CHANGES IN STREAM TEMPERATURE FOR SELECTED STREAMS IN GEORGIA, 1955–2004

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Abstract. Results from analysis of stream temperatures at 39 streamgaging stations located throughout Georgia, show that stream temperatures changed little from the 1950s, through 1970s, but increased from the 1980s through early 2000s. Results also indicate that at station 02349500 on the Flint River, the median temperature began to increase during the 1960s and continued to rise through 2004, with a rise of about 1 degree Celsius. Additionally, results from gages in the Yellow River Basin indicate that stream temperatures are rising in that basin, which is evinced by the rising trend at station 02206500 during the 1965–1994 time period, followed by a similar trend for stations 02207300, 02209260, and 02212600 during the 1974–2004 time period. Finally, there is some indication that the stream temperature of the Ogeechee River may be increasing because of the rise measured at station 02202500 during the 1965–1994 period, and the rise at station 02202190 during the 1975–2004 period.

INTRODUCTION

Stream temperature is one of a number of important properties used to assess the health of a stream. Temperature and barometric pressure affect the saturation level of dissolved oxygen in stream water and, thus, affect the biota of the stream. Stream temperature also plays an important role in the maintenance and design of current and future industrial infrastructure. For example, many manufacturing operations require specific water temperatures for the water used in their manufacturing processes, and thermoelectric-power plants are mandated to maintain specific temperatures in their downstream effluent. For these and many other reasons, the Georgia Environmental Protection Division and the U.S. Geological Survey (USGS) are interested in the long-term trends in Georgia stream temperatures.

TEMPERATURE DATA

Temperature data were analyzed from 39 streamgaging stations throughout Georgia (Fig. 1). These gages were selected from those used for a previous study by Dyar and Alhadeff (1997) on streams that are relatively unaffected by human activity. Although the length of the temperature records at these stations varies, the records generally included a 50-year period from 1955–2004. From the beginning of the study through the late 1990s, temperatures were measured by the USGS with an accuracy of +/– 0.5 degrees Celsius (°C). During the late 1990s, however, widespread introduction of thermistors increased measurement accuracy to +/– 0.1°C. Because of this and the statistical methods chosen, it was necessary to round the 0.1°C data to the nearest 0.5°C. Temperature data generally were collected on a monthly basis, but the frequency varies from gage to gage and by year. Temperature data were analyzed for three time periods, 1955–1984, 1965–1994, and 1975–2004. The 30-year time periods correspond to reference periods used by the National Weather Service and are coincident with the previous study by Dyar and Alhadeff (1997). The analysis was extended to incorporate more recent data and more robust measurement and analytical techniques.

STATISTICAL ANALYSIS OF STREAM-TEMPERATURE DATA

Several different graphical and statistical analyses were completed to quantify and visualize stream-temperature trends. Stream-temperature data initially were analyzed using the analytical methods described in Schertz and others (1991), a graphical and statistical software package, ESTREND, designed for analyzing trends in stream water-quality data. This package was originally implemented as a series of FORTRAN programs, but has since been updated to work within the S-Plus statistical language (Insightful, 2005) and, more specifically, is implemented as a routine within the USGS S-Plus Library called S-ESTREND (Slack and others, 2003). In this study, the nonparametric seasonal Kendall test implemented in ESTREND was used to evaluate trends in the stream-temperature data.

Analysis in ESTREND proceeds first by visual inspection of boxplots to aid in the determination of seasonality (Fig 2*C*). Boxplots depict data distribution around the median and allow the investigator to more easily detect large changes in variance. After reviewing the data distribution, a monthly seasonal period was selected. The seasonal Kendall test is a nonparametric regression for monotonic trend or, in other words, a test for whether temperature tends to increase or decrease over time.

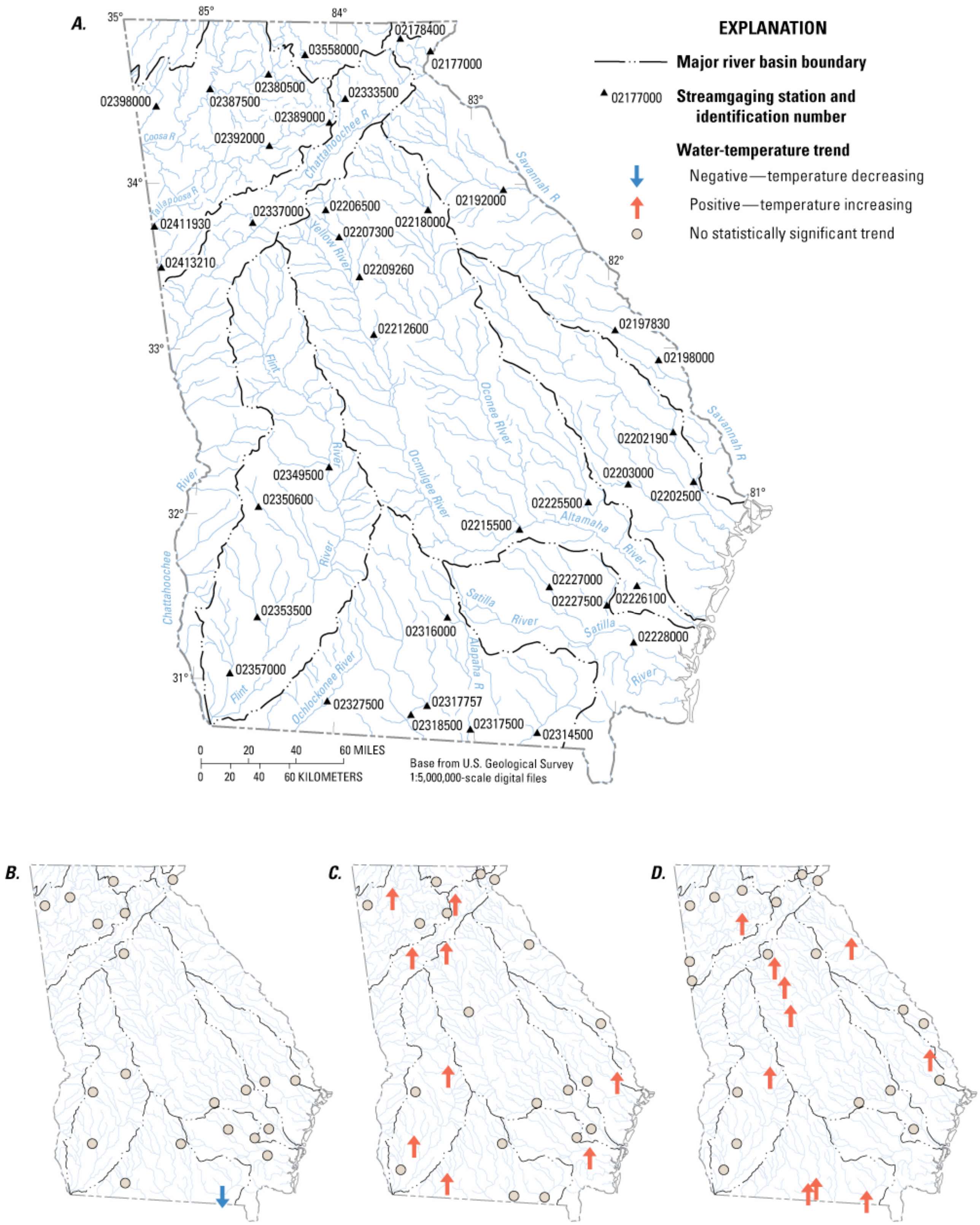

Figure 1. (A) Locations of 39 streamgaging stations in Georgia where temperature data were analyzed for trends, and graphical representation of the statistical results for the periods (B) 1955–1984, (C) 1965–1994, (D) 1975–2004.

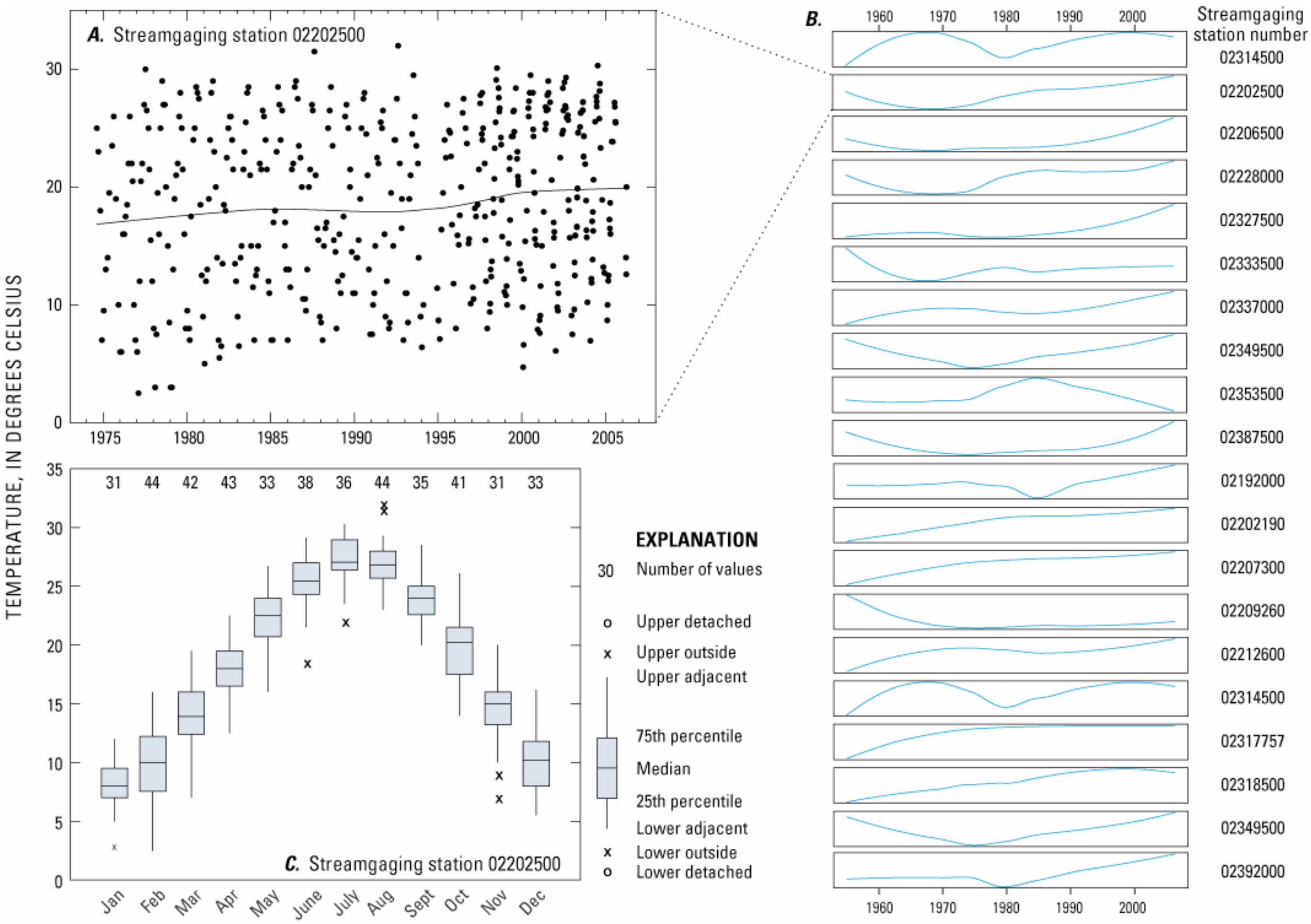

Figure 2. (*A*) Locally weighted scatter-plot smooths (Loess), including data, (*B*) without data, and (*C*) boxplot of temperature data for selected streams in Georgia. Boxplot includes all monthly data for the station and illustrates how boxplots were used to derive the seasonal component of the analysis. Loess plots are provided as a visual aid to depict changes in stream temperature over time.

The test results are the direction of trend (+ or –), the goodness of fit (τ), and the statistical significance (*p*) of the fit. Because the test can only detect monotonic trend, a locally weighted scatter-plot smooth or Loess (Helsel and Hirsch, 1992) was used to demonstrate the variations in the data over time (Figure 2). The seasonal Kendall test was applied during three periods of interest—1955–1984, 1965–1994, and 1975–2004. For this study, the statistical significance for the seasonal Kendall test was set at an alpha level of <0.05.

RESULTS

Statistically significant results from the seasonal Kendall test are presented in a table and maps with graphical presentation of Loess for selected streamgages. Table 1 shows the median value, τ, and the significance of the trend (*p*) for selected stations and time periods where $p < 0.05$. Figure 1 shows the locations of streamgaging stations where data were analyzed for each of the three periods.

For the period 1955–1984, results show that stream-temperature measurements at 1 (02314500) of the 21 gages analyzed had a statistically significant decrease (Table 1, Fig. 1*B*) with no apparent positive trends. For the period 1965–1994, results show that stream temperature at 9 of the 28 gages had a statistically significant increase, with no decrease in temperature in any of the streams (Fig. 1*B*, Table 1). For the period 1975–2004, results show that stream temperature analyzed at 10 of the 29 gages had a statistically significant increase, with no decrease in temperature in any of the streams (Fig. 1*D*, Table 1).

Any number of factors could explain decreases in stream temperature, including increased rainfall and subsequent runoff, decreased air temperature, increased ground-water discharge, increased riparian or catchment plant cover, and changes in land use (Jones and others, 2006). Similar, but opposite, factors could explain increases in stream temperature, including decreased rainfall and subsequent decreases in runoff, increased air temperature, decreased ground-water discharge, decreased riparian or catchment plant cover, and changes in land use (Jones and others, 2006).

Table 1. Statistically significant (p<0.05) results of seasonal Kendall-τ test on three time periods reported as the median temperature, τ, and the significance of trend (*p*) for stream-temperature data from 1955–2004 at selected sites in Georgia.

Streamgaging station	Begin year	End year	Median	τ	*p*
02314500	1957	1984	20.5	–0.0929	0.0231
02202500	1965	1994	19.5	0.1569	0.0116
02206500	1965	1994	16	0.1447	0.0256
02228000	1965	1994	22	0.2011	0.0070
02327500	1965	1994	19	0.1292	0.0140
02333500	1965	1994	14.5	0.1971	0.0297
02337000	1965	1994	16.25	0.1079	0.0203
02349500	1965	1994	18	0.1272	0.0195
02353500	1965	1994	20.5	0.2745	0.0072
02387500	1965	1994	16	0.1217	0.0299
02192000	1975	2004	16.6	0.2817	0.0364
02202190	1975	2004	18.9	0.1561	0.0019
02207300	1974	2000	16	0.1069	0.0443
02209260	1975	2004	16	0.1103	0.0266
02212600	1975	2004	16	0.1265	0.0309
02314500	1975	2004	20.03	0.1065	0.0278
02317757	1974	2003	20	0.1951	0.0013
02318500	1977	2006	20.3	0.1087	0.0416
02349500	1975	2002	19	0.1517	0.0102
02392000	1975	2004	14.25	0.1578	0.0296

Based on these results, some general conclusions can be drawn regarding changes in stream temperature in Georgia; more specific results for a few locations are apparent. The results indicate that, in general, stream temperatures throughout Georgia have gone from a period of little change, during the 1950s–1970s, to a period of increasing temperatures during the 1980s through early 2000s. In addition, results indicate that at site 02394500 on the Flint River, the median temperature began to increase during the 1960s and continued to rise through 2004, with a rise of more than 1°C. Records from several gages indicate that stream temperatures also are rising in the Yellow River Basin. This increase in temperature is evinced by the rising trend observed at station 02206500 during the 1965–1994 time period, followed by a similar trend for stations 02207300, 02209260, and 02212600 during the 1974–2004 time period. Finally, there is some indication that the stream temperature of the Ogeechee River may be increasing because of the rise measured at site 02202500 during the 1965–1994 period, and the rise at site 02202190 during the 1975–2004 period.

Increasing stream temperatures could have a significant affect on stream biota and influence decisions regarding the location of future infrastructure. For example, Jones and others (2006) have estimated that in Georgia, stream-temperature increases attributed to the reduction in riparian buffer width could cause an 87-percent reduction in young trout biomass in trout streams. In another example, effluent discharge permitted under the National Pollutant Discharge Elimination System is often constrained by the temperature of the receiving stream. Consequently, it is possible that as stream temperatures increase, facilities that discharge water may have to decrease their rate of discharge or modify systems to have a lower thermal impact. Because of the strong link between changes in the width of the riparian buffer and plant coverage in riparian basins (Jones and others, 2006), stream-temperature and land-use monitoring of certain basins could prove helpful in identifying streams that may be affected in the future.

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