DISSOLVED-OXYGEN CHARACTERISTICS OF GEORGIA STREAMS

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Abstract. Dissolved-oxygen (DO) measurements from the Georgia Department of Natural Resources, Environmental Protection Division and the U.S. Geological Survey water-quality sampling program from 1966 to 2001 were analyzed using a harmonic curve-fitting procedure. Statistics for data from 31 stations, selected as representing mostly natural stream DO and temperature conditions, were used to compute a statewide stream DO model whose principal variables include latitude and elevation. Based on the 1966–2001 reference period, the model may be used to compute long-term, seasonal characteristics of DO in Georgia streams. Using the same 31 stations, a second model to compute long-term seasonal characteristics of DO in Georgia streams was derived using harmonic characteristics of stream temperatures. The model quantitatively links long-term stream temperatures to long-term stream DO as a cause-and-effect relation.

INTRODUCTION

The Georgia Department of Natural Resources, Environmental Protection Division (GaEPD) and the U.S. Geological Survey (USGS) are using geographic information systems databases and time-series analytical techniques to analyze data collected from the joint water-quality sampling program from 1966 to 2001. This paper summarizes results from a statewide analysis of the dissolved-oxygen (DO) characteristics of Georgia streams. The analysis is being done in two parts: Part 1 is determining the long-term normal DO characteristics of Georgia streams, summarized herein; Part 2 is the more-detailed basin-by-basin analysis, which is work (2005) in progress. The basin-by-basin analysis includes discussion of stations in Georgia having more than one year of recorded DO measurements, and techniques for estimating stream DO characteristics for ungaged reaches.

This DO analysis is very similar to the two-part statewide stream temperature analysis from an earlier cooperative study, Stream-Temperature Characteristics in Georgia (Dyar and Alhadeff, 1997). The stream temperature analysis was sponsored by the GaEPD, USGS, and Georgia Power Company (GPC) and is being updated this year (2005) to include 1985–2004 to quantify any significant time trends in Georgia stream temperatures. The 1997 stream temperature report noted that "many reaches of Georgia streams exhibit modified thermal characteristics because of waste heat discharge, reservoirs, diversions, or proximity to urban areas" (Dyar and Alhadeff, 1997, p. 19). The report summarized stream temperatures for the period 1955–1984, for which 78 stream temperature stations were selected as mostly natural, to establish long-term stream temperature characteristics for the State. Because of the large population increase in Georgia in recent years, from about 3.4 million during 1950 to about 9.0 million today (U.S. Department of Commerce, 2005), more stream reaches exhibit modified stream temperatures than were indicated in the Dyar and Alhadeff (1997) report. This paper shows that stream DO characteristics are directly and proportionally affected by stream temperature and exhibit similar seasonal characteristics. The quantitative linkage of stream DO to stream temperature is important for maintaining the State's water-quality standards and for the economics of wastewater treatment.

Factors other than stream temperature also affect stream DO. Stream reaches high in turbulence from cascades or waterfalls typically have high re-aeration and sometimes produce supersaturated DO reaches. Oxygen may be emitted from biological processes such as the photosynthesis of algae. However, most resource managers' concerns about the oxygen content in streams are reductions in stream DO. These reductions are most often associated with elevated stream temperature or by biochemical oxygen demand from municipal, industrial or feedlot wastes or from stormwater runoff. Because many streams are in rapidly-developing basins, relatively few opportunities remain in Georgia to select mostly natural DO streams for regional analysis. In the statewide Total Maximum Daily Load (TMDL) program, DO values below State standards can trigger remediation efforts. The analyst making the determinations and recommending solutions needs to be able to determine quantitatively the contributing aspects of the cause of DO deficits in streams.

DO characteristics are used to assess, manage, and protect the water resources of Georgia. DO is perhaps the most important indicator of the ability of a stream to sustain aquatic life and to assimilate waste. Georgia stream DO is an important water-quality parameter for Georgia's rotating basin monitoring program, water-quality assimilative capacity studies, required TMDL evaluations, and stream health assessments.

LONG-TERM NATURAL STREAM DISSOLVED-OXYGEN CHARACTERISTICS

Thirty-one water-quality stations having periodic DO measurements were selected for regression analysis. No continuous-record stations were selected for analysis because most are located on hydrologically modified streams or were already represented by periodic DO measurements at the same locations. Stations with stream DO substantially affected by human activities were excluded from analysis. To help ensure statistical independence, most mainstem stations were excluded; however, 11 stations with drainage areas greater than 1,000 square miles were included to provide sufficient drainage area variability for the regional analysis. The 31 stations selected for analysis are listed in Table 1, and their locations are shown in Figure 1.

Several limitations of the data used to compute DO characteristics should be noted. First, for the analysis to be rigorous, stations having completely natural conditions upstream should be used. Natural DO as used in this paper is the DO at saturation level for the prevailing stream temperature and partial gas pressure of atmospheric oxygen (Streeter, 1957). DO measurements for this paper reflect the climatic conditions of 1966–2001. Because some hydrologic modifications have occurred on most major streams, computation of completely natural DO characteristics was not possible; however, long-term natural DO values should predominate at each of the 31 stations used for analysis (Table 1). Second, most periodic data collection occurs during daylight hours, causing a slight DO bias. This bias typically is 0.2 milligrams per liter (mg/L) or less; most bias occurs on smaller streams during the warmer seasons.

Table 1. Stream water-quality stations in georgia exhibiting mostly long-term natural dissolved oxygen.

[USGS, U.S. Geological Survey; ID, identification; °, degree; ', minute; ", second; mi^2, square mile; ft, feet; msl, mean sea level; °C, degrees Celsius]

USGS station ID	USGS station name	Longitude	Latitude	Drainage area (mi^2)	Elevation (ft above msl)	Harmonic mean temperature (°C)
02177000	Chattooga River near Clayton, Ga.	–83°30'61"	34°81'39"	207.00	1,165.60	13.85
02178400	Tallulah River near Clayton, Ga.	–83°53'06"	34°89'03"	56.5	1,868.93	12.43
02192000	Broad River near Bell, Ga.	–82°77'00"	33°97'42"	1,430	357.16	16.25
02198000	Brier Creek at Millhaven, Ga.	–81°65'14"	32°93'33"	646	95.88	17.21
02202500	Ogeechee River near Eden, Ga.	–81°41'61"	32°19'14"	2,650	19.64	18.38
02209260	Alcovy R, Newton Factory Brdg Rd Nr Stewart, Ga.	–83°82'83"	33°44'94"	254	560	15.86
02212600	Falling Creek near Juliette, Ga.	–83°72'36"	33°09'97"	72.2	366.52	16.00
02212950	Ocmulgee River above Macon, Ga.	–83°65'42"	32°86'97"	2,230	270	17.43
02219000	Apalachee River Near Bostwick, Ga.	–83°47'42"	33°78'81"	176	544.14	15.48
02220900	Little River near Eatonton, Ga.	–83°43'72"	33°31'39"	262	356.03	16.25
02225500	Ohoopee River near Reidsville, Ga.	–82°17'75"	32°07'83"	1,110	73.8	18.12
02226000	Altamaha River at Doctortown, Ga.	–81°82'81"	31°65'44"	13,600	24.48	19.35
02228000	Satilla River At Atkinson, Ga.	–81°86'75"	31°22'11"	2,790	14.79	19.21
02314500	Suwannee River at Fargo, Ga.	–82°56'06"	30°68'06"	1,260	91.9	19.30
02317500	Alapaha River at Statenville, Ga.	–83°03'33"	30°70'39"	1,400	76.77	19.34
02318500	Withlacoochee River at U.S. 84, near Quitman, Ga.	–83°45'17"	30°78'94"	1,480	84.3	19.28
02328200	Ochlockonee River near Calvary, Ga.	–84°23'67"	30°73'14"	930	100	19.15
02331000	Chattahoochee River near Leaf, Ga.	–83°63'58"	34°57'69"	150	1,219.47	13.87
02331600	Chattahoochee River near Cornelia, Ga.	–83°62'06"	34°54'08"	315	1,128.53	14.26
02332830	West Fork Little River near Clermont, Ga.	–83°82'17"	34°41'53"	18.3	1,093	13.50
02333105	Dicks Creek above Waters Creek near Neels Gap, Ga.	–83°93'75"	34°68'00"	9.39	1,700	12.25
02338840	Yellowjacket Cr at Hammett Rd Blw Hogansville, Ga.	–84°97'53"	33°13'94"	91	640.93	15.68
02347500	Flint River near Culloden, Ga.	–84°23'25"	32°72'14"	1,850	334.54	17.41
02349500	Flint River at Montezuma, Ga.	–84°04'39"	32°29'81"	2,900	255.83	18.01
02350600	Kinchafoonee Creek at Preston, Ga.	–84°54'83"	32°05'25"	197	337.7	17.24
02353500	Ichawaynochaway Creek at Milford, Ga.	–84°54'78"	31°38'28"	620	150.3	18.41
02380000	Ellijay River at Ellijay, Ga.	–84°47'92"	34°69'25"	87.7	1,242.32	13.57
02380500	Coosawattee River near Ellijay, Ga.	–84°50'86"	34°67'17"	236	1,216.04	13.94
02389000	Etowah River near Dawsonville, Ga.	–84°05'58"	34°38'25"	107	1,049.8	14.15
02392000	Etowah River at Canton, Ga.	–84°49'64"	34°23'97"	613	944.55	14.97
02411930	Tallapoosa River below Tallapoosa, Ga.	–85°33'64"	33°74'08"	272	920	15.16

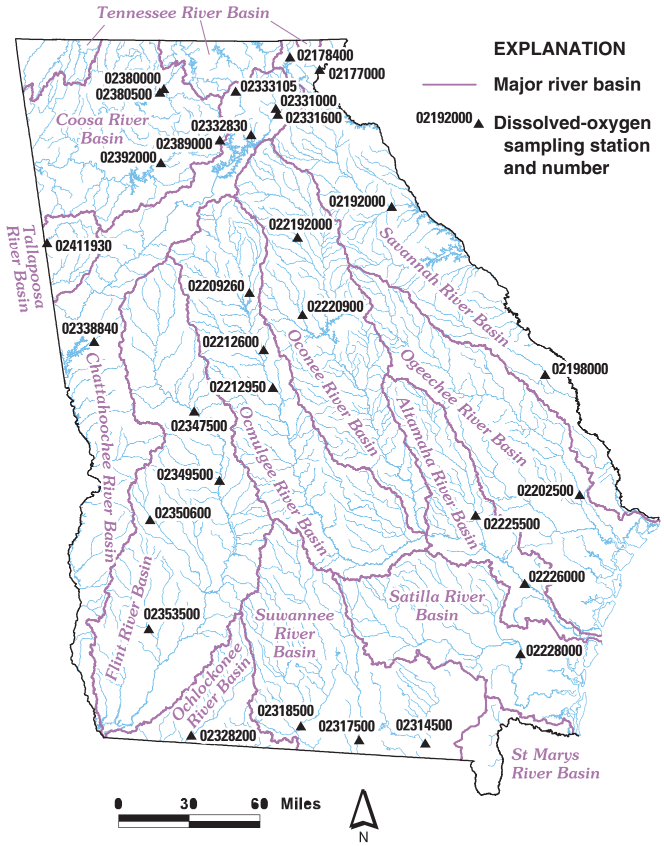

Figure 1. Locations and major river basins of the 31 natural dissolved-oxygen (DO) water-quality stations used to compute the harmonic coefficients for the Georgia statewide DO model.

Data from the GaEPD–USGS water-quality sampling program for 1966–2001 contain approximately 47,734 pairs of stream DO and stream temperature values. DO values greater than 12.5 mg/L and less than 3.0 mg/L were outside the normal range of this analysis and were excluded; there were relatively few of these values. The expected standard error of each DO measurement and its representation of the stream cross section is estimated to be from about 0.2 to 0.4 mg/L, with the most error expected on the larger streams.

One or more DO concentrations were measured at 1,118 stream sampling stations. Of these stations, 141 had 36 or more DO measurements. These data spanned 7 or more years of record, which is considered the acceptable minimum number of years for this analysis. Many of the 141 stations had DO measurements affected by industries, municipalities, or both. Of the remainder, 31 stations were selected as exhibiting mostly natural DO measurements; that is, they produced a comparatively high annual DO regimen. The 31 stations are sufficiently independent, range across all major river basins in the State, and are representative of a suitable range of drainage areas. Table 1 lists regression variables used to compute the statewide DO models shown in this paper and an important variable used in the river basin selection criteria, drainage area. Twenty-four of the 31 selected natural DO stations are a subset of the 78 mostly natural stream temperature stations used in Dyar and Alhadeff (1997).

ANALYSIS TO DETERMINE ESTIMATES OF LONG-TERM NORMAL DO CHARACTERISTICS

The statewide regression analysis for each harmonic coefficient was performed in the same manner used for determining harmonic characteristics of Georgia stream temperatures (Dyar and Alhadeff, 1997, which contained stream temperature data for the period, 1955–84). This analysis is to enable estimation of long-term normal (long-term daily mean value) stream DO characteristics for the sampling period 1966—2001.

An annual harmonic analysis of the DO data for each of the 31 stations produced the harmonic coefficients, harmonic mean, amplitude and phase coefficient, which are summarized in Table 2, in columns 2, 4, and 6, respectively. A regression analysis of the DO harmonic coefficients was performed using selected basin characteristic data as was done in Dyar and Alhadeff (1997). Independent variables selected as significant during the regression analysis included latitude for the harmonic mean and latitude and elevation for the harmonic amplitude The phase coefficient was essentially a constant, 5.94 radians, as indicated in Table 2.

The regional regression analysis of the DO harmonic coefficients yielded the following “normal DO characteristics in Georgia streams” model, or Equation 1, shown below. The equation is of the form:

DO, in mg/L (day = 1,365) = Harmonic Mean + Amplitude * (SIN (2*PI * day/365+Phase Coefficient))

Where the sinusoidal model coefficients have the following values:

Harmonic mean = –9.73 + 0.557 * Latitude

Amplitude = –3.66 + 0.174 * Latitude – 0.00057 * Elevation

Phase coefficient = Average (31 sites) = 5.94

Equation 1: DO = –9.73 + 0.557 * Latitude + (–3.66 + 0.174 * Latitude – 0.00057 * Elevation) * (SIN (2*PI * day/365 + 5.94))

Where day is cumulative days in the water year, which begins October 1 and ends September 30

Latitude is in decimal degrees

Elevation is station or stream location altitude in feet above mean sea level

PI = 3.142

SIN function is in radians

The insertion of latitude and elevation values into Equation 1, while incrementing "t" day-by-day throughout a year, generates a harmonic curve, which tends to provide a good description of DO response to stream temperature from solar radiation, season by season, throughout the State. The regression analysis to determine the harmonic mean coefficient yielded an r^2 of about 0.92, while the standard error is 0.24. The r^2 for the amplitude coefficient is about 0.45, while the standard error is about 0.17.

The empirical model, Equation 1, used to estimate long-term normal DO values in Georgia streams, predicts that higher values occur at higher latitudes and higher elevations, whereas lower values occur at lower latitudes and lower elevations. In Georgia, the elevation variable may influence the amplitude coefficient by as much as about 1.0 mg/L. The latitude and elevation variables account for the long-term effects of temperature (from solar radiation) and atmospheric pressure, respectively, on stream DO values. The stream DO measurement data for the 31 stations shown in Table 2 are mostly normally distributed about the Equation 1 curve.

Harmonic Mean and Amplitude Coefficients

The harmonic mean and amplitude coefficients generated by Equation 1 closely match the individual harmonic stream DO coefficients for the 31 stations. Equation 1 produces harmonic mean coefficient values that range from low values as low as about 6.5 mg/L in the lower latitudes; to high values as great as about 10.0 mg/L in the higher latitudes.

Amplitude coefficient values range from low values as low as about 1.3 in the southwest and northeast corners of the State; to high values as great as about 2.1 mg/L in the remainder of the State, with high values trending toward the east. The low values in the northeast are likely attributable to the effects of higher elevations, and low values in the southwest may be attributable to the relatively large contributions of groundwater in this area of the State. The elevation and latitude components of the amplitude are about equal in explaining the amplitude variance of about 0.45.

Residuals obtained by subtracting both the harmonic mean and amplitude coefficients determined by Equation 1 from the values calculated by harmonic analyses of station data were examined and observed to be spatially random, small numerical departures (Table 2).

Table 2. Harmonic coefficients from Georgia stream water-quality station dissolved-oxygen data measurements as compared with statewide Equation 1.

[USGS, U.S. Geological Survey; ID, identification; station HM, harmonic mean coefficient of station dissolved oxygen (DO); statewide HM, harmonic mean coefficient of DO from Equation 1; station amplitude, amplitude coefficient of station DO; statewide amplitude, amplitude coefficient from Equation 1; station PC, phase coefficient of station DO; statewide PC, phase coefficient from Equation 1; S.E.E., standard error of estimate from station DO; S.E.E. Equation 1, standard error of estimate from Equation 1]

USGS station ID	Station HM	Statewide HM	Station amplitude	Statewide amplitude	Station PC	Statewide PC	S.E.E.	S.E.E. Equation 1	Number of samples
02177000	9.88	9.66	1.65	1.69	5.91	5.94	.56	.61	334
02178400	9.89	9.70	1.42	1.27	5.87	5.94	.59	.63	87
02192000	8.90	9.19	1.82	2.03	5.89	5.94	.85	1.03	73
02198000	8.40	8.61	2.13	2.01	6.10	5.94	.76	.73	72
02202500	7.85	8.20	2.06	1.93	6.14	5.94	.89	.94	206
02209260	9.00	8.90	1.80	1.82	5.88	5.94	.58	.68	350
02212600	9.08	8.71	1.62	1.88	5.90	5.94	.73	.88	221
02212950	8.73	8.58	2.07	1.89	5.80	5.94	.73	.79	328
02219000	8.89	9.09	2.12	1.89	5.77	5.94	.86	.93	55
02220900	8.99	8.83	1.96	1.92	5.84	5.94	.67	.77	71
02225500	8.04	8.14	2.02	1.88	6.08	5.94	.96	.93	85
02226000	7.90	7.90	1.72	1.83	6.02	5.94	.81	.96	67
02228000	7.27	7.66	1.92	1.76	6.01	5.94	.88	.85	230
02314500	7.10	7.36	1.87	1.62	6.03	5.94	.87	.78	369
02317500	7.88	7.37	1.28	1.64	6.10	5.94	.68	.93	66
02318500	7.37	7.42	1.43	1.65	5.89	5.94	.75	.89	311
02328200	7.24	7.39	1.85	1.63	6.11	5.94	.71	.66	347
02331000	9.68	9.53	1.45	1.61	5.79	5.94	.63	.77	54
02331600	9.40	9.51	1.51	1.66	5.83	5.94	.73	.84	174
02332830	9.41	9.44	1.71	1.66	5.93	5.94	.59	.65	98
02333105	9.83	9.59	1.47	1.34	5.82	5.94	.52	.62	137
02338840	8.74	8.73	1.80	1.72	5.84	5.94	.81	.81	121
02347500	8.67	8.50	1.95	1.83	5.87	5.94	.81	.78	128
02349500	8.63	8.26	1.82	1.80	5.99	5.94	.63	.72	340
02350600	8.27	8.12	1.69	1.71	6.16	5.94	.67	.87	128
02353500	8.15	7.75	1.59	1.71	6.06	5.94	.61	.72	97
02380000	9.57	9.59	1.55	1.62	5.98	5.94	.69	.74	43
02380500	9.42	9.58	1.90	1.63	5.89	5.94	.73	.69	53
02389000	9.45	9.42	1.89	1.68	5.91	5.94	.64	.63	65
02392000	9.20	9.34	1.89	1.72	5.88	5.94	.77	.69	186
02411930	8.75	9.06	1.85	1.65	5.74	5.94	.78	.80	182

Phase Coefficient

Long-term mean DO values are most likely to occur in natural streams on or about April 20 and October 19. Maximum and minimum natural DO values are likely to occur on or about January 19 and July 20, respectively. DO values near the annual maximum and minimum are likely to persist for several months. For example, DO values within 1 mg/L of the maximum DO are likely to occur from about December through February. Similarly, DO values within 1 mg/L of the minimum value are likely to occur from about June through August. The individual phase-coefficient values for each of the selected 31 stations indicate that the phase-coefficient data are adequately described by the constant of 5.94 radians.

The comparison of the least squares best-fit harmonic curve from DO measurements of each of the 31 DO stations to the statewide DO model (Equation 1), standard error of about 0.78 mg/L, is shown in Table 2. A graphical example comparing the sinusoidal analysis of DO measurements at each station to the statewide model, Equation 1, for the Chattooga River near Clayton (station 02177000) is shown in Figure 2. The remaining 30 DO stations produce similar graphics with standard errors about the DO measurement data for each station as shown in column 8 (S.E.E.) of Table 2. Each station's DO measurements are compared to Equation 1 in column 9 (S.E.E. Eq 1) of Table 2.

DISSOLVED-OXYGEN ANALYSIS USING HARMONIC STREAM TEMPERATURE VARIABLES

A comparison of Figures 2 and 3 shows that the harmonic analysis of stream temperatures and the harmonic analysis of stream DO produce similar, but exactly out-of-phase, graphics. The harmonic analysis of stream temperature and stream DO from station 02177000, Chattooga River near Clayton, Georgia, shows that higher DO values accompany low temperatures and vice versa. The inversely proportional relation between DO and water temperature is well known and has been described by Veltz (1970). The relation shows that the solubility of (atmospheric) oxygen in water is inversely proportional to water temperature.

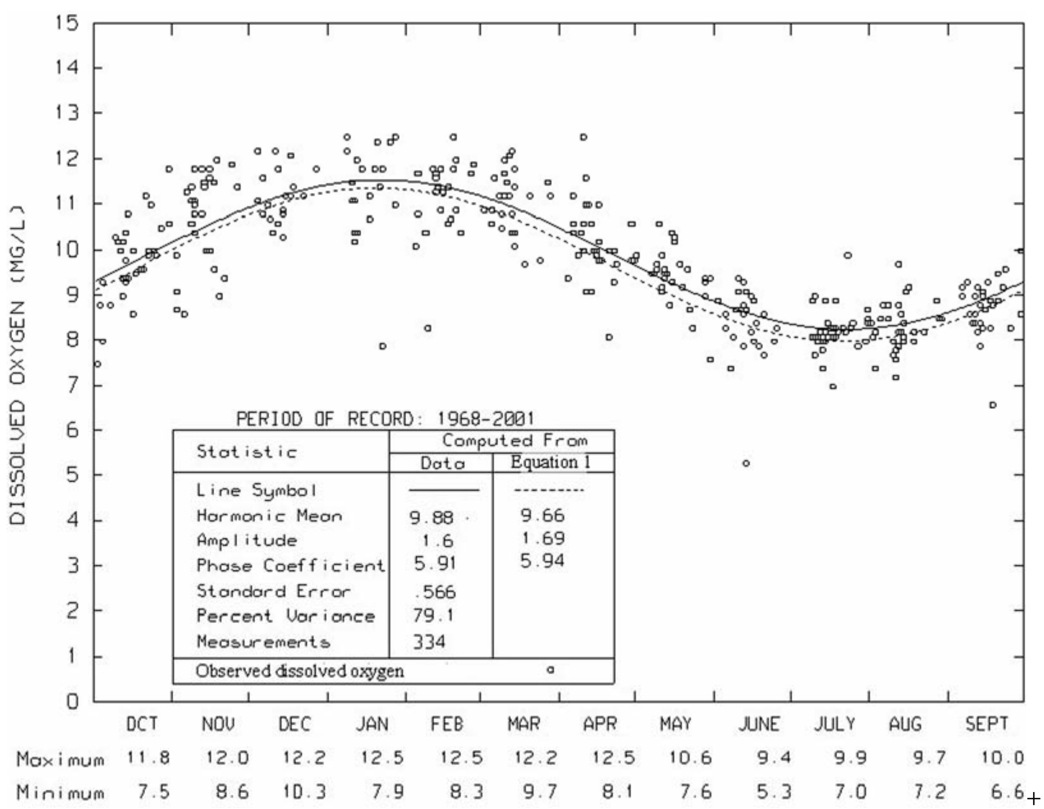

Figure 2. Sinusoidal analysis of dissolved-oxygen measurements for station 02177000, Chattooga River near Clayton, Georgia, compared with statewide Equation 1.

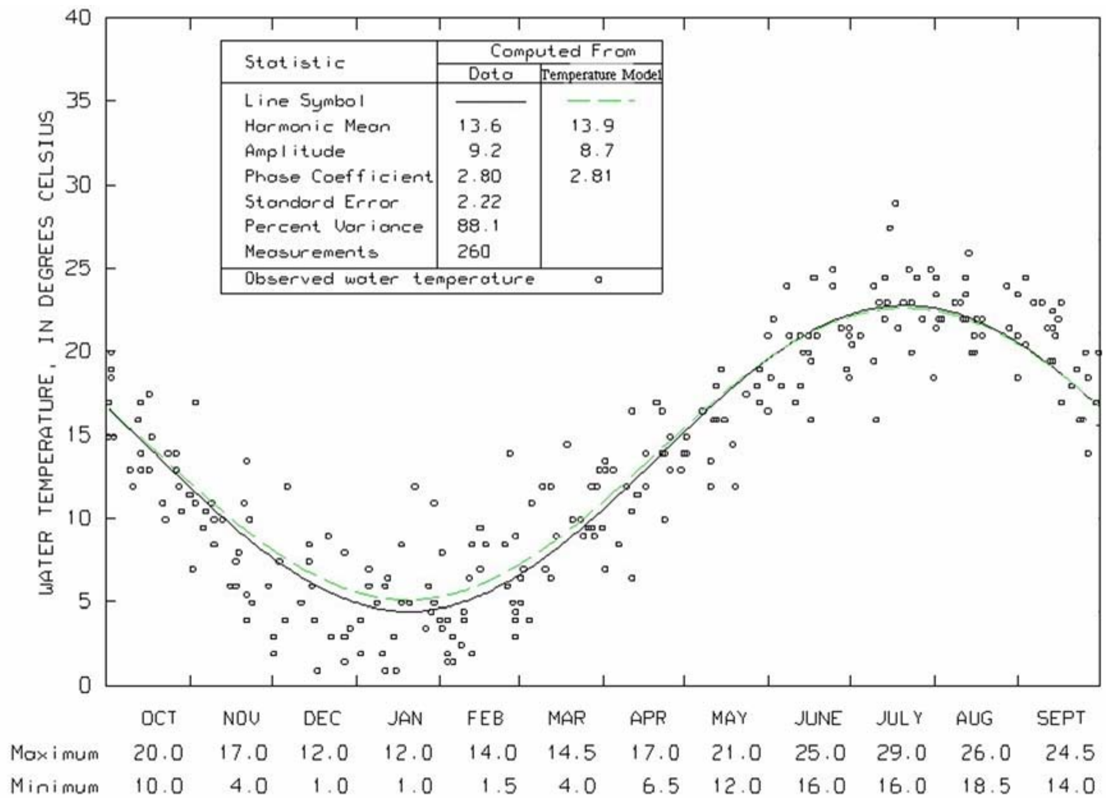

Figure 3. Sinusoidal analysis of stream temperature measurements for station 02177000, Chattooga River near Clayton, Georgia, compared with statewide stream temperature model (from Dyar and Alhadeff, 1997).

Using the same 31 stations, a regression analysis was performed to determine harmonic coefficients for the statewide DO model directly from harmonic stream temperature coefficients (Dyar and Alhadeff, 1997). The harmonic mean temperature coefficient is shown in column 7 of Table 1. This analysis yielded the following "normal DO characteristics in Georgia streams" model:

Harmonic Mean = 14.32 - 0.345*(harmonic mean temperature)

Amplitude= 1.83

Phase Coefficient = Average (31 sites) = 5.94

The amplitude coefficient is the average of the amplitude coefficients computed from the statewide harmonic analysis of DO amplitude values at the 31 stream stations. The standard error of the amplitude coefficient is about 0.04 mg/L.

The value of 5.94 radians for the phase coefficient is expected from the earlier statewide stream temperature regionalization (Dyar and Alhadeff, 1997) and is PI radians out of phase with the stream-temperature phase coefficient and its value of 2.81 radians, as shown in Figure 3.

Equation 2: DO = 14.32 – 0.345 * (harmonic mean temperature) + 1.83 * (SIN (2*PI * day/365 + 5.94))

Where day is cumulative days in the water year, which begins October 1 and ends September 30.

Harmonic mean temperature is in degrees Celsius (from Table 1)

PI = 3.142

SIN function is in radians

The model, Equation 2, was developed to show cause-and-effect between long-term stream temperature and long-term stream DO. Equation 2 also corroborates the estimation of long-term normal DO characteristics at stream reaches from Equation 1. Equation 2 may also have value when stream temperature or long-term stream-temperature characteristics are well known, such as for the more detailed stream-temperature characteristics from the basin-by-basin analysis in Dyar and Alhadeff (1997) or from stream reaches, which may have modified stream-temperature characteristics such as below reservoirs (this is being documented in the ongoing [2005] basin-by-basin analysis). Because stream temperature is the primary influence on the solubility of oxygen in water, factors that affect stream temperature (Dyar and Alhadeff, 1997) proportionally affect stream DO.

The primary objective of the ongoing (2005) basin-by-basin analysis of DO is to aid in the estimation of DO characteristics at ungaged locations. The best estimates of

DO characteristics at a stream location are obtainable near stream stations with sufficient DO measurements. The next best estimates are derived from using more widely available stream temperature data with Equation 2, and last, estimating DO characteristics at ungaged locations from the regional DO model, Equation 1. The first two scenarios involve estimating DO characteristics using nearby actual measured DO or stream temperature data. The last scenario entirely depends on the use of the DO model, Equation 1.

Determining the long-term normal DO harmonic characteristics at a site from DO measurements compares well with their determination through the use of Equation 2, as is shown in Table 3. There is little practical difference in the results (goodness of fit) of Equation 1, standard error of about 0.78 mg/L; and Equation 2, standard error of about 0.82 mg/L. The standard error of calculating the harmonic mean coefficient for Equation 2 is 0.28. Excluding other factors affecting stream DO mentioned previously, Equation 2 quantifies the cause-and-effect relation between normal stream DO and normal stream temperature.

A graphical example comparing the sinusoidal analysis of DO measurements at the Chattooga River near Clayton station (02177000) to the statewide model from stream temperature data, Equation 2 is shown in Figure 4. The remaining 30 DO stations produce similar graphics, with standard errors about the DO measurement data for each station as shown in column 8 (S.E.E.) of Table 3. Each station's DO measurements are compared to Equation 2 in column 9 (S.E.E. Eq 2) of Table 3.

Table 3. Harmonic coefficients from Georgia stream water-quality station dissolved oxygen data measurements as compared with statewide Equation 2.

[USGS, U.S. Geological Survey; ID, identification; station HM, harmonic mean coefficient of station dissolved oxygen (DO); statewide HM, harmonic mean coefficient of DO from Equation 2; station amplitude, amplitude coefficient of station DO; statewide amplitude, amplitude coefficient from Equation 2; station PC, phase coefficient of station DO; statewide PC, phase coefficient from Equation 2; S.E.E., standard error of estimate from station DO, S.E.E. Equation 2, standard error of estimate from Equation 2]

USGS station ID	Station HM	Statewide HM	Station amplitude	Statewide amplitude	Station PC	Statewide PC	S.E.E.	S.E.E. Equation 2	Number of samples
02177000	9.88	9.54	1.65	1.83	5.91	5.94	.56	.61	334
02178400	9.89	10.03	1.42	1.83	5.87	5.94	.59	.89	87
02192000	8.90	8.71	1.82	1.83	5.89	5.94	.85	.90	73
02198000	8.40	8.38	2.13	1.83	6.10	5.94	.76	.69	72
02202500	7.85	7.98	2.06	1.83	6.14	5.94	.89	.89	206
02209260	9.00	8.85	1.80	1.83	5.88	5.94	.58	.69	350
02212600	9.08	8.80	1.62	1.83	5.90	5.94	.73	.88	221
02212950	8.73	8.31	2.07	1.83	5.80	5.94	.73	.79	328
02219000	8.89	8.98	2.12	1.83	5.77	5.94	.86	.88	55
02220900	8.99	8.71	1.96	1.83	5.84	5.94	.67	.76	71
02225500	8.04	8.07	2.02	1.83	6.08	5.94	.96	.92	85
02226000	7.90	7.64	1.72	1.83	6.02	5.94	.81	.87	67
02228000	7.27	7.69	1.92	1.83	6.01	5.94	.88	.91	230
02314500	7.10	7.66	1.87	1.83	6.03	5.94	.87	.87	369
02317500	7.88	7.65	1.28	1.83	6.10	5.94	.68	.96	66
02318500	7.37	7.67	1.43	1.83	5.89	5.94	.75	.95	311
02328200	7.24	7.71	1.85	1.83	6.11	5.94	.71	.78	347
02331000	9.68	9.53	1.45	1.83	5.79	5.94	.63	.79	54
02331600	9.40	9.40	1.51	1.83	5.83	5.94	.73	.88	174
02332830	9.41	9.66	1.71	1.83	5.93	5.94	.59	.65	98
02333105	9.83	10.09	1.47	1.83	5.82	5.94	.52	.78	137
02338840	8.74	8.91	1.80	1.83	5.84	5.94	.81	.92	121
02347500	8.67	8.31	1.95	1.83	5.87	5.94	.81	.82	128
02349500	8.63	8.11	1.82	1.83	5.99	5.94	.63	.78	340
02350600	8.27	8.37	1.69	1.83	6.16	5.94	.67	.76	128
02353500	8.15	7.97	1.59	1.83	6.06	5.94	.61	.82	97
02380000	9.57	9.64	1.55	1.83	5.98	5.94	.69	.81	43
02380500	9.42	9.51	1.90	1.83	5.89	5.94	.73	.75	53
02389000	9.45	9.44	1.89	1.83	5.91	5.94	.64	.64	65
02392000	9.20	9.16	1.89	1.83	5.88	5.94	.77	.86	186
02411930	8.75	9.09	1.85	1.83	5.74	5.94	.78	.90	182

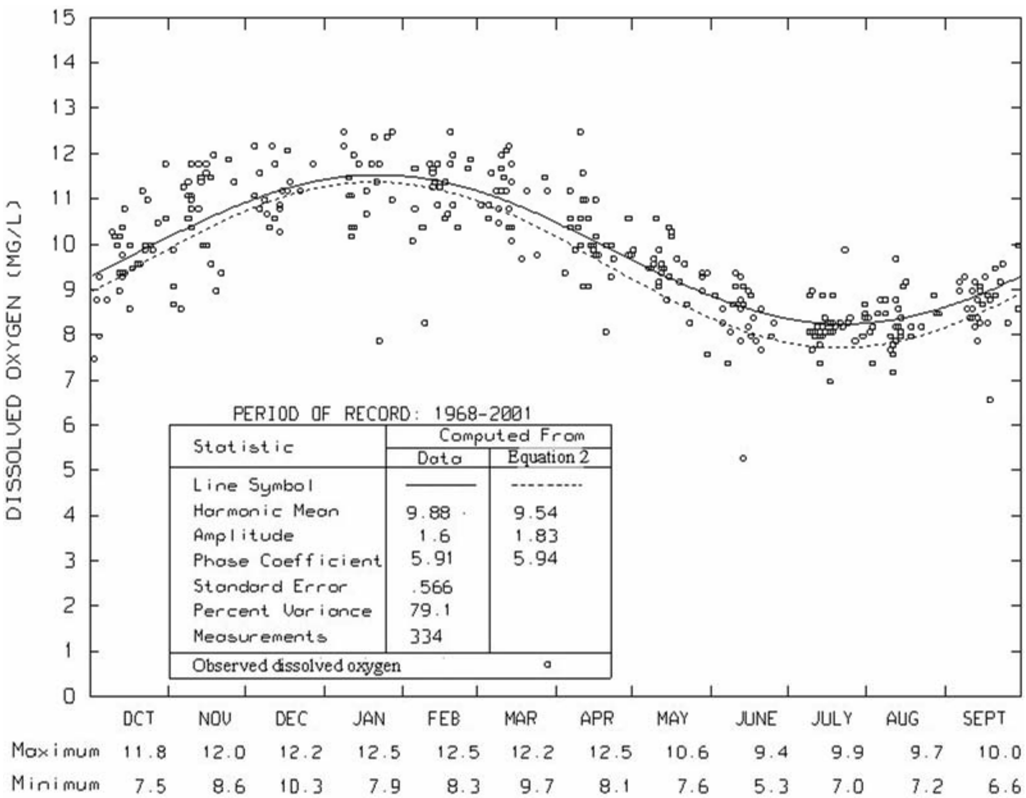

Figure 4. Sinusoidal analysis of dissolved-oxygen measurements for station 02177000, Chattooga River near Clayton, Georgia, compared with statewide Equation 2.

SUMMARY

An equation (Equation 1) describing statewide normal seasonal DO characteristics of Georgia streams was developed from examining data collected by the USGS and GaEPD during the period 1966–2001. This equation gives a seasonal estimate of the long-term normal stream DO characteristics of Georgia streams to within a standard error of about 0.78 mg/L. The long-term normal seasonal DO characteristics also could be calculated using long-term stream-temperature characteristics (Equation 2). Excluding other factors affecting DO, equations 1 and 2 establish a quantitative link between the harmonic characteristics of long-term stream temperature and DO. These results provide the framework for the ongoing basin-by-basin analyses currently (2005) being undertaken by GaEPD, GPC, and USGS.

SELECTED REFERENCES

Dyar, T.R., and S.J. Alhadeff. 1997. *Stream Temperature Characteristics in Georgia*. U.S. Geological Survey Water Resources Investigations Report 96-4203, Atlanta, Ga., 150 pp.

Georgia Department of Natural Resources. *Environmental Protection Division, revised 2004*, *Rules and Regulations for Water Quality Control,* chap. 391-3-6, 141 pp.

Hatcher, K.J. Spring 1982. How and Why to Estimate the Sediment Oxygen Demand. *The Georgia Operator*, pp. 10, 30–33.

McKenzie, S.W., W.G. Hines, D.A. Rickert, and F.A. Rinella. 1972. *Steady-state, Dissolved Oxygen Model of the Willamette River, Oregon*. U.S. Geological Survey Circular 715J, 28 pp.

Streeter, H.W. 1957. *The Oxygen Sag and Dissolved Oxygen Relationships in Streams*. Seminar at Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio, 6 pp.

Tsivoglou, E.C., and L.A. Neal. 1970. Predicting the Re-aeration Capacity of Inland Streams, *Journal of Water Pollution Control Federation*, Washington, D.C., v. 48, no. 12, pp. 2669–689.

U.S. Department of Commerce, Bureau of Census, http://www.census.gov.2005.

U.S. Department of Health, Education and Welfare. 1958. Oxygen Relationships in Streams. Public Health Service, The Robert Taft Sanitary Engineering Center Technical Report W58-2, 194 pp.

U.S. Environmental Protection Agency. 1976. *Quality Criteria for Water.* Washington, D.C., 256 pp.

Velz, C.J. 1970. Applied Stream Sanitation. Wiley-Interscience, New York, N.Y., 619 pp.