TIME-SERIES STREAM TEMPERATURE AND DISSOLVED OXYGEN MODELING IN THE LOWER FLINT RIVER BASIN

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Abstract In the Lower Flint River Basin (LFRB), excessive groundwater withdrawals and possible water supply reservoirs threaten to exacerbate low flow conditions during summer droughts, possibly leading stream temperature and dissolved oxygen (DO) levels detrimental to aquatic biota. To evaluate possible effects of human modifications to stream habitat, summer time-series of stream temperature and DO were monitored over the last three years along these streams. Continuously Stirred Tank Reactor (CSTR) models for temperature and DO were developed and calibrated with these data. The dominant drivers of stream temperature and DO were identified by this model. Simulations were conducted with assumed managed flow conditions to illustrate potential effects of various stream flow regimes on stream temperature and DO time-series. The goal of this research is to provide an accurate simulation tool to guide management decisions.

INTRODUCTION

The Lower Flint River Basin (LFRB) is located between Lakes Blackshear and Seminole in southwest Georgia. Many tributaries in this area are incised into the upper Floridan semi-confined limestone aquifer. The strong seepage of relatively old groundwater sustains baseflows and provides some control over stream temperature and dissolved oxygen fluctuations. This hydrologic and geologic setting creates aquatic habitat that is unique in the state of Georgia and supports rich aquatic life, including some endangered species (USGS, 2002).

The LFRB area is also known as the Dougherty Plain, one of the state's most important agricultural areas. Irrigation pumping from both surface and ground water has been an important measure to ensure productive crop harvest. In drought years, agricultural pumping would create conflicts in water resources management. In August year 2000, record daily minimum low flow occurred (USGS, 2000). Major Fish and Mussel kills were seen in tributary streams apparently due to low DO levels.

Reduced groundwater input to tributaries exacerbated the drought's effect on flows. Due to continuous drought and excessive irrigation pumping, new record low water levels were recorded in more than 40 wells in the statewide groundwater monitoring network from January to August 2000, and most of the wells were located in LFRB (USGS, 2000).

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 efficiency of the FRDPA depends on whether natural resource managers and planners are well 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 water quality, especially on stream water temperatures and DO, needs to be predicted and evaluated beforehand. Therefore, it is necessary to develop models to evaluate the effect of stream flow and groundwater discharge on stream temperature and DO.

METHODS

Study Area Description

Study streams cross the Dougherty plain, where karst physiography controls hydrology. Land use in the study area is predominantly agricultural and residential. The interactions between surface water and upper floridan aquifer is active (Hyatt and Jacobs, 1996). Low flows in these streams occur from June to October during high late summer temperatures and solar insolation.

Data Collection

Data were collected from year 2002 - 2004 by different means. Stream morphology data, including Bankfull width, Flow velocity, Bankfull Depth, and Canopy cover, were collected by site survey. Water quality time-series data of stream temperature, DO, pH, and electric conductivity, were collected using hydrolabs. Some grab sampling data, such as, BOD/COD and *Chlorophyll a*, were also collected. Weather time-series data were from the nearest local weather station. And stream flow time-series data were downloaded from USGS. All the time-series data were in 15 minutes interval for every 2 or 3 weeks.

Process Analysis

For stream temperature modeling, the key task is to estimate the net heat flux between the waterbody and its surroundings. Generally, heat flux processes for a stream reach include solar radiation, long wave radiation, sensible heat, latent heat, and streambed conduction (Brown, 1970; Bowie *et al.*, 1985; LeBlanc *et al.*, 1996).

Dissolved oxygen models are usually based on mass balance analysis. Three primary processes, e.g., photosynthesis,

Table 1: Energy/Mass Exchange Process Description

Location	Processes	
	Temperature	DO
Stream surface	Solar Radiation Long wave Radiation Sensible heat Latent heat	Reaeration
Streambed	Conduction	SOD decay
Stream water		Photosynthesis Respiration BOD decay
Boundaries	Advection	Advection

respiration, and reaeration, are commonly considered in DO modeling (Guasch *et al.*, 1998; Wang *et al.*, 2003). Dissolved oxygen is also lost due to decay of biochemical oxygen demand (BOD) and sediment oxygen demand (SOD) (Young and Beck, 1974; McIntyre *et al.*, 2003). Cox (2003) provides a rather complete review on DO modeling.

Both stream temperature and DO are affected by groundwater discharge/recharge advection. While the advection causes spatial transportation of mass/energy, the groundwater discharge advection, with its relatively lower temperature and DO level, has a special effect: cooling down the high summer stream temperature but also bringing in relatively low DO water. However, the cooling action seems to have a net positive effect on stream DO levels. The processes included in our models are shown in table 1.

Model Structure Selection

For stream water quality mechanistic modeling, mass balance analysis based on the continuity equation is required. There are three commonly used approaches, e.g., *One Dimensional Advection-diffusion* models, *Lagrangian* models, and *Continuously Stirred Tank Reactor* (CSTR) models (Young and Beck, 1974; James, 1984; Chapra, 1997). Based on our data availability, the CSTR models were selected. That is, the stream reach is segmented as a series of continuously connected CSTR. For each CSTR, the changing rate of the state variable is controlled by the rate of influent, effluent, and other possible sources and sinks. It assumes that the system is mixed immediately and perfectly after its interaction in each time step. Thus the output value of the state variable is exactly the same as that inside the tank. The governing equation of such a system is an ordinary differential equation (ODE) and takes the following form:

$$\frac{dx}{dt} = \frac{Q}{V}(x_0 - x) + s \tag{1}$$

Where,

x — State variable of the effluent;
x_0 — State variable of the influent;
t — Time;
Q — Stream flow;
V — Volume of the CSTR;
s — Source and sink terms;

There are three sub-models in total. The stream flow sub-model gives parameters values of Q and V, thus served as a basis of temperature and DO sub-models. The output of the temperature sub-model in turn forces some influences on stream DO model. The complete representation of these three sub-models are as below:

$$\frac{dx_1}{dt} = (Q_0 + q_g - x_1)/(\frac{L}{a}(1-b)x_1^{-b}) \tag{2}$$

$$\frac{dx_2}{dt} = \frac{x_1}{V}(T_0 - x_2) + \frac{E_S + E_L + E_H + E_C + E_B}{C_p \rho H} \tag{3}$$

$$\frac{dx_3}{dt} = \frac{x_1}{V}(C_0 - x_3) + K_a(C_s - x_3) + P - R - D \tag{4}$$

Where,

x_1, x_2, x_3 —- Stream flow, temperature, and DO respectively;
Q_0, T_0, C_0 —- Input stream flow, temperature, and DO;
$E_{S,L,C,H,B}$ — The five processes for energy flux;
P, R — Rate of photosynthesis, respiration. Function of x_2;
C_p, ρ — Water specific heat and density;
H — Stream water depth;
D — Total decay rate of BOD and SOD. Function of x_2;
C_s — Saturated DO concentration at temperature x_2;

Simulation approaches

The objective of the model development is to identify the effect of stream flow and groundwater discharge on stream water temperature and DO. Our simulation was focused on the combination of these two flow scenarios. We used four low flow conditions and three groundwater discharge conditions. The four low flows included Lowest Daily Flow, $7Q10$, $7Q2$, and 90% Exceedance flow. The three groundwater flow conditions were simply $Gaining\ groundwater$, $No\ groundwater$, and $Losing\ groundwater$. In total there were 12 different flow scenarios were fed into the calibrated model for simulation.

RESULTS

Water Quality Characterization

Both stream temperature and DO showed diurnal variation in the tributaries. The difference between daily maximum and minimum temperature was as large as 3 $°C$. Diurnal DO fluctuations ranged from 0.30 - 0.85 mg/L for the same time period. There were also evident trends of these two water quality parameters along the stream reach. From upstream to downstream, stream temperature increased and DO decreased. As expected, there is a significant negative correlation between the average daily maximum stream temperature and daily minimum stream DO (Fig. 1).

Model Calibration

The model was calibrated with data collected in September year 2002. The stream temperature sub-model calibration fit observed data well (Fig. 2), while the DO sub-model performed less well but acceptably (Fig. 3).

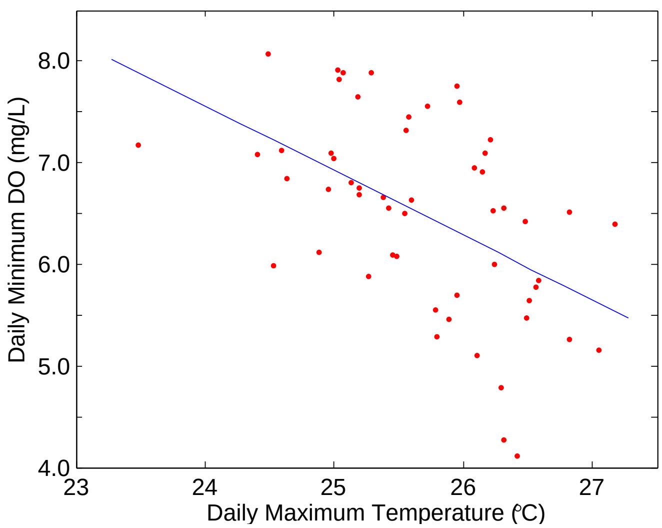

Fig. 1: Daily stream minimum DO vs. maximum temperature.

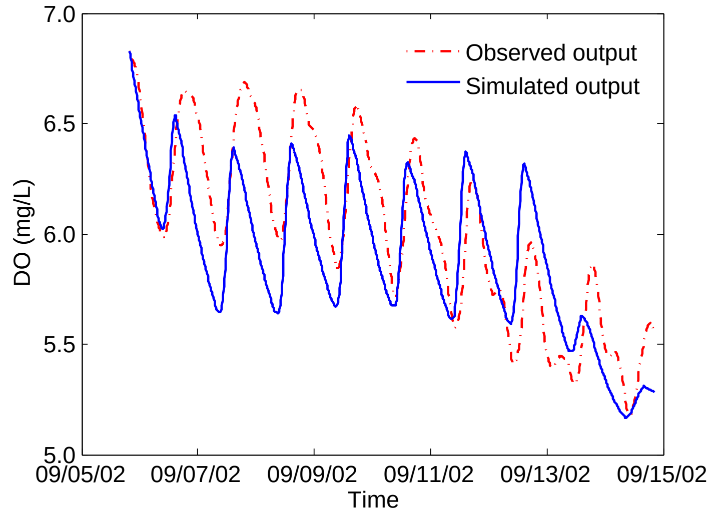

Fig. 3: Stream DO sub-model calibration.

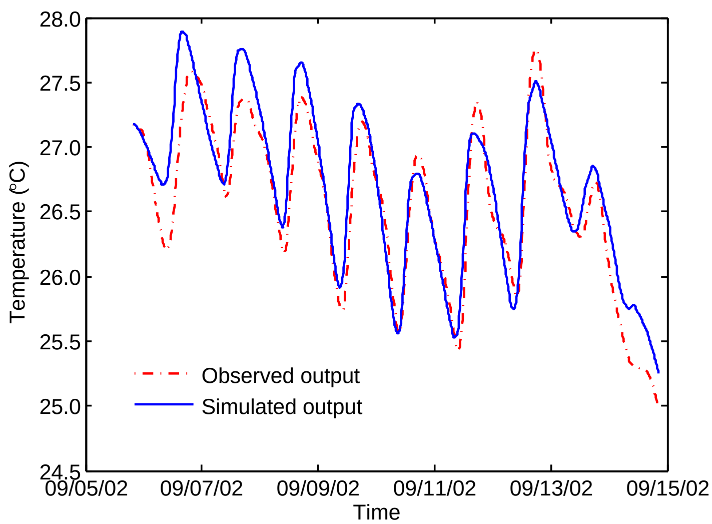

Fig. 2: Stream temperature sub-model calibration.

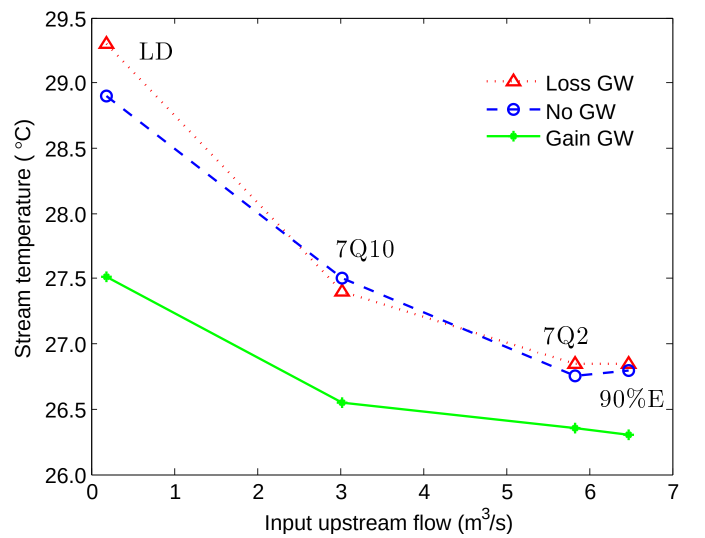

Fig. 4: Stream temperature simulation.

Model Simulation

Before simulation, the model was validated by its acceptable performance when feeding in datasets collected in year 2003. This validation ensured a reliable simulation. The simulation was conducted based on dataset from year 2002. The highest daily maximum stream temperature and the lowest minimum stream DO picked out from the simulated output were plotted against their corresponding flow conditions (Fig. 4 and Fig. 5).

The highest stream temperature occurs when stream is experiencing Lowest Daily Low Flow and at the same time is losing Groundwater. There is an negative correlation between stream temperature and flow. Under the same surface flow conditions, stream temperature is much lower when stream is gaining colder groundwater discharge. The changing rate of temperature against flow becomes faster when flow becomes very low.

The lowest DO occurs at exactly the same time as the highest stream temperature. Again, the slop of DO becomes larger when flow becomes very low. However, the correlation between DO and flow becomes positive, and there is no apparent difference in DO between the 3 different groundwater flow conditions.

CONCLUSIONS

From the simulation results, we concluded that daily maximum stream temperature and minimum DO are relatively insensitive to flow until flows become very low. The discharge of relatively colder ground water into the stream decreases the daily maximum stream temperature. Due to the fact that groundwater itself has a lower DO level (4mg/L in simulation), groundwater discharge does not improve stream DO levels very much. There is little difference in T and DO levels between losing groundwater and no groundwater situa-

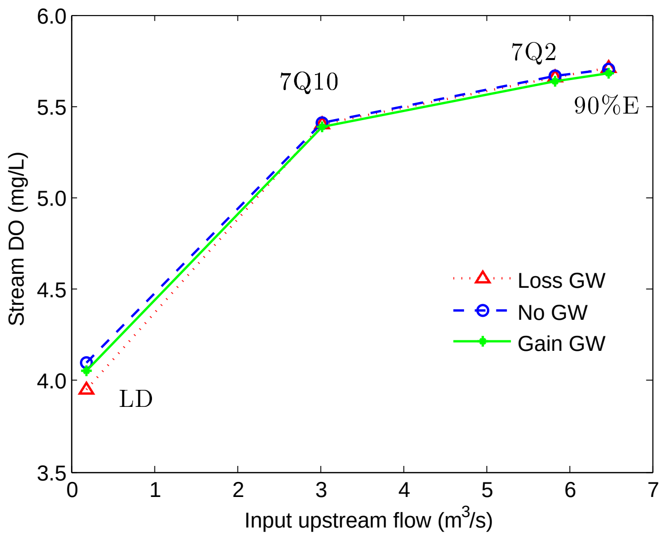

Fig. 5: Stream DO simulation.

tions. Our simulation results indicate that low flow conditions and reduced groundwater discharge have apparent impact on stream water temperature and DO, and thus at least partly account for the deduction and degradation of aquatic habitat in the LFRB.

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