Journal of Hydrology 527 (2015) 718–733

Contents lists available at ScienceDirect

Journal of Hydrology

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

Karst estuaries are governed by interactions between inland hydrological conditions and sea level

Damian M. Menning [a], Jonathan G. Wynn [b], James R. Garey [a,*]

[a] Department of Cell Biology, Microbiology, and Molecular Biology, University of South Florida, 4202 E. Fowler Ave., ISA 2015, Tampa, FL 33620, United States
[b] School of Geosciences, University of South Florida, 4202 E. Fowler Ave., NES 107, Tampa, FL 33620, United States

ARTICLE INFO

Article history:
Received 25 March 2015
Received in revised form 27 April 2015
Accepted 11 May 2015
Available online 19 May 2015
This manuscript was handled by Peter K. Kitanidis, Editor-in-Chief, with the assistance of Barbara Mahler, Associate Editor

Keywords:
Aquifer
Geochemistry
Mixing zone
Salt water intrusion

SUMMARY

Karst estuaries represent unique systems created by freshwater inputs that flow directly into the sea through karst conduits and/or matrices. In order to determine the characteristics of a karst estuary resulting from the brackish discharge of Double Keyhole Spring into the Gulf of Mexico, we monitored short-term tidal fluctuations, long-term rainfall patterns, aquifer levels, spring discharge, and multiple geochemical parameters along a transect from the spring through the estuary. We monitored four sites along a spring/estuary transect and a nearby inland freshwater spring to represent the freshwater portion of the Upper Floridan Aquifer. Datasondes were deployed in Double Keyhole Spring to measure discharge volume, tidal fluctuations, and physical water parameters for two years. Water samples were collected quarterly from both springs and the surrounding surface sites over the same time period. An isotopic/trace element mass balance tracer method was used to determine the hydrogeological components of the spring discharge from three possible sources: (1) freshwater from the upper portion of the Upper Floridan aquifer, (2) freshwater from the lower portion of the Upper Floridan aquifer, and (3) saltwater from the Gulf of Mexico. Within the water column of the submarine spring conduit, there were no significant differences of the sampled parameters over short sampling distances (<400 m) and periods (<1 h). Spring discharge directly correlated to aquifer level and negatively correlated to tidal level. The brackish nature of the spring discharge is due to simple mixing between Gulf of Mexico saltwater and freshwater from the lower portion of the Upper Floridan aquifer. The composition of the spring discharge varied seasonally, showing increased marine influence during the wet season. In June 2012, Tropical Storm Debby resulted in measurable freshwater inputs from the upper portion of the Upper Floridan aquifer that discharged directly to the estuary and bypassed the spring. The number of spring reversals (salt water intrusion events) into Double Keyhole Spring increased as the dry season progressed, stopped immediately after Tropical Storm Debby, and then gradually increased into the next dry season. Statistically significant geochemical differences were found along the spring/estuary transect on each collection date and seasonally at the individual sites. Our data shows that this karst estuary system is governed by the interactions between inland hydrological conditions and sea level.

1. Introduction

Submarine groundwater discharge (SGD) through subterranean estuaries has been recognized as a major source of nutrients to coastal ecosystems (Burnett et al., 2006; Moore, 2010; Smith and Cave, 2012; Szymczycha et al., 2012). This influx of nutrients may have dramatic impacts on the ecology of the surrounding estuaries (Johannes, 1980; Kotwicki et al., 2014) and can be seen by the resulting geochemical gradients (Burnett et al., 2003; Kim et al., 2005). Increased aquifer usage and/or increased sea levels may result in salt water intrusion to coastal aquifers by shifting the mixing zone underneath estuaries inland, and turning them from estuarine to salt marsh habitats. This may have dramatic effects on the biological communities which currently serve as nurseries for numerous invertebrate and fish species (Beck et al., 2001).

Estuaries are semi-enclosed bodies of water which have a free connection to the open sea and within which sea water is measurably diluted with freshwater derived from land drainage (Pritchard, 1967). This definition generally applies to freshwater inputs from surface rivers and streams which may be secondary to subterranean drainage in karst regions. Moore (1999) defined the subterranean estuary as a coastal aquifer where terrestrial

* Corresponding author. Tel.: +1 (813) 974 7103.
E-mail address: garey@usf.edu (J.R. Garey).

http://dx.doi.org/10.1016/j.jhydrol.2015.05.021
0022-1694/

groundwater measurably dilutes seawater that has invaded the aquifer through a free underground connection to the sea. Along karst-dominated coasts (Durr et al., 2011), subterranean estuaries are the primary source of freshwater and nutrient inputs to the sea due to the lack of surface rivers or streams. Karst estuaries represent habitats along karst-dominated coasts where freshwater inputs are not derived from surface drainage but instead derived from groundwater (Fig. 1).

The study of SGD has primarily focused on diffuse flow over large regions (Moore, 1996; Santos et al., 2008) but less research has been conducted on point-source discharges such as conduit flow through submarine springs (Swarzenski et al., 2001; Peterson et al., 2009). In Florida there are over 700 documented springs (http://www.dep.state.fl.us/springs/), most of which are inland, but there are also numerous undocumented springs along the coast (Fig. 2). Some of these springs discharge aquifer water directly to the Gulf of Mexico forming karst estuaries and act similarly to surface rivers bringing freshwater and nutrients to the estuary (Harrington et al., 2010).

Under reverse-flow conditions, submarine springs may also be potential points for salt water intrusion of coastal aquifers that could be harmful to the freshwater sources used by many coastal communities (Fleury et al., 2007; Vera et al., 2012). Terrestrial coastal springs typically discharge freshwater but are also tidally influenced because of underlying marine water. Nearshore and offshore springs may discharge fresh or brackish water depending on inland hydrological conditions (Michael et al., 2005). Changes in long term weather patterns and human water use can have deleterious impacts on coastal springs (Wetland-Solutions-Inc., 2007; Quinlan et al., 2008), and thus these springs can act as sentinels of hydrological change in coastal regions. For example, an offshore submarine spring known as Jewfish Sink (Garman and Garey, 2005), approximately one km offshore of West Central Florida, ceased flow completely in 1962 following a prolonged drought and increased aquifer use by a nearby citrus industry.

Storm events play an important role in determining the hydrological conditions of coastal springs (Lerner et al., 1990). There is limited understanding of the influence that tidal fluctuations and rainfall patterns have on submarine spring discharge (Ozyurt, 2008; Valle-Levinson et al., 2011). In karst regions, rainfall events are the primary source of direct aquifer recharge (Lerner et al., 1990) which result in higher water tables and subsequent increases in aquifer discharge through springs (reviewed in de Vries and Simmers, 2002). Heavy rainfall due to storm events can create a surge of freshwater through the system that may contribute as much as 25% of the total spring discharge (Lakey and Krothe, 1996). This surge plays an important role in not only aquifer recharge but in defining the geochemical gradients formed by aquifer discharge through coastal springs.

Ecosystems within karst estuaries are likely governed by inland hydrological conditions and sea level. Events that shift the balance between these two forces may have a dramatic impact on the biological communities of these environments (Santoro et al., 2008). The goal of this study is to describe the hydrological and geochemical drivers of a specific karst estuary. We (1) describe the influence of tidal fluctuations on spring discharge, (2) demonstrate the impact rainfall patterns have on aquifer level and spring discharge, (3) define the hydrogeological conditions of the nearshore brackish

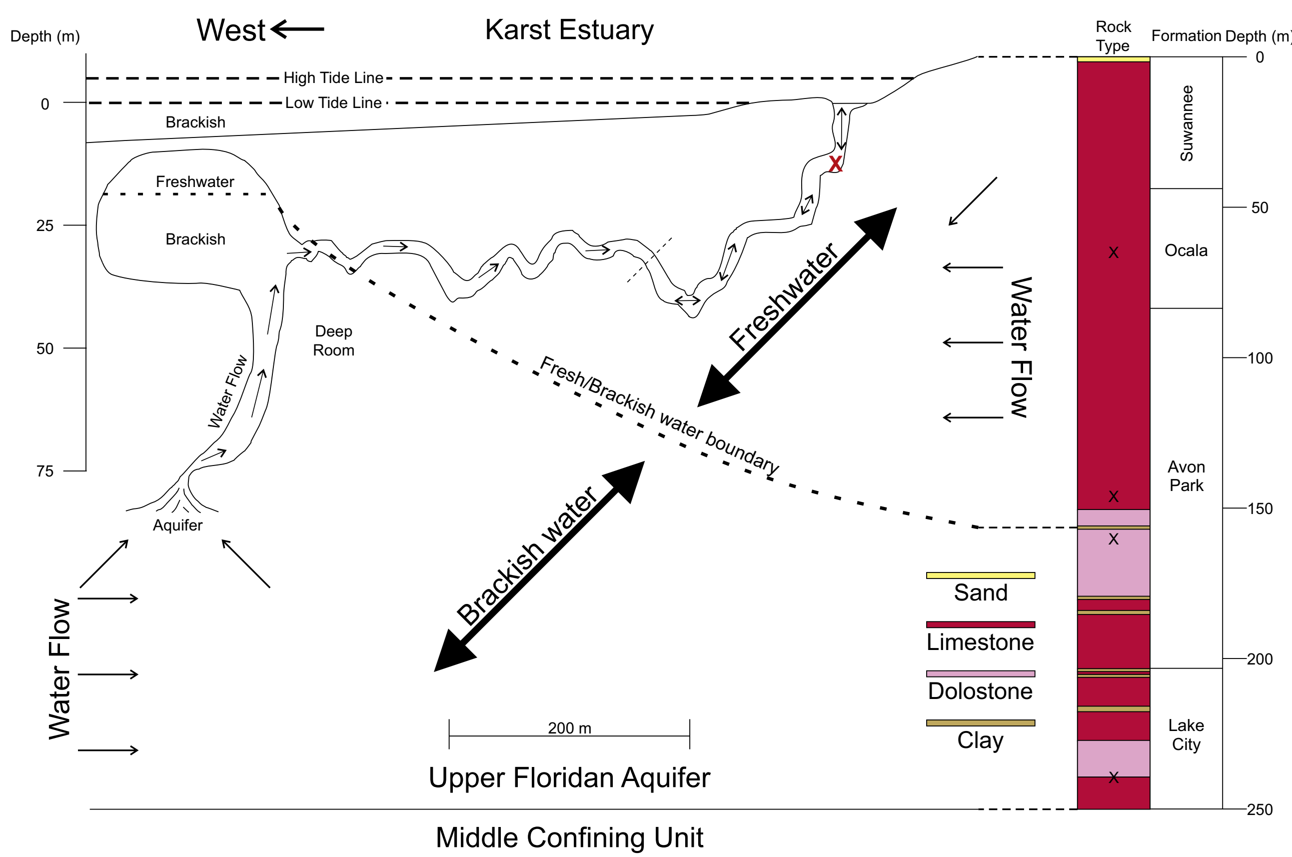

Fig. 1. Double Keyhole Spring profile and the geology of the nearby area. On the left side is the cross section of Double Keyhole Spring showing the direction of water flow. The red X near the entrance indicates the datasonde deployment location. The dashed line across the conduit path estimates the location of the deepest penetration of surface water during reversals noted during the study period. The right side of the figure shows the geology of the nearby area with data from Decker (1983). Black X's indicate the approximate depth of SWFWMD hydraulic head gauges. The dashed line across the middle of the figure indicates the edge of the mixing zone between the Gulf of Mexico and the Upper Floridan aquifer. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)