# PHYSICAL AND CHEMICAL CHARACTERISTICS OF STREAMS IN THE LOWER FLINT RIVER BASIN

Guoyuan Li[1] and C. Rhett Jackson[2]

*AUTHORS:* [1]PhD student, [2]Assistant Professor, Warnell School of Forest Resources, The University of Georgia, Athens, GA 30602.
*REFERENCE: Proceedings of the 2003 Georgia Water Resources Conference*, held April 23-24, 2003, at the University of Georgia. Kathryn J. Hatcher, editor, Institute of Ecology, The University of Georgia, Athens, Georgia.

**Abstract.** In recent years, increasing pumpage of groundwater has created conflicts in water management on the Dougherty plain within the Lower Flint River Basin (LFRB), making it essential to develop a better understanding of stream water quality, quantity, and the potential impacts of proposed water management measures in the area. Geomorphic and basic water chemistry data were collected on 20 reaches from the LFRB tributaries in order to develop a local channel classification system. Based primarily on conductivity, pH, geology, and valley morphology, the streams on LFRB were classified into five categories. Time series data of stream water quality, including water temperature, dissolved oxygen, pH, conductivity, and turbidity were collected to characterize spatial and temporal water quality dynamics. A preliminary temperature model was developed to help support management decisions in the basin. The model performed well in base flow temperatures predictions. These data and model will be further used by fisheries scientists to develop tools with which to analyze possible reservoir and groundwater pumping effects on stream biota.

## INTRODUCTION

The Dougherty plain, located within the Lower Flint River Basin (LFRB) between Lakes Balckshear and Seminole in southwest Georgia, is one of the state's most important agricultural areas. In recent years, increasing population and increased use of surface water and groundwater for crop irrigation have created conflicts in water resources management.

Continuous drought and increased water withdrawal has brought record low flow to streams in the LFRB (USGS, 2000). Low-flow events often lead to increased temperatures in summer due to high heat energy input and low heat buffer capability. High temperatures may also exacerbate oxygen problems in low gradient streams (Sabo et al, 1999; Caruso, 2002; Gilvear et al, 2002). Together, these can decrease the availability of aquatic habitat and thus decrease fish diversity and populations (Matthews 1998, Lind 1985). Increased water demand and use has been identified as one of the primary problems threatening stream fishes and other aquatic biota in the Southeastern U.S. (Richter et al, 1997).

To protect stream flows in these tributaries of the LFRB, the state has established the Flint River Drought Protection Act (FRDPA), initiated in March 2001, to limit farmland irrigation from surface water during drought seasons. However, the efficacy of the FRDPA depends on whether natural resource managers and planners are informed as to the nature and extent of potential impacts. Also, there are proposals to construct dams to regulate the water distribution in different seasons. The effect that the proposed dams would have on downstream aquatic habitat, especially on stream water temperatures and dissolved oxygen, needs to be predicted and evaluated beforehand. Therefore, there is a need for natural resource managers and planners to have a clear understanding of stream water quantity, quality, and their interactions.

This study is the first step of the project "The Development and Evaluation of Tools for Evaluating Flow Requirements in Streams in the Lower Flint River Basin, Georgia", started in year 2001 to develop a comprehensive approach to examining flow requirements and managing warm-water stream resources. The purpose of this phase of the project is to provide a general description of the hydrology, geomorphology, and water chemistry of streams in the Dougherty plain. A predictive water temperature model was also developed. These data and model will be used by fisheries scientists to develop tools with which to analyze possible reservoir effects on stream biota.

## METHODS

### Study Area Description

Study streams cross the Dougherty plain, where karst physiography controls hydrology (Hyatt and Jacobs, 1996). Land use in the study area is predominantly agricultural and residential (Warner et al, 2002).

There are three kinds of topography in the study area. Most streams originate Northwest of the plain in an area of rolling hills, composed of cretaceous sands. Most of the Dougherty plain lies along the west bank of the Flint River main channel. The Dougherty plain is a northeast-trending, wedge-shaped, level to very gently rolling lowland. The Pelham escarpment forms the southeastern basin divide. The streams in this area are short and sometimes disappear on the Dougherty plain before reaching the Flint River.

Under the Dougherty plain, four principal aquifers have been the main water sources of the area. They are, in descending order, the Upper Floridan aquifer, Claiborne aquifer, Clayton aquifer, and Providence aquifer (Warner, 2002). Numerous sinkholes have been an important pathway for the flow exchange between surface streams and the Upper Floridan aquifer (Hyatt and Jacobs, 1996).

Within the study area, the main tributaries are (meanings of Indian names in parentheses): Muckalee Creek (pour-upon-me), Kinchafoonee Creek (mortar bone or pounding block), Ichawaynochaway Creek (buck sleeping place), Chickasawhatchee Swamp (council house), and Spring Creek (Utley and Hemperley, 1975).

The monthly mean stream flows at the lower reaches of the three main tributaries are shown in figure 1. Stream flows were evidently higher in winter months and much lower in late summer, indicating that the low flows in these streams correspond with high air temperatures.

## Data Collection

Along the main tributaries of LWFB, 20 stream reaches were selected to survey and collect water samples. These reaches were selected to reflect natural features representative of the entire channel. Each reach was approximately 20 times the bankful width of the channel, including a minimum of two bends, an entire meander, when possible.

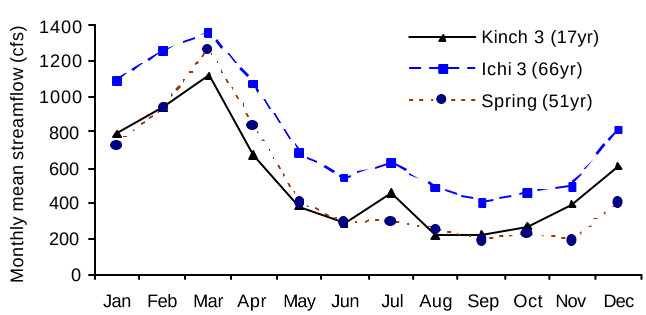


**Fig. 1. Monthly mean streamflow of the main tributaries.**

Site surveys of stream morphology, including depth, gradient and large wood debris frequency (LWDF), were conducted at low flow period during the summer of year 2002. During this period, time series of water quality data, including water temperature, dissolved oxygen (DO), pH, conductivity (EC), and turbidity, were collected using Hydrolabs at 10-minute intervals. Other water quality parameters such as concentration of N, P and chemical oxygen demand (COD) were measured at about two-week intervals. Ambient air temperatures of the sites were recorded by temperature loggers suspended on trees. Stream flow data were downloaded from USGS website.

## RESULTS

### Geomorphology

Stream width had a great range, from 7.4m to 30.3m, and showed a strong positive relationship with basin area (Table 1, Fig. 2). This indicates that the larger the basin area, the more volume of stream flow, and the more extensive bank erosion.

High gradients and high fine sediment concentrations (FS) occurred at residuum area. High depth/width ratios occurred at lower reaches of streams. Canopy cover was very low at stream reaches wider than 20m. Large wood debris frequency (LWDF) did not show evident relationship with stream reaches.

**Table 1. Stream geomorphology of the area**

| Stream | Width (m) | Depth (m) | W/D | Gradient (‰) | FS (%) | LWDF $(m^{-1})$ | Canopy (%) | pH | EC (ms/cm) | CL |
|---|---|---|---|---|---|---|---|---|---|---|
| Chick 1 | 7.4 | 1.0 | 7.7 | 0.94 | 100 | 0.62 | 81 | 6.57 | 101 | RD |
| Muck 1 | 8.2 | 1.5 | 5.6 | 0.97 | 93 | 0.75 | 95 | 6.90 | 162 | RD |
| Ichi 1 | 9.7 | 1.2 | 8.3 | 0.83 | 95 | 1.23 | 82 | 6.27 | 47 | RD |
| Bear | 10.4 | 1.5 | 7.0 | 1.45 | 100 | 0.88 | | 6.41 | 44 | RD |
| Carter | 11.0 | 2.3 | 5.0 | 3.02 | 100 | 1.03 | | 6.90 | 40 | RD |
| Chick 2 | 11.4 | 1.2 | 9.4 | | 100 | 1.26 | | 6.66 | 130 | OW |
| Mill | 11.7 | 1.5 | 7.8 | 0.82 | 26 | 0.69 | 78 | 7.74 | 220 | RD |
| Cool 2 | 12.0 | 1.7 | 7.6 | 0.13 | 59 | 0.66 | 97 | 7.38 | 241 | OD |
| Chick 3 | 13.2 | 1.4 | 9.3 | | 84 | 0.98 | 94 | 6.89 | 298 | OW |
| Ichi 2 | 17.9 | 3.3 | 6.2 | 0.58 | | | 95 | 6.60 | 56 | OD |
| Spring | 20.1 | 2.4 | 8.4 | 0.54 | 79 | 0.75 | 39 | 7.49 | 217 | OD |
| Muck 2 | 21.9 | 1.6 | 13.6 | 0.36 | | | | 6.69 | 85 | OD |
| Muck 3 | 24.4 | 2.3 | 10.8 | 0.18 | | | | 6.97 | 98 | OD |
| Kinch 3 | 29.2 | 2.6 | 11.7 | | 85 | 0.91 | 57 | 6.63 | 62 | OD |
| Ichi 3 | 30.3 | 2.2 | 14.7 | | 5 | 1.02 | | 6.88 | 67 | OD |
| Cool 1 | Forest wetland | | | | | | | 7.19 | 389 | OW |
| Kinch 1 | Forest wetland | | | | | | | 6.28 | 250 | RW |
| Kinch 2 | Forest wetland | | | | | | | 6.19 | 35 | RW |
| FMC | | | | | | | | | | PT |
| Lime | 11.2 | 1.5 | 7.6 | 0.21 | 14 | 0.74 | | | | PT |

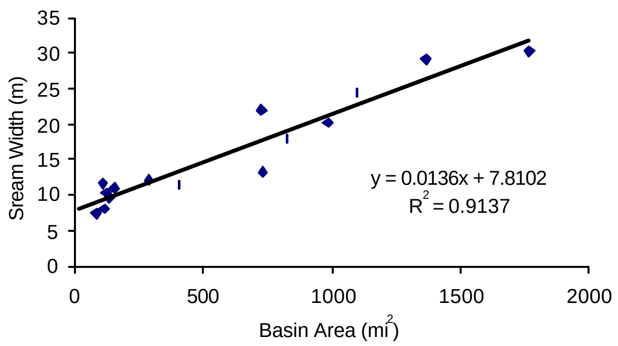


**Fig. 2. Stream bank width vs. drainage area.**

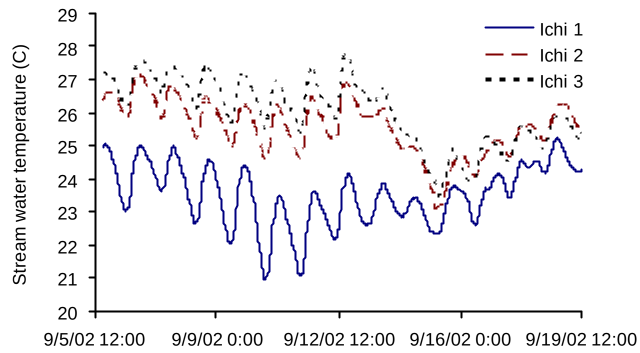


**Fig. 3. Stream water temperature characteristics.**

**Table 2. Stream pH and EC with groundwater discharge**

| | Residuum Dominated | Mixed | Goundwater Dominated |
|---|---|---|---|
| pH | 6.44 | 6.75 | 7.45 |
| EC (μs/cm) | 49 | 74 | 267 |

Stream pH and EC were highly related to groundwater discharge. From the residuum area down to Ocala area, the average pH and EC of the streams increased greatly with the increase of groundwater discharge (Table 2).

Because the groundwater influence is likely to affect fish communities through temperature influences, pH and EC were used as the primary determinant in channel classification.

Based on geomorphology, together with stream pH and EC, the streams in this area were classified into five categories, e.g., Residuum well-defined streams (RD), Residuum wetland (RW), Ocala well-defined streams (OD), Ocala wetland (OW), and Pelham tributaries (PT), as shown in table 1. This classification will provide assistance for the water quality analysis and temperature model development.

## Water Quality

The data from three typical sites located at different reaches of the Ichawaynochaway Creek were taken as to illustrate stream water quality characteristics in detail. These sites, from upstream to downstream, were tagged as Ichi1, Ichi2, and Ichi3. The time series data collecting period experienced a long drought and then a five inch precipitation event on September 14, and 15.

Stream temperature showed a diel fluctuation of as much as 5°C (Fig. 3). Daily maximum temperature occurred in the early evening (16:00~20:00), while minimum temperature occurred in the morning (around 11:00), which showed an evident delay compared with the extreme values of the solar radiation. The range of temperatures was from 21 to 28°C. The stream temperature increased downstream, indicated an increasing heat energy input from the ambient surroundings and the direct solar radiation due to the traveling time, increasing stream width, and the lower canopy cover. The precipitation during the data collection period had a dramatic mixing impact on water temperatures along the stream.

Daily fluctuations of DO were found in all of the 3 sites (Fig. 4). The declining trend of DO from upstream to downstream suggested a negative relationship between DO and increased water temperature. Daily maximum DO occurred around 12:30, 16:00, and 18:30 from Ichi1 to Ichi 3, while daily minimum DO occurred around 23:00, 3:00, and 11:00 respectively. The delay of daily extreme DO concentrations from Ichi1 to Ichi3 indicated that other factors, such as photosynthesis, respiration, stream velocity, were also important factors affecting the concentration of DO. Critical DO values, e.g. value less than 3, were not found during the observation period.

Stream pH also showed a slight diel fluctuation, with ranges from 0.05 to 0.1 (Fig. 5). The daily maximum value occurred in the late afternoon or the early evening, while the daily minimum value occurred sometime in the morning. The diel pattern of pH closely related to that of stream temperature. It could be inferred that the higher pH during the day was because of the consumption of $CO_2$ by photosynthesis, and the lower pH during the night was because of the release of $CO_2$ by respiration. It could also be inferred that the higher stream temperature, the higher rate of photosynthesis.

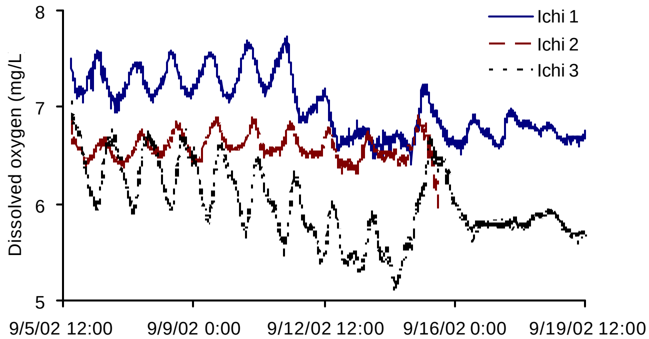


**Fig. 4. Stream water DO characteristics.**

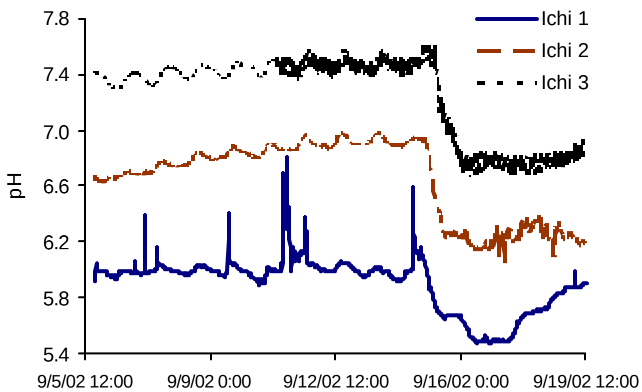


**Fig. 5. Stream water pH characteristics.**

Stream pH also increased downstream. Two factors could account for this trend: 1)the groundwater from the Upper Floridan aquifer, usually with pH levels around 7.5 because of high concentration of dissolved $Ca(HCO_3)_2$, moved into the stream during baseflow period between these sites (Maslia and Hayes, 1988); and 2)the increasing solar radiation and stream temperature increased the rate of photosynthesis. The dramatically decrease of pH on September 15 indicated dilution by precipitation, which usually has a low pH at about 5 to 6.

During baseflow period, stream pH showed an increasing trend with time. It was attributed to the increasing ratio of groundwater input due to the decreasing surface water supply.

Electrical conductivity increased downstream (Fig. 6). This trend indicated that groundwater with high concentration of ions, predominately $Ca^{2+}$ in karst area, was discharged into the stream. There was a dramatic increase of EC from Ichi2 to Ichi3. It could be inferred that there exists undercut or sinkholes into the Upper Floridan aquifer between the sites, which accelerated stream-aquifer flux (Hyatt and Jacobs, 1996;

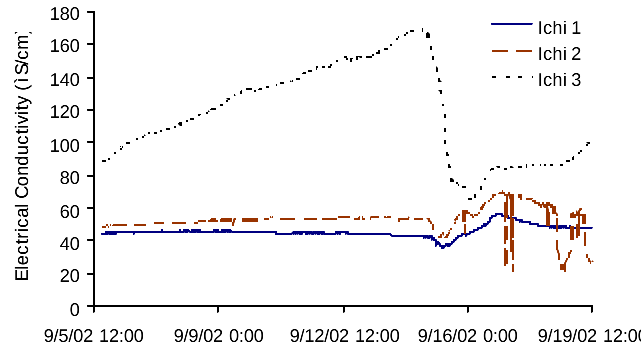


**Fig. 6. Stream water EC characteristics.**

**Table 3. Water chemistry parameters**

| Stream | Site | $NO_2$ (mg/L) | $NO_3$ (mg/L) | $NH_4$ (mg/L) | $PO_4$ (µg/L ) | COD (mg/L) |
|---|---|---|---|---|---|---|
| Chick | 1 | 0.0792 | 0.480 | 0.26 | 0 | 24 |
| Chick | 3 | 0.0495 | 0.128 | 0.29 | 10 | 32 |
| Cool | 2 | 0.1485 | 2.743 | 0.12 | 30 | 26 |
| Ichi | 1 | 0.0792 | 0.178 | 0.02 | 40 | 7 |
| Ichi | 2 | 0.0594 | 0.341 | 0.16 | 70 | 18 |
| Ichi | 3 | 0.0396 | 0.464 | 0.09 | 0 | 12 |
| Kinch | 3 | 0.0429 | 0.469 | 0.76 | 40 | 21 |
| Mill | | 0.0528 | 0.182 | 0.22 | 100 | 24 |
| Muck | 1 | 0.0429 | 0.349 | 1.01 | 40 | 17 |
| Spring | | 0.0264 | 0.256 | 0.15 | 30 | 14 |

Torak, 1996). Stream EC in Ichi3 increased greatly with time from 9/5 to 9/16. It verified that the ratio of groundwater input from the limestone area, which has higher EC, against the surface water input increased, since the surface water supply was decreasing during baseflow period while groundwater input kept constant. Again, the Dilution by precipitation led to dramatically decreased EC levels.

Turbidity was less than 10 NTU in most sites. In site Ichi1 the turbidity was much higher during the day. It might be because of the increased photosynthesis causing biological turbidity. The levels of N, P and COD were low in the streams of the Dougherty plain (table 3).

In general, none of the physical and chemical measures of water quality were causes for concern during the data collection period.

**Stream Temperature Model**

Stream temperature prediction has been studying extensively (Brown, 1969; Sinokrot and Stefan, 1993;

LeBlanc et al, 1997; Rutherford et al, 1997; Mohseni and Stefan, 1999; Caissie et al, 2001). In these studies, deterministic (i.e. energy balance) and stochastic approaches are the two commonly used types of modeling methods (Caissie et al, 2001). Deterministic modeling works better on streams that have different energy sources, such as direct solar radiation, long wave radiation, and inflows with different temperatures from reservoirs, aquifers and waste water treatment plants. Stochastic modeling, characterized as using very few input parameters, sometimes can provide very good result using only air temperatures (Mohseni and Stefan, 1999; Caissie et al, 2001).

As described above, the streams in the Dougherty plain have high flux interactions with groundwater. However, since almost all of the stream water comes from groundwater during baseflow period, little flow mixing could be expected in the short distance of stream reaches. As a result, it could be feasible to develop time series models that only take solar radiation, long wave radiation, and the heat conduction as the total energy flux between stream water and its surroundings. That is:

$$\Delta T_t = f(E_S, E_L, E_C, F; t)$$

$\Delta T_t$ --- *Stream temperature change at time t*
$E_S$ --- *Solar radiation input*
$E_L$ --- *Long wave radiation*
$E_C$ --- *Conduction flux*
$F$ --- *Stream flow*
$t$ --- *Local time*

When using the energy balance equation, it is meaningful only when the same column of water is considered. However, when measuring time series stream water temperatures, we can only deploy the equipments in a fixed stream cross section. Therefore, each time of a new sampling denotes the temperature of new water coming from upstream. The way to solve this paradox is to assume that the temperatures are the same for the whole stream at the same time. It is not true actually, as shown in figure 6. But it is close enough if the geomorphology is similar and the distance between two cross sections is small.

Three coefficients are used to denote the contribution of $E_C$, $E_L$, $E_C$ in this model. The coefficients may change due to different stream systems. Thus the model has to be calibrated to determine the coefficients before being employed. The solar radiation time series, air temperature time series, stream flow time series, stream

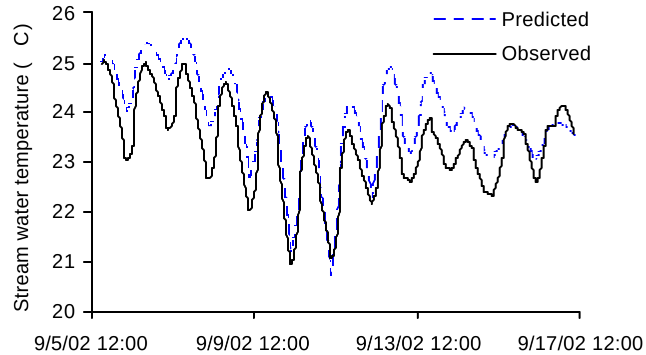


**Fig. 7. Stream temperature predicting in site Ich1.**

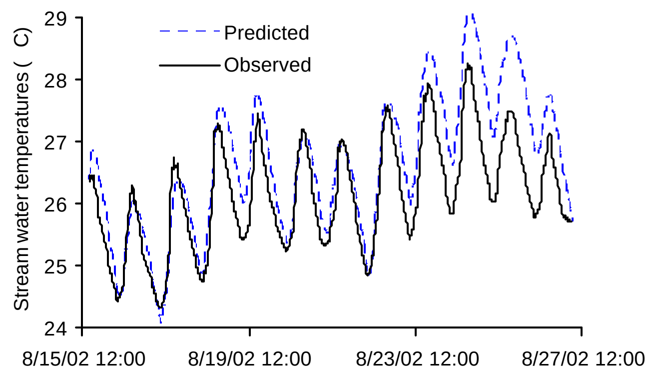


**Fig. 8. Stream temperature predicting in site Chick3.**

temperature time series, canopy coverage, and stream site latitude are needed to calibrate the model.

Once calibrated, the model is ready to predict the time series stream water temperatures. The input parameters of the model include the original stream water temperature, the stream flow time series, the latitude of the stream site, the canopy coverage over the stream, the air temperature time serious, and the solar radiation time series.

The recursive method is employed in the model, that is, the first predicted stream temperature will be used as input for the next heat energy flux calculation. Using this model, the time series stream temperatures in stream Ich1 and Chick3 were predicted. The predicting results were very good (Fig. 7 and 9). The errors were between -0.5~1.0°C, and between -0.8~1.4°C, respectively. This model can show the impacts of changed input parameters on stream temperatures.

## CONCLUSION AND DISCUSSION

The Lower Flint River Basin can be divided into three small sub-areas, e.g., the Residuum area, the Ocala area, the Pelham area. Accordingly, the streams in the plain are divided into five classifications. They are, respectively, Residuum defined streams, Residuum wetland, Ocala defined streams, Ocala wetland, and Pelham tributaries. The upland streams and the Dougherty plain streams carry distinct chemical signatures due to differing groundwater inputs.

The low stream flow period occurs in late summer and early fall when stream temperatures are elevated. Width and depth of streams are positively related to drainage area, while the gradient, the fine sediment concentration, and the canopy cover show negative relationship to stream width. All of these characteristics have impacts on stream water quality.

There are four principle aquifers under the Dougherty plain. As the main stream water sources during baseflow, the water quality and quantity of these aquifers had a strong impact on these streams.

Most of the streamwater quality parameters showed diel fluctuations. These variables also changed with the difference of stream geomorphic characteristics, and could be affected dramatically by precipitation.

During baseflow period, the stream temperatures can be predicted very well by the model developed in this paper. The model requires solar radiation and air temperature time series data as heat flux parameters. It also requires stream flow time series, original stream temperature, canopy cover, and stream latitude as input parameters.

By adjusting the input parameters, such as the stream flow, the original water temperature, and the canopy cover, the model can show how much the temperature will be impacted by these modifications.

The mixing effect by inflows with different water temperatures from other sources, such as precipitation, tributaries, and ground waters, are not considered in this model. The model will be more robust when these factors are counted in.

Further work will be done to perfect the stream water temperature predicting model and to develop DO predicting models. These data and models will finally be used by fisheries scientists to develop tools with which to analyze possible reservoir effects on stream biota.

## ACKNOWLEDGMENTS

This research is funded by a grant from the Georgia Wildlife Resources Division.

## REFERENCES CITED

Brown, G.W., 1969. Predicting temperatures of small streams. Water resources research. 5(1):68-75.

Caissie, D., N. El-Jabi and M.G. Satish, 2001. Modelling of maximum daily water temperatures in a small stream using air temperatures. Journal of Hydrology. 251(1-2, 15 14-28.

Caruso, B.S., 2002. Temporal and spatial patterns of extreme low flows and effects on stream ecosystems in Otago, New Zealand. Journal of hydrology. 257:115-133.

Gilvear, D.J., K.V. Heal, A. Stephen, 2002. Hydrology and the ecological quality of Scottish river ecosystems. The Science of the Total Environment. 294:131–159.

Hyatt, J.A. and P.M. Jacobs, 1996. Distribution and morphology of sinkholes triggered by flooding following Tropical Storm Alberto at Albany, Georgia, U.S.A. Geomorphology. 17:305-316.

LeBlanc, R.T., R.D. Brown, and J.E. FitzGibbon, 1997. Modeling the Effects of Land Use Change on the Water Temperature in Unregulated Urban Streams. Journal of Environmental Management. 49(4):445-469.

Lind, O.T. 1985. Handbook of common methods in limnology, 2nd edition. Dubuque, Iowa: Kendall Hunt Publishing Co. 184p.

Maslia, M.L. and L.R. Hayes. 1988. Hydrogeology and simulated effects of ground-water development of the Floridan aquifer system, southwest Georgia, northwest Florida, and southernmost Alabama. U.S. Geological Survey Professional Paper 1403-H: 8,23p.

Matthews, W.J. 1998. Patterns in freshwater fish ecology. United States of America: International Thompson Publishing. 756p.

Mohseni, O. and H.G. Stefan, 1999. Stream temperature/air temperature relationship: a physical interpretation, Journal of Hydrology. 218(3-4, 24):128-141.

Richter, B.R., D.P. Braun, M.A. Mendelson and L.L. Master, 1997. Threats to imperiled freshwater fauna. Conservation Biology. 11:1081-1093.

Rutherford, J.C., S. Blackett, C. Blackett, L. Saito, R.J. Davies-colley, 1997. Predicting the effects of shade on water temperature in small streams. New Zealand journal of Marine and freshwater research. 31:707-721.

Sabo, M.J., C.F. Bryan, W.E. Kelso and D.A. Rutherford, 1999. Hydrology and aquatic habitat characteristics of a riverine swamp: I. influence of flow on water temperature and chemistry. Regul. Rivers: Res. Mgmt. 15:505-523.

Sinokrot, B.A. and H.G. Stefan, 1993. Stream temperature dynamics: measurements and modeling. Water resources research. 29(7):2299-2312.

Torak, L.J., G.S. Davis, G.A. Strain and J.G. Herndon, 1996. Geohydrology and evaluation of stream-aquifer relations in the Apalachicola-Chattahoochee-Flint River basin, southeastern Alabama, northwestern Florida, and southwestern Georgia. USGS water-supply paper 2460, 1996:30-33p.

USGS, 2000. Droughts in Georgia. http://ga.water.usgs.gov/publications/ofr00-380.pdf.
Utley, F.L., and M.R., Hemperley, 1975. http://ga.water.usgs.gov/nawqa/basinall.html.
Warner, D., J.A. Easoz and S. Priest,2002. Ground-Water-Quality Data for Albany and Surrounding Areas, Southwest Georgia, 1951-99. USGS Open-File Report 02-124. http://ga.water.usgs.gov/publications/ofr02-124/.