USING STREAM GAGE DATA TO QUANTIFY SURFACE WATER/GROUNDWATER EXCHANGES BETWEEN THE UPPER FLORIDAN AQUIFER AND THE LOWER FLINT RIVER, GEORGIA, USA, 1989-2003

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Abstract. Historical discharge measurements from two U. S. Geological Survey (USGS) gaging stations were used to quantify surface water/groundwater exchanges between the lower Flint River and the Upper Floridan aquifer (UFA) in south Georgia. This approach, based on differences between offset-corrected (OC) downstream and upstream discharge estimates ($Q_{downstream}(OC)-Q_{upstream}=Q_{diff}$), was feasible because of the unique geohydrology of this 55 kilometer (km) stream section in which numerous large spring conduits substantially supplement base flow, and tributary stream contributions are relatively minor. Q_{diff} values for 1989 through 2003 revealed patterns in groundwater/surface water exchanges that included streamflow losses that exceeded 150 cubic meters per second (cms) during floods with corresponding flow returns of equal magnitude as river stage declined. Field data from temperature sensors placed inside large springs demonstrated flow reversals that were identified by negative Q_{diff} values. After adjustments were made to account for small tributary creek inputs, estimates of groundwater contributions to this stream section ranged from 6 to 22 cms with a mean of 13 cms when averaged over the study period. The highest groundwater discharge to the stream occurred during the spring when regional groundwater levels peak following heavy winter/spring rains and corresponding rates of evapotranspiration are low. During extreme periods of drought, groundwater contributions to the lower Flint River greatly declined.

INTRODUCTION

In the lower Flint River basin, it is critical to understand the nature of surface water/groundwater exchanges because groundwater entering the lower Flint River helps to sustain flows during dry periods, offers thermal refuge to aquatic biota such as the striped bass during the summer, and provides a source of high quality water which helps mitigate the negative effects of wastewater discharge directly into the river and its tributaries (Opsahl et al., 2003). The UFA may also provide a natural flood storage capacity that could significantly reduce overland flooding. Furthermore, there are concerns that the ecological integrity of the Flint River system is threatened by the growing demand on surface and groundwater supplies within the Flint River basin.

Studies conducted in the Coastal Plain Physiographic region of the United States indicate that regional groundwater discharge can account for 13 – 82% of annual stream discharge (Mosner, 2002; Bosch et al., 2003). There have been a number of studies conducted in the lower Flint River basin over the past 20 years that illustrated dynamic surface water/groundwater exchanges and identified potential impacts of anthropogenic activities, notably groundwater pumpage (Hayes et al., 1983; Hicks et al., 1987; Torak and McDowell, 1996; Albertson and Torak, 2002; Mosner, 2002). Hicks et al. (1987) reported that the Flint River received 26 cms of groundwater between Leesburg and Newton during the low-flow period in late November 1984. Using differences in stream discharge measurements avoids problems inherent in other methods of groundwater quantification, but it has not been applied seasonally or over the long-term record.

Here, we present a data-driven approach that utilizes long-term stream discharge data to quantitatively describe surface water/groundwater exchanges.

STUDY AREA

The Flint River basin drains an area of approximately 21,900 km^2. Below the Fall Line, the Flint River passes into the Coastal Plain and flows through exposed portions of the Ocala Limestone formation proximate to the water table of the UFA. The lower Flint River basin encompasses a 21 county area in which there are approximately 280,000 hectare (ha) of cropland irrigated with water from the UFA.

DATA ANALYSIS

Stream discharge data were obtained from USGS gaging stations upstream at Albany, GA (USGS 02352500) and downstream at Newton, GA (USGS

02353000) which are approximately 55 km apart. Additional data were obtained from the Spring Creek gaging station near Iron City, GA (USGS 02357000). Hourly mean streamflow data from both lower Flint River stations were available for the period of record covering October 1, 1989 through December 31, 2003.

I. Estimating offsets in transit time to temporally equate gage data prior to calculating Q_{diff}.

The hourly mean streamflow data were used to identify changes in discharge (peaks) that could be systematically recognized and flagged in both data sets. This was facilitated by the fact that flow just above the Albany gage is regulated by the Lake Chehaw dam which usually releases water in pulses. Programming parameters were chosen to ensure that accurate transit times were calculated across a spectrum of flow conditions (50 to 550 cms) which span all but the more extreme periods of flooding and drought.

Upstream peaks. The following equation was used to identify peaks that represented flow volume increases of greater than 20%/h of the average discharge, and represented the peak discharge spanning the subsequent 12 h period:

$PEAK_{up} = dQ_{up} \geq 0.2\ Q_{up}$, mean and 12 following $dQ_{up} < 0.2\ Q_{up}$, mean (eq. 1)

$PEAK_{up}$ is a clearly discernable peak in the hydrograph,

dQ_{up} is the hourly difference in measured stream discharge at the upstream gage,

Q_{up}, mean is the mean hourly Q_{up} between 10/1/1989 and 12/31/2003 (= 32.1 cms)

A threshold of much greater than 20% resulted in an inadequate number of peaks across the range of normal stream discharge values. A threshold much less than 20% yielded peaks that were difficult to identify at the downstream station.

Downstream peaks. The following equation was used to identify the same peak that was identified upstream:

$PEAK_{down} = dQ_{down}$ such that it is $\geq$ previous 3 dQ_{down} values and > the 3 following dQ_{down} values (eq. 2)

$PEAK_{down}$ is the peak which corresponds to the previously flagged upstream peak,

dQ_{down} is the hourly difference in measured stream discharge at the downstream gage.

This approach included an empirically-derived assumption of a 5 h minimum transit time. A smaller time frame was used downstream compared to upstream because of the natural dampening of upstream peaks that occurs. Identified peaks with transit times greater than 20 h were considered spurious.

II. Calculating Q_{diff} from hourly streamflow measurements

The relationship between upstream discharge and transit time was used to match each upstream hourly discharge measurement from the appropriate offset-corrected downstream hourly discharge measurement. From this, an hourly Q_{diff} dataset was derived using the following equation:

$$Q_{downstream}(OC) - Q_{upstream} = Q_{diff} \quad \text{(eq. 3)}$$

$Q_{downstream}(OC)$ is the offset-corrected downstream hourly discharge measurement,

$Q_{upstream}$ is the upstream hourly discharge measurement,

Q_{diff} is the difference between the $Q_{downstream}(OC)$ and $Q_{upstream}$

III. Calculating stream-corrected Q_{diff} to estimate groundwater input

There are three small tributary creeks (Dry, Raccoon, and Cooleewahee Creeks) along this stretch of the lower Flint River. Dry and Raccoon Creeks are usually dry except during floods. None of these three creeks are regularly monitored, but it was possible to pool a small number of discharge measurements from Cooleewahee Creek from available USGS data. The data from Cooleewahee Creek were compared to discharge data from Spring Creek, a similar creek in the lower Flint River basin with a USGS gaging station (USGS 02357000). Individual discharge measurements from Cooleewahee Creek were correlated to daily discharge measurements from Spring Creek to derive a surrogate flow measurement for Cooleewahee Creek (Q_{trib}). Daily values of Q_{trib} were then subtracted from daily Q_{diff} values to yield approximate values of groundwater inputs.

IV. Using temperature anomalies to ground-truth groundwater flow reversals

Aquifer water temperature varies little, ranging from 19 °C to 21 °C annually. Thus, flow reversals are evident by the infusion of relatively warm surface water in the summer and relatively cold water in the winter. Temperature data were collected from three of the largest springs along the lower Flint River between August 1999 and June 2000. Recorders were placed approximately 10 m into the springs and retrieved by cave divers.

RESULTS AND DISCUSSION

ing peak transit times

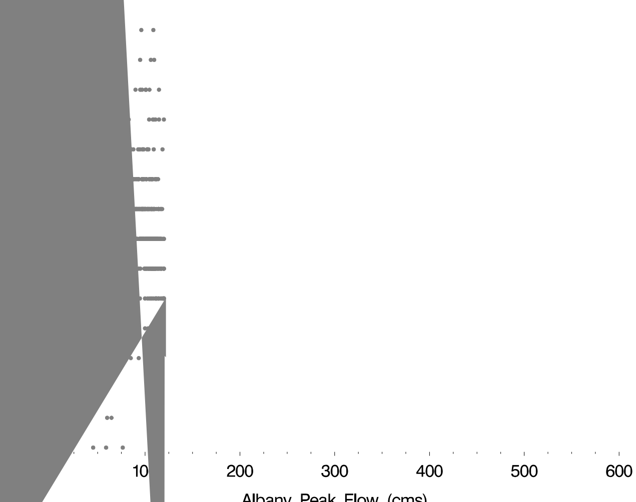
1,700 discernable peaks were used to derive the ship between transit time and the discharge ed with each peak at the Albany gaging station Transit times ranged from 14.5 h at a discharge 50 cms to 7.7 h at a discharge approaching 600 Transit times decreased approximately 2-fold discharges of 50 and 300 cms, but varied little at es between 300 and 600 cms. The data were ng Loess smoothing techniques. The chosen fit moothing parameter of 0.27 (AICC=2.312) and ing 95% confidence band shows a small range of in the transit time estimate around the fit. The fidence band increased slightly below discharges ns and above discharges of 400 cms. This may uted to fewer available data at these flow . Overbank flooding is not a factor because ccurs at higher discharges (780 cms at Albany cms at Newton) than the limits used in Fig. 1.

inear relationship between transit time and provided a more accurate means of equating nd downstream flows than an average or simple on between transit times at high and low

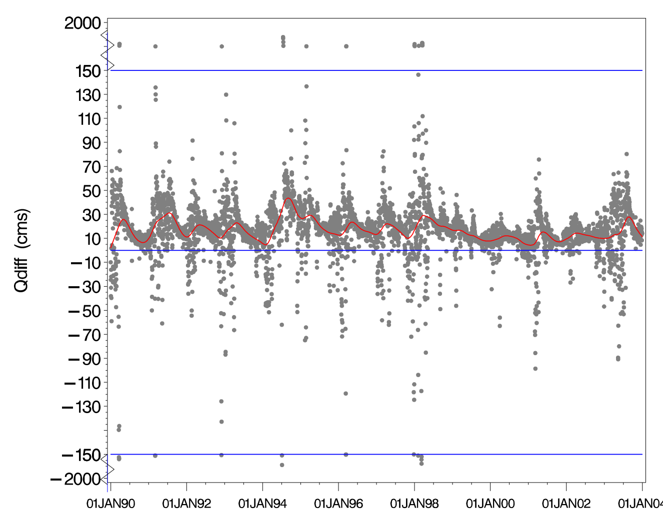
Q_{diff} from hourly mean stream discharge data

al Q_{diff} values spanned a range from -150 cms with occasional higher and lower values (Fig. e data were fitted with a cubic spline function, erns emerged over the period of record. There nal trend to Q_{diff} with maximum values during and spring and minimum values during the fall. Subsequent to 1998, the annual periodicity in Q_{diff} was less evident and there was an overall decline in Q_{diff}. This corresponded to the extreme period of drought that occurred throughout the Flint River basin between 1998 and 2002. In spring of 2003 a higher Q_{diff} more typical of non-drought conditions returned. The long-term trends in Q_{diff} demonstrate that this reach of the lower Flint River is a gaining stream receiving input from both tributary creeks and groundwater from numerous large springs of the UFA.

There were many instances in which Q_{diff} values were negative for extended periods of time (Fig. 2). Q_{diff} values from 2001 were used to examine this in more detail (Fig. 3). In March 2001, a large rain event was followed by three distinct peaks in stream discharge. These occurred on March 9 (716 cms), March 22 (765 cms), and April 9 (623 cms) and none exceeded the flood stage at Albany of 780 cms. Three large negative Q_{diff} periods were evident during this time and corresponded proportionately to the three peaks in streamflow. Negative Q_{diff} values persisted for as long as 10 days and were as large as -102 cms. After streamflow subsided, Q_{diff} declined to values that were similar to those prior to the large pulse of water generated by rainfall. Although much smaller in magnitude, similar events were observed in June 2001 after small increases in stream discharge occurred following rainfall. Similar events were also evident after the major flood events of 1994 and 1998. Although Q_{diff} estimates during extreme floods were compromised by overland flooding, they appeared to be much larger than 200 cms. In the lower Flint River, the increased head pressure that accompanies higher stream discharge can exceed the head pressure of the aquifer causing substantial flow reversals into the aquifer and a similar pattern of return flow through the spring conduits along the river.



ure 1. The ransit time between Albany and Newton nd peak flow t Albany. The 95% confidence interval s shown aroun d the fit.



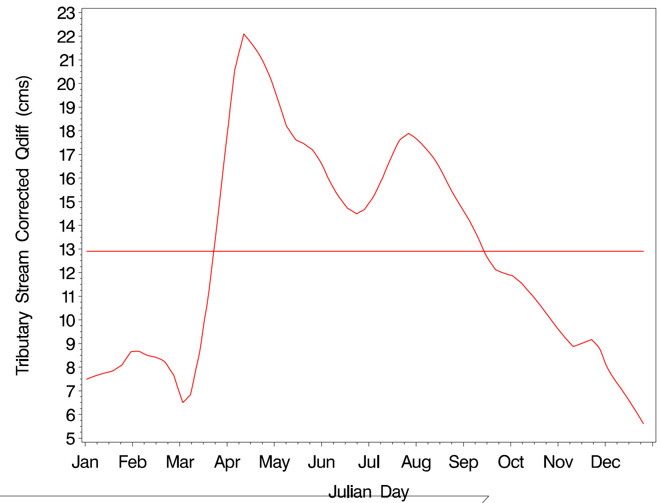


Figure 3.. Daily average Q_{diff} for 2001.

During the Summer and Fall 2001, extreme drought conditions resulted in an extended dry period with near record low stream discharge measurements and no tributary creek inflow. Q_{diff} values during this period showed a progressive decline indicating reduced groundwater contributions to stream discharge that approached 7 cms (Fig. 3). Corresponding groundwater levels in regional monitoring wells also declined. Thus, groundwater contributions from the UFA to the lower Flint River can vary as regional groundwater levels fluctuate.

Estimating groundwater inputs by adjusting Qdiff values for tributary creek contributions

The discrete discharge measurements from Cooleewahee Creek were found to correlate significantly to Spring Creek (r^2=0.87, $p<0.05$, n=46). From this, surrogate daily mean discharge data for Cooleewahee Creek (Q_{trib}) were estimated for the entire period of record. Q_{trib} was then subtracted from Q_{diff} to provide an approximation of groundwater inputs into the lower Flint River (Fig. 4). Groundwater inputs averaged over the entire record show an annual average that ranged from 6cms to 22 cms with an average of about 13 cms. A seasonal pattern is evident with highest groundwater inputs in April through May and lowest in December through February. This is consistent with patterns of regional groundwater levels. Typically, winter rains, reduced evapotranspiration, and reduced groundwater pumpage all contribute to regional aquifer recharge in the winter/spring season. During the Summer/Fall season, higher rates of evapotranspiration and groundwater pumpage preclude

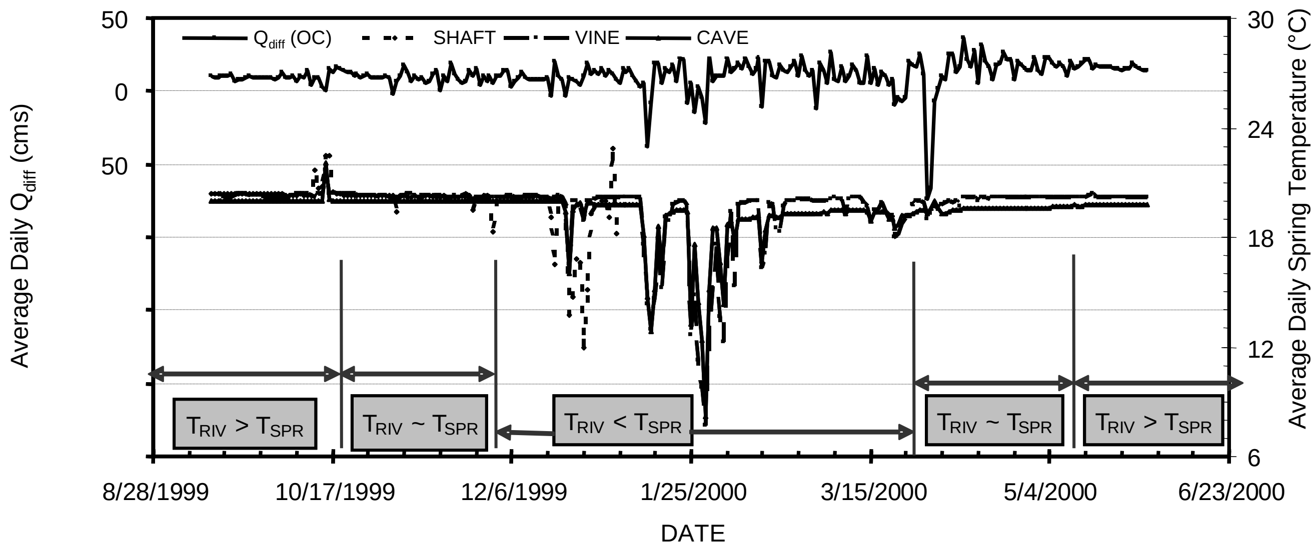


Figure 5. Relationship between Q_{diff} and spring water temperature during October 1999 through June 2000.

MANAGEMENT IMPLICATIONS

Reductions in groundwater due to the combined effects of drought and water use reduce aquifer inputs to major springs which serve as thermal refugia for the gulf strain striped bass. This also limits the capacity for groundwater to mitigate the effects of wastewater discharge (Opsahl et al., 2003). This approach provides estimates of the magnitude of flow reversals which equates to storage and release of flood water in the lower Flint River basin. Finally, these techniques can easily be applied to other stream systems with similar hydrologic properties.

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