2.** Seasonal variations of river and groundwater levels for the four selected sites. Data were collected in June, October, January, and April for the four seasons.