Georgia Water Resources Institute
Annual Technical Report
FY 2001

Introduction

In Fiscal Year 2001, the Georgia Water Resources Institute (GWRI) was involved in a wide range of activities at the state, national and international levels. The following section is a brief introduction to the mission, research focus, education and technology transfer impact and professional and policy impact of GRWI.

Mission: The Georgia Water Resources Institute (GWRI) at Georgia Tech is one of 54 water resources research institutes authorized by the U.S. Congress in 1964. GWRI is a government-industry-university partnership that brings to bear the knowledge and resources necessary to address current water resources issues. GWRI goals are to (a) develop new scientific knowledge, modeling tools, and comprehensive information to support river basin planning and management, (b) educate scientists, engineers, and water professionals in the theory and application of new research methods, and (c) disseminate useful information to water managers, policy makers, citizen groups, and the general public.

Research Focus: The principal GWRI research focus is to develop better understanding and comprehensive information and modeling systems to support water resources planning and management decisions. GWRI sponsored research aims to address all water resources planning and management process aspects including the effective use of conventional and remote environmental sensors (ground gages, radars, and satellites) and the development of models for climate and weather forecasting, hydrologic watershed and aquifer simulation, river and reservoir regulation, hydropower scheduling, urban and agricultural planning, environmental and eco-system assessment, and economic valuation.

Educational and Technology Transfer Impact: The GWRI educational impact is realized through the research support and involvement of graduate and undergraduate students. GWRI supported students are presently employed in academia, government, and industry. Furthermore, GWRI supports several technology transfer and information dissemination activities including the Georgia Water Resources Conference (biennially), annual specialty workshops (most recently on shared river basins), continuing education courses, and project-specific training workshops (most recently in East Africa on remote sensing, hydrologic modeling, river and reservoir management, agricultural planning, hydropower scheduling, and decision support). Other means of information dissemination include archival and trade publications and the GWRI web site.

Professional and Policy Impact: GWRI research involvement has had significant impact in Georgia as well as other US and world regions. Two examples of GWRI research contributions and policy impact include the development of decision support systems for the Apalachicola-Chattahoochee-Flint (ACF) and the Alabama-Coosa-Tallapoosa (ACT) River Basins in the Southeastern US and the Nile River Basin in Africa. The ACF and ACT basins are shared by the states of Alabama, Florida, and Georgia and have been the subject of intense negotiations for over a decade. The negotiations aim to establish equitable water sharing compacts that will serve the needs of several stakeholders GWRI is working with federal and state agencies, environmental organizations, and other stakeholders to assess the implications of various water compacts in support of the negotiation process. GWRI tools also support the development of comprehensive water resources management strategies

The Nile is the worlds longest river, and its watershed is shared by 10 countries. Few basins would surpass the Nile in its diversity of geography and culture and the complexity of its hydrology and politics. As the riparian nations plan their economic and social development, it is clear that equitable sharing of water resources is the key for a sustainable and peaceful future. In partnership with United Nations Agencies, the World Bank, and the Nile Basin Governments, GWRI is developing information and modeling systems to aid decision-makers in formulating shared vision policies for agriculture, urban water supply, energy resources, industry, and the environment

Research Program

Investigation in the role of oxidized iron in the surface water phosphorus dymamics in the Georgia Piedmont

Basic Information

Title:	Investigation in the role of oxidized iron in the surface water phosphorus dymamics in the Georgia Piedmont
Project Number:	2001GA4141B
Start Date:	3/1/2001
End Date:	2/28/2002
Funding Source:	104B
Congressional District:	11
Research Category:	Water Quality
Focus Category:	Nutrients, Non Point Pollution, Water Quantity
Descriptors:	surface water, iron, nutrient dynamics,phosphorus
Principal Investigators:	Bruce Beck

Publication

1. Parker, A K, and Beck, M B (2003), "The role of transported sediment in the cycling of phosphate in Georgia Piedmont impoundments," 2003 Georgia Water Resources Conference, Athens, Georgia

Final Report

Investigating the role of oxidized iron in surface water phosphorus dynamics in the Georgia Piedmont

M. B. Beck, Parker, A. K., M.L. Mayhew

Investigating the role of oxidized iron in surface water phosphorus dynamics in the Georgia Piedmont

Introduction

The complex interactions iron and phosphorus play a primary role in the availability of phosphorus in surface waters of the Georgia Piedmont. Exploration of these dynamics can provide information for nutrient management in surface water systems of this region. The soils of the Georgia Piedmont are rich in iron primarily as iron hydroxides (oxidized iron). Iron hydroxides form a ligand exchange with phosphate ions, making the phosphate biologically unavailable. Phosphorus, particularly inorganic phosphate, delivered through non-point source runoff to receiving waterbodies may be sorbed to iron hydroxides and not biologically available, while phosphorus, as organic phosphorus, delivered from a point source (such as an effluent pipe) may be immediately biologically available. Illuminating the biogeochemistry of phosphorus in surface waters rich in iron hydroxides will provide information useful in setting local water quality criteria and standards, and will help define the relationship between point and non-point pollution in surface waters receiving runoff from iron-rich soils.

The paradigm for phosphorus cycling was developed based on data from lakes in northern temperate regions. Lakes in north temperate regions tend to be glacial in origin. The phosphorus cycling paradigm in north temperate systems involves the sinking of inorganic particulates and organic material which result in a steady increase in dissolved phosphorus in the hypolimnetic waters of strongly stratified lakes. The dissolved phosphorus is then recirculated to the lake at fall mixis (Hutchinson 1957; Wetzel 1983; Goldman and Horne 1994). In contrast, Southeastern Piedmont lakes are primarily man-made impoundments. The climate in the southeastern US provides for a longer growing season and warmer annual average temperatures than those found in north temperate regions. This difference in climate affects the strength and length of summer stratification, and creates the conditions for monomictic rather than dimictic lakes in the southeastern Piedmont. The parent geology of the southeastern Piedmont is responsible for the differences in the cycling of phosphorus in southeastern Piedmont systems. The high iron content of the soils in the southeastern Piedmont provides transport of iron via runoff to aquatic systems in this region. The steady increase in hypolimnetic P during stratification, and the pulse of soluble P at fall turnover, is not found in southeastern Piedmont lakes. Oxidized iron in the water column binds phosphate via surface sorption and ligand exchange. We hypothesize that this sorption removes inorganic phosphorus from the biologically available fraction, thus creating a different lake phosphorus cycling regime for systems in the southeastern Piedmont.

We investigated the biogeochemical processes involved in the cycling of phosphorus as phosphate in the iron-rich waterbodies of the Georgia Piedmont. We explored the sorption chemistry of iron and phosphorus using the chemical equilibrium model MINTEQ. We conducted laboratory studies of the geochemical processes involved in phosphorus and iron interactions in surface water. We also conducted corresponding fieldwork on Lake Lanier sampling metals and phosphorus at depth four times in the annual cycle, to investigate the current roles of iron and phosphorus in the surface waters of Lake Lanier. The work conducted in this study will allow us to help identify appropriate in waterbody concentrations of phosphorus, given the local geochemistry, for local waterbody specific water quality criteria and standards, and may help evaluate appropriate parameters for monitoring significant changes in water quality of Lake Lanier.

The MINTEQ model program was released initially by USEPA in 1991 as a chemical equilibrium model for the calculation of dilute aqueous solutions in the laboratory or in natural aqueous systems. The model can calculate the equilibrium mass distribution among dissolved species, adsorbed species, and multiple solid phases under a variety of conditions and gas phase partial pressures. MINTEQ comes complete with a comprehensive database, and also allows for user defined parameter input [http://www.epa.gov/ceampubl/minteq.htm]. We used the VMINTEQ model program, which is a modified form of the MINTEQ model to explore the iron-phosphorus chemistry of Georgia Piedmont lake systems. VMINTEQ has been modified by the addition of a Visual Basic interface and the Stockholm Humic Model sub-model to include dissolved organic matter interactions using the diffuse layer model rather than the Gaussian distribution for organic matter physical chemistry (Gustaffson 2001). The laboratory experiments we conducted utilized the results of the model runs to determine initial conditions for the sorption capacity experiments.

The laboratory experiments were conducted in multiple phases. The first phase involved 24 and 48 hour sorption capacity experiments. The second phase involved measuring changes in sorption of phosphorus to iron in the presence of elevated organic matter introduced as concentrated humate in the form of Agrolig powder. The final phase of the planned laboratory work involving algal response to additions of iron complexed phosphorus was not completed due to time and funding constraints.

The third component of our work included depth measurements of metals, nutrients, and basic water chemistry parameters taken four times in the annual cycle on Lake Lanier. We analyzed these data to evaluate the hypothesis that phosphorus cycling in Georgia Piedmont lakes differs significantly from the northeast temperate lake paradigm. Measurements at depth of iron, manganese, and phosphorus show the lack of phosphate in the anoxic bottom waters, and the lack of soluble iron at the sediment-water interface. These measurements help define the role of iron in the phosphorus cycle in Georgia Piedmont lakes.

Methods

VMINTEQ Model Investigations

The VMINTEQ model platform (Gustaffson 1999) was used to investigate the chemical and physicochemical interactions of iron and phosphorus in a circumneutral, low ionic strength environment. Initial parameters for the model were selected to investigate exclusively the iron and phosphorus interactions. The model was initially run as a straight chemical equilibrium problem to determine the direct bonding of phosphate with oxidized iron. Subsequent model input included activation of the adsorptive surfaces sub-model to mimic the surface adsorption of phosphate onto oxidized iron. The Stockholm Humic Model sub-model was also activated to determine interactive effects of dissolved organic matter on the chemical complexation of phosphate with oxidized iron. The input parameters were varied for different model runs to explore the effects of changes in ionic strength, pH, and concentrations of iron and phosphorus.

WinHumic Model Investigations

The VMINTEQ model platform is not specifically designed to identify the thermodynamic chemical equilibrium reactions that involve dissolved organic matter. The WinHumicV model, a model modified from the Tipping and Hurley (1992) Humic Ion Binding Model V. This model program was developed to explore chemical equilibrium and adsorption characteristics involving humic substances. Humic substances can be modeled as fulvic or humic acids. It includes a surface complexation sub-model that can be used to simulate iron or aluminum oxide adsorption.

The initial parameters used in the VMINTEQ modeling system were used in the WinHumicV model program, with additional required parameters included to ensure model performance.

Laboratory Experiments

A series of experiment to explore the capacity of iron oxyhydroxide (FeOOH), Bt horizon soil, and Lake Lanier sediments to sorb phosphate were conducted. Soil and sediments were air dried, pulverized and sieved through 2 mm and 250 Fm sieves. Three grams of catalyst grade FeOOH, Bt horizon soil, or Lake Lanier sediments were added to 50 ml centrifuge tubes. Thirty milliliters of deionized water and stock phosphate solution was added to create final phosphorus concentrations of 0, 100, 500, 1000, 1500 Fg P per tube. The tubes were shaken for 24 or 48 hours, vacuum filtered through a 0.45 Fm filter, and the filtrate was stored at 4EC until analyzed. Sorption experiments were conducted with and without the inclusion of powdered concentrated humic matter. Concentrated humic matter, Agrolig powder (minimum 70% humic acid) --an agricultural soil amendment of concentrated humic material, was included as a treatment in the sorption capacity experiments. In the humic substances treatment, 0.3 g of Agrolig powder was added to each centrifuge tube prior to the addition of soil or sediment; concentrations of P were as described above, the tubes were shaken for 24 hours and filtered. Filtrate from the sorption experiments was analyzed for phosphate using the Murphy-Riley analysis with a Shimadzu UV mini spectrophotometer following APHA (1999) methods.

Lake Lanier Water Chemistry

Water chemistry was collected at multiple depths in the water column at each of four lake sampling stations seasonally during the annual cycle (April, August, December 2001, and February 2002). Common water quality monitoring parameters, dissolved oxygen, temperature, pH, conductivity, and turbidity were collected with a Hydrolab DataSonde 4a or MiniSonde at each station concurrent with water chemistry samples. Secchi disk depth was also measured at each station sampled. Samples for chemical analyses were collected with a 2.2 liter Kimmerer bottle, stored on ice in the field, filtered through a 0.45 Fm filter and frozen until analyzed. Filtered and unfiltered samples were analyzed on a Thermo Jarrell-Ash Enviro 36 Inductively Coupled Argon Plasma mass spectrometer in a 20 element sweep for metals. Wet chemical analyses included orthophosphate, total phosphorus, nitrate-nitrite, ammonium, sulfate, and alkalinity. These analyses were conducted using a Braun-Luebbe Continuous Flow Auto Analyzer II. Analyses for total inorganic and total organic carbon were also conducted using an O.I.Corporation model 700 Total Organic Carbon (TOC) analyzer.

Results

Model Investigations

Simulations of iron phosphorus chemical equilibrium reactions show that no phosphate binds to iron when it is included as ferrihydrite, a finite solid. The phosphate remains in solution when the adsorption sub-model of iron oxide surface sorption is not included. However, when surface sorption is included almost all of the phosphate is sorbed to the oxidized iron. Increasing the pH above 7 decreases the amount of phosphate sorbed to the iron Figure 1. Adding dissolved organic matter with the Stockholm Humic sub-model binds iron to the humic substances, and does reduce some of the sorption of phosphate on oxidized iron.

Investigations of humic substances and iron phosphorus interactions were explored with the WinHumicV humic ion binding model. WinHumicV model runs indicate that much of the oxidized iron can be sorbed to humic substances and clays, leaving no oxidized iron in solution. This model program does not return output that indicates surface sorption to oxidized iron by anions such as phophate. The model results therefore, can be interpreted with respect to iron and humic substances interactions, but can not be used to define the effect of humic substances on the capacity of oxidized iron to sorb phosphate. These results can be used to interpret the reduced ability of oxidized iron to bind phosphate in the presence of humic substances.

Laboratory Experiments

Experiments to investigate the capacity of iron oxyhydroxide, Piedmont soil from the Bt horizon, and Lake Lanier sediments to adsorb phosphate were conducted in a series of treatments. Lake Lanier sediments had the greatest capacity to sorb phosphate in all treatments, and sorbed all the phosphate in solution in most experiments (Figures 2-4). Bt horizon soil sorbed more phosphorus than iron oxyhydroxide (FeOOH). The amount of phosphate sorbed by Bt horizon soil and iron oxyhydroxide was greater in the 48 hour experiments than in the treatment shaken for 24 hours. The addition of concentrated humic substances reduced the sorption capacity of Bt horizon soil, but resulted in the sorption of all phosphorus by Lake Lanier sediments (Figure 4). There was substantial sorption to sediment or soil in all treatments, with the majority of the phosphate bound to the soil or sediment rather than in solution at the end of all experiments. The results of these experiments support the hypothesis that oxidized iron introduced from runoff can bind phosphate in Piedmont surface waters.

Lake Lanier Water Chemistry

Profiles of temperature, dissolved oxygen, pH, and conductivity for all sampling sites are presented in Figures 5 a-d, 6 a-d, 7 a-d, and 8 a-d. Water chemical analyses on Lake Lanier are presented in Table 1. Phosphate is generally below the detection limit at all sites. The increase in manganese in the bottom waters, and the depletion of nitrate in the hypolimnetic waters during stratification, however, indicate that the bottom waters become more reduced over time during stratification as organic matter is oxidized and oxygen is depleted from the hypolimnion. The very low iron concentrations in the hypolimnetic waters, even in December just prior to turnover, indicates that the hypolimnetic waters never become reduced enough for the massive reduction of oxidized iron in the sediments that would be required for release of phosphate to the surface waters at mixis. The increase of ammonium and total inorganic carbon (TIC), and the decrease in total organic carbon (TOC) in the hypolimnetic waters (Figure 9) indicates organic matter degradation in the hypolimnetic waters and sediments of Lake Lanier. The lack of phosphate in the bottom waters however indicates that reduction of oxidized iron and the release of the bound phosphate has not occurred at these sites.

Discussion

The VMINTEQ model program runs and the phosphate sorption capacity experiment results were largely in agreement. The VMINTEQ model did identify reduced sorption of phosphate to oxidized iron in the presence of humic substances due to sorption of iron on humic and fulvic acids. The model also showed reduced sorptive capacity with increased pH, and with increased ionic strength.

The sorption capacity experiments show that the iron-rich Bt horizon soil has the capacity to bind large amounts of phosphorus. This binding of phosphate is the likely reason that much of the phosphate delivered to Lake Lanier is never seen in the biological response of this waterbody. The oxidized iron transported with sediments has the capacity to bind phosphate and thus remove it from the biologically available fraction. Lake Lanier sediment has a greater capacity for sorbing phosphate than either FeOOH or Bt horizon soil. This may be due to the size of the particles in Lake Lanier sediments, as compared to the Bt horizon soil and FeOOH. Lake Lanier sediments used in these experiments contain a large clay/silt size fraction. The larger quantity of smaller particles provides for greater surface area for sorption of anions and cations in solution, and consequently have a greater capacity for phosphate sorption than do the larger sized particles in the Bt horizon Piedmont soil and catalyst grade FeOOH. The binding of oxidized iron to the humic acids explain the reduced capacity of Bt horizon soil and FeOOH to bind phosphate in the presence of humates. In addition, the greater the concentration of phosphate in solution, the greater the capacity for Bt horizon soil and FeOOH to bind the phosphate. This effect is probably due to the difference in ionic strength. Solutions with a greater ionic strength can effectively increase the area of sorption by increasing the area of the diffuse charge around the oxidized iron molecule. This effect results in more phosphate binding in the diffuse layer at higher ionic strength.

The water chemistry data for Lake Lanier show dissolved oxygen, temperature, pH profiles with depth typically seen for reservoirs in the Piedmont region of Georgia (Figures 5-8). The water chemistry data shows little evidence of iron reduction in the hypoxic and anoxic hypolimnion, as soluble iron does not increase in the hypolimnetic waters during stratification. The increase in TIC at depth during the annual cycle (Figure 9), indicates organic matter oxidation and inorganic carbon evolution in the sediments and bottom waters. The lack of oxygen to fuel organic matter oxidation requires that other electron acceptors be used in organic matter decomposition. The depletion of oxygen and nitrate/nitrite in the hypolimnion, together with the increase in manganese and ammonium (Table 1) shows that nitrate/nitrate and manganese are being reduced as organic material is degraded. However the absence of an increase in iron in the bottom waters suggests that iron is not being reduced in great enough quantities to allow for release of phosphate from the sediments into the overlying water.

Thus, the massive reduction of oxidized iron in the sediments and subsequent release of phosphate bound to the iron has not yet occurred. This is good news for Lake Lanier, but perhaps a more cautionary tale for those interested in maintaining long-term water quality in Lanier. While the lack of iron reduction indicates that much of the phosphate buried in the sediments is likely to stay there, the introduction of increasingly more organic material over time without iron-rich sediment, may have adverse water quality results for Lake Lanier. In effect the scenario of increasing organic matter in the system over time--as is typical in lakes and reservoirs--coupled to a reduction in sediment loading--as is currently being recommended by the US EPA and GA EPD--would provide more organic matter for oxidation in the sediments and bottom waters of Lake Lanier and could lead to the release of phosphate and significant water quality problems.

Figure 1. VMINTEQ output, P adsorbed to Fe: pH sweep.

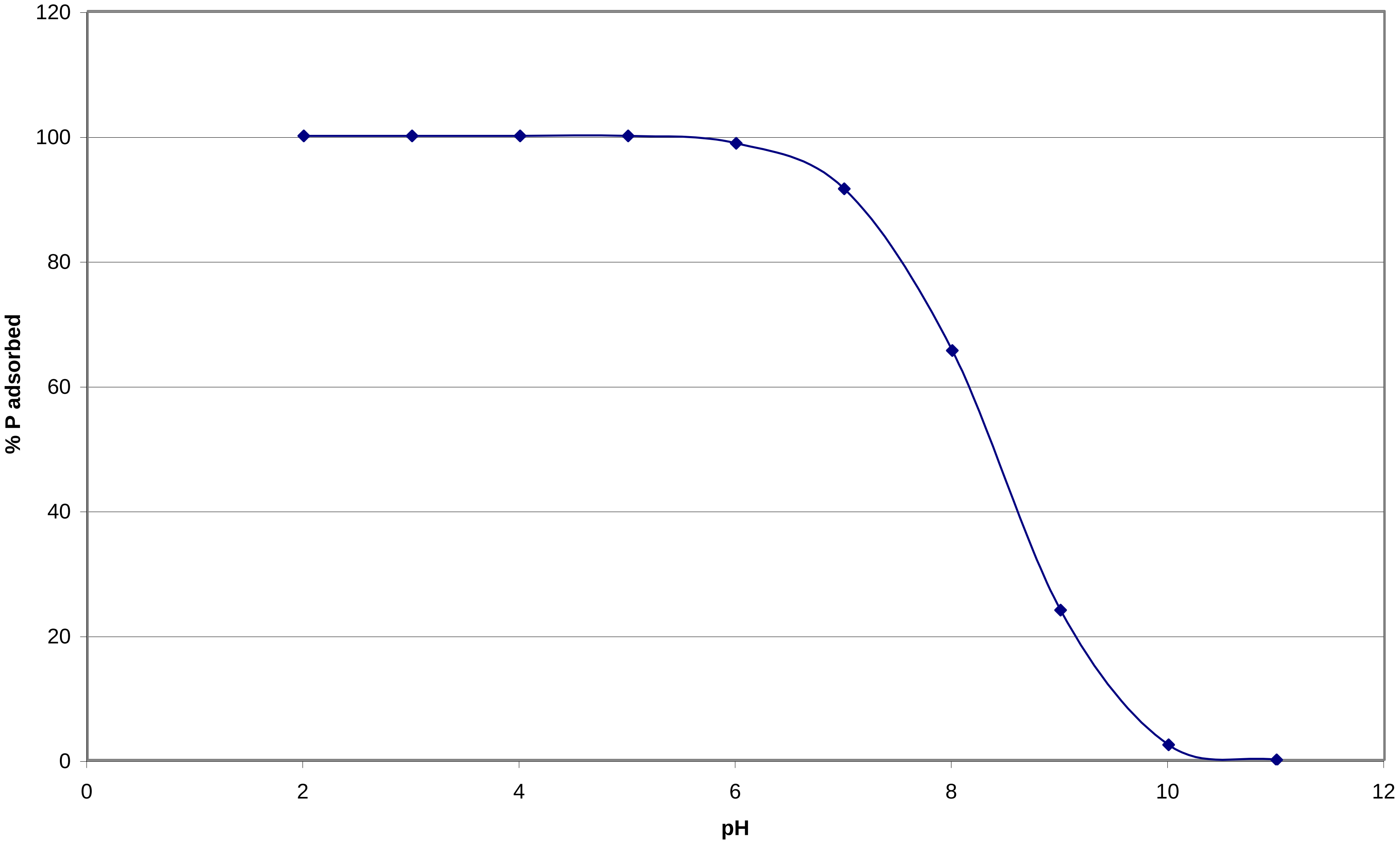

Figure 2. 24 hour sorption capacity experiment.

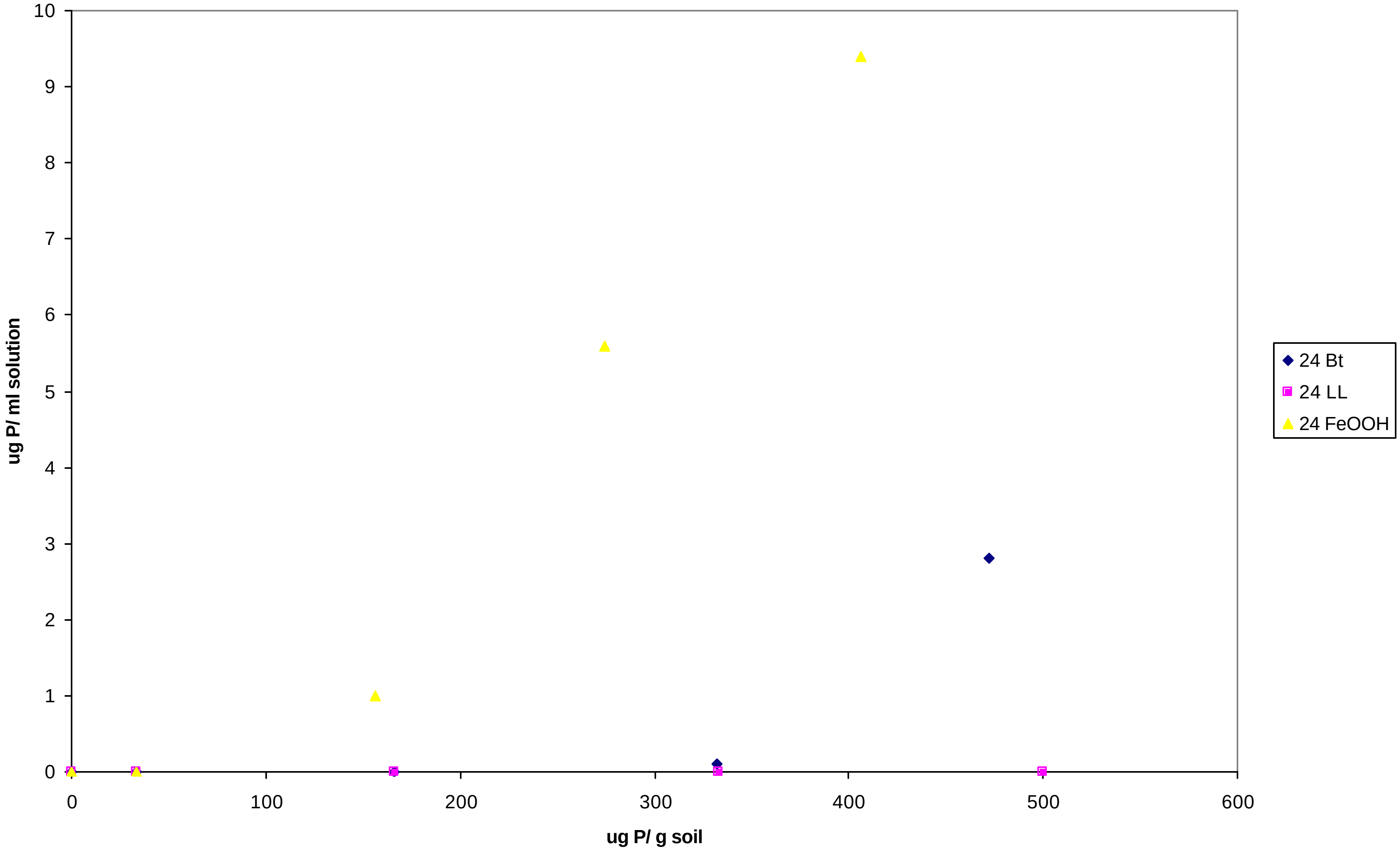

Figure 3. 48 hour sorption capacity experiment.

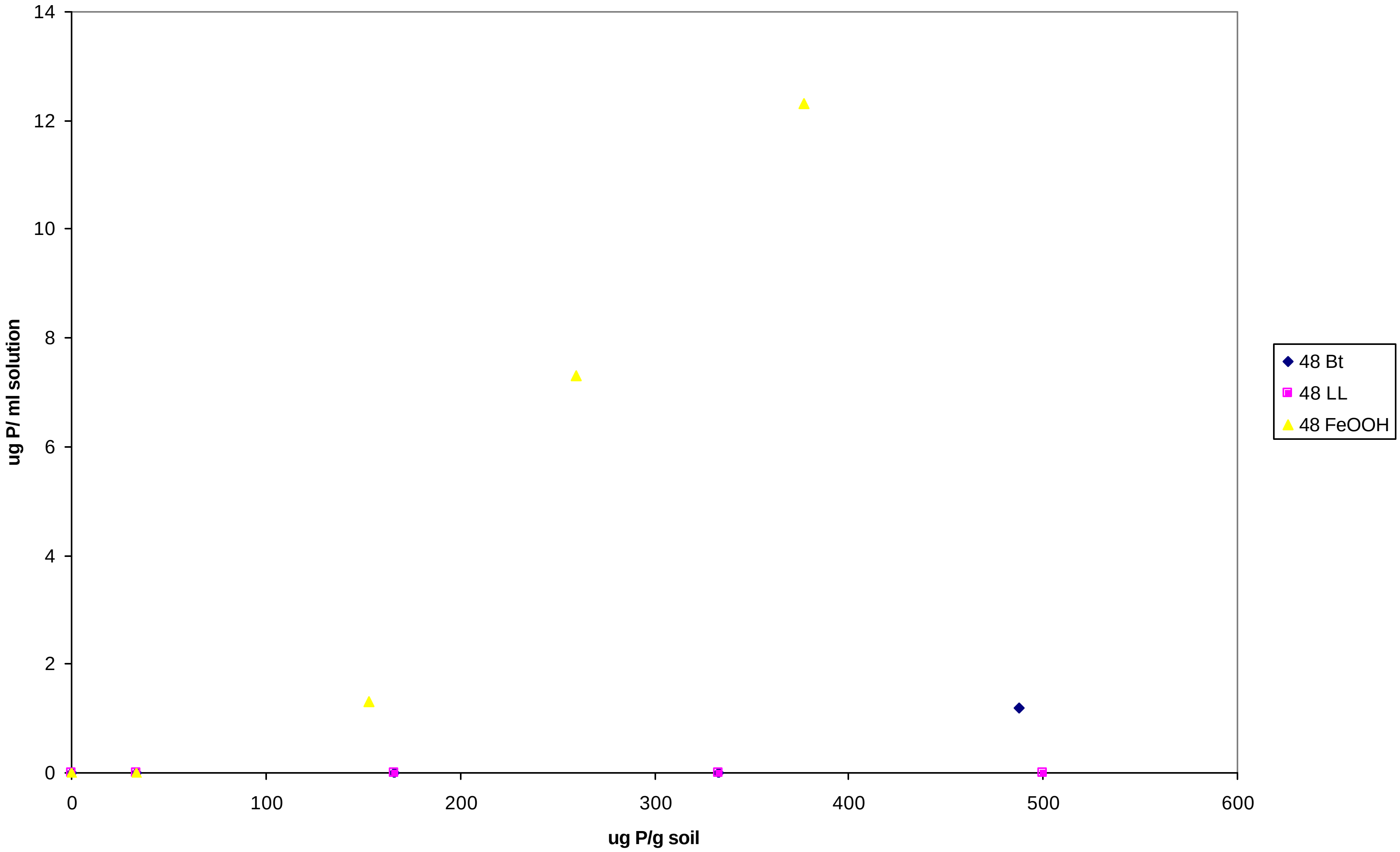

Figure 4. Sorption capacity experiment with humates added as Agrolig powder.

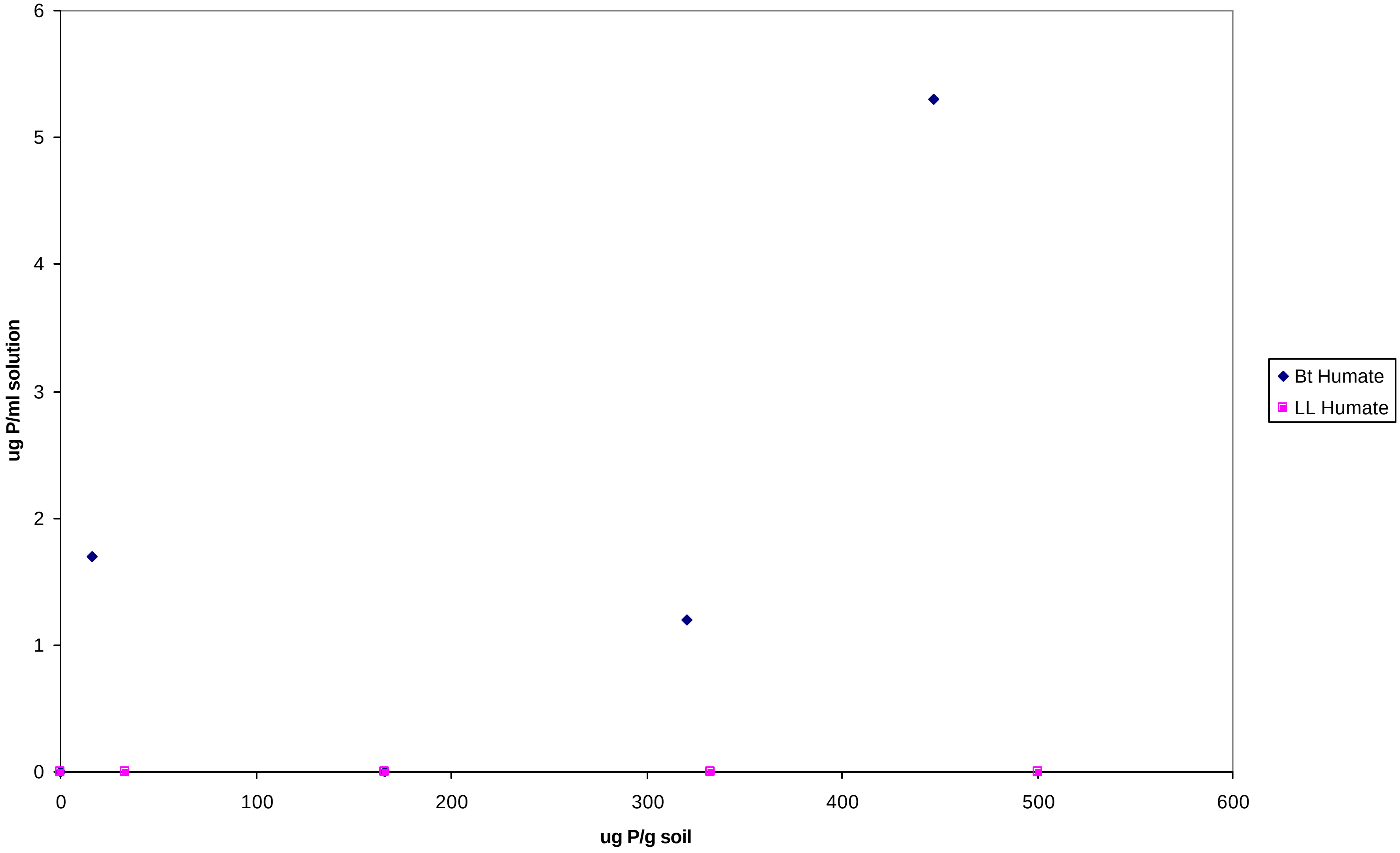

Figure 5 a. Browns Bridge water quality profiles for April 2001.

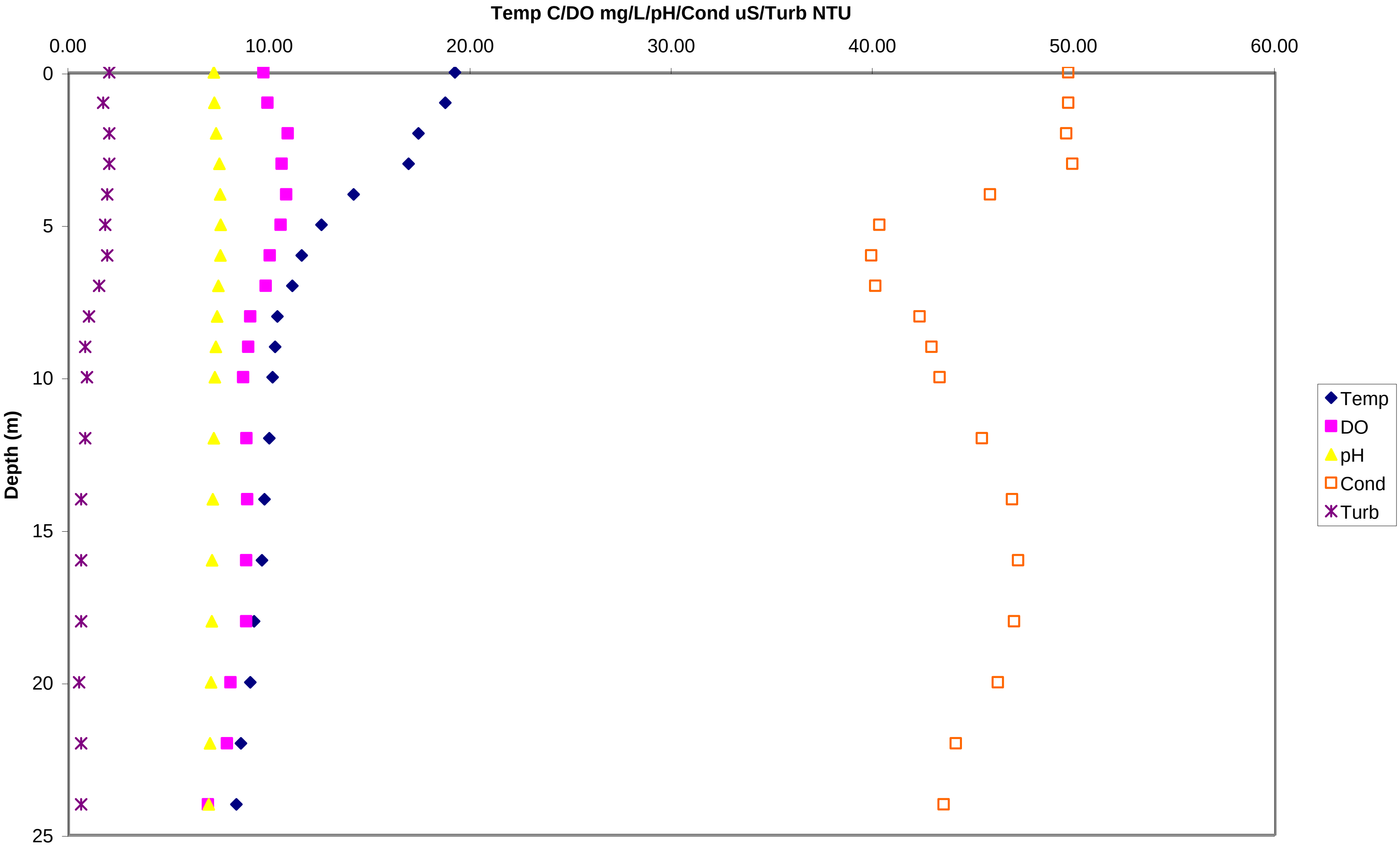

Figure 5 b. Browns Bridge water quality profiles for August 2001.

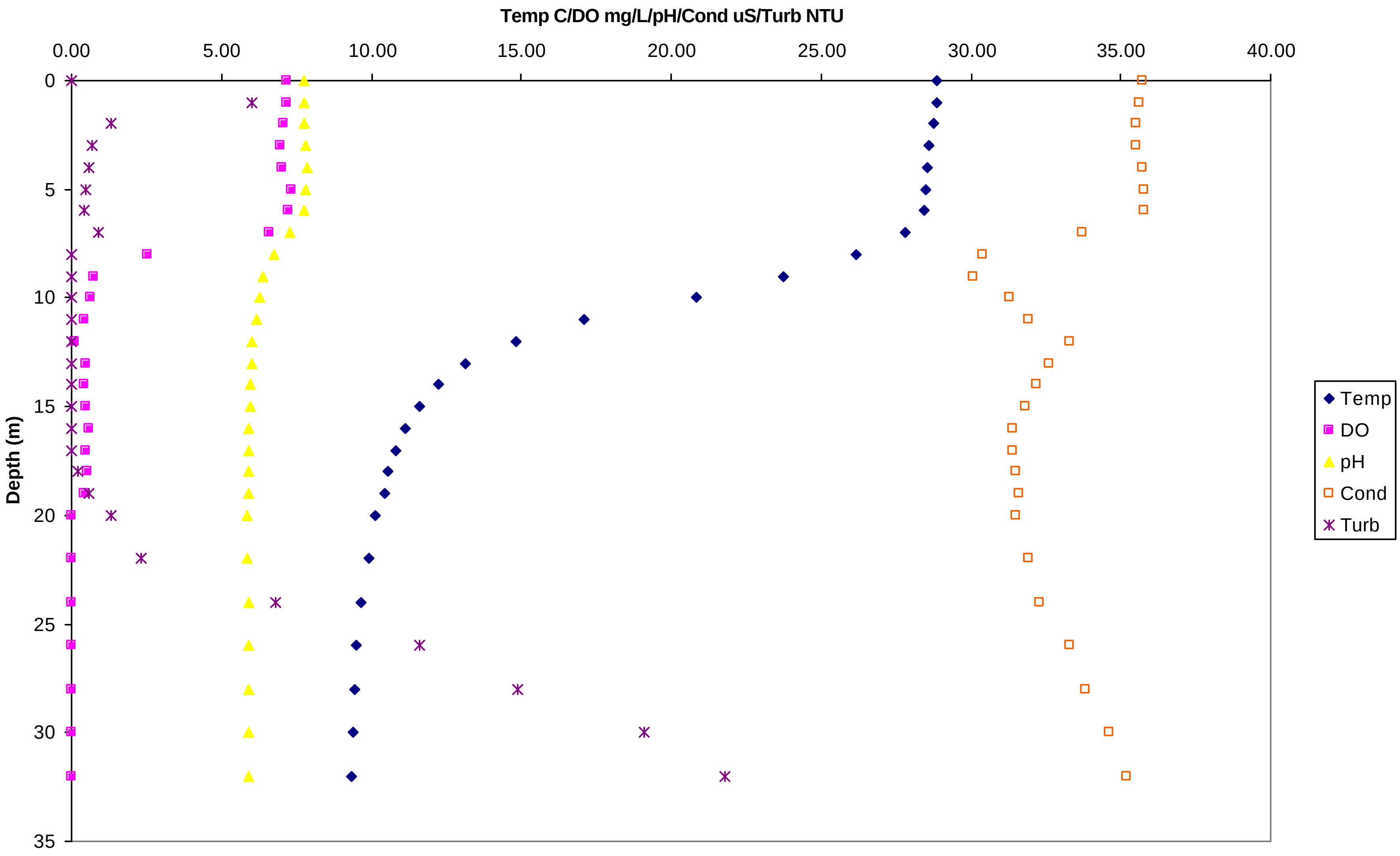

Figure 5 c. Browns Bridge water quality profiles for December 2001.

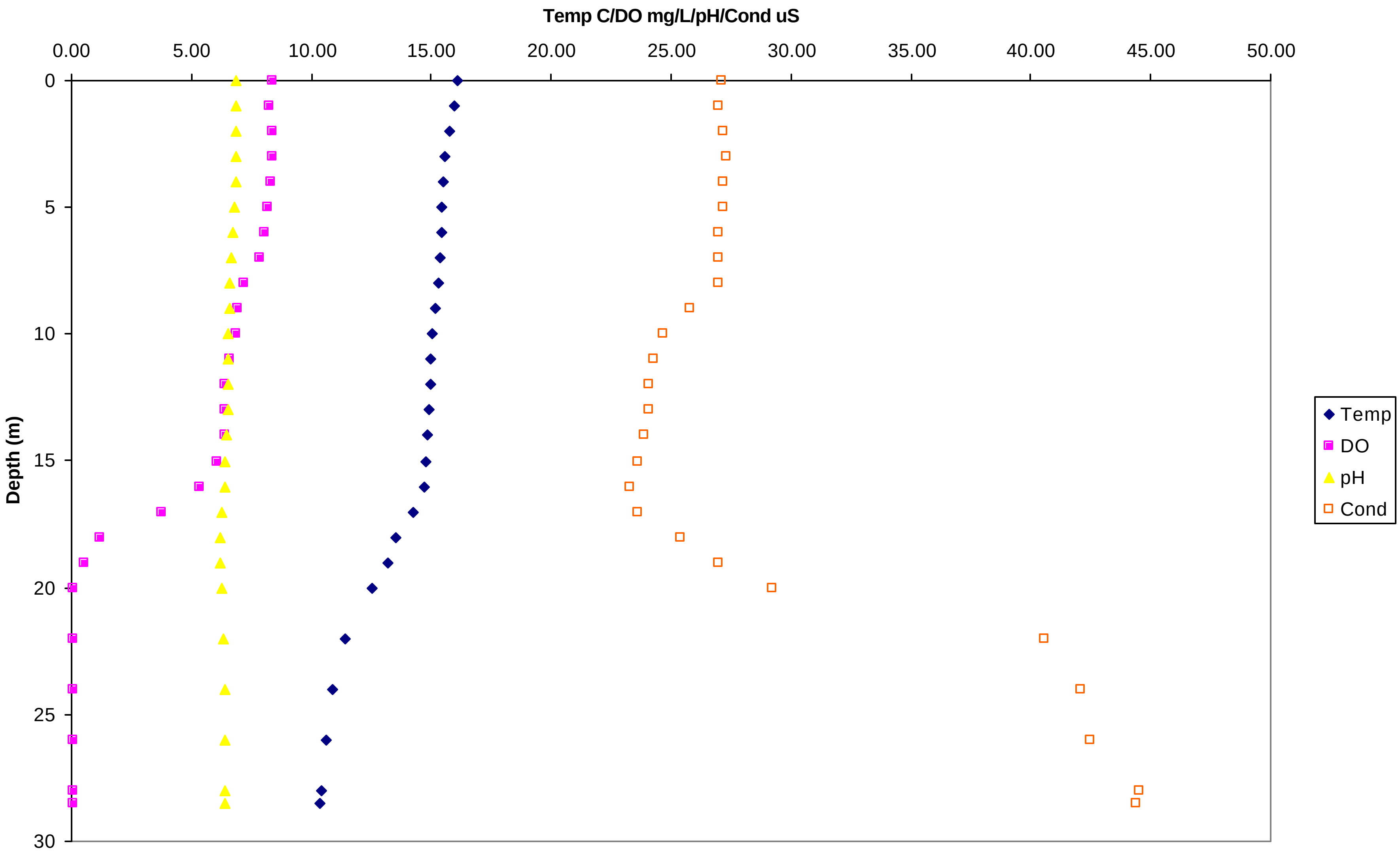

Figure 5 d. Browns Bridge water quality profiles for February 2002.

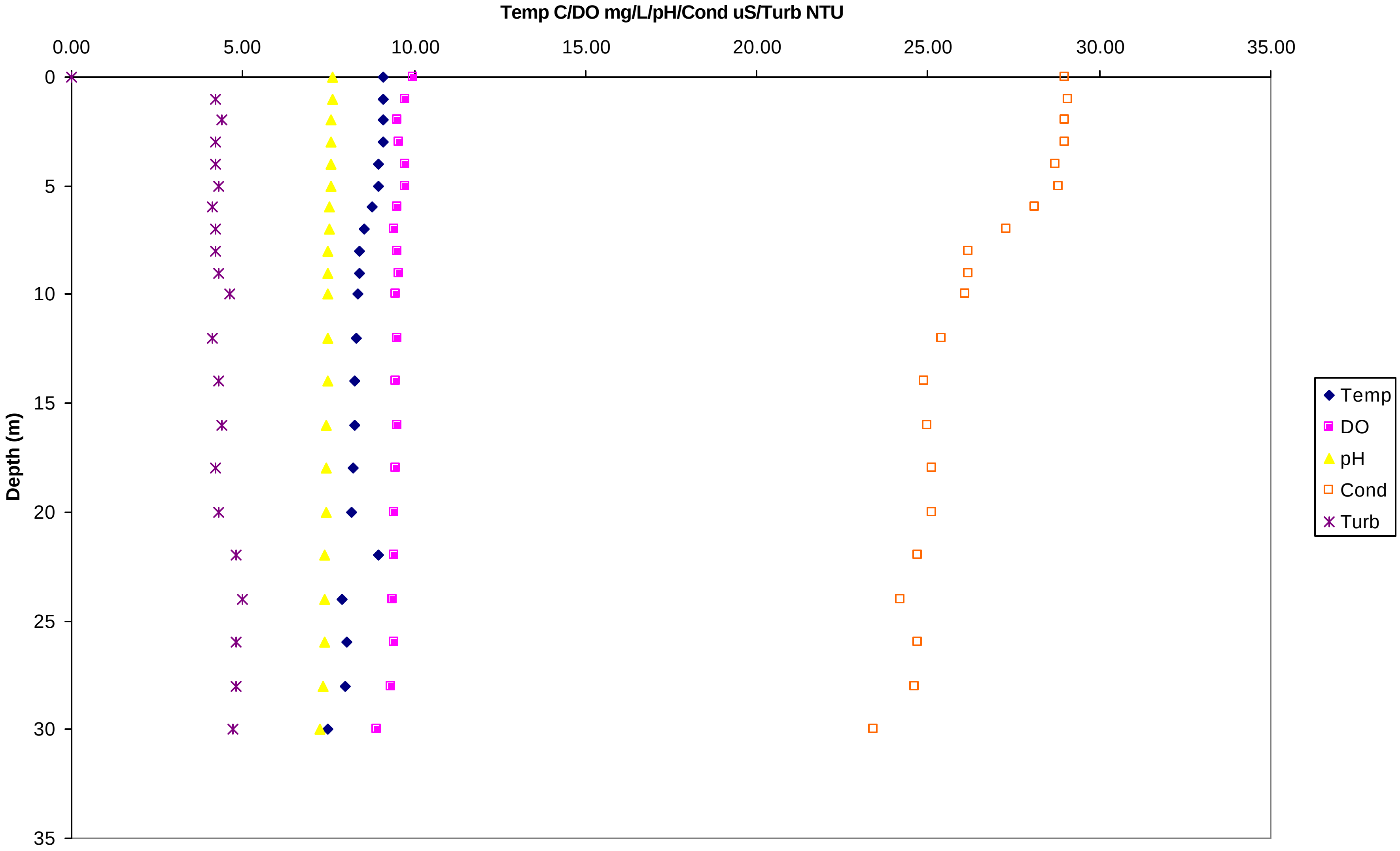

Figure 6 a. Flat Creek embayment water quality profiles April 2001.

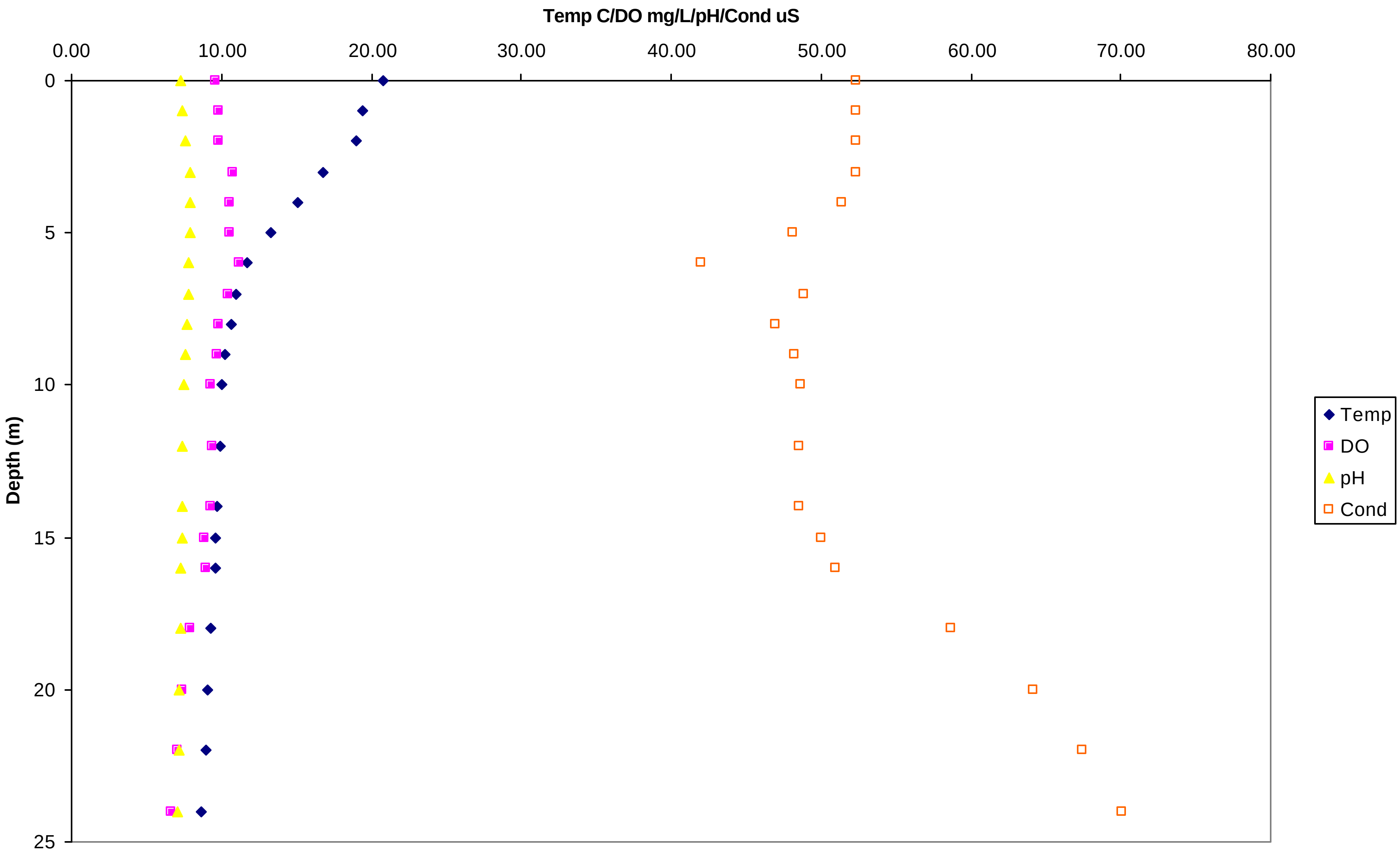

Figure 6 b. Flat Creek embayment water quality profiles August 2001.

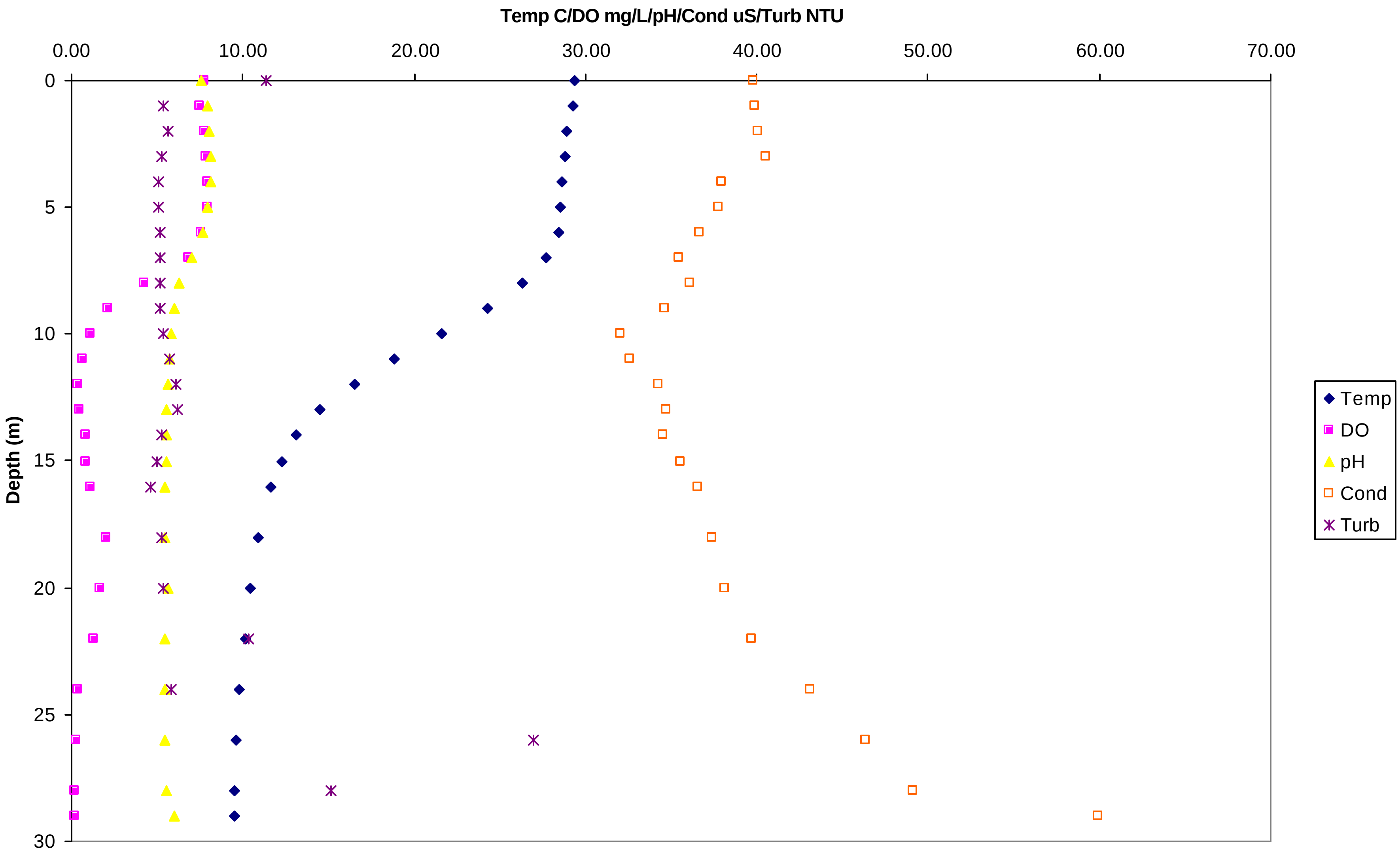

Figure 6 c. Flat Creek embayment water quality profiles December 2001.

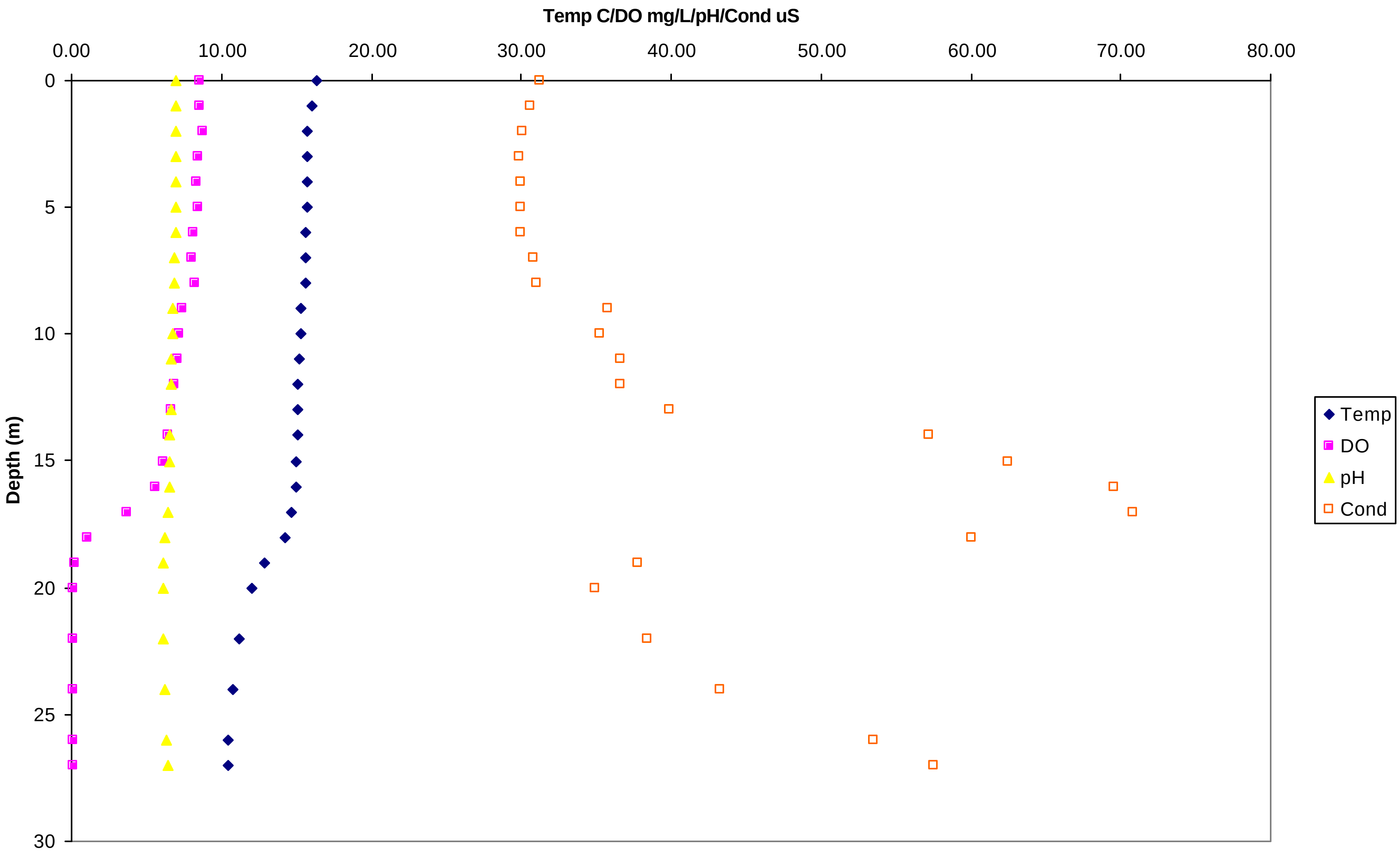

Figure 6 d. Flat Creek embayment water quality profiles February 2002.

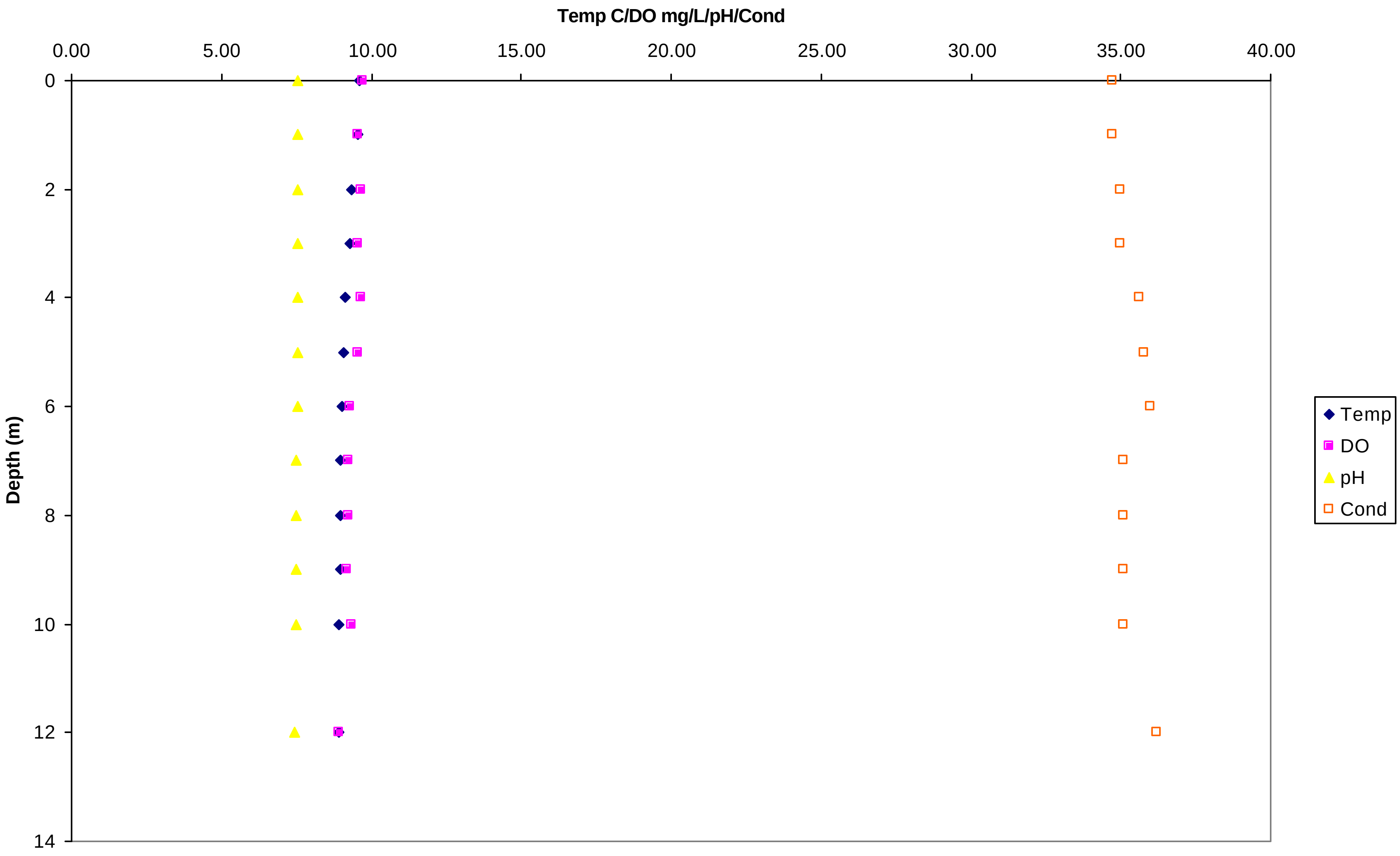

Figure 7 a. Flowery Branch Channel water quality profiles April 2001.

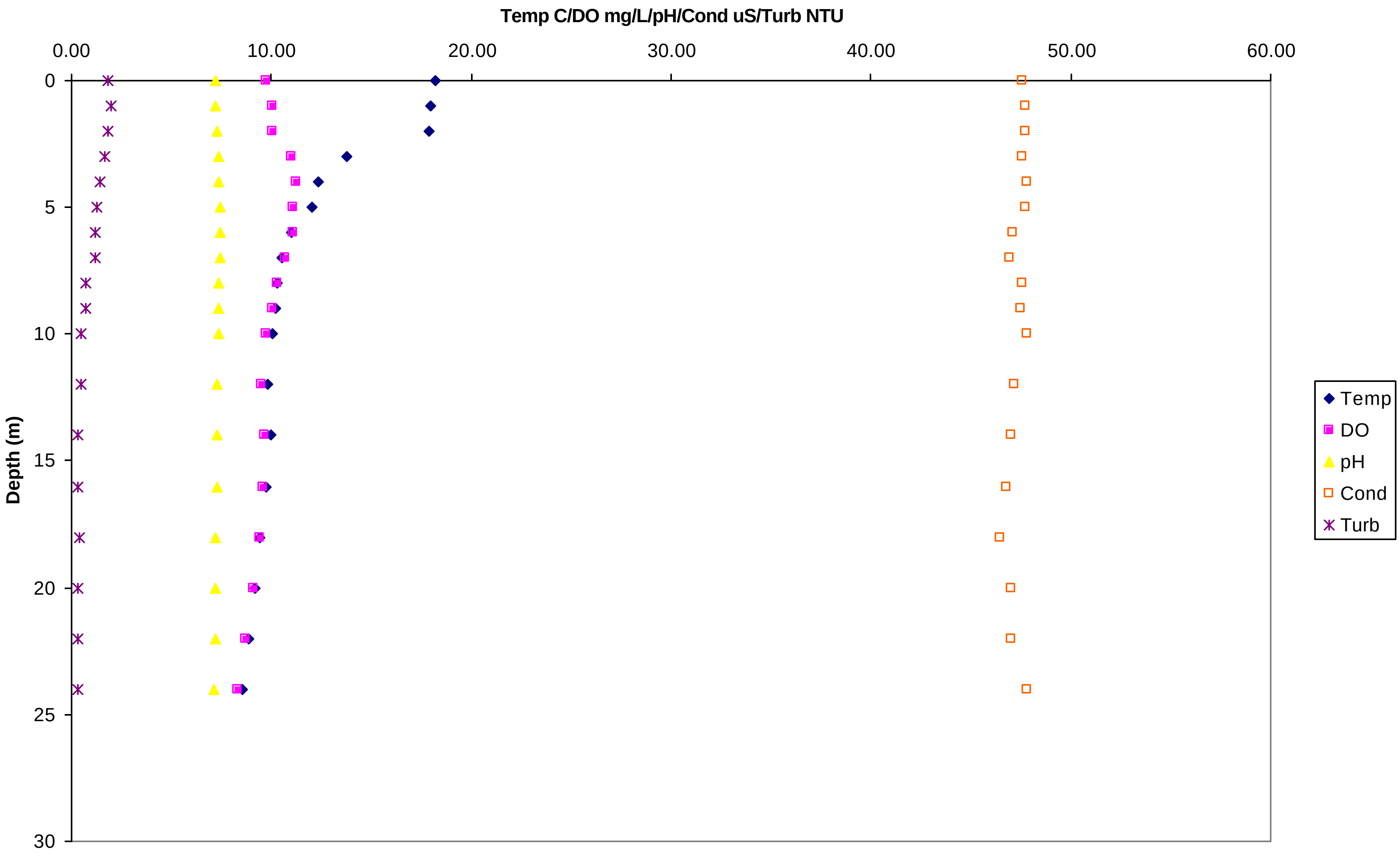

Figure 7 b. Flowery Branch Channel water quality profiles August 2001.

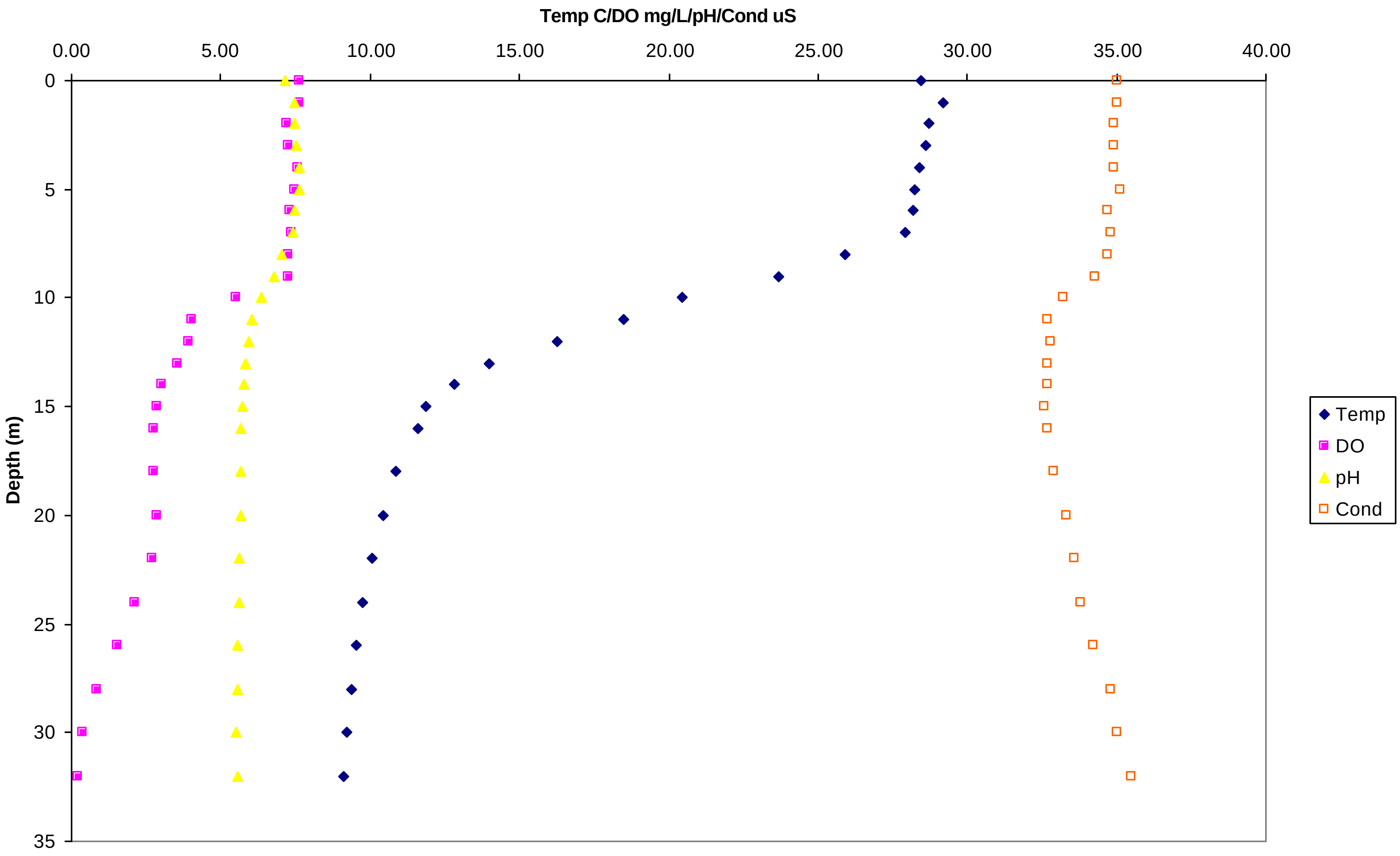

Figure 7 c. Flowery Branch Channel water quality profiles December 2001.

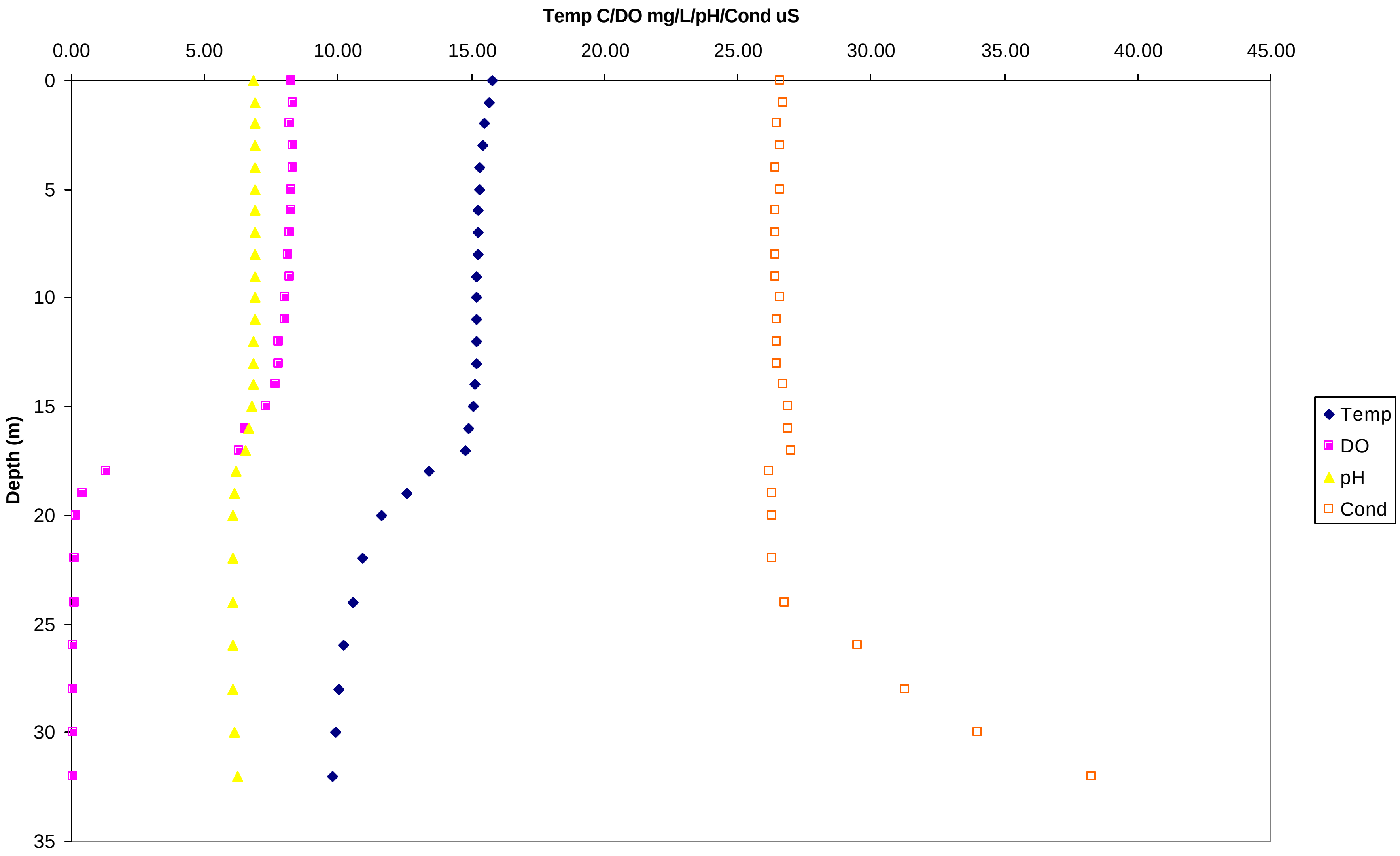

Figure 7 d. Flowery Branch Channel water quality profiles February 2002.

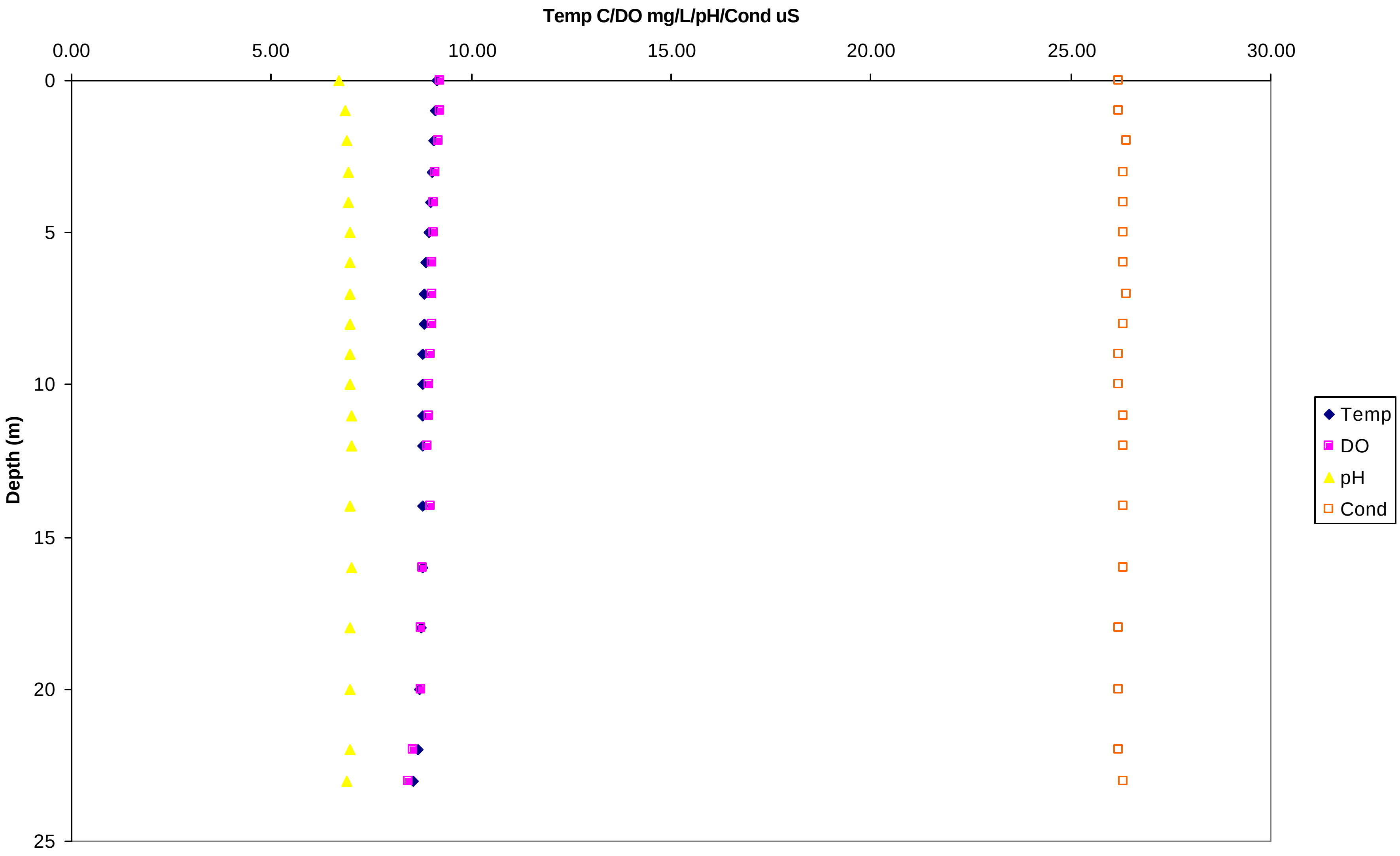

Figure 8 a. Flowery Branch Bay water quality profiles April 2001.

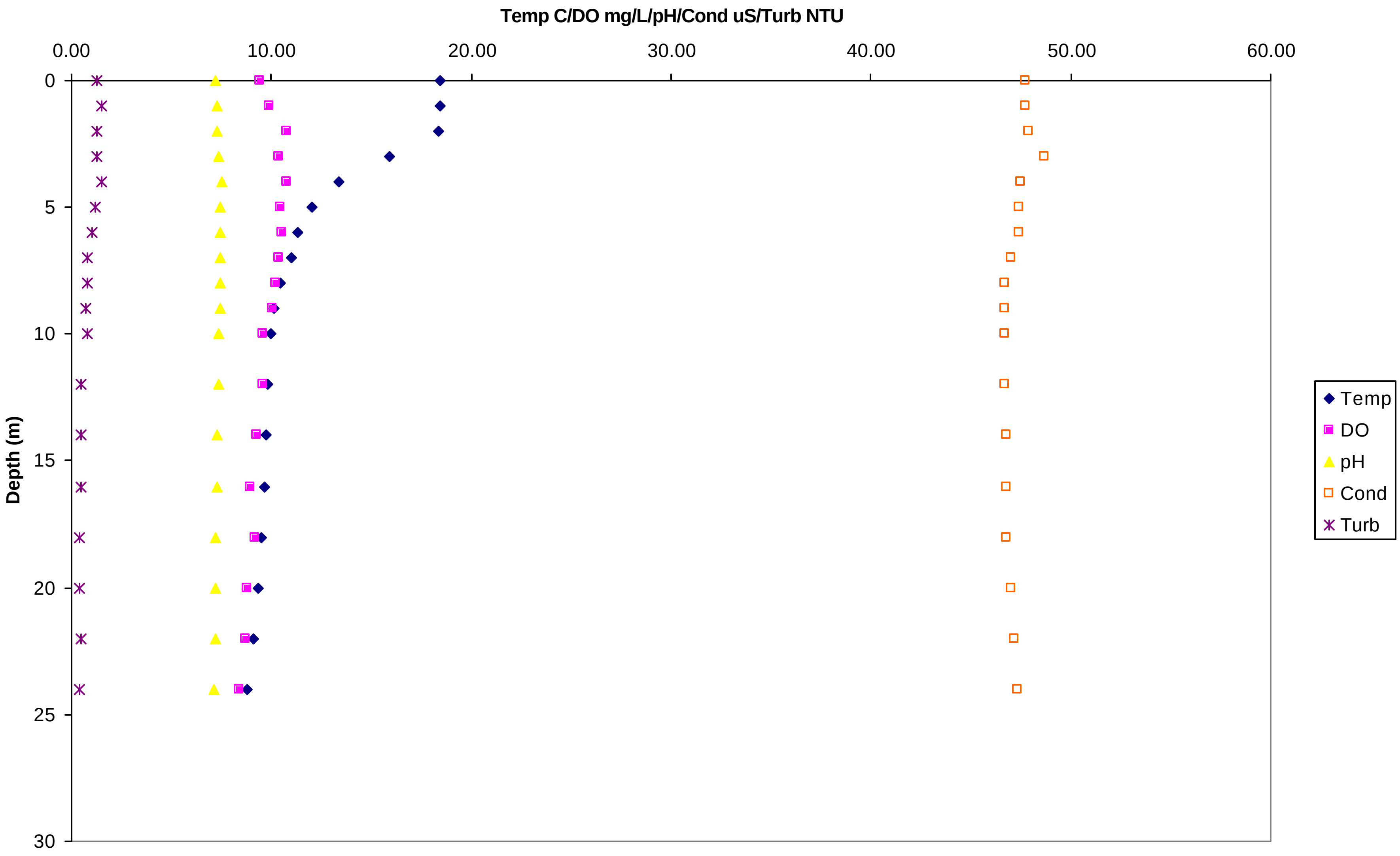

Figure 8 b. Flowery Branch Bay water quality profiles September 2001.

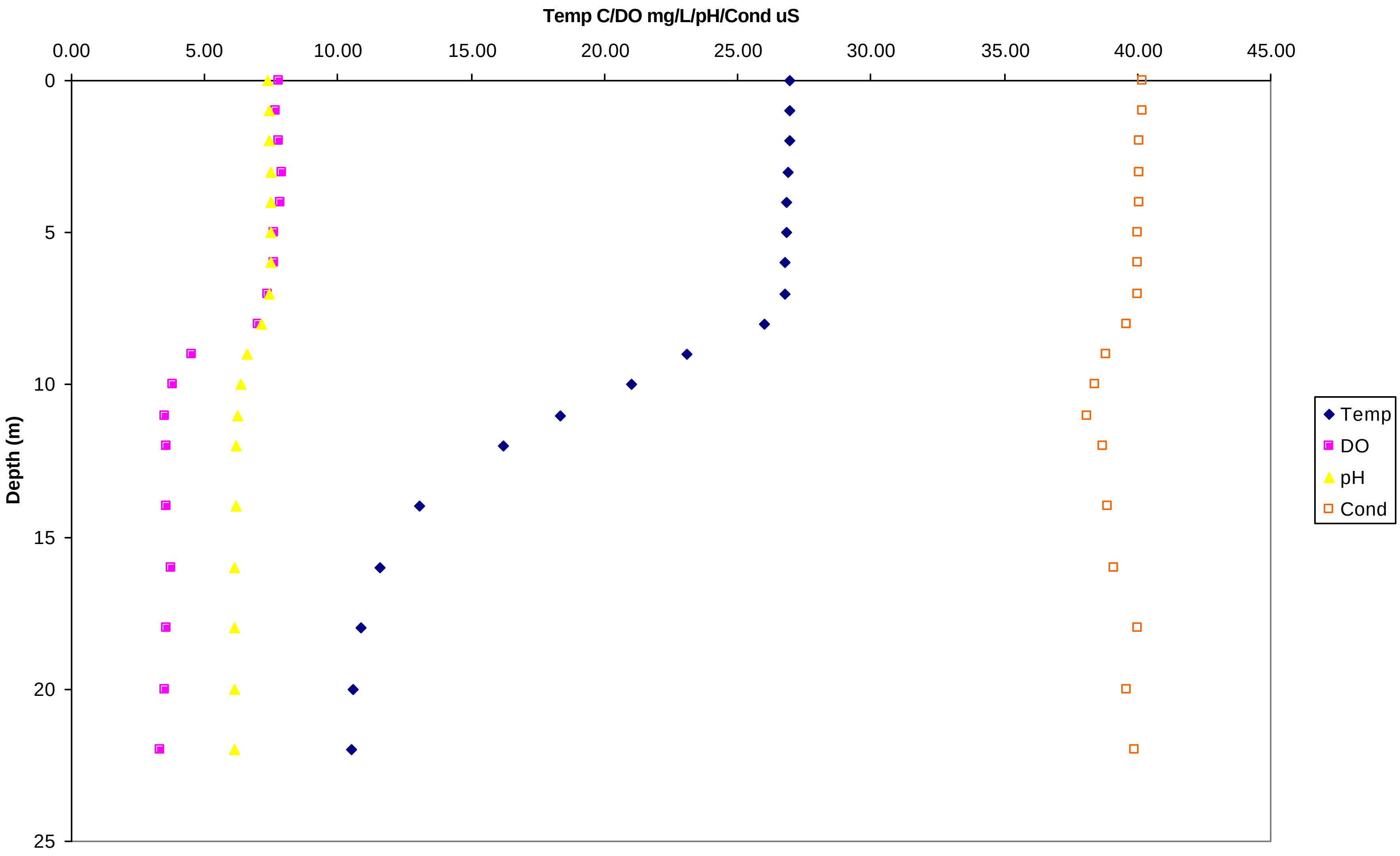

Figure 8 c. Flowery Branch Bay water quality profiles December 2001.

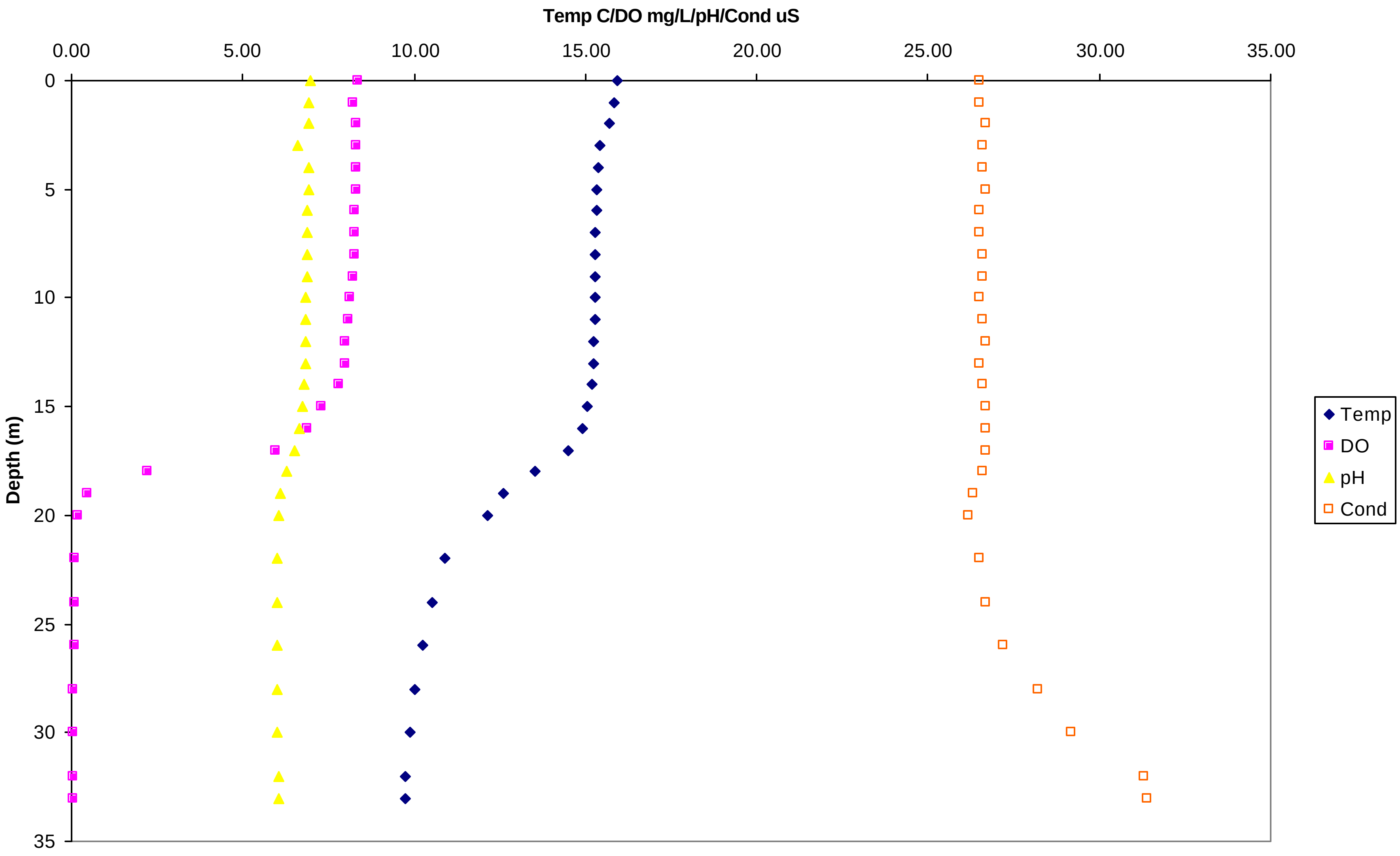

Figure 8 d. Flowery Branch Bay water quality profiles February 2002.

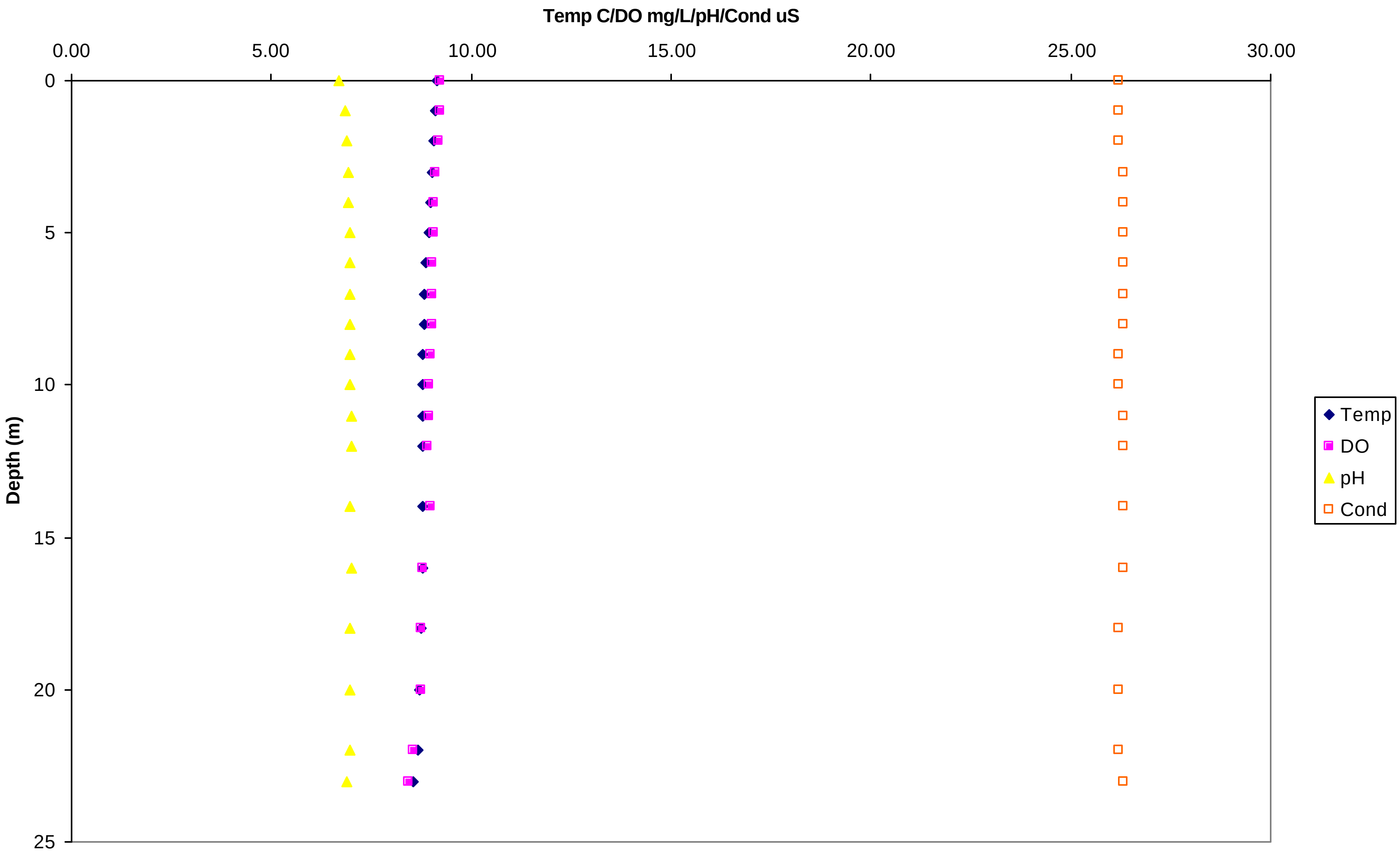

Figure 9. Flat Creek TIC and TOC during stratification.

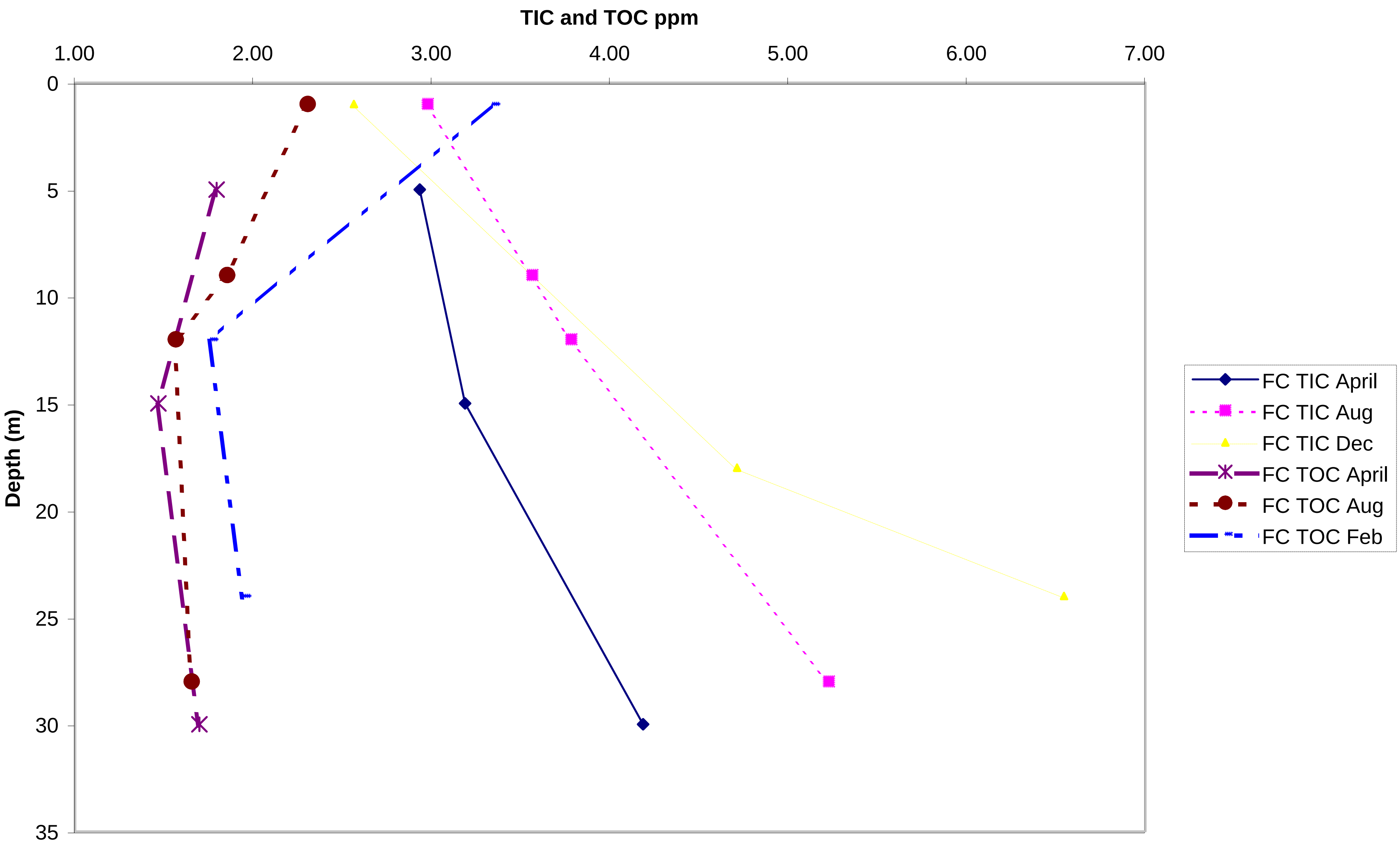

Table 1. Lake Lanier water chemical analyses four times in the annual cycle.

	Detection Range		.05-400		.05-600		.05-600		0.10-300		0.02-2.0		0.02-2.0
			Al ppm		**Ca ppm**		**Fe ppm**		**Mn ppm**		**NO2+NO3 ppm**		**NO2 ppm**
Date	**Station**	**Depth m**	**Filt**	**Unfilt**	**Filt**	**Unfilt**	**Filt**	**Unfilt**	**Filt**	**Unfilt**	**Filt**	**Unfilt**	**Unfilt**
4/12/2001	BB	5	0.00	0.00	2.25	1.90	0.00	0.00	0.00	0.00	0.33	0.33	0.00
		15	0.05	0.00	2.41	2.66	0.00	0.00	0.00	0.00	0.26	0.27	0.00
		32	0.02	0.05	2.05	2.35	0.01	0.04	0.03	0.05	0.38	0.45	0.00
	FC	5	0.00	0.03	2.63	2.67	0.00	0.01	0.00	0.00	0.39	0.41	0.00
		15	0.00	0.00	2.56	2.33	0.00	0.00	0.01	0.01	0.27	0.27	0.00
		30	0.00	0.08	3.18	3.10	0.00	0.12	0.07	0.09	0.71	0.78	0.00
	FBCh	5	0.00	0.01	2.61	2.60	0.00	0.00	0.00	0.00	0.25	0.26	0.00
		15	0.00	0.00	2.04	2.55	0.00	0.00	0.00	0.00	0.19	0.20	0.00
		30	0.00	0.00	2.57	2.59	0.00	0.00	0.00	0.00	0.43	0.39	0.00
	FBBay	5	0.00	0.06	2.73	2.57	0.00	0.01	0.00	0.00	0.21	0.22	0.00
		15	0.02	0.00	2.15	2.45	0.00	0.00	0.00	0.00	0.18	0.19	0.00
		30	0.00	0.00	2.74	2.63	0.00	0.00	0.00	0.01	0.34	0.37	0.00
	DH2O		0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00

	Detection Range		.05-400		.05-600		.05-600		0.10-300		0.02-2.0		0.02-2.0
			Al ppm		**Ca ppm**		**Fe ppm**		**Mn ppm**		**NO2+NO3 ppm**		**NO2 ppm**
Date	**Station**	**Depth m**	**Filt**	**Unfilt**	**Filt**	**Unfilt**	**Filt**	**Unfilt**	**Filt**	**Unfilt**	**Filt**	**Unfilt**	**Unfilt**
8/20-9/7/01	BB	1	0.06	---	2.35	---	0.01	---	0.00	---	---	0.12	0.00
		12	0.04	---	2.49	---	0.00	---	0.00	---	---	0.40	0.00
		20	0.06	---	2.44	---	0.00	---	0.08	---	---	0.52	0.00
		32	0.05	---	2.76	---	0.01	---	0.29	---	---	0.26	0.00
	FC	1	0.03	---	2.63	---	0.01	---	0.00	---	---	0.19	0.00
		9	0.03	---	2.68	---	0.00	---	0.00	---	---	0.22	0.00
		12	0.05	---	2.83	---	0.01	---	0.02	---	---	0.40	0.00
		28	0.09	---	3.35	---	0.01	---	0.34	---	---	0.31	0.01
	FBCh	1	0.05	---	2.41	---	0.01	---	0.00	---	---	0.11	0.00
	FBBay	1	0.03	---	2.51	---	0.00	---	0.00	---	---	0.10	0.00
		4	0.06	---	2.50	---	0.01	---	0.00	---	---	0.11	0.00
		8	0.06	---	2.38	---	0.01	---	0.00	---	---	0.10	0.00
		12	0.05	---	2.55	---	0.00	---	0.00	---	---	0.30	0.00
		20	0.06	---	2.49	---	0.01	---	0.02	---	---	0.35	0.00
	DH2O		0.05	---	0.06	---	0.00	---	0.00	---	---	0.00	0.00

Table 1. Lake Lanier water chemical analyses four times in the annual cycle.

	Detection Range		.05-400		.05-600		.05-600		0.10-300		0.02-2.0		0.02-2.0
			Al ppm		**Ca ppm**		**Fe ppm**		**Mn ppm**		**NO2+NO3 ppm**		**NO2 ppm**
Date	**Station**	**Depth m**	**Filt**	**Unfilt**	**Filt**	**Unfilt**	**Filt**	**Unfilt**	**Filt**	**Unfilt**	**Filt**	**Unfilt**	**Unfilt**
12/2/2001	BB	1	0.00	0.00	2.33	2.35	0.00	0.00	0.00	0.00		0.08	0.01
		18	0.00	0.00	2.17	2.40	0.00	0.01	0.06	0.08		0.00	0.01
		24	0.00	0.00	2.24	2.79	0.02	0.08	0.35	0.54		0.00	0.01
	FC	1	0.00	0.00	2.54	2.59	0.00	0.00	0.01	0.00		0.16	0.01
		18	0.00	0.00	4.38	4.67	0.00	0.01	0.02	0.02		0.84	0.02
		24	0.00	0.00	3.08	3.16	0.02	0.02	0.39	0.51		0.00	0.01
	FBCh	1	0.00	0.01	2.36	2.61	0.00	0.00	0.00	0.00		0.14	0.01
		18	0.00	0.00	2.33	2.37	0.00	0.00	0.01	0.00		0.12	0.01
		24	0.00	0.00	3.24	2.55	0.01	0.02	0.59	0.45		0.00	0.01
	FBBay	1	0.00	0.00	2.31	2.25	0.00	0.00	0.00	0.00		0.09	0.01
		18	0.00	0.00	2.50	2.38	0.00	0.00	0.01	0.00		0.16	0.01
		24	0.00	0.01	2.46	2.68	0.00	0.01	0.25	0.33		0.09	0.03

	Detection Range		.05-400		.05-600		.05-600		0.10-300		0.02-2.0		0.02-2.0
			Al ppm		**Ca ppm**		**Fe ppm**		**Mn ppm**		**NO2+NO3 ppm**		**NO2 ppm**
Date	**Station**	**Depth m**	**Filt**	**Unfilt**	**Filt**	**Unfilt**	**Filt**	**Unfilt**	**Filt**	**Unfilt**	**Filt**	**Unfilt**	**Unfilt**
2/9-2/15/02	BB	1	0.00	0.00	2.63	2.80	0.00	0.01	0.00	0.00		0.18	0.01
		15	0.01	0.00	2.53	2.52	0.00	0.01	0.00	0.00		0.12	0.02
		25	0.00	0.00	2.44	2.39	0.01	0.01	0.01	0.01		0.17	0.01
	FC	1	0.00	0.01	3.16	3.11	0.00	0.01	0.00	0.00		0.35	0.02
		4	0.00	0.00	2.90	2.96	0.00	0.01	0.00	0.00		0.37	0.01
		12	0.00	0.01	2.92	3.07	0.00	0.01	0.00	0.00		0.41	0.01
	FBCh	1	0.00	0.01	2.39	2.63	0.00	0.01	0.00	0.00		0.10	0.01
		15	0.00	0.00	2.33	2.67	0.00	0.01	0.00	0.00		0.11	0.01
		30	0.00	0.00	2.44	2.29	0.00	0.01	0.00	0.00		0.15	0.01
	FBBay	1	0.00	0.00	2.51	2.59	0.00	0.01	0.00	0.00		0.13	0.01
		10	0.00	0.00	2.43	2.62	0.00	0.01	0.00	0.00		0.09	0.01
		20	0.00	0.00	2.53	2.61	0.00	0.01	0.00	0.00		0.13	0.01

Table 1. Lake Lanier water chemica

	Detection Range		0.02-3.0		0.02-2.0	0.04-2.0	0.04-2.0	3.0-100					
			NH4 ppm		**TN ppm**	**TP ppm**	**PO4 ppm**	**SO4 ppm**	***Alk ppm**	**TIC ppm**		**TOC ppm**	
Date	**Station**	**Depth m**	**Filt**	**Unfilt**	**Unfilt**	**Unfilt**	**Unfilt**	**Unfilt**	**Unfilt**	**Filt**	**Unfilt**	**Filt**	**Unfilt**
4/12/2001	BB	5	0.05	0.07	0.60	0.00	0.00	1.56	24.00	2.72	2.88	1.85	1.82
		15	0.12	0.12	0.50	0.00	0.00	2.50	22.78	3.40	3.35	1.64	1.62
		32	0.17	0.11	0.65	0.00	0.00	2.80	21.87	3.37	3.77	1.44	1.48
	FC	5	0.03	0.06	0.55	0.00	0.00	3.51	21.32	2.79	2.93	1.79	1.79
		15	0.11	0.12	0.53	0.00	0.00	2.85	27.27	3.17	3.18	1.53	1.47
		30	0.08	0.01	0.90	0.00	0.00	5.48	25.03	4.22	4.18	1.67	1.70
	FBCh	5	0.05	0.07	0.44	0.00	0.00	2.83	22.35	2.76	2.92	1.62	1.70
		15	0.31	0.09	0.40	0.00	0.00	2.40	25.33	3.38	3.46	1.89	1.56
		30	0.06	0.03	0.52	0.00	0.00	2.79	23.45	3.80	3.79	1.83	1.51
	FBBay	5	0.05	0.06	0.41	0.00	0.00	2.85	24.30	2.84	2.91	1.97	1.70
		15	0.09	0.09	0.40	0.00	0.00	3.93	19.43	3.38	3.47	1.56	1.58
		30	0.06	0.03	0.48	0.00	0.00	2.93	23.57	3.71	3.84	1.94	1.47
	DH2O		0.00	0.00	0.01	0.00	0.00	0.14	12.26	0.14	0.25	0.25	0.26

	Detection Range		0.02-3.0		0.02-2.0	0.04-2.0	0.04-2.0	3.0-100						
			NH4 ppm		**TN ppm**	**TP ppm**	**PO4 ppm**	**SO4 ppm**	***Alk ppm**		**TIC ppm**		**TOC ppm**	
Date	**Station**	**Depth m**	**Filt**	**Unfilt**	**Unfilt**	**Unfilt**	**Unfilt**	**Unfilt**	**Unfilt**	**Filt**	**Filt**	**Unfilt**	**Filt**	**Unfilt**
8/20-9/7/01	BB	1	---	0.01	0.27	0.01	0.03	3.87	0.00		---	2.80	---	2.05
		12	---	0.10	0.60	0.01	0.03	3.98	0.32		---	3.44	---	1.46
		20	---	0.07	0.64	0.01	0.02	1.19	0.00	0.00	---	3.05	---	1.36
		32	---	0.22	0.50	0.01	0.03	2.83	6.69		---	4.56	---	1.43
	FC	1	---	0.01	0.38	0.01	0.04	5.16	0.00		---	2.98	---	2.30
		9	---	0.10	0.54	0.01	0.03	5.14	0.00		---	3.56	---	1.85
		12	---	0.07	0.56	0.01	0.04	2.71	0.00		---	3.78	---	1.56
		28	---	0.24	0.63	0.02	0.02	3.65	0.00		---	5.23	---	1.65
	FBCh	1	---	0.01	0.27	0.01	0.02	3.35	0.00		---	3.05	---	2.25
	FBBay	1	---	0.05	0.26	0.01	0.02	2.86	0.00	0.00	---	2.88	---	2.14
		4	---	0.01	0.28	0.01	0.02	3.87		0.00	---	3.01	---	2.17
		8	---	0.01	0.25	0.01	0.02	3.99	0.00		---	3.10	---	2.28
		12	---	0.05	0.46	0.01	0.02	4.76	16.26	0.00	---	3.48	---	1.79
		20	---	0.01	0.48	0.01	0.24	3.47	0.00		---	3.76	---	1.42
	DH2O		---	0.01	0.00	0.01	0.02	0.89	0.00		---	0.26	---	0.26

Table 1. Lake Lanier water chemica

	Detection Range			0.02-3.0	0.02-2.0	0.04-2.0	0.04-2.0	3.0-100					
			NH4 ppm		TN ppm	TP ppm	PO4 ppm	SO4 ppm	*Alk ppm	TIC ppm		TOC ppm	
Date	**Station**	**Depth m**	**Filt**	**Unfilt**	**Unfilt**	**Unfilt**	**Unfilt**	**Unfilt**	**Unfilt**	**Filt**	**Unfilt**	**Filt**	**Unfilt**
12/2/2001	BB	1		0.08	0.41	0.00	0.02	2.85	0.00		3.18		2.04
		18		0.42	0.44	0.00	0.02	0.41	0.00		3.86		1.55
		24		0.93	0.98	0.00	0.02	0.00	0.00		5.88		1.67
	FC	1		0.10	0.41	0.00	0.02	2.32	0.00	2.98	2.56	1.86	2.11
		18		0.37	1.39	0.00	0.03	8.25	0.00	3.80	4.71	1.79	2.00
		24		0.72	0.74	0.00	0.02	1.16	0.00	5.70	6.54	1.37	1.47
	FBCh	1		0.05	0.40	0.00	0.02	3.15	0.00	2.93	3.22	2.26	2.19
		18		0.18	0.41	0.00	0.02	2.19	0.00		3.56		1.71
		24		0.56	0.57	0.00	0.02	0.76	0.00	4.07	5.11	1.53	1.73
	FBBay	1		0.07	0.28	0.00	0.02	1.22	0.00	2.91	3.17	2.22	2.15
		18		0.10	0.50	0.00	0.02	2.38	0.00	2.60	3.68	1.48	1.78
		24		0.29	0.47	0.00	0.02	2.67	0.00	3.76	4.76	1.77	1.37

	Detection Range			0.02-3.0	0.02-2.0	0.04-2.0	0.04-2.0	3.0-100						
			NH4 ppm		TN ppm	TP ppm	PO4 ppm	SO4 ppm	*Alk ppm	**TIC ppm		**TOC ppm		
Date	**Station**	**Depth m**	**Filt**	**Unfilt**	**Unfilt**	**Unfilt**	**Unfilt**	**Unfilt**	**Unfilt**	**Filt**	**Unfilt**	**Filt**	**Unfilt**	
2/9-2/15/02	BB	1		0.19	0.56	0.00	0.02	0.59	0.00					
		15		0.20	0.53	0.00	0.02	0.60	0.00					
		25		0.20	0.56	0.00	0.02	0.55	0.00					
	FC	1		0.18	0.68	0.00	0.02	2.08	0.00	3.24	3.27	1.78	3.34	1
		4		0.19	0.77	0.00	0.02	2.33	0.00	3.57	3.49	1.85	1.76	12
		12		0.19	0.86	0.00	0.03	2.40	0.00	3.81	3.87	2.05	1.94	24
	FBCh	1		0.14	0.37	0.00	0.04	1.66	0.00					
		15		0.16	0.40	0.00	0.02	0.55	0.00					
		30		0.18	0.41	0.00	0.02	0.35	0.00					
	FBBay	1		0.15	0.43	0.00	0.04	0.55	0.00					
		10		0.13	0.38	0.00	0.07	0.55	0.00					
		20		0.13	0.41	0.00	0.02	1.10	0.00					

* Alk is not accurate below 40 ppm; don't have exact detection limits--6.6 is below limit

** TIC-TOC samples collected 2/1/02 at FC at depths of 1m, 12m and 24 m

References

APHA. 1999. Standard methods for examination of water and wastewater. 19th ed. A. D. Eaton, L. C. Clesceri and A. E. Greenberg (eds.) American Public Health Association, Washington, DC.

Goldman, C. R. and A. J. Horne. 1983. *Limnology*. McGraw-Hill Book Company, New York, NY.

Gustafsson, J.P. 1999. WinHumicV For Win95/98/NT. http://amov.ce.kth.se/people/gustafjp/winhumicv.htm.

Gustafsson, J. P. 2001. Modeling the acid-base properties and metal complexation of humic substances with the Stockholm Humic Model. Journal of Colloid and Interface Science 244: 102-112.

Hutchinson, G. E. 1957. *A Treatise on Limnology, Volume 1*. John Wiley & Sons, New York.

Tipping, E. and Hurley, M.A. 1992. A unifying model of cation binding by humic substances. Geochim. Cosmochim. Acta 56:3627-3641.

Wetzel, Robert G. 1983. *Limnology*. W.B. Saunders Company, Philadelphia, PA.

Impacts of Flow Regime on Ecosystem Processes in the Apalachicola-Chattahoochee-Flint River Basin

Basic Information

Title:	Impacts of Flow Regime on Ecosystem Processes in the Apalachicola-Chattahoochee-Flint River Basin
Project Number:	2001GA4261B
Start Date:	3/1/2001
End Date:	2/28/2002
Funding Source:	104B
Congressional District:	11
Research Category:	Biological Sciences
Focus Category:	Ecology, Management and Planning, Nutrients
Descriptors:	Ecosystem processes; basin-wide analysis for water management; solute transport; flow regime; Apalachicola-Chattahoochee-Flint River Basin
Principal Investigators:	Judith Meyer

Publication

FINAL REPORT

Impacts of Flow Regime on Ecosystem Processes in the Apalachicola-Chattahoochee-Flint River Basin.

Cathy Gibson and Judy Meyer
Institute of Ecology
University of Georgia
Athens, GA

Funded by: Georgia Water Resources Institute
Georgia Institute of Technology
Atlanta, GA

May 20, 2002

Problem and Research Objectives

The quantity and timing of river flow is critical to the ecological integrity of river systems (Poff et al. 1997). Flow is strongly correlated with physical and chemical characteristics of the river such as channel shape, water temperature and velocity, and habitat type and complexity (Jowett and Duncan 1990, Poff et al. 1997). Five main components of the flow regime impact ecological processes: magnitude of discharge at critical time periods, frequency of the various discharge magnitudes, duration of time associated with a particular discharge, timing or predictability of discharge events of particular magnitudes, and the rate of change of hydrologic conditions (Richter et al. 1996, Poff et al. 1997). These five components of the flow regime influence the ecological dynamics of river systems directly and indirectly by affecting water quality, energy sources, physical habitat, and biotic interactions (Karr 1991, Poff et al. 1997).

Although there are many different types of hydrologic and channel alterations that result in changes to the flow regime, dams are one of the most conspicuous and prevalent forms of flow alteration on large and some smaller rivers and streams. In the contiguous United States, there are only 42 rivers with greater than 200 river kilometers unregulated by major dams (Benke 1990). Though there have been a number of studies of the impacts of dams on channel morphology (Ligon et al. 1995), fish (Moyle et al. 1998), habitat availability (Bogan 1993), and riparian species survival and recruitment (Rood et al. 1995), less is known about the impact of dams and flow regime on basic ecosystem processes such as nutrient uptake and metabolism, especially in larger rivers. In many cases, these ecosystem processes are directly linked to the ecosystem services (e.g. water supply, pollution control, and fisheries) expected from the river system.

We are studying the relationship between flow and nutrient uptake and metabolism on the Chattahoochee River below Atlanta. The fixation of energy through primary production and the subsequent release through respiration are primary ecosystem functions, and the addition or loss of energy to the system can influence energy flows in downstream systems. In order to determine net addition or loss of energy to the system, net daily metabolism can be calculated. Net daily metabolism is defined as the difference between gross primary productivity and total system respiration (Bott 1996). Metabolism has been shown to vary with high stream discharge as a result of shifts in primary production (Uehlinger and Naegeli 1998). However, relationships between net daily metabolism and low flow conditions are uncertain, particularly in large river systems.

The uptake and processing of nutrients by rivers is essential to maintaining downstream and instream water quality. In unregulated rivers, the downstream ecosystems that could be affected by high nutrient loadings are typically estuaries. However, in regulated rivers, there are typically a series of reservoirs that are connected by sections of flowing water. This is the situation on the Chattahoochee River. In addition, the flowing river section between Lake Lanier and West Point Lake receives approximately 220 million gallons a day of wastewater treatment plant effluent (Frick et al. 1996). The retention and transformation of the nutrients associated with these inputs is essential to maintaining water quality in this section of the river and in West Point Lake. Nutrient uptake length is the length of stream traveled by the average nutrient molecule in the water column before being taken up by biota (Stream Solute Workshop 1990). Nutrient uptake lengths in small streams is related to discharge (Stream Solute Workshop 1990). Uptake lengths in streams receiving wastewater treatment plant effluent are typically much longer than uptake lengths in streams with similar discharge but no wastewater inputs (Marti et al. In press). However, it is uncertain how nutrient uptake lengths vary with low flows in large rivers.

Our objectives were to determine how net ecosystem metabolism and nutrient uptake lengths vary with discharge under baseflow conditions in the Chattahoochee River below Atlanta. In addition, we wanted to determine the importance other factors that may influence metabolism and nutrient uptake such as temperature, total suspended solids, light, dissolved organic carbon, water column chlorophyll a concentrations, and nutrient concentrations. We hope that these analyses will help to give a better understanding of how flow regime influences ecosystem processes in a regulated river.

Methodology

We examined the relationship between flow and ecosystem function through measures of nutrient uptake length and net daily metabolism on the Chattahoochee River below Atlanta, Georgia. We used the USGS real time gauging station at Fairburn, GA (station # 02337170) and at State Road 280 near Atlanta (station # 02336490) to obtain discharge every 15 minutes. We sampled only during periods of stable flow. Because of hydropeaking during the week, sampling was conducted during weekend stable flows.

Nutrient uptake length was measured using the methods described by Webster and Ehrman (1996) and Stream Solute Workshop (1990). We used effluent of wastewater treatment plants as the source of the conservative tracer (chloride, Cl^-), soluble reactive phosphorus (SRP) and ammonium (NH_4^+) (Marti et al. in press). We sampled NH_4^+, SRP, and Cl^- concentration at one site above Atlanta, one site below the majority of the major municipal discharges from Atlanta, and thirteen sites below a small municipal wastewater treatment plant discharge (Camp Creek WWTP) on ten different days during summer 2001. The most upstream site was the Highway 166 crossing; Camp Creek WWTP is 3.68 km downstream, and the next thirteen sites were 0.66, 1.51, 3.01, 4.81, 5.78, 6.73, 9.93, 12.43, 14.51, 16.81, 18.47, and 20.67 km downstream respectively. The site above Atlanta was used to correct for background concentrations. All samples were taken during baseflow, filtered in the field with Gelman A/E glass fiber filters, and stored on ice for transport to the lab. Samples were then frozen until nutrient analysis could be performed. SRP concentration was determined using the colorimetric methods of Wetzel and Likens (1992). NH_4^+ concentration was determined using the fluorometric methods of Holmes et al. (1999). Chloride was determined with an ion chromatograph (UGA Soil Ecology Lab). Nutrient uptake length is the inverse of the slope of the regression line between distance (km) and ln (nutrient : chloride ratio) after correcting for background concentrations (Webster and Ehrman 1996). In cases where the SRP: chloride ratio increased downstream we assumed that there was no uptake, since this implies a net release of SRP from the sediments. We also assumed no uptake when the NH_4^+:chloride ratio increased downstream.

We determined net daily metabolism for a 650 m reach just below Highway 166 using the upstream-downstream diurnal dissolved oxygen change technique (Marzolf et al. 1994, Young and Huryn 1998). We determined travel time for a variety of discharges by floating oranges from the upstream to downstream station. Travel time was estimated from the median orange. We continuously measured dissolved oxygen and temperature using a YSI dissolved oxygen probe for a 40-hour period. Oxygen concentrations were corrected for diffusion using the energy dissipation model (APHA 1992). Channel slope for this model was determined by using 1:24,000 USGS topographic maps and determining the average slope for the river between Atlanta and West Point Lake.

Principal Findings and Significance

The Chattahoochee River at Highway 166 is a highly heterotrophic system. SRP uptake length for this 46 km reach of the river ranged from no uptake at all to 143 km, and no NH_4^+ uptake occurred (Table 1). Highly negative net ecosystem metabolism, low P/R ratios, and high rates of respiration demonstrate that this system is fueled by allochthonous carbon and that a large amount of organic matter processing is occurring. In contrast, long uptake lengths and evidence of a lack of uptake suggests that there is little assimilation of the nutrients from the wastewater treatment plants.

Nutrient Uptake

Uptake of ammonium was never observed, an uptake of soluble reactive phosphorus only occurred on one date in summer 2001 (Table 1). The other four dates had no measurable SRP uptake. The uptake length for the one date was 143 km. The distance between the Highway 166 crossing and Franklin, GA (the site of the river/reservoir transition) is 76 km. Therefore, the average phosphorus molecule will have not been assimilated prior to reaching West Point Lake. This means that much of the phosphorus and ammonium from Atlanta's municipal wastewater facilities is transported to West Point Lake. This high nutrient loading could lead to eutrophication of the reservoir and algal blooms. In addition, these long uptake lengths indicate that the river is no longer capable of providing the service of nutrient assimilation to downstream water users.

SRP uptake length (143 km) in this study was almost two orders of magnitude longer than those found in a Mediterranean river with similar discharge, but not receiving any waste water treatment plant effluent (1.5 km) (Butturini and Sabater 1998). Third order Mediterranean streams receiving wastewater treatment plant effluent also had much longer SRP uptake lengths than non-polluted streams with similar discharge (Marti et al.

in press). Similar to our study, phosphorus concentrations in the Mediterranean streams receiving effluent did not consistently decline downstream in 33% of the cases (Marti et al. in press). In our study, the instances of no measurable uptake were associated with an increase in phosphorus concentrations downstream with little change in chloride concentration. This increase in phosphorus concentrations could be caused by the flux of phosphorus out of the sediments (Reddy et al. 1996).

Net Ecosystem Metabolism

In contrast to nutrient uptake, organic matter processing rates seem fairly high. P/R ratios ranged from 0.01 to 0.7 indicating that this is a highly variable, but predominately heterotrophic system, which is dominated by allochthonous inputs. Gross primary production ranged from <0.1 to 3.3 g O_2 m^{-2} day^{-1}. GPP was lower than that of a similar sized river, River Thur, that also receives WWTP effluent in the pre-alpine region of Switzerland (Figure 1) (Uehlinger 2000). This difference in GPP may be partially attributable to the substrate composition of the 2 rivers. The study reach on the Chattahoochee was sandy bottomed and typically unstable, while the while the River Thur bed sediments are mainly gravel (Uehlinger 2000). Respiration was also variable and ranged from 3.04 to 12 g O_2 m^{-2} day^{-1}. These variations are similar to the variations seen in several streams and rivers throughout the U.S. and in Switzerland (Figure 2) (Meyer and Edwards 1990, Paul 1999, Uehlinger 2000, Mulholland et al. 2001). These P/R ratios are similar to P/R ratios (0.02 to 0.4) found in the Ogeechee River, which is dominated by allochthonous organic matter inputs from the floodplain (Meyer and Edwards 1990).

Neither GPP nor R were correlated with discharge in the Chattahoochee River. In two pre-alpine rivers in Switzerland, GPP dramatically declined following bed-moving spates and took several days to weeks to recover (Uehlinger 2000). Respiration was more resistant in these rivers, not declining as dramatically after bed-moving spates, but recovering more slowly (Uehlinger 2000). As a result of hydropeaking associated with power generation from upstream dams and the fine bed sediments, the Chattahoochee River below Atlanta has bed-moving spates almost daily during the week. Stable flows that are typically present on weekends, appear to not be long enough to allow a significant build-up of periphyton. Hence, GPP in the Chattahoochee River is al the lower end of the range observed in the Swiss rivers (Figure 1).

Multiple regression analysis indicated that 71% of the variation in GPP could be explained by a model that includes temperature, total solar radiation, and chlorphlyll *a* (Table 3). There was not a significant model for total ecosystem respiration or heterotrophic respiration. However, a model including total phosphorus, DOC, and total radiation explained 62% of the variation in NEP (Table 3).

Conclusions

Upstream dam operations exert a strong influence on ecosystem function in the Chattahoochee River below Atlanta. Daily discharge fluctuations appear to function as spates in unregulated systems, reducing GPP with inadequate time for system recovery between spates. Ecosystem respiration appears to be less affected by discharge fluctuations, and the ecosystem is consistently heterotrophic. There is little evidence for uptake of phosphorus or ammonium in the river. Hence these nutrients entering the river from wastewater treatment plants in Atlanta are being transported downstream to West Point Lake.

Literature Cited

APHA, AWWA, and WEF. 1992. Standard Methods for the Examination of Water and Wastewater. 18th ed. American Public Health Association, Washington DC.

Benke, A.C. 1990. A perspecitve on America's vanishing streams. Journal of North American Benthological Society 9: 77-88.

Bogan, A.E. 1993. Freshwater bivalve extinctions (Mollusca: Unionida): a search for causes. American Zoologist 33: 599-609.

Bott, T.L. 1996. Primary productivity and community respiration. In. *Methods in Stream Ecology* F.R. Hauer and G.A. Lamberti (editors). Academic Press, San Diego, CA. pp. 533-556.

Butturini and F. Sabateur 1998 Ammonium and phosphate retention in a Mediterranean stream: hydrological versus temperature control. Canadian Journal of Fisheries and Aquatic Sciences 55: 1938-1945.

Frick, E.A., G.R. Buell, and E.E. Hopkins. 1996. Nutrient sources and analysis of nutrient-water-quality data, Apalachicola-Chattahoochee-Flint River Basin, Georgia, Alabama, and Florida, 1972-1990. U.S. Geological Survey Water-Resources Investigations Report 96-4101. 120 pages.

Holmes, R.M., A. Aminot, R. Kerouel, B.A. Hooker, and B.J. Peterson. 1999. A simple and precise method for measuring ammonium in marine and freshwater ecosystems. Canadian Journal of Fisheries and Aquatic Sciences 56: 1801-1808.

Jowett, I.G. and M.J. Duncan. 1990. Flow variability in New Zealand rivers and its relationship to in-stream habitat and biota. New Zealand Journal of Marine and Freshwater Research 24: 305-317.

Karr, J.R. 1991. Biological integrity: a long-neglected aspect of water resource management. Ecological Applications 1: 66-84.

Ligon, F.K., W.E. Dietrich, and W.J. Trush. 1995. Downstream ecological effects of dams: A geomorphic perspective. BioScience 45: 183-192.

Marti, E., J. Aumatell, L. Gode, M. Poch, and F. Sabateur. In press. Effects of wastewater treatment plant inputs on stream nutrient retention. Water Resources Research.

Marzolf, E.R., P.J. Mullholland, and A.D. Steinman.1994. Improvements to the diurnal upstream-downstream dissolved oxygen change technique for determining whole-stream metabolism in small streams. Canadian Journal of Fisheries and Aquatic Sciences 51: 1591-1599.

Meyer, J.L. and R.T. Edwards. 1990. Ecosystem metabolism and turnover of organic carbon along a blackwater river continuum. Ecology 71: 668-677.

Moyle, P.B., M.P. Marchetti, J. Baldridge, and T.L. Taylor. 1998. Fish health and diversity: justifying flows for a California stream. Fisheries 25: 6-15.

Mulholland, P.J., C.S. Fellows, J.L. Tank, N.B. Grimm, J.R. Webster, S.K. Hamilton, E. Marti, L. Ashkenas, W.B. Bowden, W.K. Dodds, W.H. McDowell, M.J. Paul, and B.J. Peterson. 2001. Inter-biome comparison of factors controlling stream metabolism. Freshwater Biology 46: 1503-1517.

Newbold, J.D., J.W. Elwood, R.V. O'Neill, and A.L. Sheldon. 1983. Phosphorus dynamics in a woodland stream ecosystem: a study of nutrient spiralling. Ecology 64: 1249-1265.

Paul, M.J. 1999. Stream ecosystem function along a land-use gradient. PhD. Dissertation, University of Georgia, Athens GA. 193 pgs.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, J.C. Stromberg. 1997. The natural flow regime; a paradigm for river conservation and restoration. BioScience 47: 769-784.

Reddy, K.R., E. Flaig, L.J. Scinto, O. Diaz, and T.A. DeBusk. 1996. Phosphorus assimilation in a stream system of the Lake Okeechobee Basin. Water Resources Bulletin 32: 901-915

Richter, B.D., J.V. Baumgartner, J. Powell, and D.P. Braun. 1996. A method for assessing hydrologic alteration within ecosystems. Conservation Biology 10: 1163-1174.

Rood, S.B., J.M. Mahoney, D.E. Reid, and L. Zilm. 1995. Instream flows and the decline of riparian cottonwoods along the St. Mary River, Alberta. Canadian Journal of Botany 73: 1250-1260.

Stream Solute Workshop. 1990. Concepts and methods for assessing solute dynamics in stream ecosystems. Journal of the North American Benthological Society 9: 95-119.

Uehlinger, U. and M.W. Naegeli. 1998. Ecosystem metabolism, disturbance, and stability in a prealpine gravel bed river. Journal of the North American Benthological Society 17: 165-178.

Uehlinger, U. 2000. Resistance and resilience of ecosystem metabolism in a flood-prone river system. Freshwater Biology 45: 319-332.

Young, R.G. and A.D. Huryn. 1998. Comment: Improvements to the diurnal upstream-downstream dissolved oxygen change technique for determining whole-stream metabolism in small streams. Canadian Journal of Fisheries and Aquatic Sciences 55: 1784-1785.

Webster, J.R. and T.P. Ehrman. 1996. Solute dynamics. In *Methods in Stream Ecology* F.R. Hauer and G.A. Lamberti (editors). Academic Press, San Diego, CA. pp. 145-160.

Wetzel, R.G. and G.E. Likens. 1992. Limnological Analyses. Springer-Verlag, New York, NY.

Table 1: Soluble reactive phosphorus and ammonium uptake lengths on 5 dates in the Chattahoochee River, downstream of Atlanta, GA.

Date	Discharge ($m^3 s^{-1}$)	Initial SRP Conc (ug L^{-1})	SRP Uptake length (km)	Initial NH_4^+ Concentration (ug L^{-1})	NH_4^+ Uptake Length (km)
7/6/2001	28.9	71	No uptake	N/A	N/A
7/13/2001	34.0	40	No uptake	43	No uptake
7/20/2001	45.9	37	No uptake	149	No uptake
8/14/2001	73.2	31	143	606	No uptake
8/17/2001	54.8	52	No uptake	253	No uptake

Table 2: Gross primary production, respiration, and net ecosystem production for ten days for the Chattahoochee River below Atlanta, GA.

Date	Discharge ($m^3\ s^{-1}$)	Gross Primary Production ($g\ O_2\ m^{-2}\ day^{-1}$)	Respiration ($g\ O_2\ m^{-2}\ day^{-1}$)	Net Ecosystem Production ($g\ O_2\ m^{-2}\ day^{-1}$)
5/5/2001	27.6	1.03	6.64	-5.61
7/14/2001	34.0	0.86	2.87	-2.01
8/14/2001	73.2	1.2	4.55	-4.35
8/15/2001	54.8	0.1	4.53	-4.43
8/25/2001	39.9	0.1	8.41	-8.31
8/26/2001	38.1	0.1	9.74	-9.64
9/15/2001	32.2	0.55	5.79	-5.24
9/16/2001	32.4	0.99	5.97	-4.98
10/20/2001	31.9	3.29	4.26	-0.97
10/21/2001	32.8	3.13	5.29	-2.16

Table 3: Results of stepwise multiple regression analysis for rates of gross primary production (GPP), and net ecosystem production (NEP) (n=16 for GPP, n=14 for NEP).

Dependent Variable	Independent Variable	Parameter Estimate (SE)	r^2	Prob > F
GPP	Intercept	4.66 (1.43)		.007
	Temperature	-0.27 (.057)	.44	.0004
	Total Radiation	.0001 (.00003)	.18	.02
	Chlorophyll a	0.14 (.06)	.1	.03
	Full Model		.71	.002
NEP	Intercept	-32.6 (8.9)		.005
	DOC	10.72 (3.2)	.29	.008
	Total radiation	.0002	.19	.047
	Total phosphorus	-.042 (.021)	.14	.081
	Full Model		.62	.018

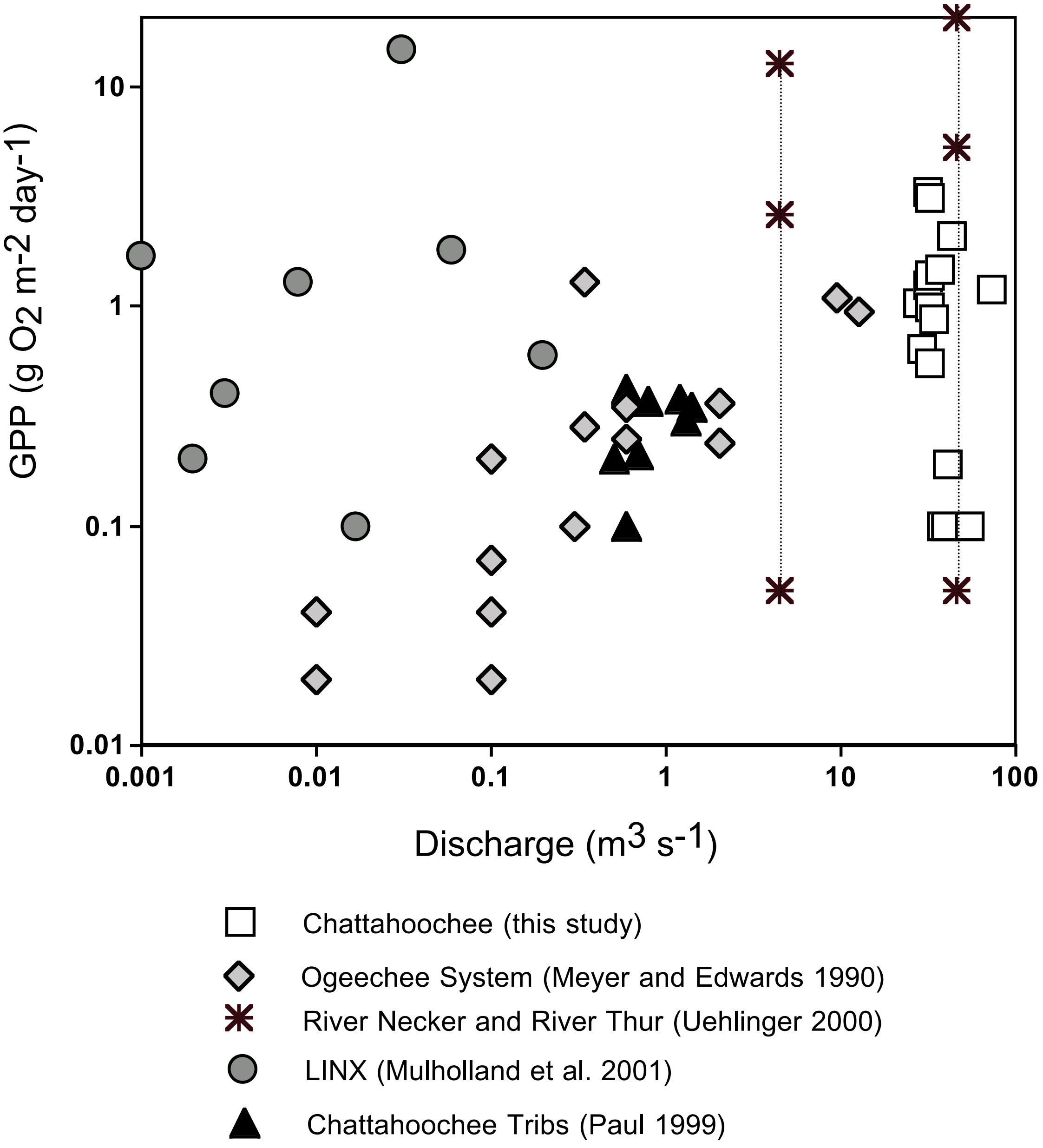

Figure 1: Comparison of gross primary production (GPP) rates in streams of a variety of different sizes. Rates for River Necker and River Thur are minimum, mean, and maximum of two years of continuous measurements. GPP rates from this study are below the mean GPP in a similar sized river in pre-alpine Switzerland (River Thur).

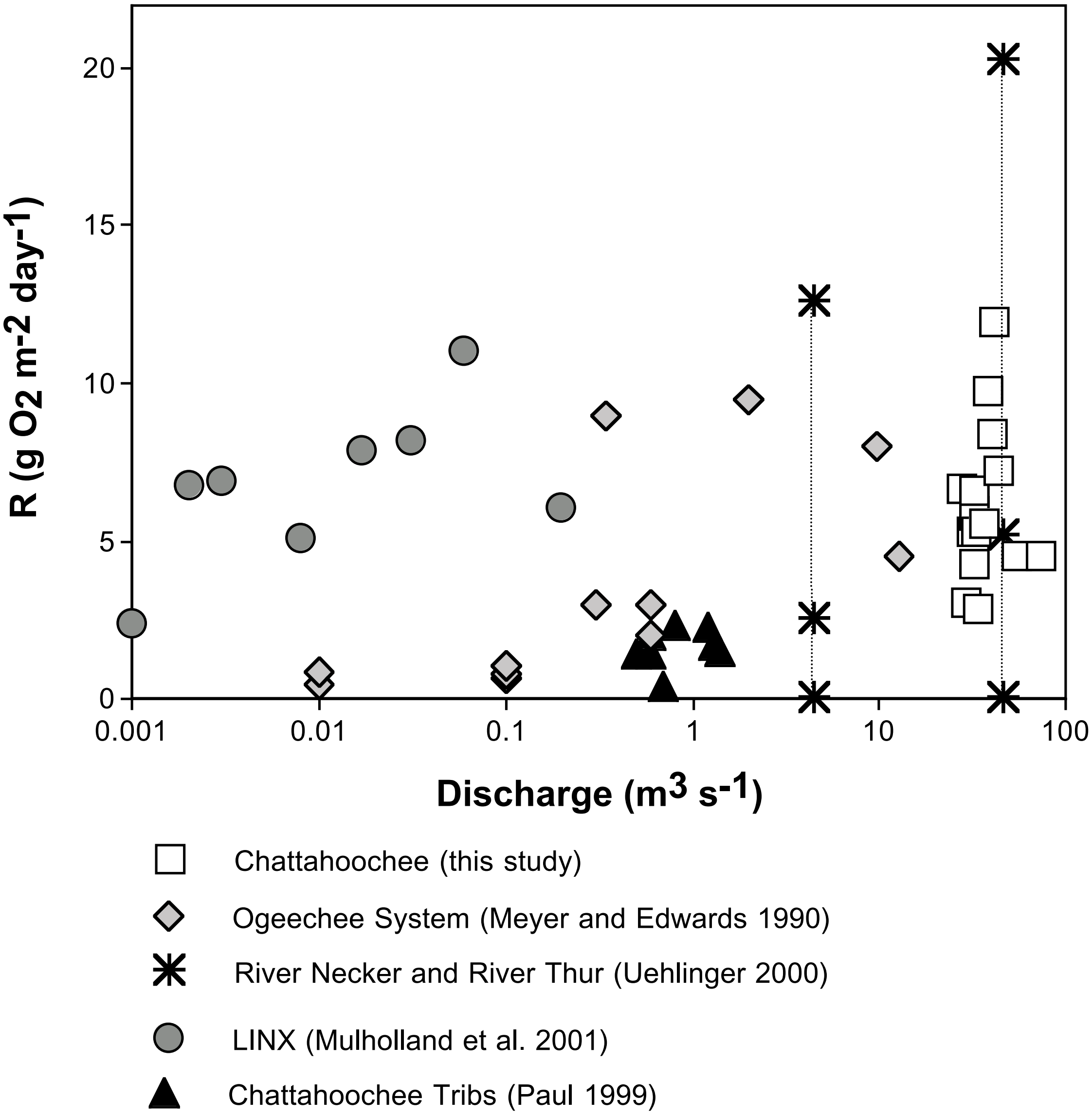

Figure 2: : Comparison of respiration (R) rates in streams of a variety of different sizes. Rates for River Necker and River Thur are minimum, mean, and maximum of two years of continuous measurements. R rates from this study are similar to those measured in a similar sized river in pre-alpine Switzerland (River Thur).

Agricultural Drought Assessment and Forecasting for the Southeastern United States

Basic Information

Title:	Agricultural Drought Assessment and Forecasting for the Southeastern United States
Project Number:	2001GA4701B
Start Date:	3/1/2001
End Date:	2/28/2002
Funding Source:	104B
Congressional District:	5th
Research Category:	Climate and Hydrologic Processes
Focus Category:	Drought, Management and Planning, Agriculture
Descriptors:	Basinwide planning; Decision support systems; Irrigation assessment; Technical analysis for policy makers
Principal Investigators:	Aris Peter Georgakakos, Kelly Brumbelow

Publication

1. Brumbelow, K., and A. Georgakakos. Agricultural drought assessment for the southern United States. Eos Trans. Amer. Geophys. Union, 83(47), Fall Meet. Suppl., Abstract H12G-05, 2002.
2. Brumbelow, K., and A. Georgakakos. Assessment of a no-irrigation compensation policy in the humid southeastern U.S., J. Water Res. Plan. Manag. (in preparation)

Agricultural Drought Assessment for the Southeastern United States

Kelly Brumbelow and Aris Georgakakos

Georgia Water Resources Institute
School of Civil and Environmental Engineering
Georgia Institute of Technology
Atlanta, Georgia 30332-0355

Technical Completion Report for
GWRI FY02 Grant E-20-G61

June 30, 2002

Abstract

The water resources systems of the Southeastern U.S. are increasingly stressed by various demands. This stress is magnified during the periodic periods of drought that occur in the region, and agriculture is particularly affected by these droughts. Recent public policy has attempted to mitigate the impacts on farmers, but reliable methods of drought assessment and forecasting are needed to allow efficient policy implementation. A methodology is presented to assess the effects of droughts on crop yields, irrigation demands, and the full yield-irrigation relationship. The technique utilizes irrigation optimization algorithms coupled with physiologically based crop models. Ensembles of climatic forcing allow for quantification of the stochastic crop-water production function at specific sites and quantification of the changes in this function in drought periods. Data needs for assessment are discussed as well as sensitivity of the methodology to some input parameters. The technique is applied to four case study sites in southwestern Georgia, and potentially useful information is derived. Options for drought forecasting are briefly discussed.

1. Introduction

As population growth and economic development continue in the southeastern United States, water resources once thought inexhaustible are increasingly stressed. This fact has become profoundly evident during the region's drought of the past several years. Competing demands for water resources have led to inter-state as well as intra-state conflicts in the political and legal realms. Agriculture in the region is a consumer of surface water and groundwater, a party to the ongoing conflicts, and particularly vulnerable to climatic variation. While rainfall is adequate in wet and average years for farms to thrive with minimal water consumption, irrigation is required in drought years if farms are to simply survive.

Previous research has addressed some characteristics of drought effects on agriculture in the region. Hook (1994) used crop models to estimate irrigation needs and crop yields for corn, soybeans, and peanuts for the 15 driest years of a 53 year record. His results showed average yield losses of between 64% and 75% in the identified drought years. Irrigation requirements were computed using a soil moisture triggering threshold calibrated to produce 90% of fully irrigated yield. Irrigation requirements were found to vary with soil type. Meteorological variation in the spatial domain was not considered. Hook and Thomas (1995) conducted a similar study whereby the effects of "emergency" curtailments of irrigation were assessed for three policies: 30-day restrictions, 60-day restrictions, and complete restrictions. Economic losses were estimated for several dates of policy implementation within the growing season. Costs were found to vary by length of restriction, date of restriction period, crop, and soil type. For the Flint River Basin of southwest Georgia, costs of water conservation ranged from $531 per million gallons for corn under a 30-day restriction imposed in July to $2,388 per million gallons for peanuts under a 30-day restriction imposed in August.

The State of Georgia currently operates a program of compensation to farmers for not irrigating in years declared as probable drought years by the state on March 1. The current state of climate prediction capability for the region is limited, however. Moreover, current policy as legislated by the "Flint River Drought Protection Act" (OCGA 12-5-540) is an "all-or-nothing" proposition for farmers. The possibility of irrigation quantity limits is not part of the present system, although such limits might be preferable for some or all concerned parties.

Compounding the difficulties of policy implementation is the lack of documented knowledge on irrigation use in the region. Georgia has not maintained measured records of irrigation applications by production farms prior to 1998 when the "Ag WATER PUMPING" project commenced to monitor irrigation application at about 2% of permitted wells in the state (Thomas et al. 2001). Prior to this program perhaps the best information available was estimates made by extension agents published every five years in the USDA Farm and Ranch Irrigation Survey (e.g., NASS 1998). However, the figures included in that publication are statewide averages and are described therein as "rough estimates" (pp. XVII-XVIII). The infrequent and spatially aggregated nature of these estimates make them unsuitable for use in determining drought effects or policy needs. Data from the Ag WATER PUMPING project will be valuable, although it is not scheduled for public release at this time, and its limited temporal extent will be a shortcoming until long-term monitoring has been achieved. Investigation of historical records of crop production is also inadequate for the purposes of discerning drought effects on agriculture. As an example, Figure 1 shows historical values of peanut yield for Tift County, Georgia (NASS 2002). The dominant mode of variation in the time-series is a large, long-term increase in crop yields from the beginning of the data in the 1930's until the late 1970's. This increase in magnitude is due to a "technology effect" of improved crop varieties, management practices, mechanization, etc. Moreover, measured field yield at the county scale is an undetermined mixture of irrigated and non-irrigated production, which makes identification of drought signals very difficult.

This report presents findings of a preliminary investigation into new technologies relevant to the problem of assessing, forecasting, and managing for agricultural droughts in the Southeastern U.S. Specifically this project has applied recently developed techniques of irrigation planning and determination of crop yield-irrigation relationships to the case of crops grown in southwest Georgia. Information on the variability of yield-irrigation response with climatic variability is determined. The possibility of using climatic teleconnections to forecast agricultural trends is discussed. Current deficiencies in data for application of these techniques are determined. Finally, future research efforts applicable to this issue are identified.

2. Methodology

The methodology for this study includes the following items: physiologically based crop modeling, optimization of irrigation schedules and yield-irrigation relationships, input data determination, study site specification, and drought period identification. These items are described in the following sections. The assessment process follows.

2.1. Physiologically Based Crop Modeling

Simulations of crop growth were conducted using the Decision Support System for Agrotechnology Transfer (DSSAT) suite of crop models. (Tsuji et al. 1994). These models are first-principles, physiologically based models of crop growth and development processes, which include daily meteorology, soil/plant water balance, phonological development, photosynthesis, carbohydrate partitioning, and management inputs among other items. The models have been developed and refined by a global cadre of scientists over the past two decades. Verification studies are abundant and show the models to be reliable.

Of particular interest to this study is the water balance component of the models. The water balance sub-model is described in detail by Jones and Kiniry (1986) and Ritchie (1998). Verification of the water balance routines has been presented by Ritchie (1972), Gabrielle et al. (1995), and Brumbelow and Georgakakos (2001) among others. The sub-model includes routines for calculation of runoff, downward soil moisture transport, evaporation from soil, transpiration from plants, root water uptake, capillary rise, and soil moisture content updating. Periods of drought stress are identified by deficiencies in plant water balance, namely when the ratio of root water uptake (inflow of water to plant) to transpiration (outflow of water from plant) falls below unity. A “soil water deficit factor” calculated as this ratio is then factored into numerous process equations.

The crop models include some routines that were not utilized in this study. Nutrient processes and damages due to pests and disease were omitted as the focus of the study was on drought stresses and irrigation. As agriculture in the region consistently uses effective programs of fertilization and pest control, this assumption is not significant.

2.2. Optimization of Irrigation Schedules and Yield-Irrigation Relationships

In contrast with previous studies, this research included determination of the entirety of the yield-irrigation relationship. That is, the full crop water production function (CWPF) was derived for each growing season in the study period rather than a single irrigation value. The method for determining CWPF's was the "Simple Yield-Irrigation Gradient" (SYIG) algorithm (Brumbelow 2001, Brumbelow and Georgakakos 2002b). This algorithm uses determination of marginal values of differential irrigation allocations to schedule additions to existing irrigation schedules in a repetitive manner. By starting at the zero-irrigation point and iterating until the full irrigation plateau is reached, a full CWPF is obtained. Since the algorithm is coupled with the capabilities of physiologically based crop models, irrigation scheduling is accomplished accounting for soil moisture conditions, solar radiation, dynamic rates of phenological development, and other physiological circumstances not accounted for by traditional irrigation scheduling methodologies (e.g., reference evapotranspiration-crop coefficients, Doorenbos and Pruitt 1977, etc.). More advanced algorithms in the YIG family have been developed, and these techniques provide optimized results. However, their computational requirements are greater, and they were not used in the interest of time of execution.

2.3. Input Data Determination

A variety of input data were needed for the study. Soils data were obtained from the USDA Natural Resources Conservation Service (NRCS) State Soil Geographic Database (STATSGO, NRCS 1994). The soil maps of this database were reviewed in a geographic information system to determine relevant variation of soils in the locales under investigation. Where soil types differed significantly in the vicinity of a study site, multiple soil types were included in the study.

Daily meteorological data were needed for six parameters as input to the crop simulations: precipitation, maximum temperature, minimum temperature, hours of bright sunshine, relative humidity, and wind run. Data for the first three parameters were easily obtainable for many stations from the National Climatic Data Center's online archives (NCDC 2002). The last three parameters posed some difficulties, as they were not commonly available for many stations.

Sunshine hours were available for the period January 1965 to May 1996 only at Macon, Georgia, and Montgomery, Alabama, in the region. Since incoming solar radiation drives photosynthetic production, knowledge of sunshine hours is very important for crop simulations, and final yield estimates can be quite sensitive to this parameter. For this reason it was decided to limit the scope of the study to the period for which measured sunshine hours were available and to use the Macon data for all sites since it was representative of the values for the region.

Relative humidity and wind run were also not commonly available in the region. As the sensitivity of crop yields to these parameters is not as great as other variables, simple estimation formulae were used to approximate values for these parameters. Relative humidity has been observed to follow a roughly sinusoidal trend in the region with some noise and elevated values during periods of precipitation (see Figure 2). Therefore, an estimation equation based upon this pattern was used for each station in the study:

$$RH = \min\left[1.00,\ \ 0.60 + \cos\left(2\pi \cdot \frac{(DOY - 80)}{365}\right) \cdot 0.20 + P \cdot 0.35\right] \qquad \textbf{(1)}$$

where RH is daily relative humidity (0.00 – 1.00), DOY is the Julian day of the year (1 – 365), and P is daily precipitation in inches. Wind run was estimated by a simple random number generator with lower and upper bounds of 0 and 20 miles per hour, respectively. Figure 3 shows typical measured values from the region, and it is seen that this approximation is adequate.

2.4. Study Site Specification

Four sites in southwestern Georgia were chosen for the study: Tifton, Colquitt, eastern Mitchell County, and southwestern Mitchell County. Both Mitchell County sites utilized meteorology from the Camilla station. Selection of the sites encompassed a variety of soil types and locales in the region, yet allowed for comparative analysis of sensitivity of results to meteorology under common soil and sensitivity to soil under common meteorology. Three of the sites (Colquitt and the two Mitchell County sites) are located in the hydrologically sensitive lower Flint River Basin and should serve as suitable benchmarks for further studies in that watershed. The Tifton site is collocated with an extensive agricultural experiment station and is thus well suited for calibration and verification against previously collected data at that site. Table 1 below relates basic information about the study sites, and Figure 4 shows the location of the sites as well as the extent of the soil types included in the assessment.

As is seen in Table 1, the Colquitt and E Mitchell County sites are both underlain by the soil noted as MUID GA050. The distance between the two sites is about 40 miles (64.5 kilometers), and separate records of precipitation and daily temperatures were used for the two sites. These circumstances allow for a preliminary test of the assessment technique for its sensitivity to site-specific meteorology with other factors held constant. In a similar fashion, the two Mitchell County sites share common meteorology from the Camilla station, but occur on two different soil types, GA050 and GA 060.

Table 1. Study sites included in the assessment case study

Name	Approximate Position	Soil Type (STATSGO MUID)	Meteorological Station
Tifton	31.45º N, 83.48º W	GA057	Tifton Exp Sta
Colquitt	31.17º N, 84.77º W	GA050	Colquitt 2 W
E Mitchell Co.	31.27º N , 84.08º W	GA050	Camilla 3 SE
SW Mitchell Co.	31.16º N , 84.35º W	GA060	Camilla 3 SE

2.5. Drought Period Identification

Within the 31 year period of recorded meteorology available for the study, it was necessary to determine when droughts occurred. Two non-independent criteria were used for this purpose. First, calculations of the Palmer Drought Severity Index (PDSI) were obtained from the National Climatic Data Center for climate division GA-7 (NCDC 2002), which includes the southwestern corner of Georgia (see Figure 5). A low-pass filter (4-year moving average) was applied to the index values. These filtered PDSI values are graphed in Figure 6a.

Additionally, the aggregate monthly precipitation values for GA-7 were also obtained from NCDC (2002). The long-term average precipitation was computed for each of the 12 months of the year using all data from 1895 to 2002. Then, the historical values of measured precipitation were compared to the long-term averages to find a time-series of monthly deviations from average. Again, a low-pass filter (4-year moving average) was applied to the time-series of deviations. The final product is shown in Figure 6b.

The two criteria are very similar upon comparison. The precipitation deviations tend to be a bit noisier and tend to lead the trends in PDSI by a few months. These observations fall in line with expectation: the PDSI is an attempt to model soil moisture conditions, which lag and dampen precipitation forcing. However, determination of drought periods by either metric yields the same conclusions. Within the study period drought periods occurred in the years: 1968-1970, 1979-1981, and 1986-1990. Because of the lag between precipitation and PDSI, the years 1967 and 1985 should be regarded as “transition” years as they experienced reduced rainfall but not the reduced soil moisture values represented by the PDSI.

2.6. Assessment Process

For each of the four sites, crop growth simulations were conducted for two crops, maize and peanuts, both economically important and commonly grown in the region. For maize simulations, planting date was set at April 15, for all sites and all meteorological years. The maize cultivar used was Pioneer 3147. Planting date for peanut simulations was set at May 15, for all sites and years. The peanut cultivar used was Pronto. The

Simple YIG algorithm was used in conjunction with the appropriate DSSAT model to determine the crop-water production function for each crop at each site for all 31 growing seasons (total of 248 functions generated). The 31 functions determined for each crop and site collectively form the crop-water production function probability distribution (CWPF-PD, Brumbelow 2001, Brumbelow and Georgakakos 2002a) for that crop and site. The 8 CWPF-PD's are presented as the "a" part of Figures 7-14. By inspecting the CWPF's of designated drought years, a sub-set of the CWPF-PD is realized, which is ideally indicative of drought effects on crop yield, irrigation needs, and the relationship between the two. The CWPF-PD's of the drought periods are shown with the full CWPF-PD's in the "b" parts of Figures 7-14. This concept and potential forecasting techniques are discussed in the next section.

3. Results and Discussion

Comparison of the two CWPF-PD's in the "b" parts of Figures 6-13 shows a clear distinction between those of the full study period and those of the drought periods. An excellent example of the difference is Figure 8b (maize grown at the Tifton site). For that case the median crop-water production function is almost exactly the same as the 25th percentile function from the full study period for irrigation amounts from 0 to 120 mm. The reduction in rainfed crop yield for the drought median function is 4184 kg/ha from the full period median function, which represents a 49% reduction. For all cases, as the CWPF-PD's reach yield plateaus, they become quite similar (or almost identical in Figure 8a). This phenomenon is expected and has been noted by Brumbelow (2001) and Brumbelow and Georgakakos (2002a): the yield plateau is that region of crop response divorced from moisture stress concerns, and variability in crop yield is determined in that regime by temperature and radiation factors rather than precipitation patterns. Interestingly, the upper quartile of the drought periods' CWPF-PD extends to high yield values for low irrigation amounts, and this occurrence is consistent among the case studies. This skew in the drought period CWPF-PD reflects natural variability in the agricultural system even in periods of pronounced stress and potential uncertainties in the definition of drought. The criteria used to designate the drought periods for this study relied on time-aggregated metrics (4-year moving averages of regional monthly values). In contrast, the crop simulations performed herein assumed spatial points and daily timesteps, and real agricultural systems respond to meteorological events at timescales of minutes. Therefore, the upper quartile spread is perhaps unavoidable and is certainly a consequence of natural variability and differences in system scales.

Sensitivity of the assessment technique to soil type can be understood by comparing the results for the Eastern Mitchell County and Southwestern Mitchell County sites (Figures 11-14). For both peanuts and maize, the two sites have virtually identical sets of CWPF-PD's. This result is not surprising as the two soil types present do not differ greatly in composition as shown in Figure 15a-b or in plant extractable water capacity (Figure 16). The lack of sensitivity observed works to increase confidence in the assessment technique as small changes in soil characteristics are not overly influential. This finding may also justify less intensive modeling efforts on a spatial basis as minor soil differences will not cause different drought responses. However, future investigation must determine the relevant threshold for soil differences to cause changed yield-irrigation response.

Sensitivity of the assessment technique to locality of meteorological observations can be understood by comparing the results for the Colquitt and Eastern Mitchell County sites, which shared the same soil type (Figures 9-12). There are noticeable differences between the CWPF-PD's for both crops at these sites. However, the general character of all distributions of yield-irrigation functions is very similar for the same crop and study period. Again, additional research is merited to determine the limits of geographic commonality, especially in heterogeneous climatic zones. Nevertheless, the present observation affirms that the study methodology is not prone to over-sensitivity to locality of meteorological observations.

The value of CWPF-PD's for drought assessment and management can be realized on multiple fonts. For the individual farmer, the shifted drought distribution provides quantitative information with which to plan field operations. This scenario is especially valid if reliable drought forecasts are available. Using the case of maize grown at Tifton (Figure 8b), management decisions for an anticipated drought season might be as follows. If median rainfed yield granted the farmer an acceptable level of profitability, his target yield would be 8501 kg/ha. Under drought conditions, this target could be produced with 50% reliability with 25 mm irrigation (all irrigation values do not include transmission and application losses). However, net profits would be reduced by irrigation costs, and the farm may not have irrigation capacity for all fields. Thus, a more desirable target might be to achieve 9500 kg/ha with at least 75% reliability. In drought periods this would require 77 mm irrigation. To achieve the same target with 100% reliability would require 172 mm irrigation.

Water resources managers could use the CWPF-PD technique to help shape drought management policy. An example might be to alter the current Flint River Drought Protection Act system of compensating farmers to forego all irrigation on acreage to a system of compensation for reduction in irrigation. A reduction target that might be satisfactory to all parties would be the irrigation level at which drought period CWPF-PD's become sufficiently similar to the distribution of all yield-irrigation functions derived from history. That is, the irrigation target could be set at the point where the inherent variability in the agro-climatic system overwhelms the reduction in function distributions forced by drought conditions. The exact location of this point is likely a subjective determination, but it may be a reasonable policy. In the case of maize grown at Tifton, this target could arguably be set at about 140 mm. This level would be appropriate at the Eastern Mitchell County site, but Colquitt would possibly require a higher target, and Southwestern Mitchell County a lower one. On the whole for the region, a 140 mm target would represent a reduction in irrigation for 14 of the 15 worst drought years identified by Hook (1994). Thus, the policy could have real impact.

The issue of reliable drought forecasts remains a difficult one for the Southeastern U.S. Studies attempting to find links between El Nino-Southern Oscillation (ENSO) phenomena and the region's climate have found weak correlations for winter months (e.g., CPC 2002), but these months are outside the growing season for many important crops. Investigation of the Pacific Decadal Oscillation (PDO, e.g., Mantua et al. 1997). time-series compared to cumulative precipitation anomalies in the region shows that long-term cycles (periods of decades to centuries) may have some correlation. Gulf of Mexico sea surface temperature anomalies also may be correlated in the same cycle as the PDO, which may provide a credible causation for Southeastern U.S. climate. However, significant work remains to be done.

4. Conclusions

This report has presented the preliminary form of a new methodology to assess and aid in decision making for agricultural and water resources systems under droughts. The technique has been applied to maize and peanut cultivation in the hydrologically, economically, and politically sensitive region of southwestern Georgia. It has been demonstrated that the assessment process provides potentially useful information.

Future work is required to refine the presented methodology and expand on its capabilities to provide useful information. The limited meteorological data for the case studies – specifically the limitations in sunshine hours data – hampered the project somewhat. Expansion of the meteorological dataset through statistical techniques of hindcasting, etc., would be valuable and allow for analysis through additional drought periods where precipitation data do exist. As was discussed, the sensitivity tests established that the study techniques are not overly sensitive to geographic heterogeneity, but the thresholds of sensitivity have not been established. Knowledge of these thresholds is needed in order to design appropriate assessment plans. Finally, reliable drought prediction techniques are needed for the Southeastern U.S. The real utility of the study techniques relies on the ability to forecast drought. Without such ability, the methods are limited to ex post analyses. However, it is a hopeful proposition that drought forecasting ability is not far off for the region.

References

Brumbelow, J. K. 2001. *Improved Methods for Agricultural and Water Resources Planning and Management*. Ph.D. Thesis. Georgia Institute of Technology, Atlanta, Georgia.

Brumbelow, K., and A. Georgakakos. 2001. An assessment of irrigation needs and crop yield for the United States under potential climate changes. *J. Geophys. Res.*, 106(D21), 27383-27405.

Brumbelow, K., and A. Georgakakos. 2002a. Consideration of temporal-climatic variability in agricultural water resources planning. *J. Clim.* (in review).

Brumbelow, K., and A. Georgakakos. 2002b. Optimal single-site irrigation planning using physiologically based crop models. *Agric. Syst.* (in review).

Climate Prediction Center (CPC). 2002. El Nino Impacts: Georgia. http://www.cpc.ncep.noaa.gov/products/predictions/threats2/enso/elnino/ga_bar.html.

Doorenbos, J., and W. O. Pruitt. 1977. Guidelines for predicting crop water requirements. FAO Irrigation and Drainage Paper no. 33. FAO, Rome, Italy.

Gabrielle, B., S. Menassaeri, and S. Houot. 1995. Analysis and field evaluation of the Ceres models water balance component. *Soil Sci. of Am. J.,* 59, 1403-1412.

Hook, J. E. 1994. Using crop models to plan water withdrawals for irrigation in drought years. *Agric. Syst.,* 45, 271-289.

Hook, J. E., and D. L. Thomas. 1995. Projected seasonal water consumption and water restrictions for row crop irrigation in the ACF basin. *Proceedings of the 1995*

Georgia Water Resources Conference. ed. K. J. Hatcher. Univ. of Georgia, Athens, Georgia.

Jones, C. A., and J. R. Kiniry. 1986. *CERES-Maize: A Simulation Model of Maize Growth and Development.* Texas A&M Univ. Press, College Station, Texas.

Mantua, N. J., S. R. Hare, Y. Zhang, J. M. Wallace, and R. C. Francis. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. *Bull. Amer. Met. Soc.,* 78(6), 1069-1079.

National Agricultural Statistics Service (NASS). 1998. 1998 Farm and Ranch Irrigation Survey. http://www.nass.usda.gov/census/census97/fris/fris.htm.

National Agricultural Statistics Service (NASS). 2002. Agricultural Statistics Data Base. http://www.nass.usda.gov:81/ipedb/.

National Climatic Data Center (NCDC). 2002. NCDC Climate Resources. http://lwf.ncdc.noaa.gov/oa/climate/climateresources.html.

Natural Resources Conservation Service (NRCS). 1994. State Soil Geographic (STATSGO) database: Data use information. U.S. Dept. of Agric., Misc. Publ. 1492, Washington, D.C.

Ritchie, J. T. 1972. Model for predicting evaporation from a row crop with incomplete cover. *Water Resour. Res.,* 8(5), 1204-1213.

Ritchie, J. T. 1998. Soil water balance and plant stress, in *Understanding Options for Agricultural Production.* ed. G. Y. Tsuji, et al. Kluwer Acad., Norwell, Mass.

Thomas, D. L., and 14 other authors. 2001. Status of Ag. WATER PUMPING: A program to determine agricultural water use in Georgia. *Proceedings of the 2001*

Georgia Water Resources Conference. ed. K. J. Hatcher. Univ. of Georgia, Athens, Georgia.

Tsuji, G. Y., G. Uehara, and G. Balas (eds.). 1994. *Decision Support System for Agrotechnology Transfer, Version 3.* Univ. of Hawaii, Honolulu, Hawaii.

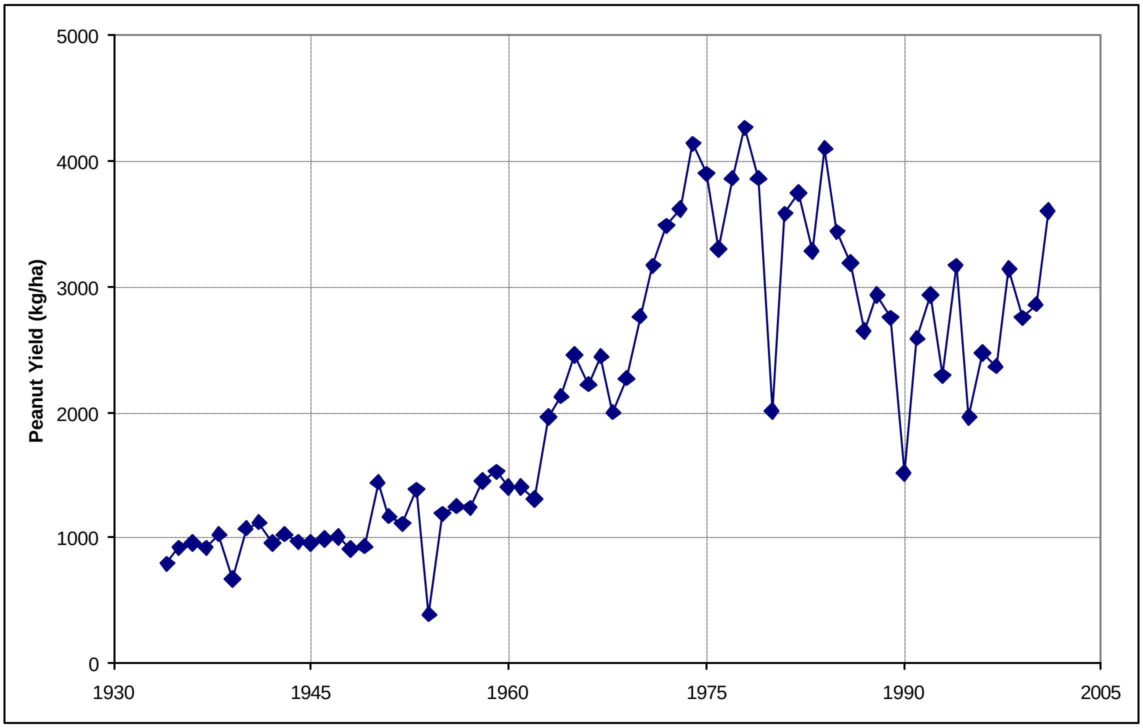

Figure 1. Peanut crop yield observed in Tift County, Georgia, 1934-2001 (NASS 2002).

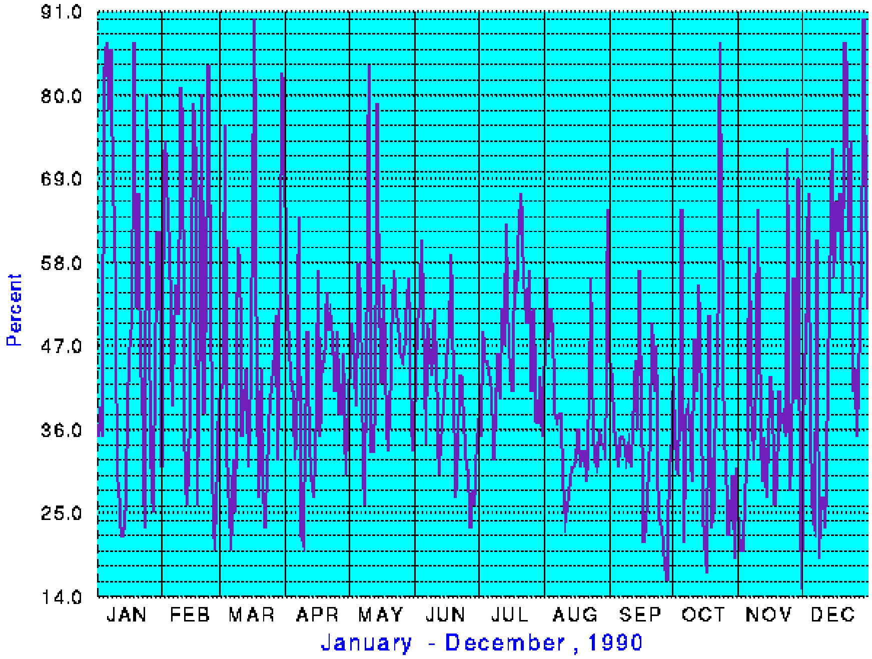

Figure 2. Daily relative humidity observed at Montgomery, Alabama, 1990 (NCDC 2002).

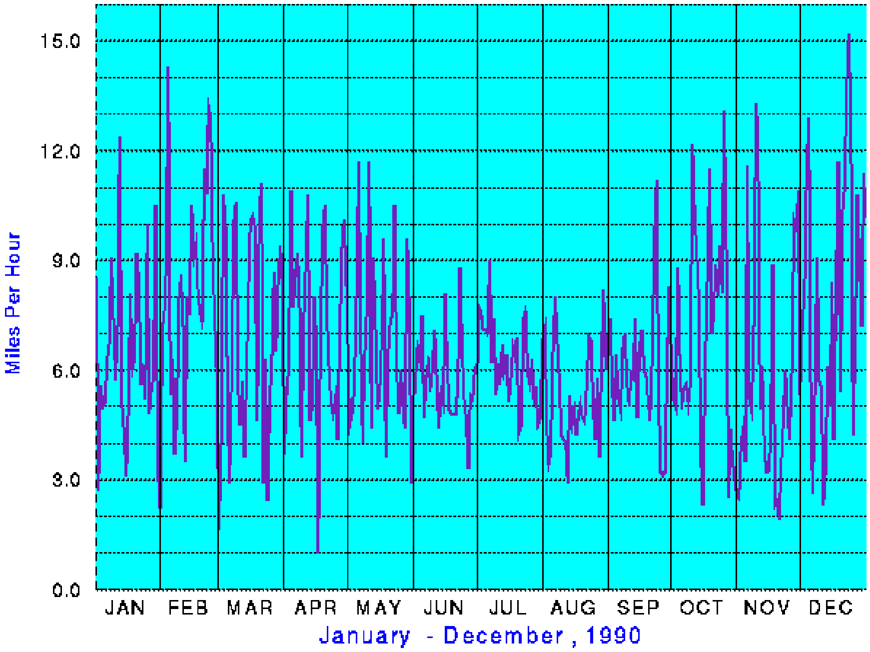

Figure 3. Daily wind speed observed at Montgomery, Alabama, 1990 (NCDC 2002).

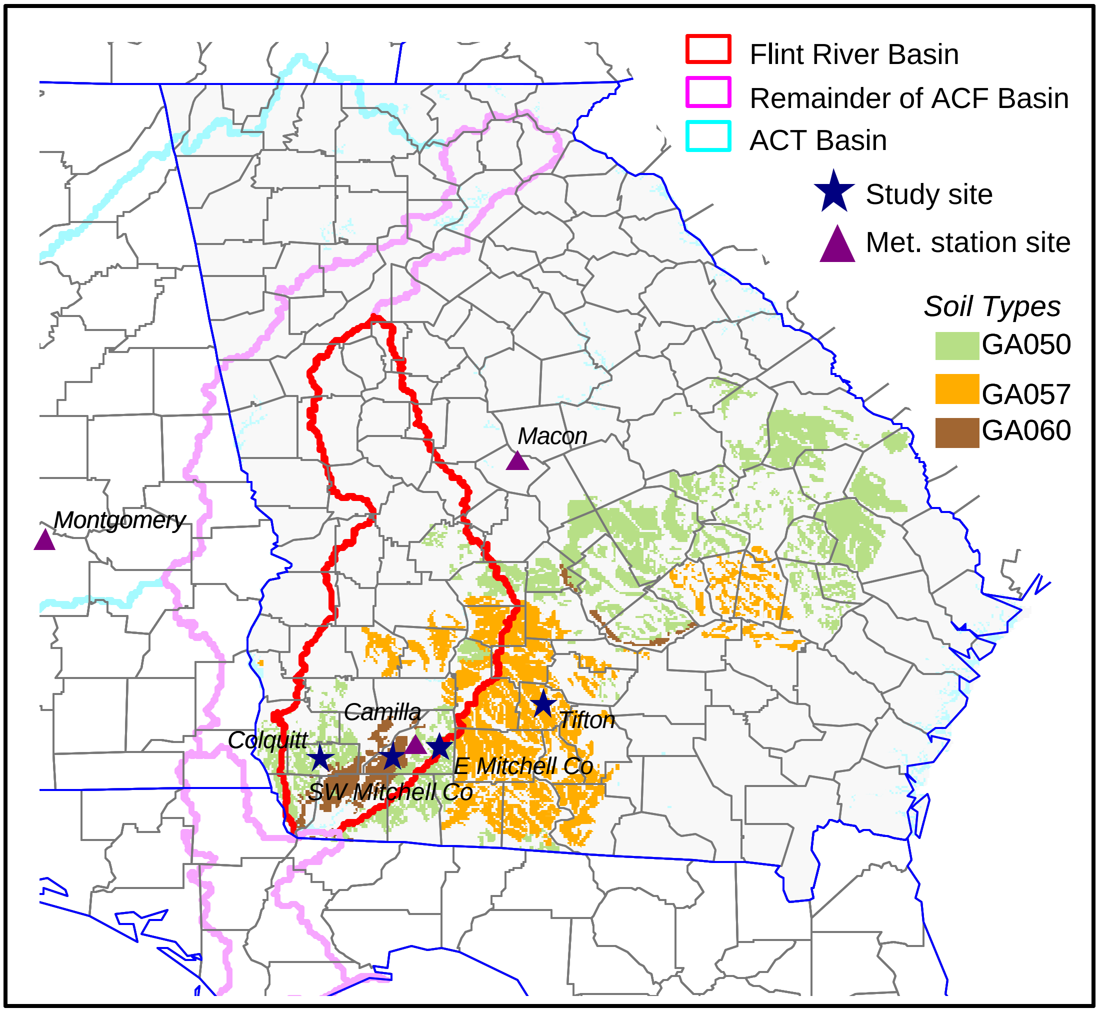

Figure 4. Map of Georgia showing locations of four study sites, other relevant meteorological stations, extent of soil types included in the study, and boundaries of important river basins in the region.

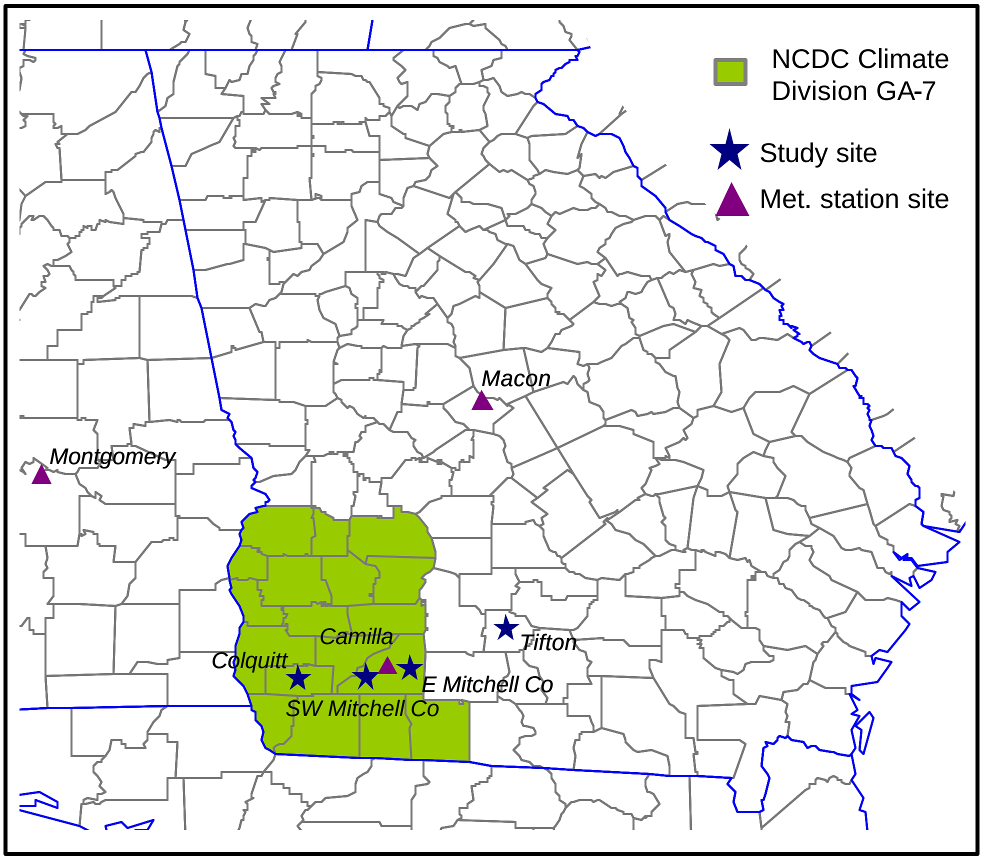

Figure 5. Location of NCDC climate division GA-7.

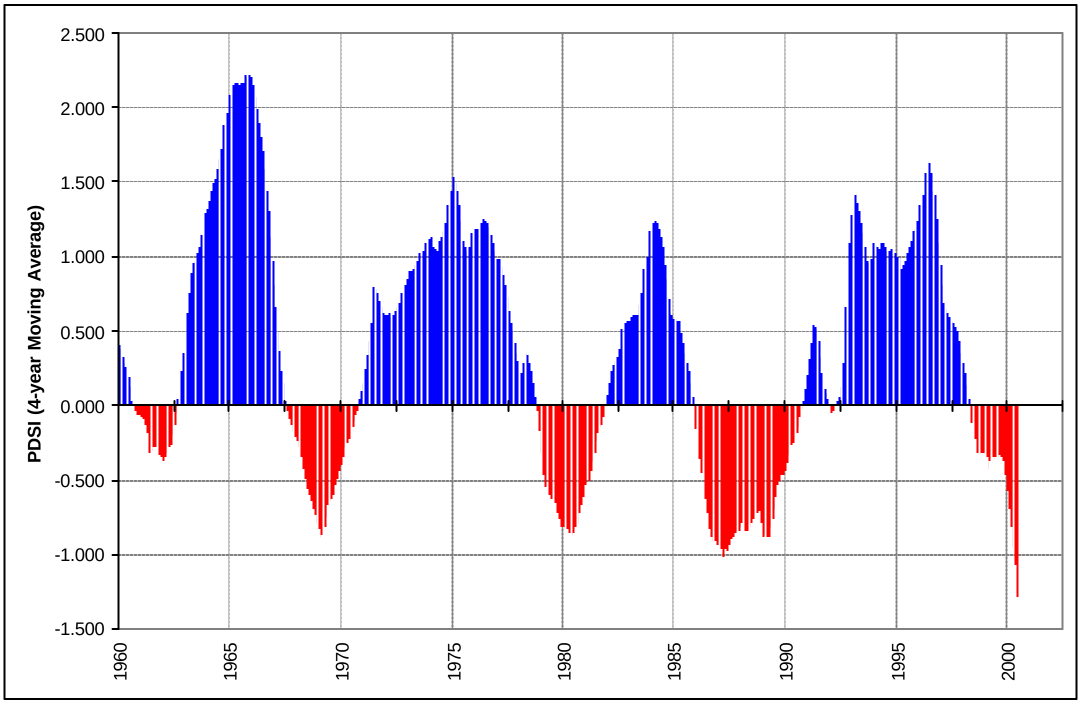

Figure 6a. Palmer drought severity index values for climate division GA-7 (NCDC 2002). The index values have been low-pass filtered to aid in identify inter-annual cycles.

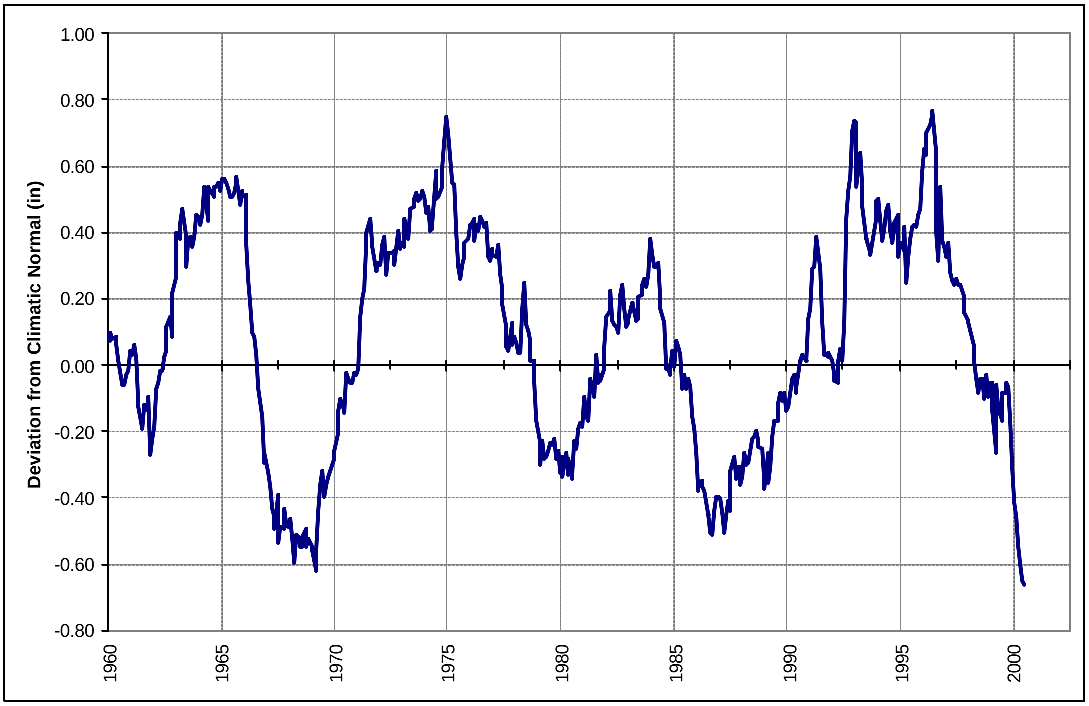

Figure 6b. Deviation of monthly precipitation values from long-term (1895-2002) averages. As above, values have been low-pass filtered.

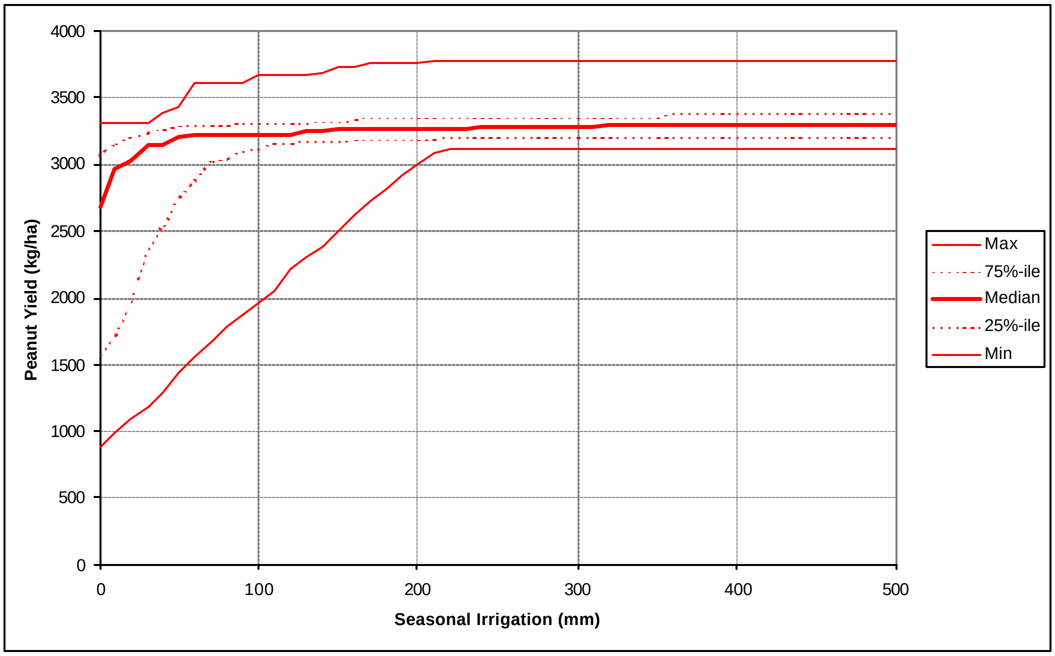

Figure 7a. Crop-water production function probability distribution (CWPF-PD) for peanuts grown at Tifton, full study period of 1965-1995.

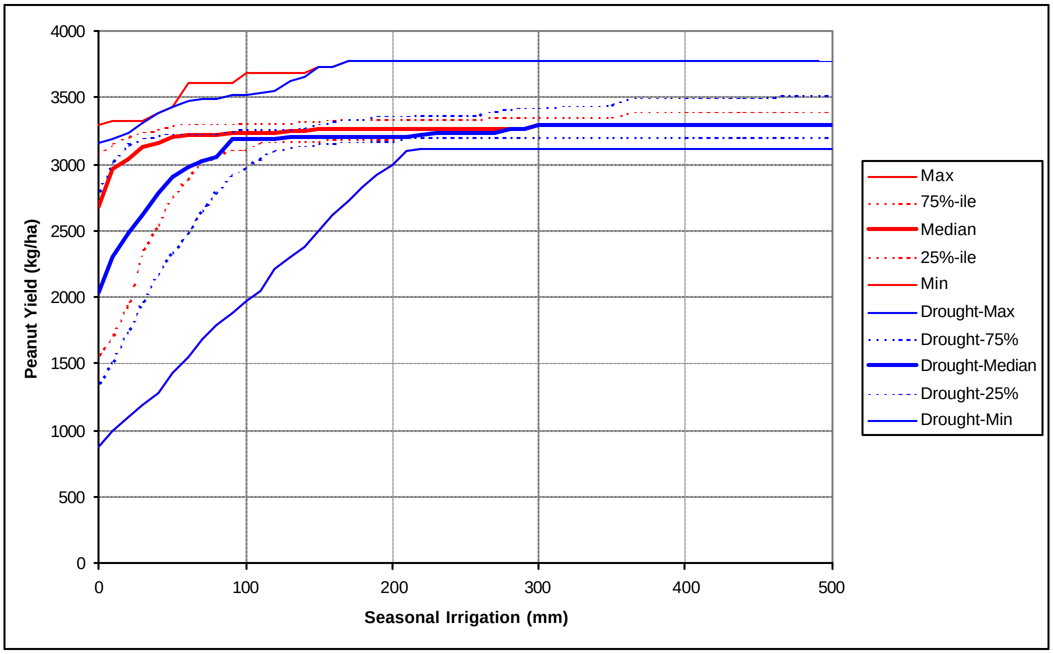

Figure 7b. CWPF-PD for peanuts grown at Tifton for both the full study period (red) and the drought seasons alone (blue).

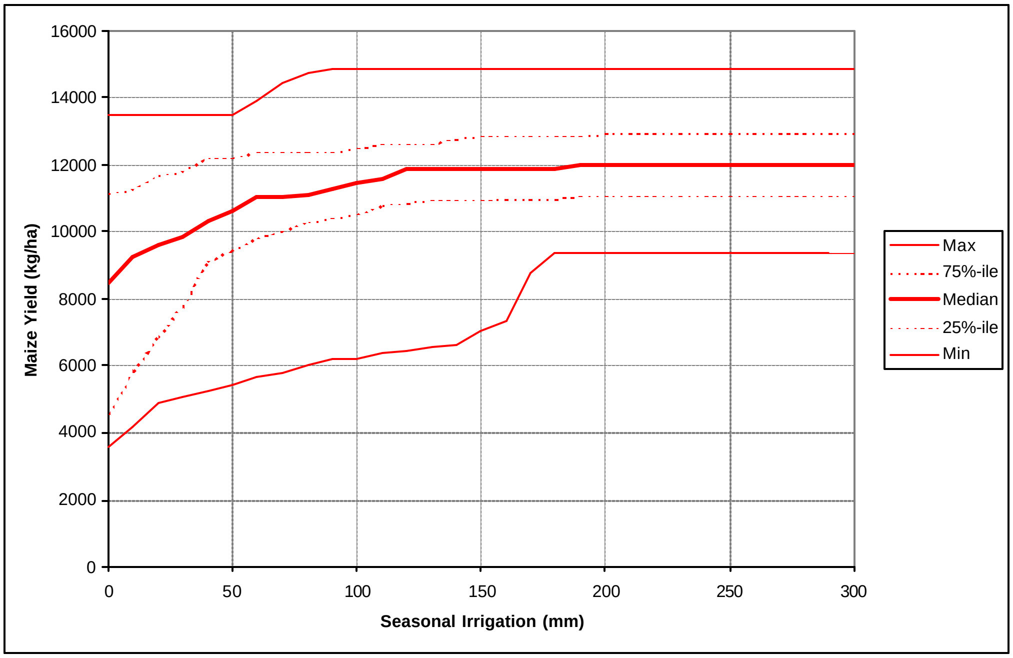

Figure 8a. CWPF-PD for maize grown at Tifton, full study period of 1965-1995.

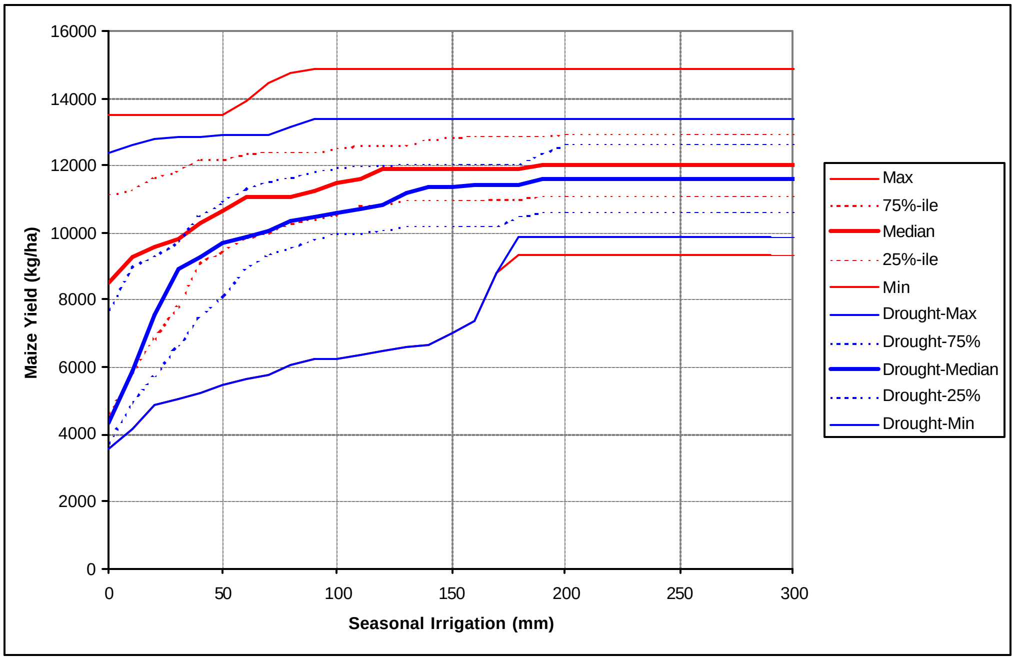

Figure 8b. CWPF-PD's for maize grown at Tifton for full study period (red) and drought seasons alone (blue).

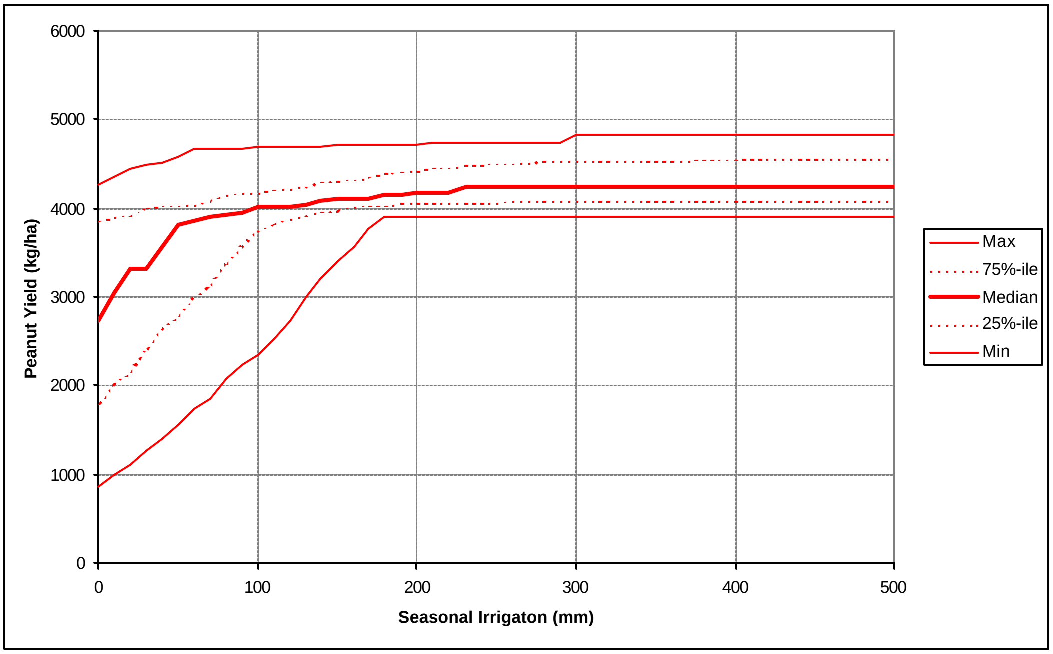

Figure 9a. CWPF-PD for peanuts grown at Colquitt, full study period of 1965-1995.

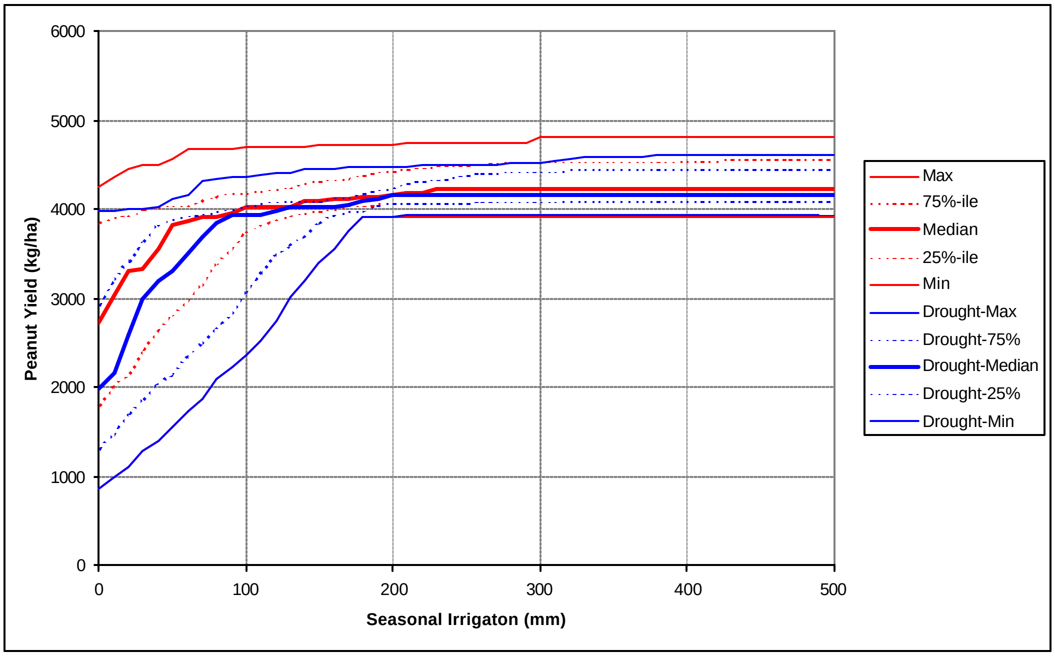

Figure 9b. CWPF-PD's for peanuts grown at Colquitt for full study period (red) and drought seasons alone (blue).

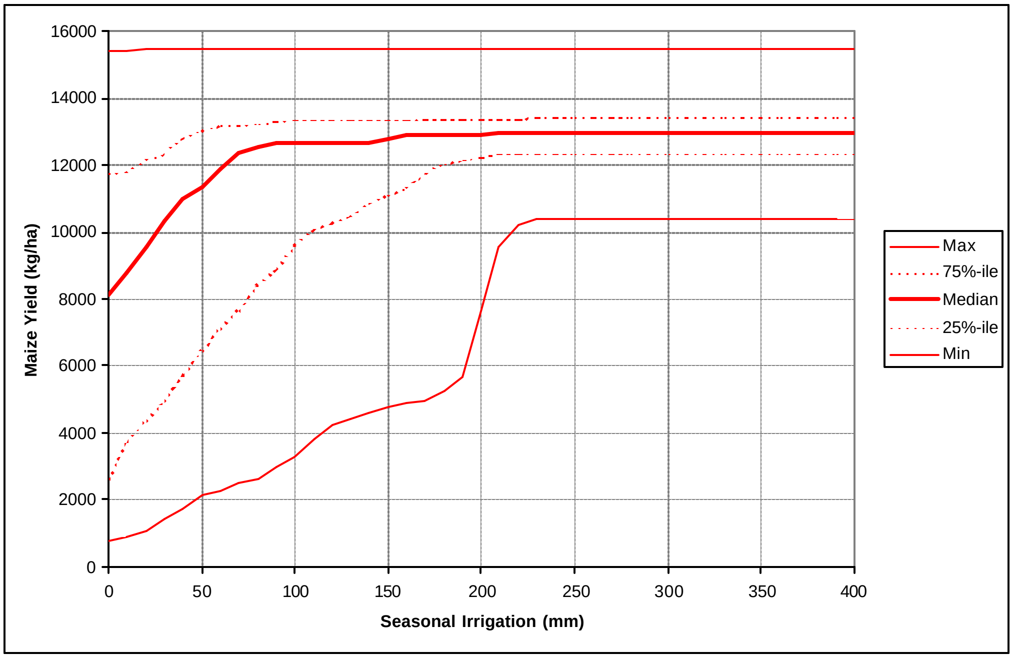

Figure 10a. CWPF-PD for maize grown at Colquitt, full study period of 1965-1995.

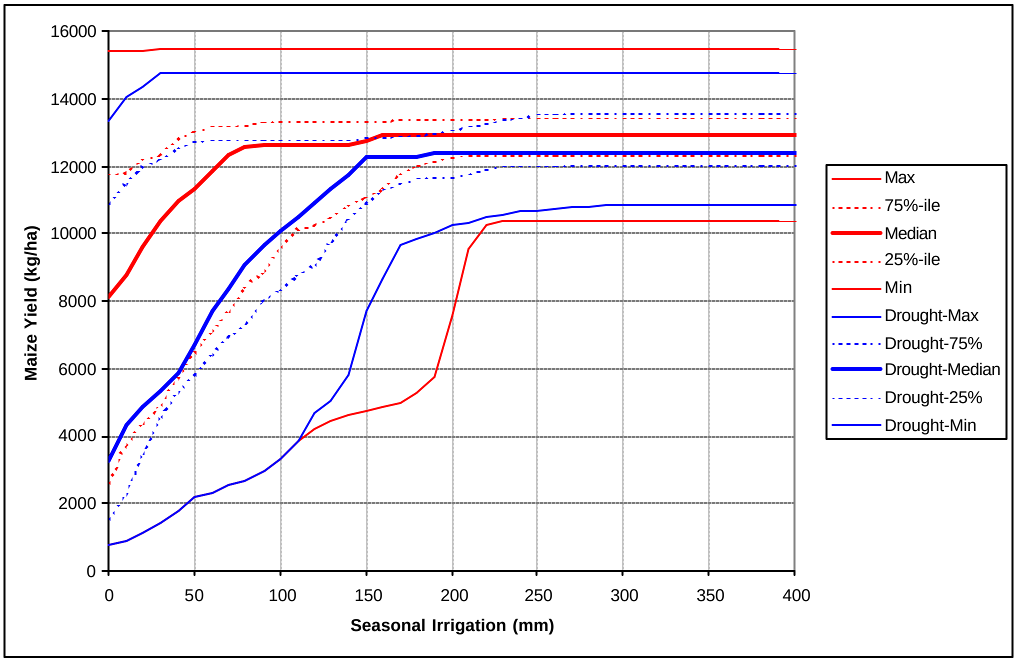

Figure 10b. CWPF-PD's for maize grown at Colquitt for full study period (red) and drought seasons alone (blue).

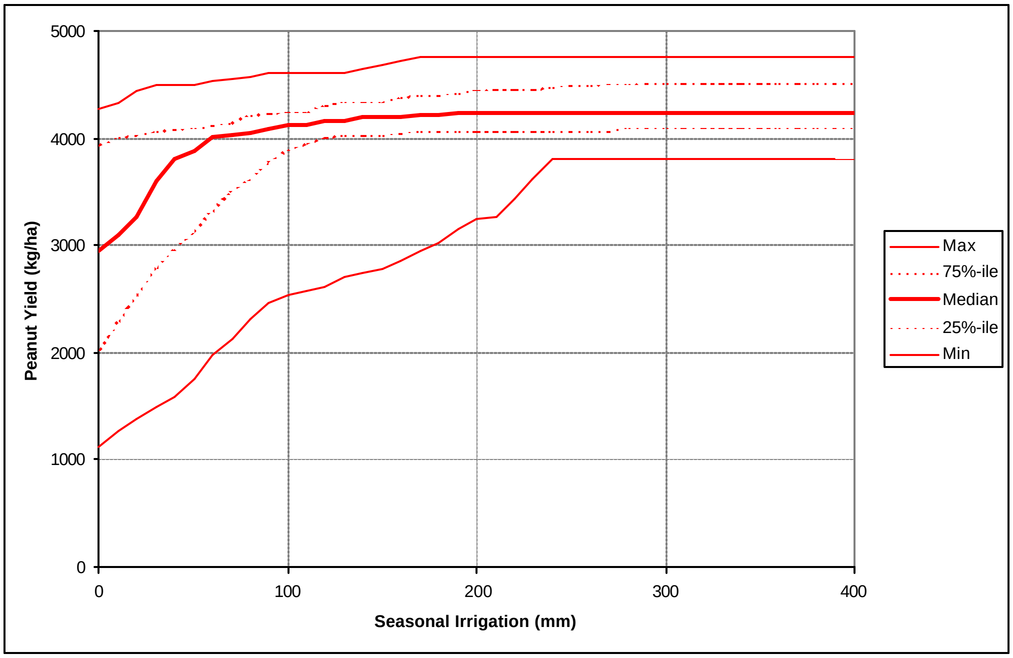

Figure 11a. CWPF-PD for peanuts grown at East Mitchell County, full study period of 1965-1995.

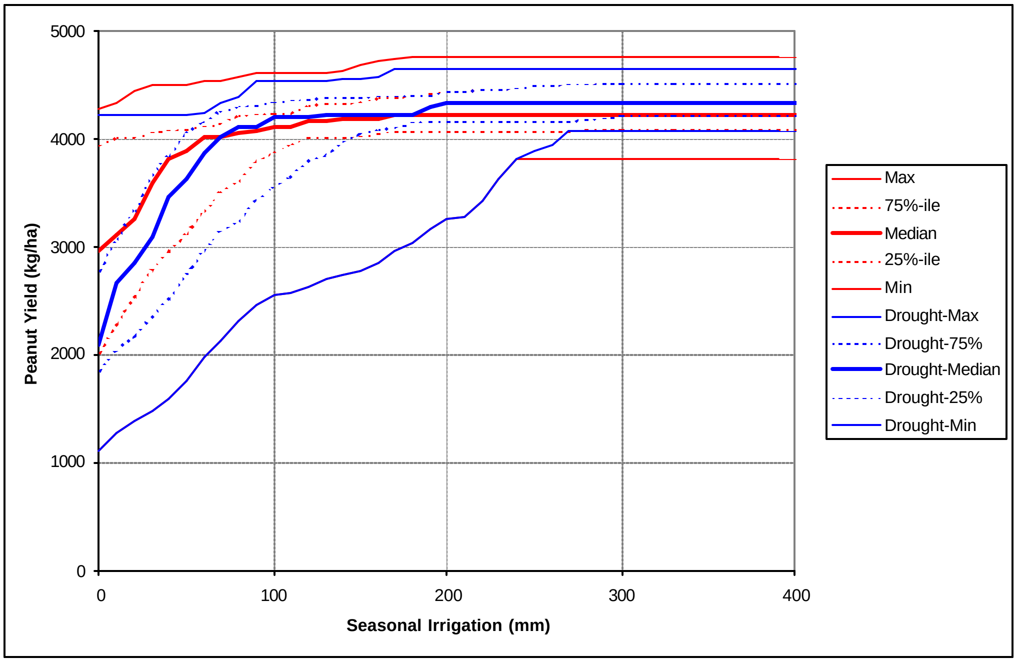

Figure 11b. CWPF-PD's for peanuts grown at East Mitchell County for full study period (red) and drought seasons alone (blue).

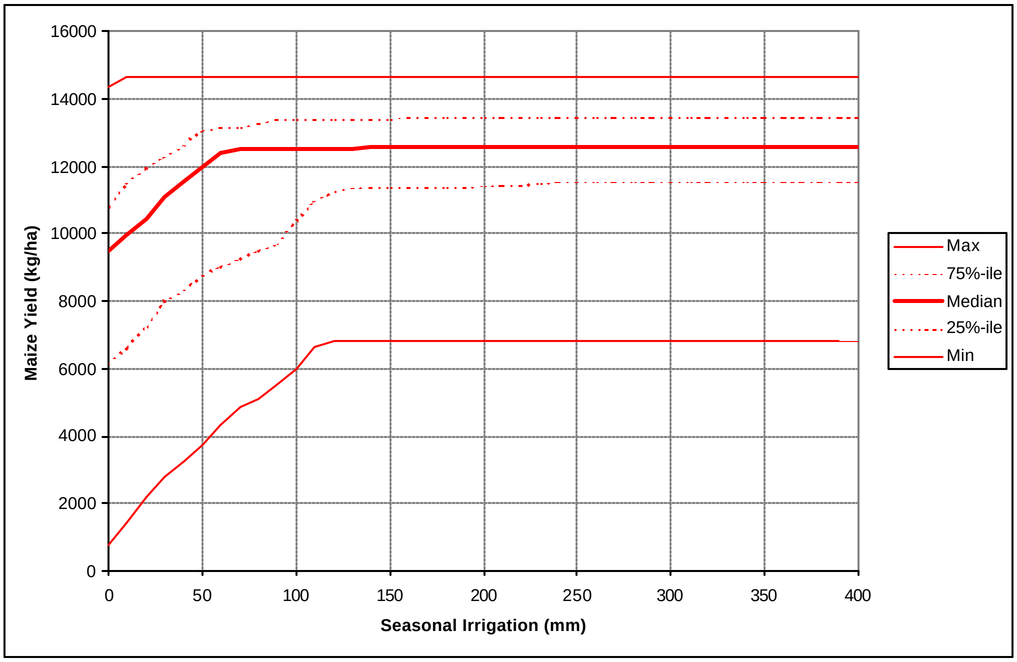

Figure 12a. CWPF-PD for maize grown at East Mitchell County, full study period of 1965-1995.

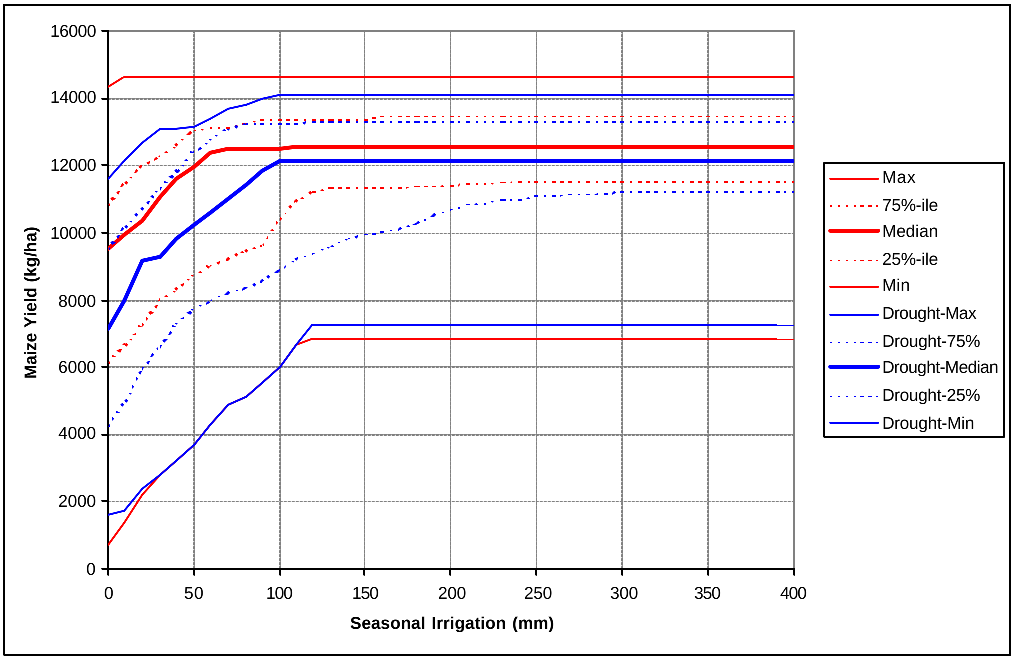

Figure 12b. CWPF-PD's for maize grown at East Mitchell County for full study period (red) and drought seasons alone (blue).

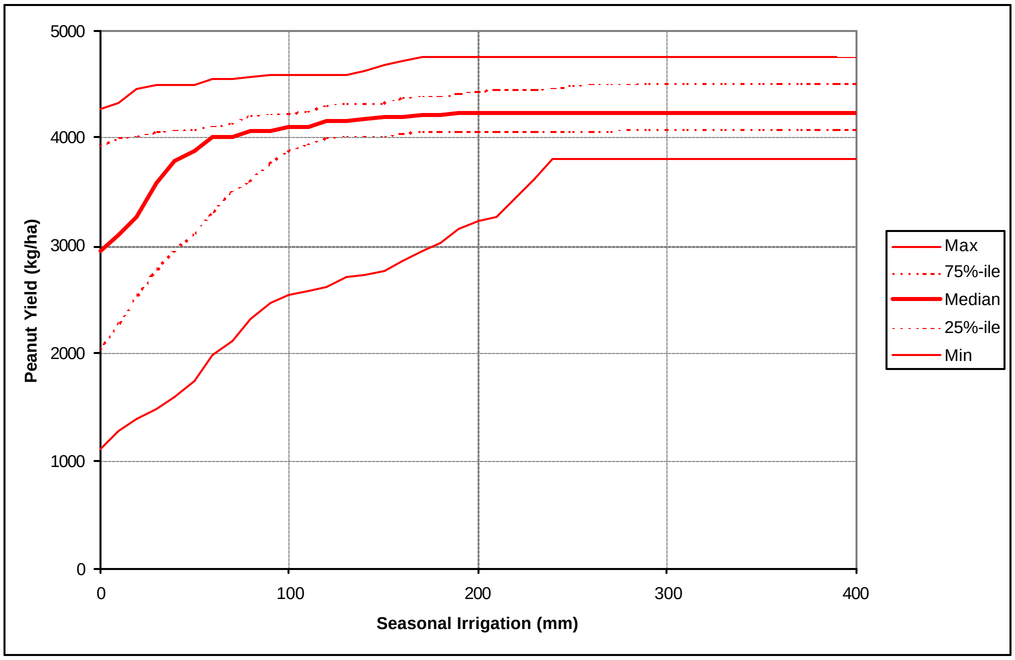

Figure 13a. CWPF-PD for peanuts grown at Southwest Mitchell County, full study period of 1965-1995.

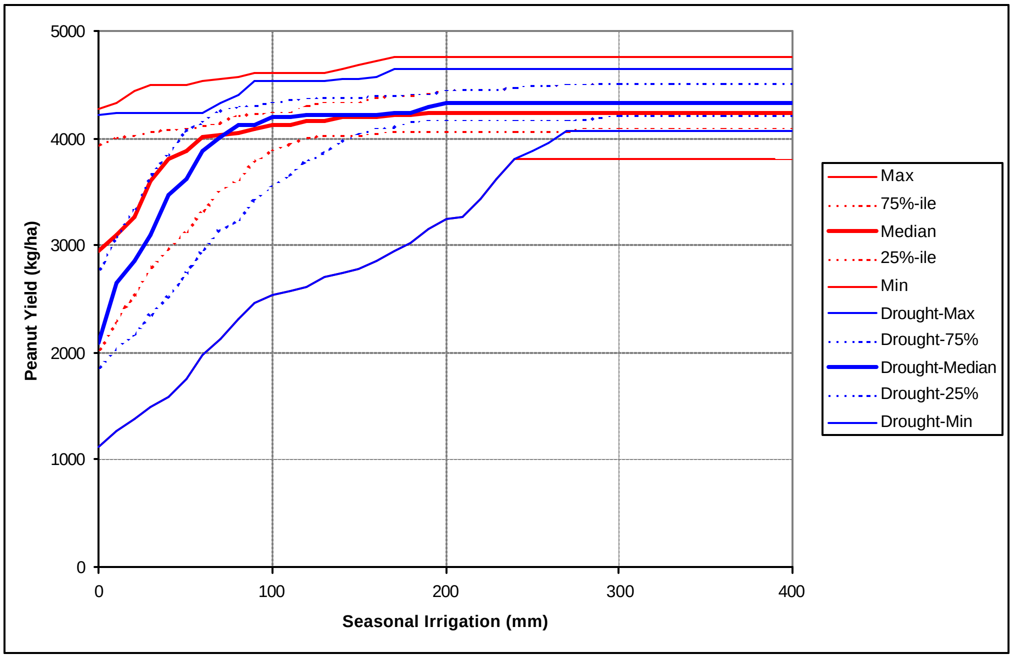

Figure 13b. CWPF-PD's for peanuts grown at Southwest Mitchell County for full study period (red) and drought seasons alone (blue).

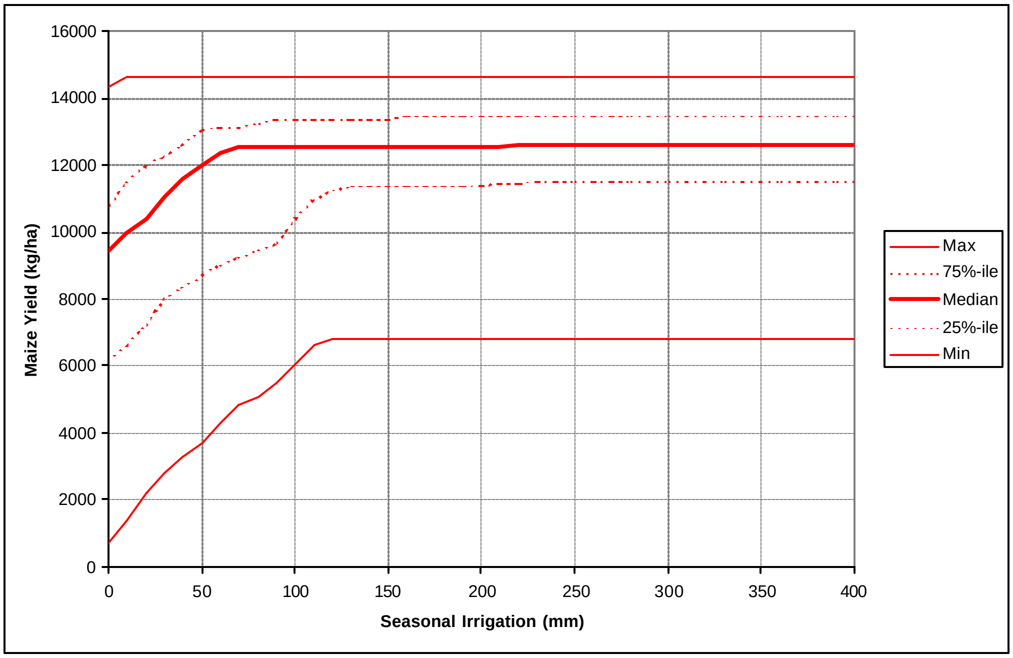

Figure 14a. CWPF-PD for maize grown at Southwest Mitchell County, full study period of 1965-1995.

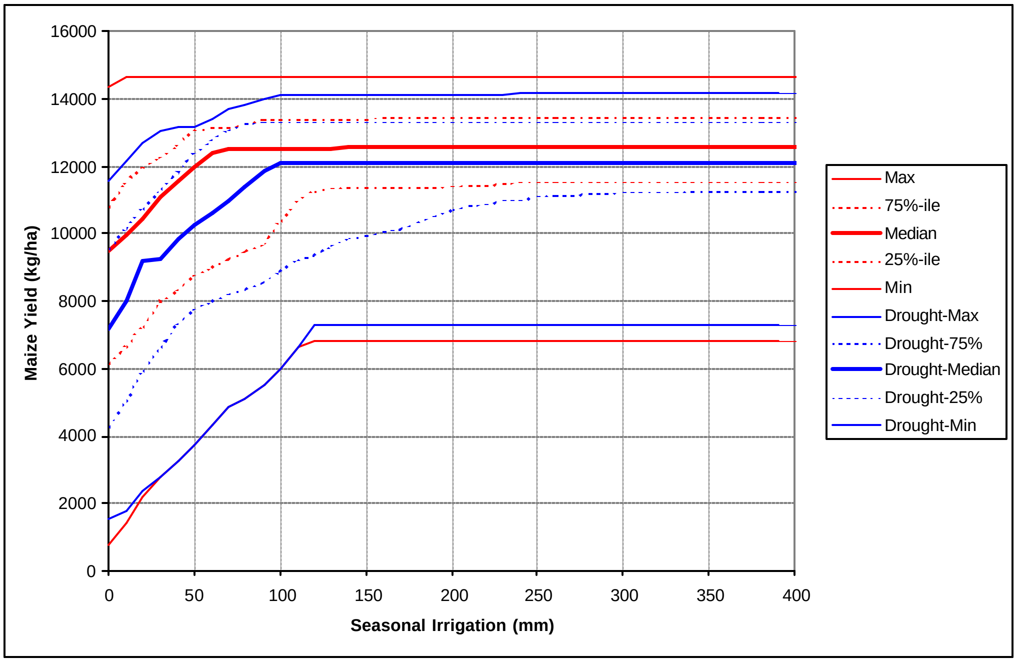

Figure 14b. CWPF-PD's for maize grown at Southwest Mitchell County for full study period (red) and drought seasons alone (blue).

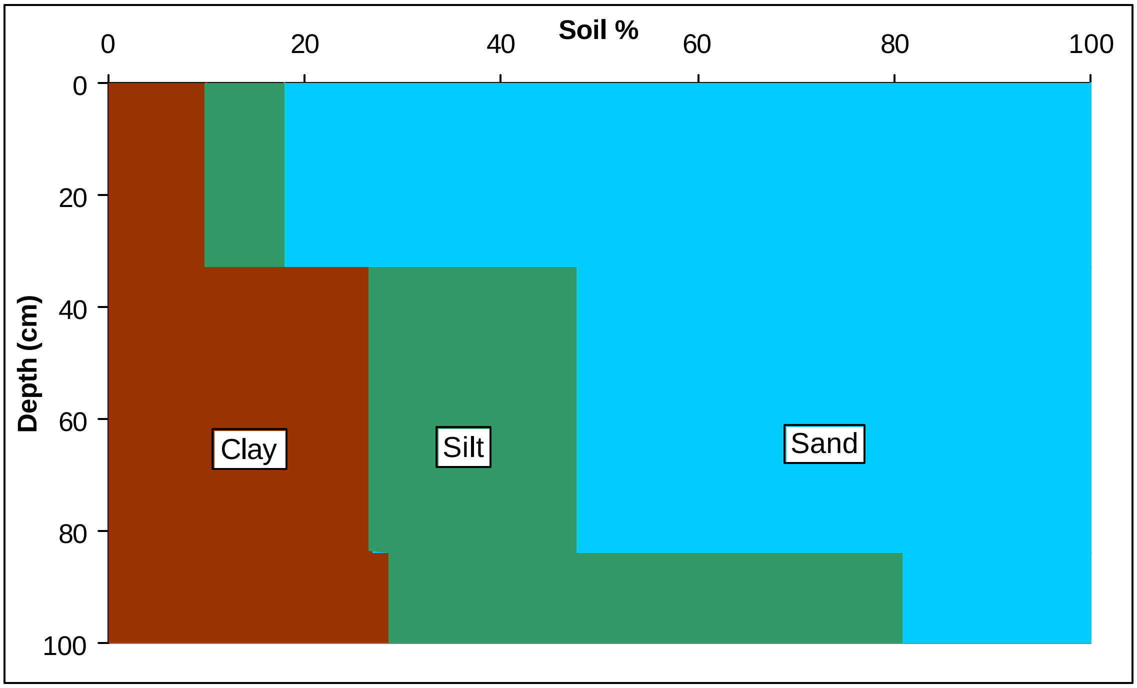

Figure 15a. Profile of soil textural composition for GA050, East Mitchell County.

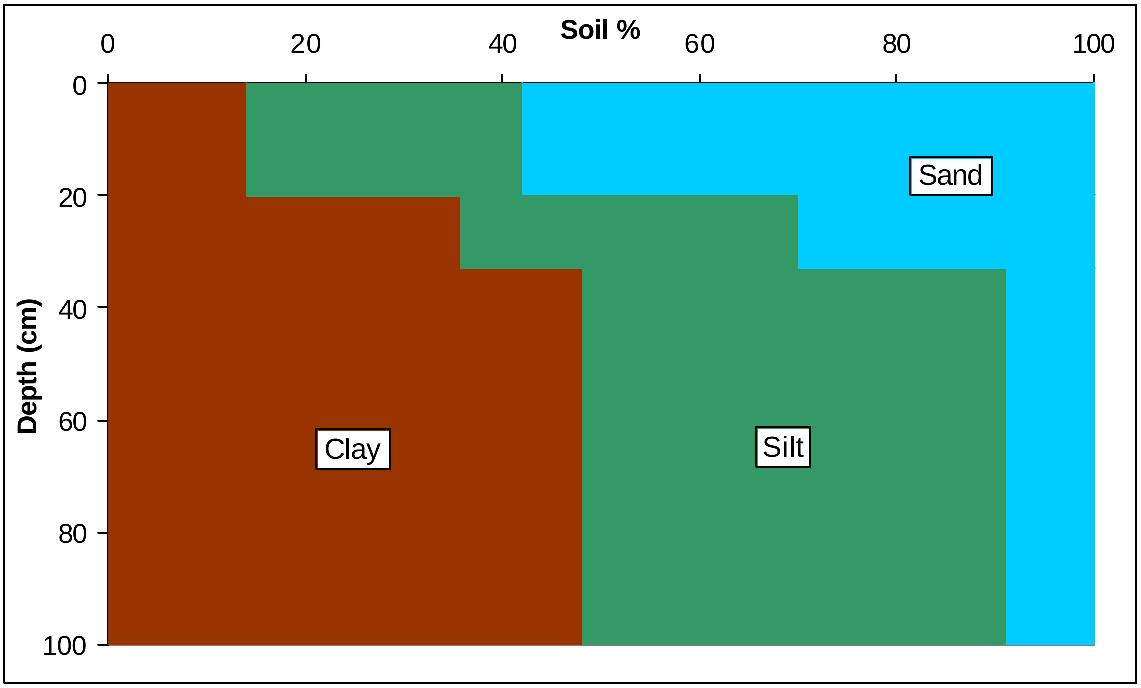

Figure 15b. Profile of soil textural composition for GA060, Southwest Mitchell County.

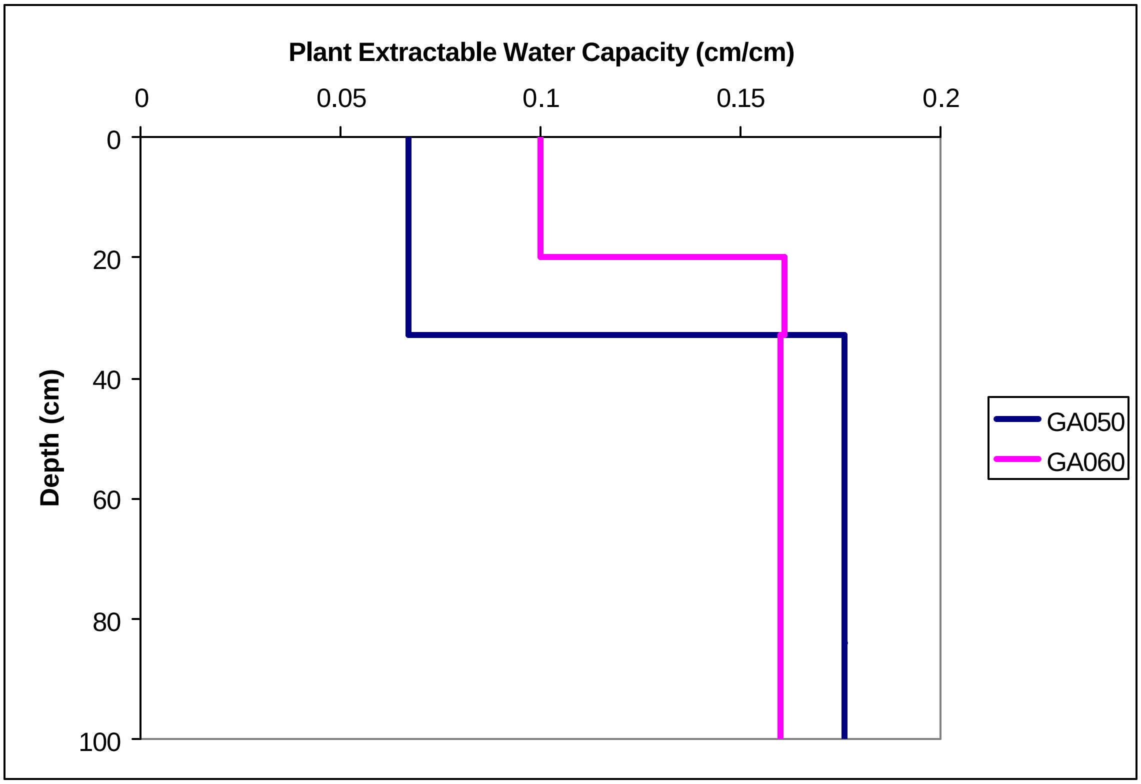

Figure 16. Comparison of profiles of plant extractable water capacity (PEWC) for soils GA050 and GA060. Integration of PEWC over the 100 cm profile yields total PEWC of 14.0 cm for GA050 and 14.8 cm for GA060.

Climate and Hydrologic Forecasts for Operational Water Resources

Basic Information

Title:	Climate and Hydrologic Forecasts for Operational Water Resources
Project Number:	
Start Date:	9/1/1999
End Date:	8/31/2002
Funding Source:	Other
Congressional District:	5th
Research Category:	Climate and Hydrologic Processes
Focus Category:	Management and Planning, Climatological Processes, Water Quantity
Descriptors:	Climate Forecasts, Decision Support Systems, Hydrologic Modeling, Optimized Multi-purpose Reservoir Operation, Global Circulation Models
Principal Investigators:	Aris P. Georgakakos

Publication

Progress Report

"Climate and Hydrologic Forecasts for Operational Water Resources Management: A Demonstration Project"

NOAA Grant NA96GP0408 (Award Period: 1 September 1999 to 31 August 2002)

Principle Investigators:
Aris Georgakakos
Georgia Water Resources Institute / Georgia Tech
and
Konstantine Georgakakos
Hydrologic Research Center / Scripps Institution of Oceanography

A. Activities of the Georgia Water Resources Institute (GWRI)

During the first project period, the Georgia Water Resources Institute worked on developing the background data and modeling elements for the Lake Norris demonstration project. The principal elements of the assessment framework are shown on Figure 1 and include (a) climate/hydrologic forecasting, (b) reservoir management, and (c) scenario assessment. The climate/hydrologic forecasting task for Lake Norris is undertaken by the Hydrologic Research Center (HRC) and is discussed in Section B of the report. Reservoir management is based on a decision system that includes three coupled models pertinent to turbine commitment and load dispatching, short/mid-term energy generation scheduling (hourly time steps), and long-term reservoir management (weekly time steps). The purpose of the scenario assessment element is to measure the benefit of using climate information within the integrated forecast-control process by replicating the system response under the guidance of the decision system.

Lake Norris data were obtained by TVA and used to develop the turbine commitment and load dispatching (TC&LD) and short-term energy generation models. The purpose of the TC&LD) model is to optimize hydro plant efficiency by determining the power load of each turbine such that a certain power level (for the entire plant) is generated at minimum discharge. This model requires the following inputs:

- beginning-of-the-period reservoir elevations;
- various turbine and reservoir characteristics (e.g., elevation vs. storage and tailwater vs. discharge relationships, power vs. net hydraulic head vs. discharge curves, and operational turbine ranges, among others);
- turbine outage schedule; and
- minimum and maximum discharge requirements.

The optimization problem associated with the TC&LD model is solved via Dynamic Programming and provides the maximum possible power associated with a particular discharge level, or (equivalently) the minimum discharge that achieves a particular power level. The role of the model is (1) to develop (off-line) the optimal (best efficiency) relationship among total outflow, total power generation, and reservoir elevation for each power plant, and (2) to determine (in an operational mode) the actual turbine loads that realize the discharge assigned to a particular plant from the upper level models. The first output is the connecting link between this and the short/mid-term energy generation model.

The first purpose of the short/mid-term model is to derive a near-optimal function among reservoir level, weekly release volume, and energy generation to be used by the long range control model. For a particular reservoir level and a weekly release volume, this relationship is obtained by determining the hourly plant releases that sum up to the given weekly volume and maximize energy generation. The complete function is developed by performing this off-line computation for various combinations of reservoir level and weekly release volume. This model requires the following inputs:

- the optimal level-discharge-power curve derived by the previous model;
- feasible reservoir level ranges; and
- minimum and maximum discharge requirements.

The second purpose of the short/mid-term model is to operationalize the weekly decisions of the long-term model by generating hourly release and energy generation schedules. The optimization process for this model is also carried out using dynamic programming.

Both models have been developed and are currently being tested for a variety of hydrologic and operational conditions. This process is scheduled for completion by the end of the first project phase (August 31, 2000). The second and third project phases will be dedicated to the development of the remaining models and the performance of the assessment investigations.

B. Activities of the Hydrologic Research Center

(Supported through a sub-contract to GWRI)

During the first project period, Hydrologic Research Center Staff in collaboration with regional National Weather Service Staff estimated the parameters of the operational Sacramento soil moisture accounting and channel routing model for both the 3,817-km^2 Clinch River at Tazewell, TN, and 1,774-km^2 Powell River at Cleveland, TN. Parameter estimation was accomplished using the methods and techniques described in NOAA-HRC (1999) using a quality-controlled database of daily data (precipitation, temperature, pan evaporation). (The database was developed as part of this project.) The Clinch and Powell Rivers provide the inflow to Lake Norris. Operational forecast models were used to allow the assessment of the value of climate information for the Lake Norris reservoir management in an operational environment.

The results of parameter estimation for the two Rivers are summarized in Figures HRC-1 and HRC-2. No significant biases exist in reproducing the annual cycle of monthly-averaged daily flows, and the variability of the flows, as indicated by the standard deviation of daily flows in each month, is reasonably well reproduced throughout the year. Slight underestimation of daily flow variability is observed for most of the winter and spring months for both catchments. The cross-correlation of daily observed and simulated flow for both catchments is about 0.9, which implies that the operational forecast model, running in simulation mode, explains approximately 80 percent of the observed daily flow variance.

For the remaining period of the first year of the project, we will develop baseline ensemble streamflow forecasts incorporating the uncertainty in precipitation and potential evapotranspiration forcing and model errors. We will validate such ensemble forecasts using reliability plots and scores (Carpenter and Georgakakos, 2000) and will provide such ensemble forecasts to the Georgia Tech team to produce quantify the benefits due to reservoir management resulting from such forecasts. These would be compared to simple regression forecasts that resemble the current operational forecasts used for the operational management of Lake Norris.

During the second year of the project we will use forecasts of global climate models (Canadian CGCM1 and ECHAM3) to condition the ensemble streamflow forecasts to allow evaluation of the value of climate information for the management of Lake Norris. Analysis of the reliability of the climate information for the region will also be performed.

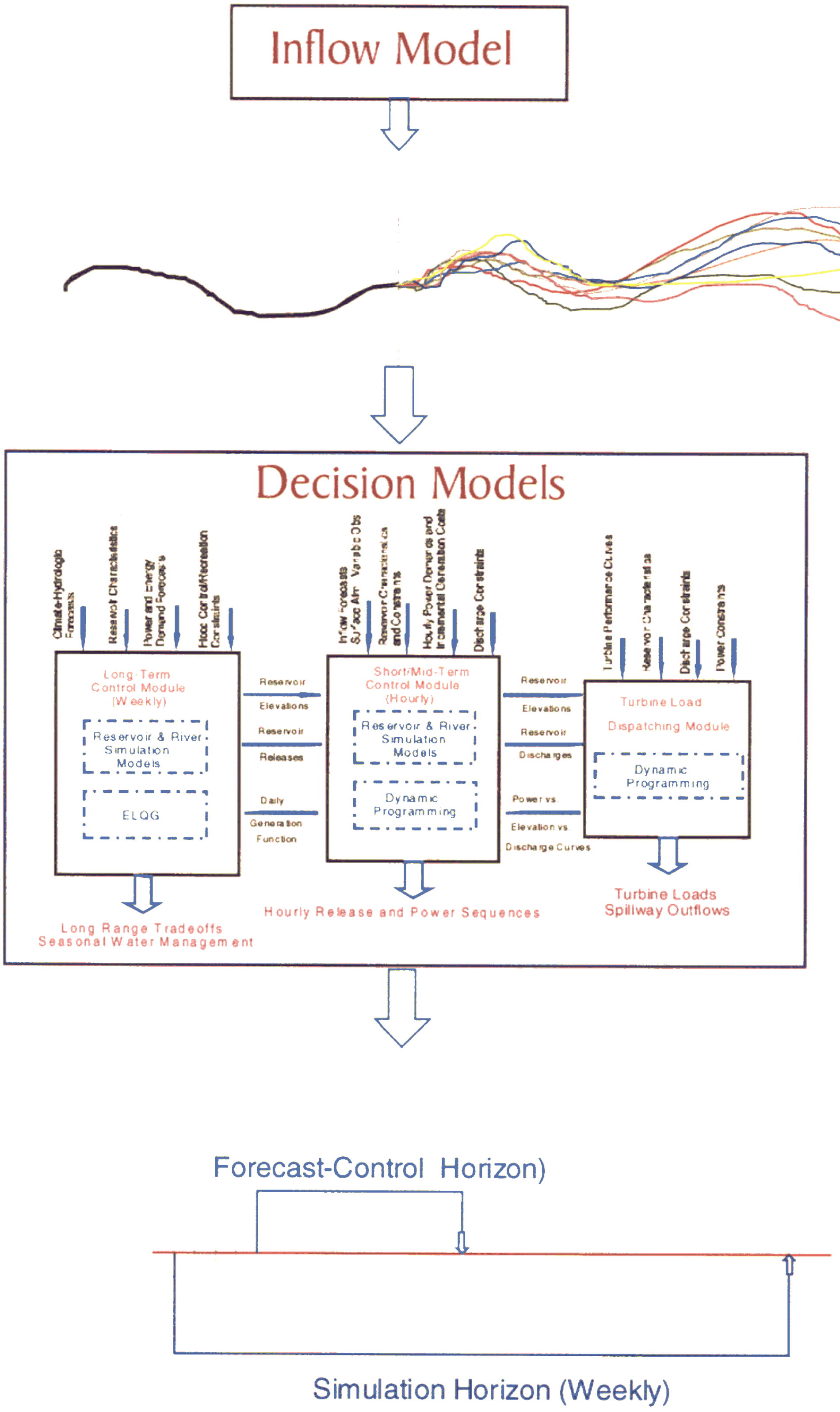

Figure GWRI-1: Modeling Framework and Assessment Process

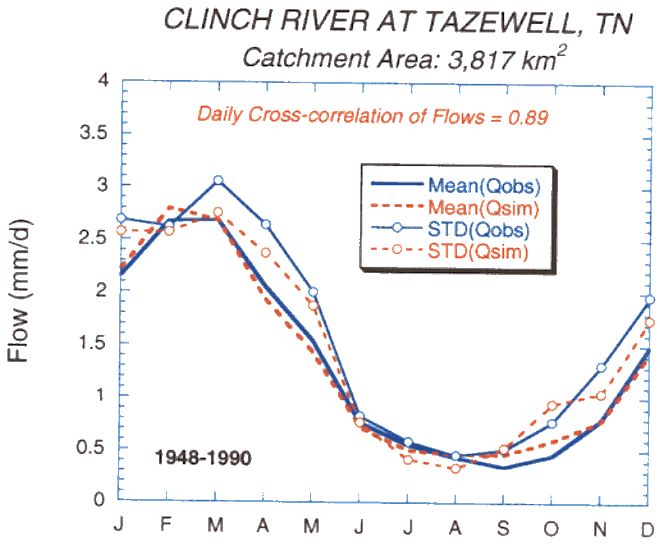

Figure HRC-1. Performance measures for Clinch River catchment for period 1/1/1948-12/31/1990.

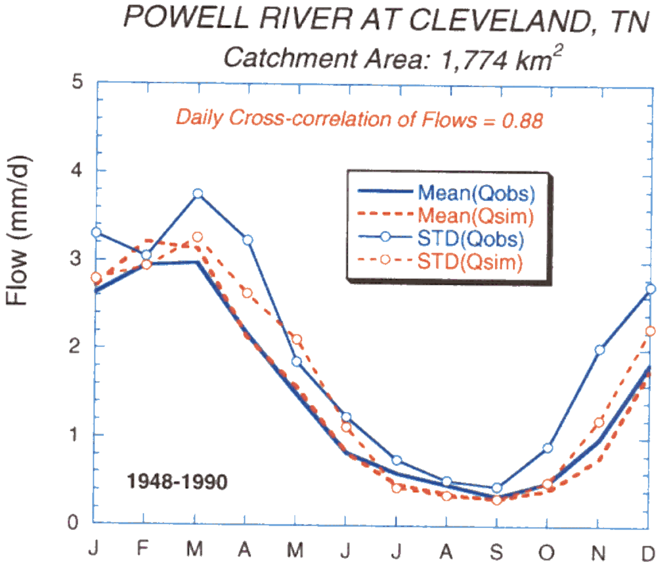

Figure HRC-2. Performance measures for Powell River catchment for the period 1/1/1948-12/31/1990.

Biological Integrity Flow Assessment for the ACF and ACT River Basins

Basic Information

Title:	Biological Integrity Flow Assessment for the ACF and ACT River Basins
Project Number:	
Start Date:	4/15/2000
End Date:	2/14/2002
Funding Source:	Other
Congressional District:	5th
Research Category:	Biological Sciences
Focus Category:	Water Quantity, Hydrology, Drought
Descriptors:	Flow requirements, In-stream Biological Integrity, Trade-off Analysis, Interbasin Transfer
Principal Investigators:	Aris Peter Georgakakos

Publication

Impacts of Biological Integrity Requirements on ACF Water Uses

1. Scope of Study

The purpose of this study is to assess the response of the ACF river basin to biological integrity requirements. These requirements are quantified in a preliminary guidance document drafted by US EPA and the Fish and Wildlife Service (1999).

2. Technical Approach

The underlying approach of this investigation is to incorporate the EPA biological integrity requirements within the ACF-DSS (a decision support system developed by Georgia Tech) and assess the impact of these requirements on the other basin water uses. The ACF-DSS has been described in detail in a separate report. A short discussion of the biological integrity requirements (BIR) follows.

The BIR are based on information gathered from life-history and habitat-use studies of particular species and species-groups native to streams and rivers in the ACF-ACT basins, and from data relating biological integrity to hydrologic alteration in specific basin segments.

The US Environmental Protection Agency (EPA) and the US Fish and Wildlife Service have translated this information into five instream flow guidelines relative to low, average, and high flow conditions, namely:

- monthly 1-day minimum flow;
- annual low flow duration;
- monthly average flow;
- annual 1-day maximum flow;
- annual high flow duration.

The inter-annual frequency component of these guidelines is as important as the flow magnitude. Aquatic populations can survive extremely stressful conditions and persist without essential habitat conditions occasionally, but not for many years in succession.

The following text is based on the EPA/FWS document (unpublished report entitled *Instream Flow Guidelines for the ACT and ACF Basins Interstate Water Allocation Formula, 1999)* and presents a justification for each of the guidelines used in the sensitivity runs described herein.

Monthly 1-Day Minimum Flow

Extreme low flows are likely among the most stressful natural events faced by river biota. As flow levels decrease, available habitat constricts and portions of the channel eventually become dry. Aquatic animals that are unable to move to remaining pools or burrow into the moisture of the stream bed itself perish.

Because of the physical and biological harshness of extreme low-flow conditions, decreasing the magnitude of the lowest 1-day flow events at a particular time of year, or increasing the inter-annual frequency of these events is likely to have detrimental effects on native river biota.

From a hydrologic frequency standpoint, this requirement can be quantified as follows: Using the complete discharge record at a particular location, compute the 1-day minimum for each month of the year in all years. Compute the minimum, 25th percentile, and 50th percentile of these values. Then, the 1-day minimum flow requirement is to simultaneously satisfy the following conditions:

- exceed the minimum in all years;
- exceed the 25th percentile in 3 out of 4 years; and
- exceed the 50th percentile (median) in half of the years.

Annual Low-Flow Duration

This guideline addresses the more ‘chronic’ effects of extended periods of flows less than average, but greater than the 1-day minimum. The critical element of this guideline is the definition of the low-flow threshold, which is based upon current velocity in pool habitats and an apparent relationship with average annual discharge.

Current velocity decreases with decreasing discharge. Extreme reduction of current velocity is detrimental for river biota, many of which depend on flowing water to deliver food, maintain oxygen/temperature levels, prevent excessive silt deposition on the stream bottom, and allow for successful reproduction. The Annual Low-Flow Duration guideline is intended to prevent excessive loss of flowing-water conditions in pools.

The guideline is defined as follows: Using the complete daily discharge record at a particular location, compute the average annual discharge (AAD) for each calendar year and the average of these annual values. Compute the number of days per year for all calendar years during which daily flow discharge is less than 25% of the AAD. Compute the maximum, 75th percentile, and 50th percentile (median) of these values. For each year, the guideline is

- do not exceed the maximum in all years;
- do not exceed the 75th percentile in 3 out of 4 years;
- do not exceed the 50th percentile in half of the years.

ACF-DSS has been modified to incorporate the previous flow magnitude and frequency constraints at six locations. These locations include Atlanta, Columbus, Chattahoochee, Griffin, Albany, and Bainbridge. In view of the weekly time resolution of the ACF-DSS, the BIR conditions were applied to weekly flow data. These flow statistics are included in the appendix.

4. Description of Sensitivity Experiments

Four series of sensitivity runs were performed and the results post-processed to assess the ACF response to the biological integrity requirements and other water uses. These runs are described below:

4.1 Impact of BIR on Reservoir Levels and Water Supply

Three runs were conducted in this series. The first run is a baseline scenario with the following specifications:

- water withdrawals will occur at the Georgia 2030/2050 projected demand levels;
- peak power generation is limited to 1 hour per weekday;
- one 14-day navigation window at the Apalachicola reach is in effect for September;
- minimum flow constraints at Atlanta, Columbus, and Chattahoochee are respectively 750 cfs, 1650 cfs, and the 1-year monthly minimum flows.

The second run is the baseline scenario with the addition of the BIR at the above-mentioned six locations. Lastly, the third run is the baseline scenario with the addition of the BIR (as in the second run) but also a uniform reduction of water withdrawals by 40%.

4.2 Sensitivity with respect to BIR and Flint Water Withdrawals

This sensitivity series includes four runs. The first is a run conducted previously using the baseline scenario with the addition of the BIR. The other three runs are identical to the first with the exception of a gradual reduction of the water withdrawals along the Flint River. These reductions amount to 0.8, 0.6, and 0.0 of the original demands.

4.3 Sensitivity with respect to BIR and Upper Chattahoochee Water Withdrawals

This sensitivity series includes three runs. The first is a run conducted previously using the baseline scenario with the addition of the BIR. The other two runs are identical to the first with the exception of a gradual reduction of the water withdrawals upstream and including the Atlanta gage. These reductions amount to 0.8 and 0.6 of the original demands.

4.4 Sensitivity with respect to peak generation hours

This sensitivity series includes three runs. The first is the last run of the 4.1 sensitivity series [BIR combined with 0.6 x (water demands)]. The other two runs are identical to the first with the exception of a gradual increase in peak generation hours (at the federal facilities) to two and three hours per weekday respectively.

5. Assessment Results

The results of the sensitivity runs are summarized in a series of figures and tables included in the Appendix. For each run, the following information is presented:

- reservoir elevation sequences from 1939 to 1993;
- flow duration frequencies at Atlanta, Columbus, Chattahoochee, Griffin, Albany, and Bainbridge;
- energy generation statistics;
- BIR violation frequency at the above-mentioned six locations; and
- total water withdrawal deficit over the simulation period (only for last sensitivity run).

These results support the following conclusions:

5.1 Comments Pertaining to the 1st Sensitivity Run

- Under the guidance of the ACF-DSS and for the baseline scenario, the response of the ACF basin is favorable (no BIR imposed). Namely, all minimum flow constraints are met, reservoir level fluctuations are relatively mild, and water deficits do not occur anywhere in the basin.

- However, post-processing of the baseline results indicate severe BIR violations. For example, the 50th percentile violation frequency at the Atlanta gage exceeds 95% from June to October, that of the 25th percentile exceeds 80% from June to December, and that of the minimum flow exceeds 20% for February and March. Furthermore, low flow duration (LFD) violations occur for Columbus and Chattahoochee.

- After explicitly imposing the BIR in the ACF-DSS, the BIR violation frequencies are reduced significantly, but continue to be higher than the expected values. More specifically, the 50th percentile highest violation frequency at the Atlanta gage is 75% (November), that of the 25th percentile is 46% (November), while no violations are recorded for the minimum BIR flow level. LFD violations are completely eliminated for Atlanta, Columbus, and Chattahoochee, while they are identical to the baseline for Griffin, Albany, and Bainbridge. The latter is expected due to the absence of a sizable regulatory project on the Flint River basin.

- However, these improvements come at the expense of severe reservoir drawdowns throughout the basin, with Lake Lanier affected the most.

- Imposing the BIR does not cause water shortages and does not appreciably impact energy generation, provided that reservoir policies are determined by the ACF-DSS.

- As the third run indicates, to fully comply with the BIR, basin-wide water withdrawals would have to be reduced to 60% of the original levels. In this scenario, reservoir levels would be affected somewhat less than the in the second scenario.

- It is re-emphasized that the previous basin response requires the use of the ACF-DSS dynamic policies. Implementation of other reservoir operating rules are likely to lead to performance degradation.

5.2 Comments Pertaining to the 2nd Sensitivity Run

- The sensitivity with respect to the Flint water withdrawals indicates that the impacts on reservoir response, energy generation, and BIR violations are relatively small. However, if future droughts are more severe than those that occurred historically, this effect would most likely amplify.

5.3 Comments Pertaining to the 3rd Sensitivity Run

- The results of the sensitivity runs relative to the Atlanta water withdrawals show that as these water withdrawals decrease, the BIR violations at Atlanta decrease toward compliance. In fact, the water withdrawals would have to be reduced to 60% of the original level for the BIR conditions to be met at Atlanta and throughout the Chattahoochee-Apalachicola system. (As expected, the Flint violations remain unchanged.)

- Energy generation and Lake Lanier levels increase as Atlanta water withdrawals decrease.

5.4 Comments Pertaining to the 4th Sensitivity Run

- The peak power sensitivity runs indicate that the ACF system can support up to 2 hours of peak generation without significant water deficits or BIR violations. (It is reminded that this conclusion applies for reduced (60% of baseline) basin-wide water withdrawals.) At 3 peak generation hours, water deficits begin to occur at the Upper Chattahoochee basin, and the minimum flow BIR conditions are violated at Atlanta and Columbus. It is noted that the 25th and 50th percentile BIR conditions improve as a result of consistently higher discharges. By contrast, Atlanta's annual low flow duration (LFD) requirement cannot be met.

- As peak power generation increases, reservoir levels experience high fluctuations and more persistent drawdowns. At the same time, primary energy generation increases, while overall generation (including primary and secondary energy) remain unchanged.

6. Conclusion

The study indicates that biological integrity requirements (BIR) may affect other ACF water uses, with the principle tradeoffs being between BIR, water supply, and reservoir levels. This stress is particularly evident in the Upper Chattahoochee Basin.

From a modeling standpoint, the ACF-DSS can effectively implement BIR conditions and explore their influence on other basin water uses. Further work is needed, however, to assess the ACF ability to meet biological integrity requirements during severe droughts, especially as they relate to daily time scales.

A Decision Support Tool for the Nile Basin

Basic Information

Title:	A Decision Support Tool for the Nile Basin
Project Number:	
Start Date:	5/1/2001
End Date:	6/29/2003
Funding Source:	Other
Congressional District:	5th
Research Category:	Climate and Hydrologic Processes
Focus Category:	Management and Planning, Water Use, Solute Transport
Descriptors:	Decision Support System, Reservoir Control and Operation, Water Resources Management and Planning, Flood and Drought Managment, Hydropower, Remote Sensing, Agricultural Planning, International Cooperation
Principal Investigators:	Aris P. Georgakakos

Publication

Problem and Research Objectives

The Nile River Basin is spread over ten countries covering an area of 3.1 million km^2 or approximately 10 percent of the African continent. The river discharge per unit drainage area is small, and almost all Nile water is generated from only 20 percent of the basin, while the remainder is in arid or semi-arid areas. Each region of this large watershed has distinct hydrologic features, water use requirements, and development opportunities.

This project is a collaborative effort among the Nile Basin countries, the Food and Agriculture Organization of the United Nations, and GWRI that has two primary objectives:

- Develop a comprehensive decision support tool to support the information needs of the Nile Basin stakeholders, and
- Transfer the decision support tool technology and associated knowledge base to the Nile Basin engineers and planners.

Methodology

The Nile Basin Decision Support Tool (NBDST) is composed of the following modules:

- Database: Data covering the entire basin for meteorology, hydrology, soil, terrain, land cover/land use, socio-economics, and infrastructure are to be compiled and assimilated into a user accessible database that includes GIS and presentation capabilities.
- Remote sensing of precipitation: Visible and infrared signals as received by geo-stationary satellites allow for estimation of precipitation where no ground measurements exists.
- Agricultural planning: Using detailed models of crop physiology and novel irrigation scheduling methods, a user can evaluate various scenarios of agricultural development to assess irrigation needs, food production, economic tradeoffs, etc.
- Watershed hydrology: The rainfall-streamflow response of sub-watershed in the river basin is modeled for purposes of streamflow prediction, reservoir inflows, soil moisture estimation, etc.
- River simulation and reservoir management: Optimized control processes are applied to the reservoirs in the basin for purposes of determining tradeoffs under various management scenarios. Objectives such as hydropower, irrigation, domestic water supply, and ecological integrity are assessed in their relationship vis-à-vis each other.

Technology transfer will occur through training seminars given by GWRI personnel in the Nile Basin and through extended training periods for Nile Basin personnel resident at GWRI.

Information Transfer Program

2001 Georgia Water Resources Conference

Basic Information

Title:	2001 Georgia Water Resources Conference
Project Number:	2001GA16O
Start Date:	3/26/2001
End Date:	3/27/2001
Funding Source:	Other
Congressional District:	11th
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	Water Resources, Water Policy, Water Quality, Watershed Protection, Groundwater
Principal Investigators:	

Publication

1. 2001 Proceedings of the Georgia Water Resources Conference; Athens, Georgia

The seventh biennial conference was held on March 26-27, 2001, at the University of Georgia. This is a forum for the discussion of current water policies, research, studies, and water management in Georgia. It provides:

- a forum for exchange of ideas and information for water resources professionals,
- an update on the current water resources situtation in Georgia, and
- transfer of data, technology and management information.

The conference is sponsored by:

- U.S. Geological Survey,
- Georgia Department of Natural Resources,
- University of Georgia,
- Georgia Tech Water Research Institute, and
- Natural Resources Conservation Service.

The conference included six tracks:

- Water Policy and Management
- Appalachicola- Chattahoochee- Flint (ACF) Water Issues
- Watershed Protection
- Water Quality,
- Atlanta Water Quality, Wasteload Allocation, TMDL
- Groundwater and Coastal Issues

Computation Fluid Dynamics for Complex Turbulent Flows

Basic Information

Title:	Computation Fluid Dynamics for Complex Turbulent Flows
Project Number:	2001GA17O
Start Date:	5/7/2001
End Date:	5/9/2002
Funding Source:	Other
Congressional District:	5th
Research Category:	Engineering
Focus Category:	Models, Methods, None
Descriptors:	CDF, Turbulent Flow
Principal Investigators:	

Publication

This continuing education course reviewed the fundamentals of and latest advancements in turbulence modeling for three-dimensional flows and addressed a number of important numerical issues that are critical for accurate predictions of flow and transport processes in environmental and industrial applications. The course was developed for research engineers, consultants, and managers involved in the application and/or development of Computational Fluid Dynamics (CFD) software. Fourteen students attended the course.

Hydrologic Engineering for Dam Design

Basic Information

Title:	Hydrologic Engineering for Dam Design
Project Number:	2001GA18O
Start Date:	10/15/2001
End Date:	10/17/2001
Funding Source:	Other
Congressional District:	5th
Research Category:	Climate and Hydrologic Processes
Focus Category:	Education, Hydrology, Water Quantity
Descriptors:	Dam Design, Hydrology, Continuing Education
Principal Investigators:	

Publication

The Hydrologic Engineering for Dam Design continuing education course was held October 15-17, 2001. The class was developed for hydrologic engineers in private practice or with federal, state, county or city agencies involved with the hydrologic design or evaluation of dams. The course covered probable maximum precipitation, intensity-duration-frequency data, hydrographs, hydraulic and hydrologic routing methods, spillways, freeboard computation and dam break analysis. Seven students attended the course.

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 RCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	1	0	0	1	2
Masters	1	0	0	1	2
Ph.D.	1	0	1	4	6
Post-Doc.	0	0	0	0	0
Total	3	0	1	6	10

Notable Awards and Achievements

Publications from Prior Projects