Ecological Engineering 38 (2012) 101–104

Contents lists available at SciVerse ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

Short communication

Estimation of shallow groundwater discharge and nutrient load into a river

Ying Ouyang*

USDA Forest Service, Center for Bottomland Hardwoods Research, 100 Stone Blvd., Thompson Hall, Room 309, Mississippi State, MS 39762, USA

ARTICLE INFO

Article history:
Received 17 July 2011
Received in revised form 25 October 2011
Accepted 29 October 2011
Available online 21 November 2011

Keywords:
Groundwater discharge
Nutrient load
River

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 1.2×10^{-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.

Published by Elsevier B.V.

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.

* Tel.: +1 662 325 8654.
E-mail address: youyang@fs.fed.us

0925-8574/$ – see front matter. Published by Elsevier B.V.
doi:10.1016/j.ecoleng.2011.10.014

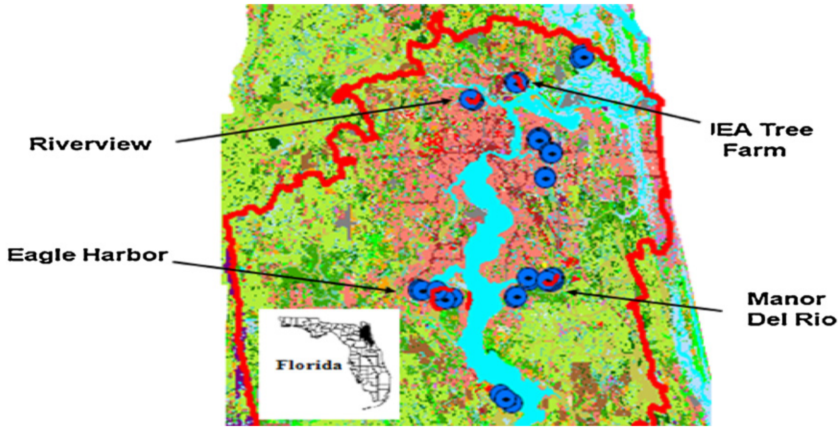

Fig. 1. Location of the shallow groundwater monitoring sites used in this study.

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:

$$R_{Nut} = 10^3 Q C_{Nut} \tag{1}$$

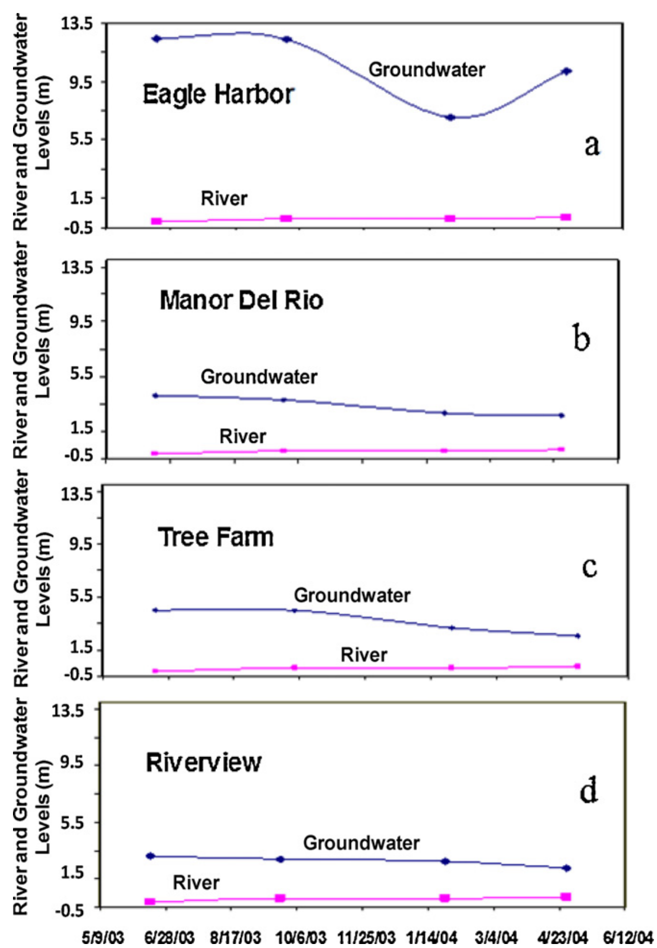

Fig. 2. Seasonal variations of river and groundwater levels for the four selected sites. Data were collected in June, October, January, and April for the four seasons.

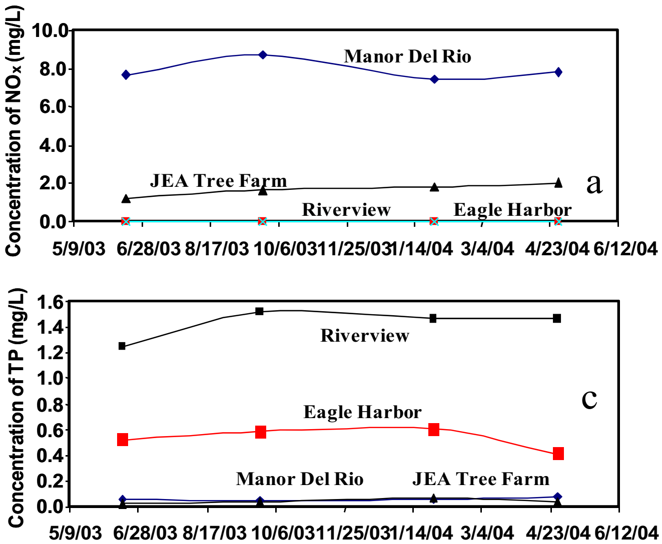

Fig. 3. Seasonal variations of average groundwater nutrient concentrations for the four selected sites. Data were collected in June, October, January, and April for the four seasons.

where R_{Nut} is the load of groundwater nutrients (mg d^{-1}), Q is the lateral groundwater discharge rate (m^3 d^{-1}), and C_{Nut} is the groundwater nutrient concentration (mg L^{-1}).

3. Results and discussion

3.1. Seasonal variations of water level and nutrients

Seasonal variations of river and groundwater levels during 2003–2004 at the four selected sites are shown in Fig. 2. The groundwater level data for the four seasons were collected from the monitoring wells in our study, whereas the river water level data were obtained from the nearby USGS stations. In general, the groundwater level was high during summer and decreased from summer to next spring. This occurred because a wet season normally takes place during summer in Florida. Comparison of groundwater levels among the four sites shows that large variations and high groundwater levels were found at the Eagle Harbor site (Fig. 2a) with a maximum level of 12 m, a minimum of 8 m, and a difference of 4 m between the two extremes. In contrast, small variations and low groundwater levels were observed for the other three sites. Fig. 2 further reveals that seasonal variations in river water levels were minimal for all of the four sites, with a maximum variation of only 0.3 m. Seasonal differences in water levels between the groundwater and river can also be deduced from Fig. 2. For instance, the maximum difference in water levels between the groundwater and river during summer (in June) at the Eagle Harbor site was 12 m (i.e., 12 − 0 = 12) (Fig. 2a). Such difference is a driving force for groundwater discharge and nutrient load into the adjacent LSJR.

Fig. 3 shows the seasonal variations in average concentrations of NO_x-N and TP in the shallow groundwater for the four selected sites. In general, the average concentration of NO_x-N at the Manor Del Rio site was higher and its seasonal variations were larger than those of the other three sites (Fig. 3a). The average maximum and minimum concentrations of NO_x-N at this site were, respectively, 8.7 and 7.4 mg L^{-1} and the difference between the two extremes was 1.3 mg L^{-1}. In contrast, the average concentrations of NO_x-N at the Eagle Harbor and Riverview sites were less than 0.02 mg L^{-1}, which is well below the natural background level (<2 mg L^{-1}) for the unaffected areas such as those natural forest lands without human activities.

3.2. Groundwater discharge and nutrient load

Table 1 shows that the rate of average groundwater discharge was high in the Riverview area (487.82 m^3 d^{-1}) but low in the Eagle Harbor area (24.95 m^3 d^{-1}) with the JEA Tree Farm (398.32 m^3 d^{-1}) and Manor Del Rio (127.55 m^3 d^{-1}) areas in between. The large discrepancy between the Riverview and Eagle Harbor areas occurred partially because of the hydraulic conductivity and partially because of the water level gradient. The hydraulic conductivity in the Riverview area (12.9 m d^{-1}) was about 74-fold larger than in the Eagle Harbor area (0.17 m d^{-1}) and the water level gradient between the groundwater monitoring well and river locations in the Riverview area (0.0161) was about 7-fold greater than in the Eagle Harbor (0.0023).

Rates of groundwater discharge per unit cross section area for the Eagle Harbor, JEA Tree Farm, Manor Del Rio, and Riverview sites were, respectively, 4.0×10^{-4}, 2.1×10^{-2}, 2.2×10^{-3}, and 2.4×10^{-2} m^3 m^{-2} d^{-1} with an average of about 1.2×10^{-2} m^3 m^{-2} d^{-1} for all of the four sites. This average rate was close the one in Jensen Beach, somewhat lower than the one in Indian River Lagoons, and 35-fold lower than the one in Florida Keys (Martin et al., 2002; Dillon et al., 2003). It should be noted that the geological settings of our study area are somewhat similar to those of Indian River Lagoons and Jensen Beach. Results suggested the rates of groundwater discharge obtained from this study are in a reasonable range.

Groundwater nutrient loads for each of the four selected sites were given in Table 1. The highest load of groundwater NO_x-N (1.0 kg d^{-1}) was in the Manor Del Rio area, whereas the highest loads of groundwater TP (0.9 kg d^{-1}) were in the Riverview area. Results suggested that the loads of groundwater nutrients into the LSJR depend not only on the groundwater discharge rates but also on the groundwater nutrient concentrations. Average groundwater nutrient loads for all of the four sites were 0.4 and 0.2 kg d^{-1}, respectively, for NO_x-N and TP. Comparison of our findings with those reported by the others shows that the load of groundwater TP was about 50% higher in Indian River Lagoons than in our study area. We attributed these discrepancies to different land uses and hydraulic conditions. Further study is warranted to estimate the groundwater discharge and nutrient load into surface water more accurately by focusing on surface water measurements, hyporheic

Table 1
Estimated average groundwater discharge and nutrient load into the LSJR.

Site	GW discharge (m^3 d^{-1})	Average TN NO_x-N	Average TP (mg L^{-1})	Average load (mg L^{-1})	NO_x-N load (mg d^{-1})	TN load (mg d^{-1})	TP load (mg d^{-1})
Eagle Harbor	24.95	0.02	2.21	0.53	380	55,048	13,182
JEA Tree farm	398.32	1.68	0.09	0.04	667,463	34,485	15,744
Manor Del Rio	127.55	8.10	0.22	0.06	1,032,555	28,217	7327
Riverview	487.82	0.01	3.37	1.76	4509	1,645,425	858,123

zone nutrient exchange, and different geological settings comparison.

Acknowledgements

The author thanks the colleagues from the St. Johns River Water Management for their valuable comments and suggestions.

References

Cable, J.E., Martin, J.B., Swarzenski, P.W., Lindenberg, M.K., Steward, J., 2004. Advection within shallow pore waters of a coastal Lagoon, Florida. Ground Water – Ocean Issue 2004 42, 1011–1020.

Campbell, D., Bergman M., Brody, R., Keller, A., Livingston-Way, P., Morris, F., Watkins, B. 1993. SWIM Plan for the Lower St. Johns River Basin. St. River Water Management District, Palatka, Florida. January 1993.

Dillon, K., Burnett, W., Kim, G., Chanton, J., Corbett, D.R., Elliott, K., Kump, L., 2003. Groundwater flow and phosphate dynamics surrounding a high discharge wastewater disposal well in the Florida Keys. J. Hydrol. 284, 193–210.

Kim, G., 2010. Integrated consideration of quality and quantity to determine regional groundwater monitoring site in South Korea. Water Res. Manage. 24, 4009–4032.

Markku, K., Sallantaus, T., Vasander, H., 2011. Post-restoration development of organic carbon and nutrient leaching from two ecohydrologically different peatland sites. Ecol. Eng. 37, 1008–1016.

Martin, J.B., Cable J.E., Swarzenski, P.W., 2002. Quantification of groundwater discharge and nutrient loading to the Indian River Lagoon. St. Johns River Water Management District, Palatka, Florida. Final Report.

Ouyang, Y., Luo, S.M., Cui, L.H., Wang, Q.R., Zhang, J.E., 2011. Estimation of real-time N load in surface water using dynamic data driven application system. Ecol. Eng. 37, 616–621.

Santos, I.R., Peterson, R.N., Eyre, B.D., Burnett, W.C., 2010. Significant lateral inputs of fresh groundwater into a stratified tropical estuary: evidence from radon and radium isotopes. Mar. Chem. 121, 37–48.

Shukla, S., Goswami, D., Graham, W.D., Hodges, A.W., Christman, M.C., Knowles, J.M., 2011. Water quality effectiveness of ditch fencing and culvert crossing in the Lake Okeechobee basin, southern Florida, USA. Ecol. Eng. 37, 1158–1163.

Sigua, G.C., Tweedale, W.A., 2003. Watershed scale assessment of nitrogen and phosphorus loadings in the Indian River Lagoon basin, Florida. J. Eng. Manage. 67, 363–372.