

Report for 2001GA4141B: Investigation in the role of oxidized iron in the surface water phosphorus dynamics in the Georgia Piedmont

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Report Follows:

Final Report

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

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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 μ m 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 μ g P per tube. The tubes were shaken for 24 or 48 hours, vacuum filtered through a 0.45 μ m filter, and the filtrate was stored at 4°C 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 μ m 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 phosphate. 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/nitrite 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.

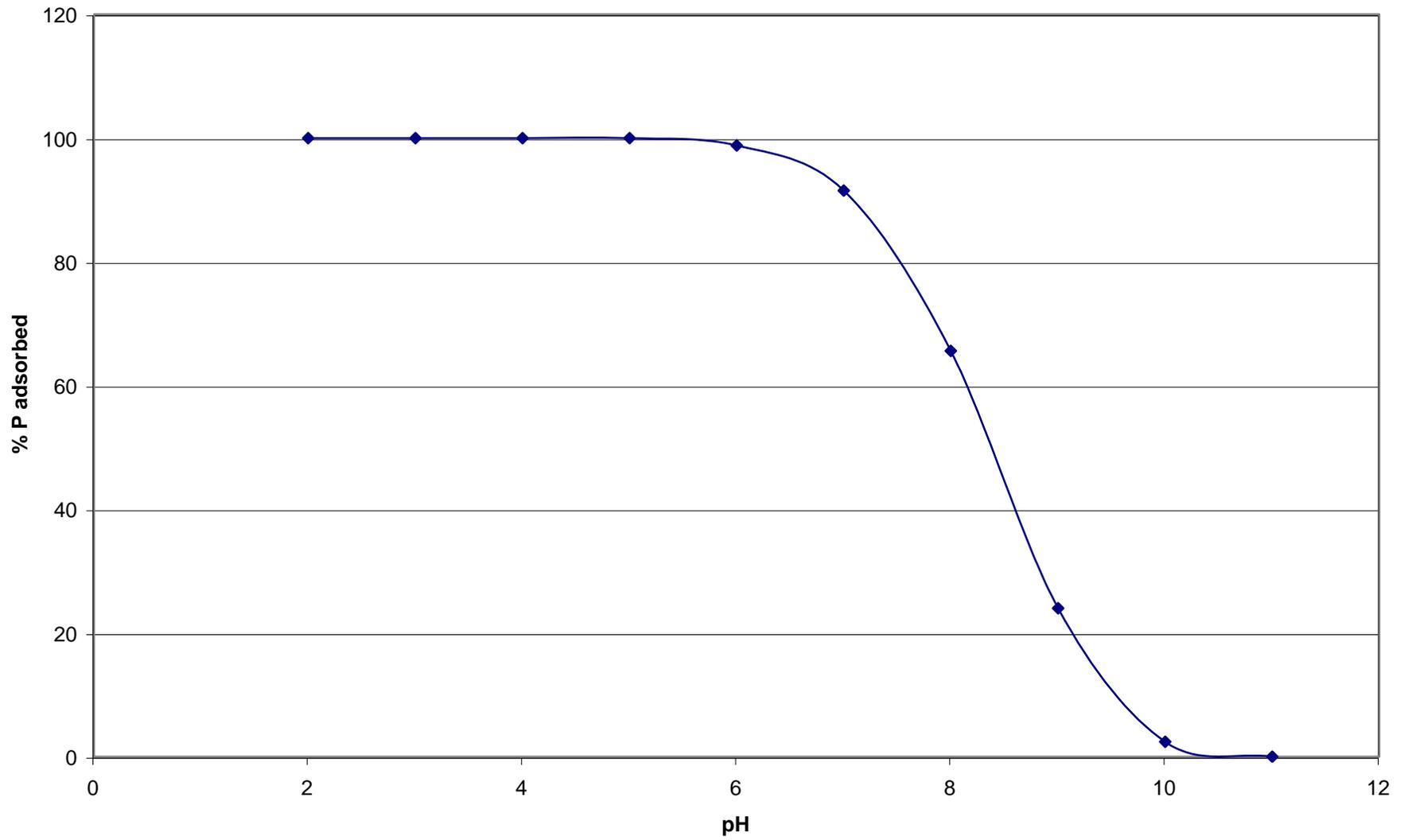


Figure 2. 24 hour sorption capacity experiment.

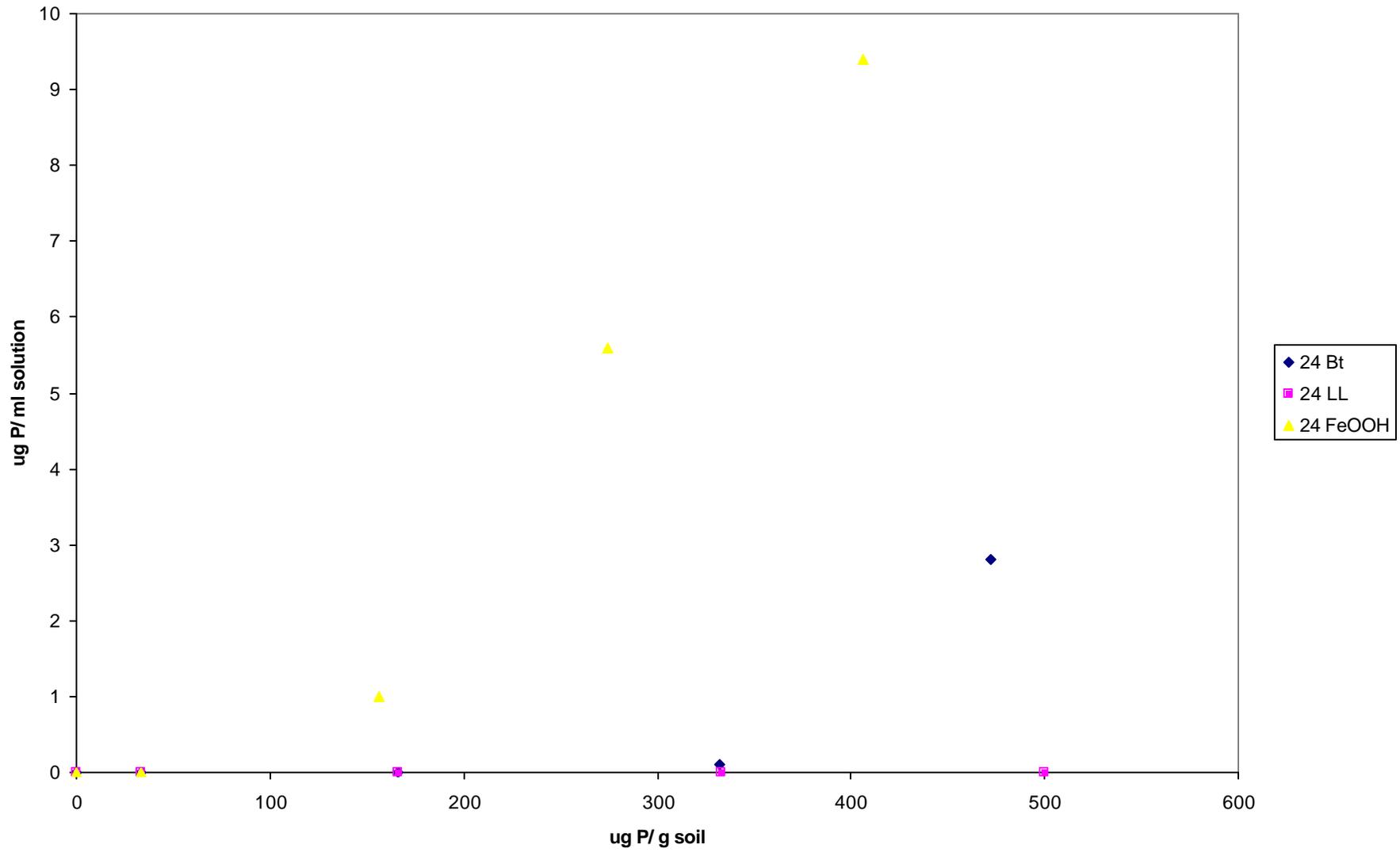


Figure 3. 48 hour sorption capacity experiment.

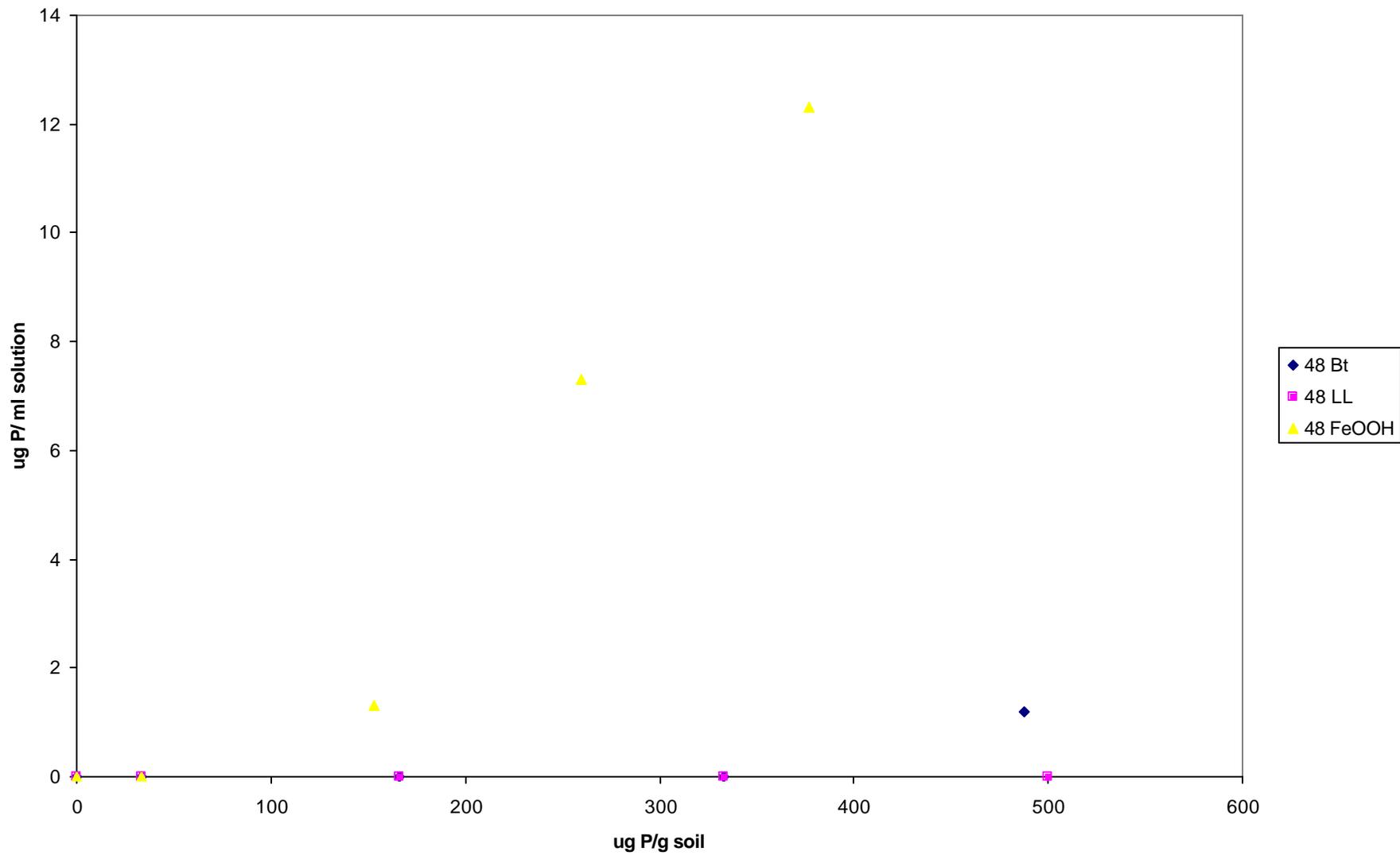


Figure 4. Sorption capacity experiment with humates added as Agrolig powder.

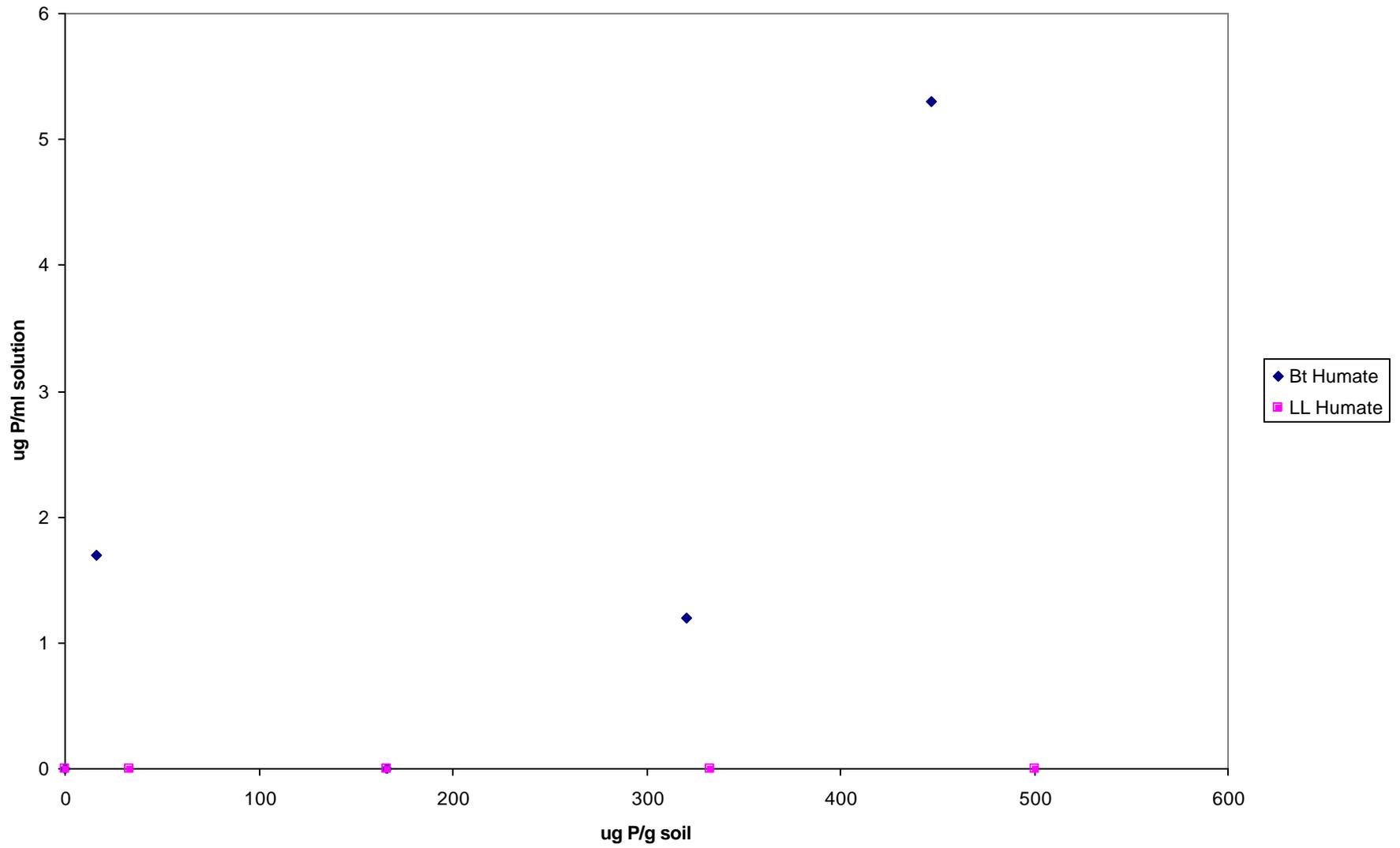


Figure 5 a. Browns Bridge water quality profiles for April 2001.

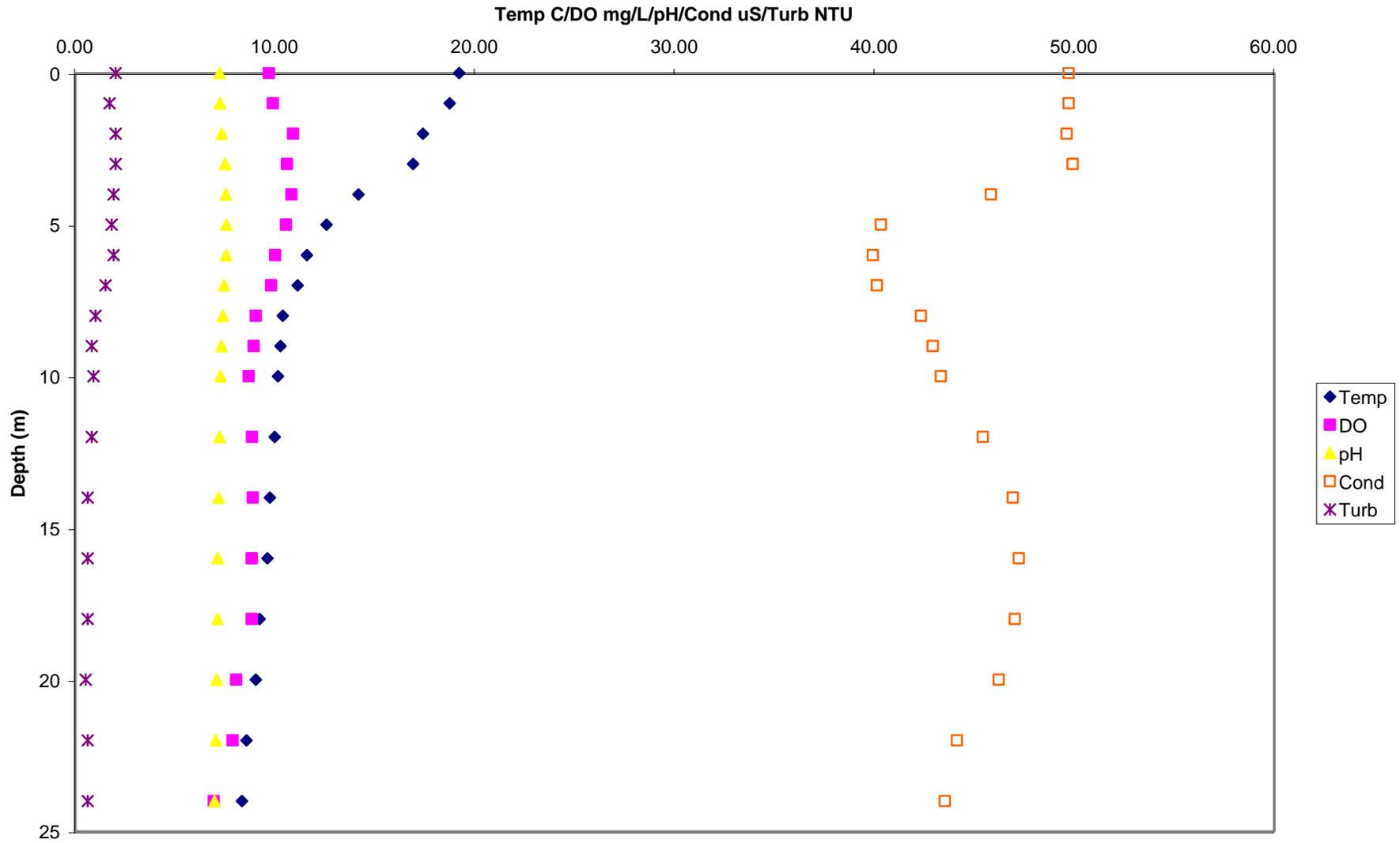


Figure 5 b. Browns Bridge water quality profiles for August 2001.

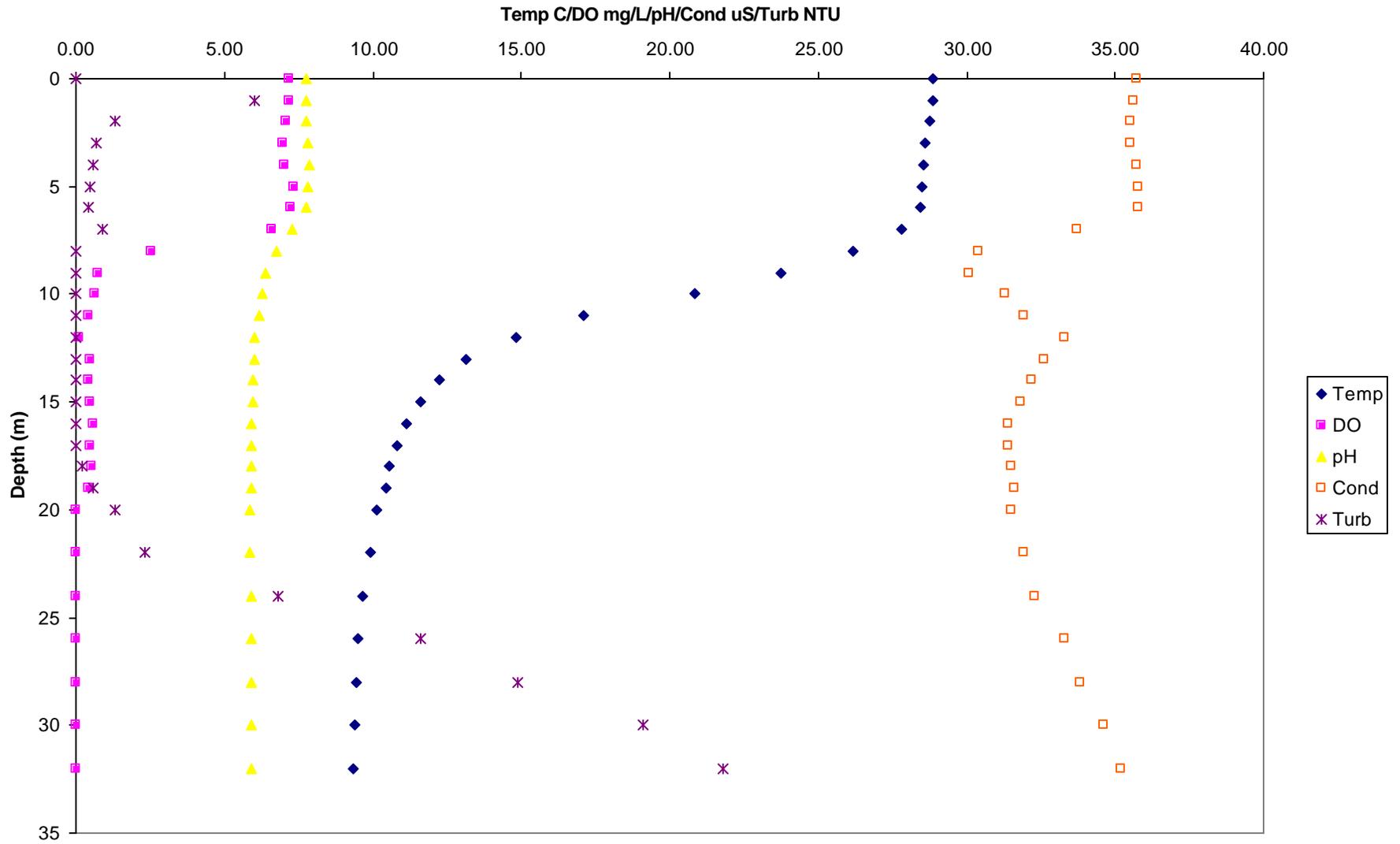


Figure 5 c. Browns Bridge water quality profiles for December 2001.

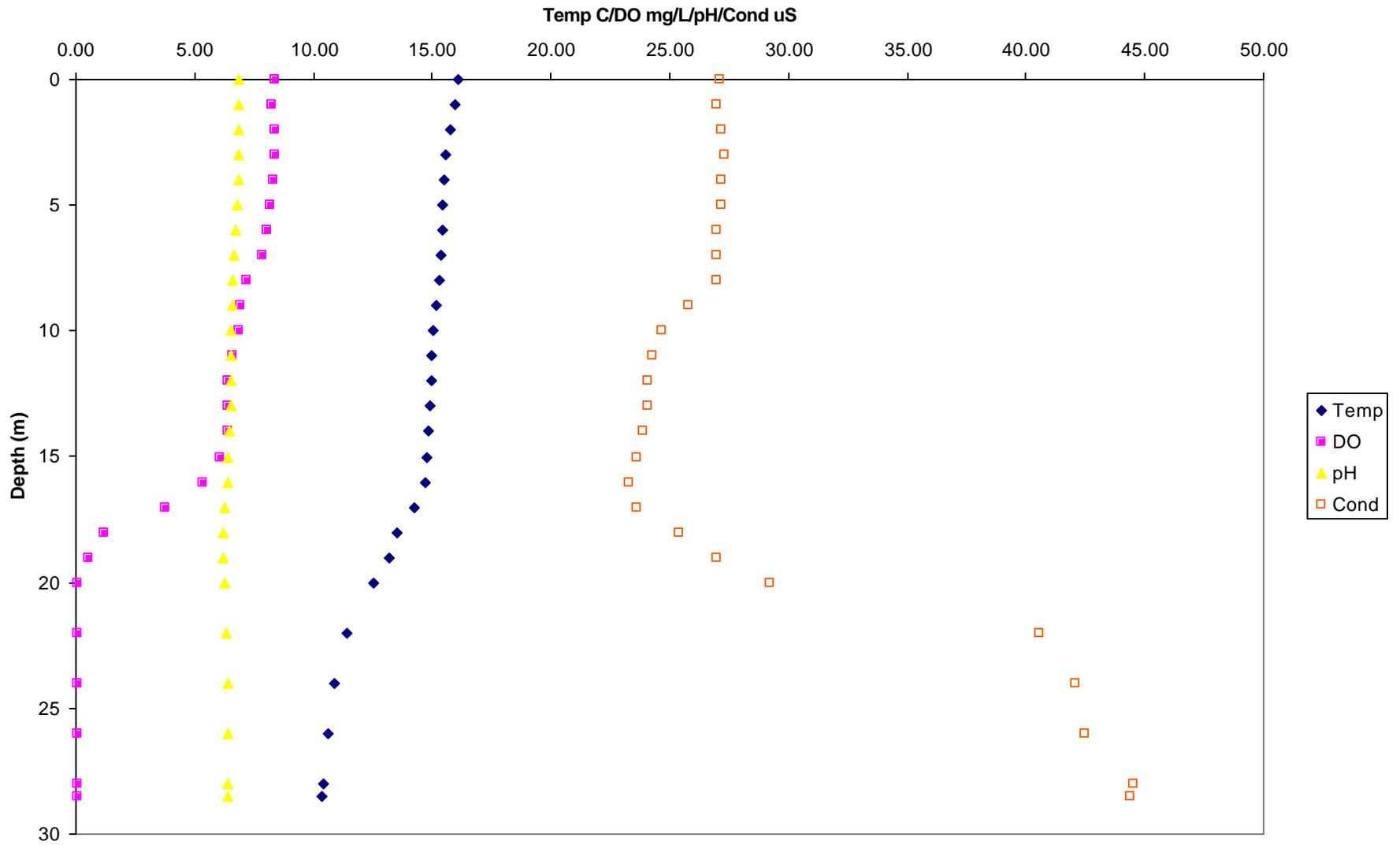


Figure 5 d. Browns Bridge water quality profiles for February 2002.

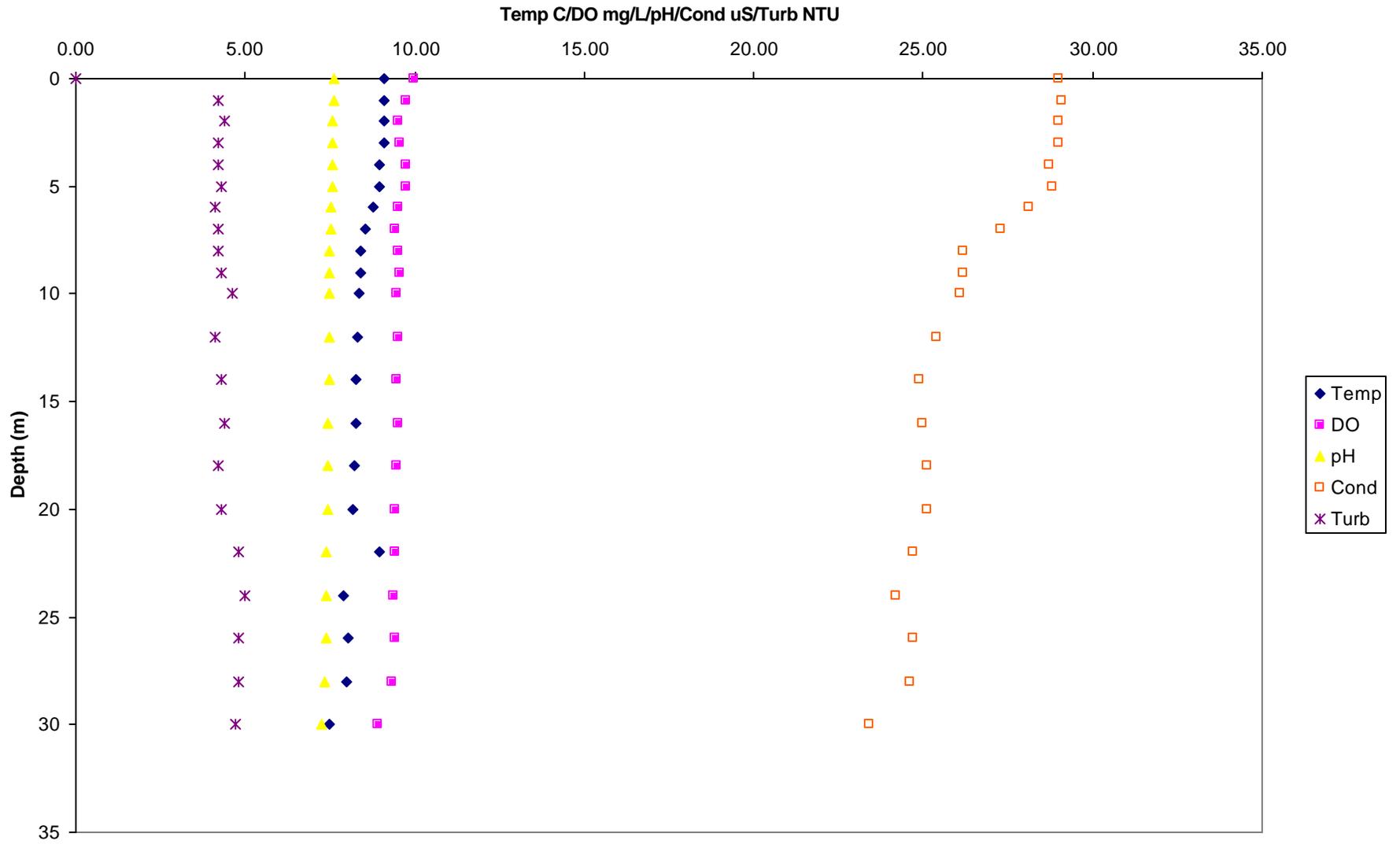


Figure 6 a. Flat Creek embayment water quality profiles April 2001.

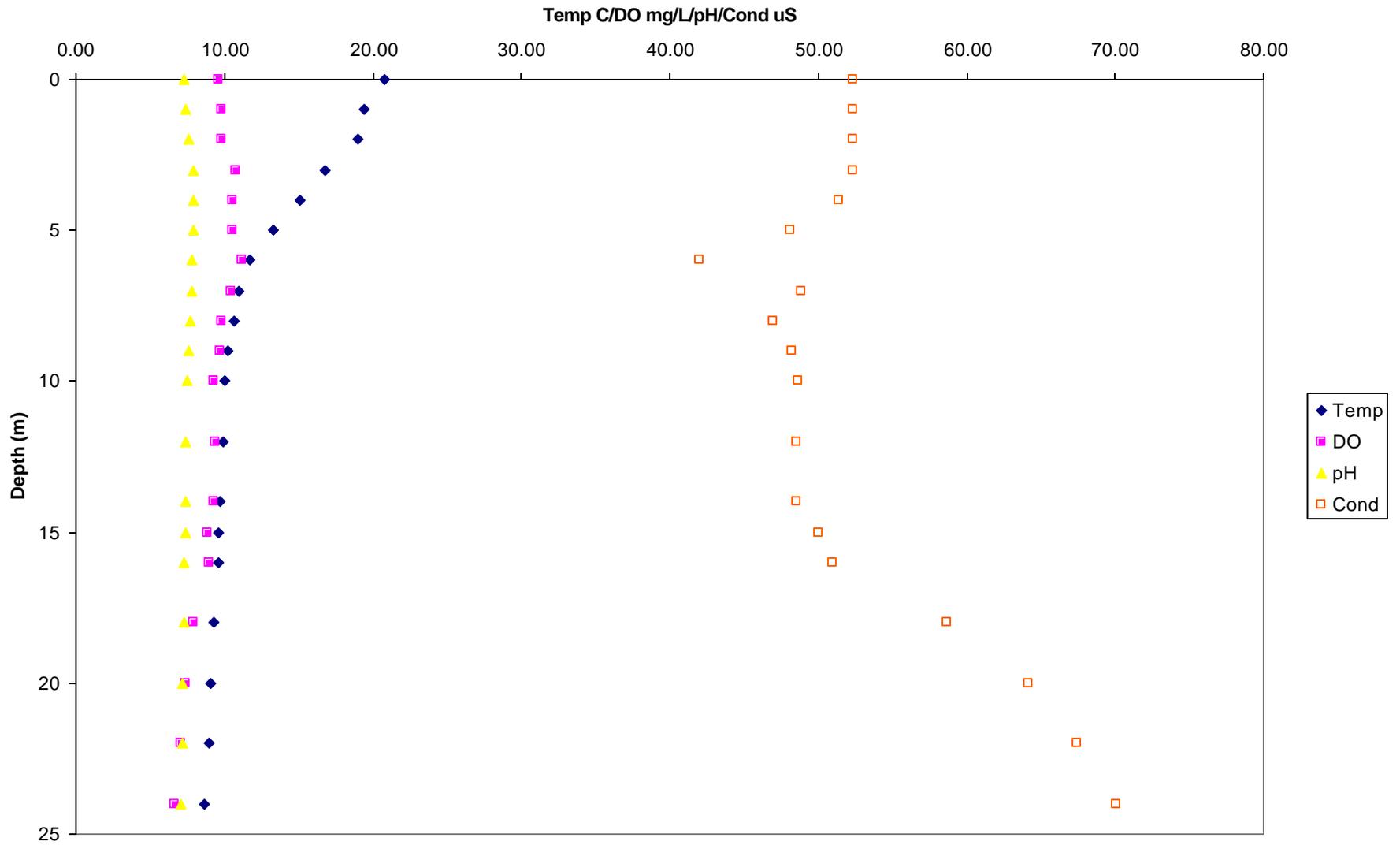


Figure 6 b. Flat Creek embayment water quality profiles August 2001.

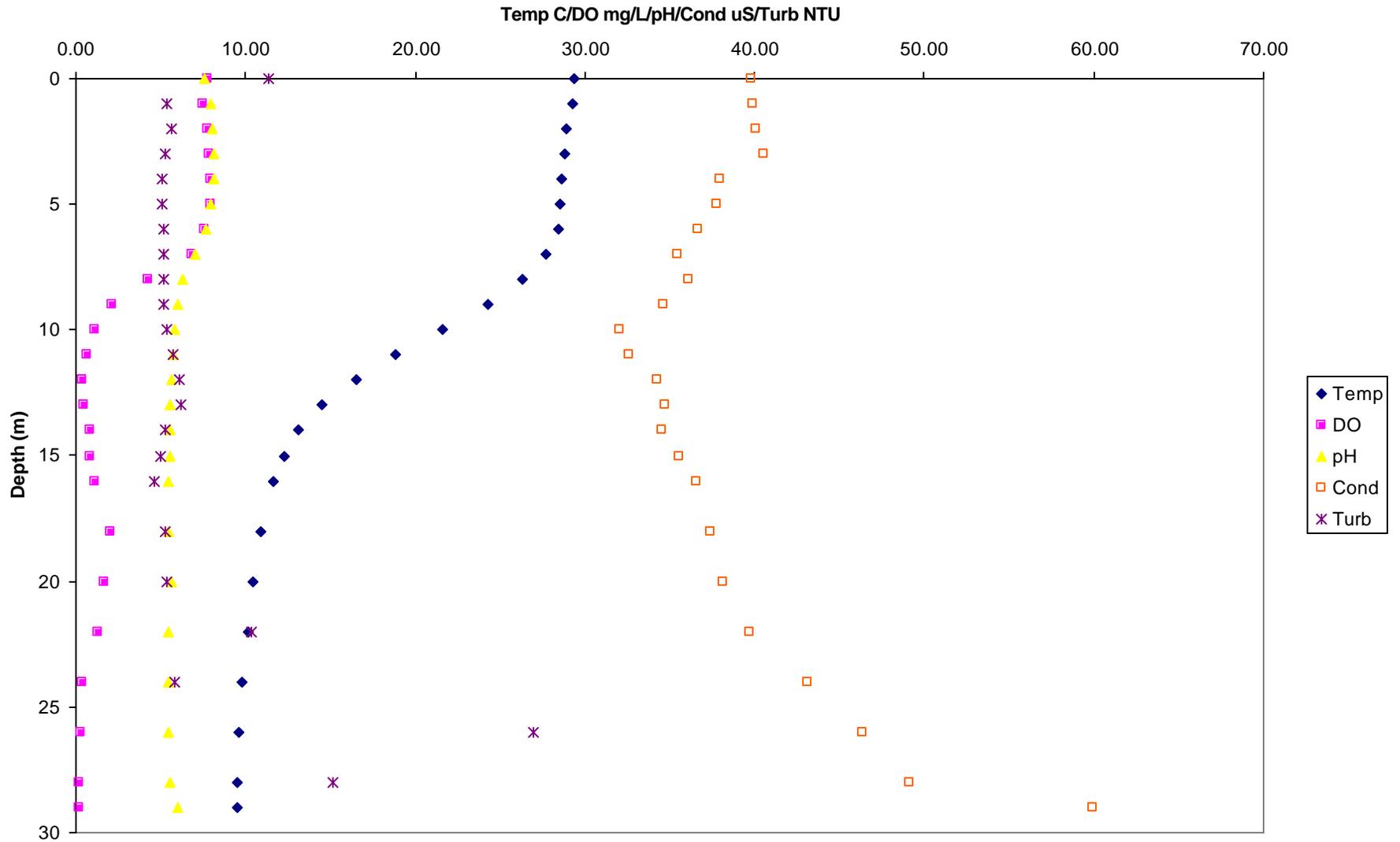


Figure 6 c. Flat Creek embayment water quality profiles December 2001.

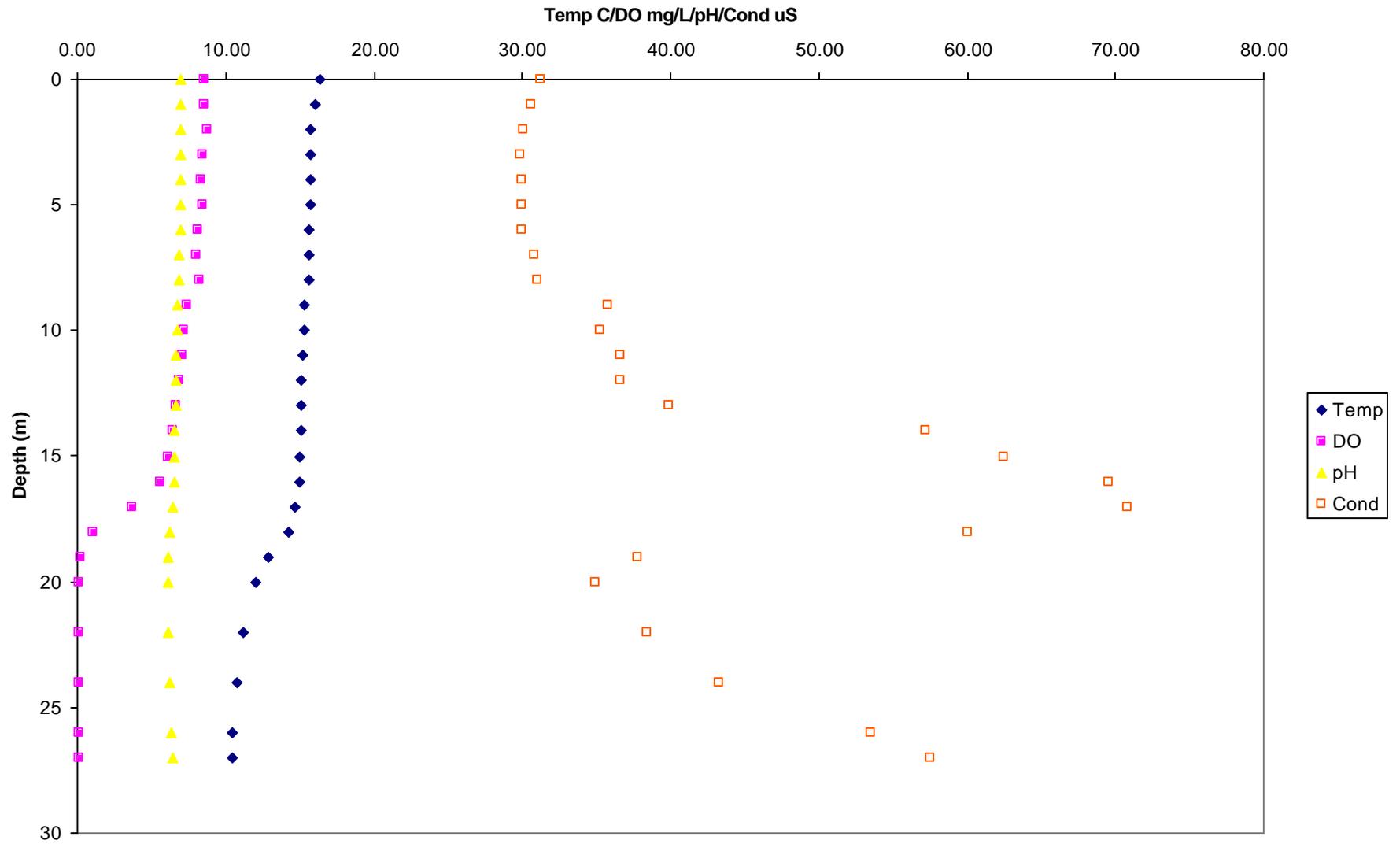


Figure 6 d. Flat Creek embayment water quality profiles February 2002.

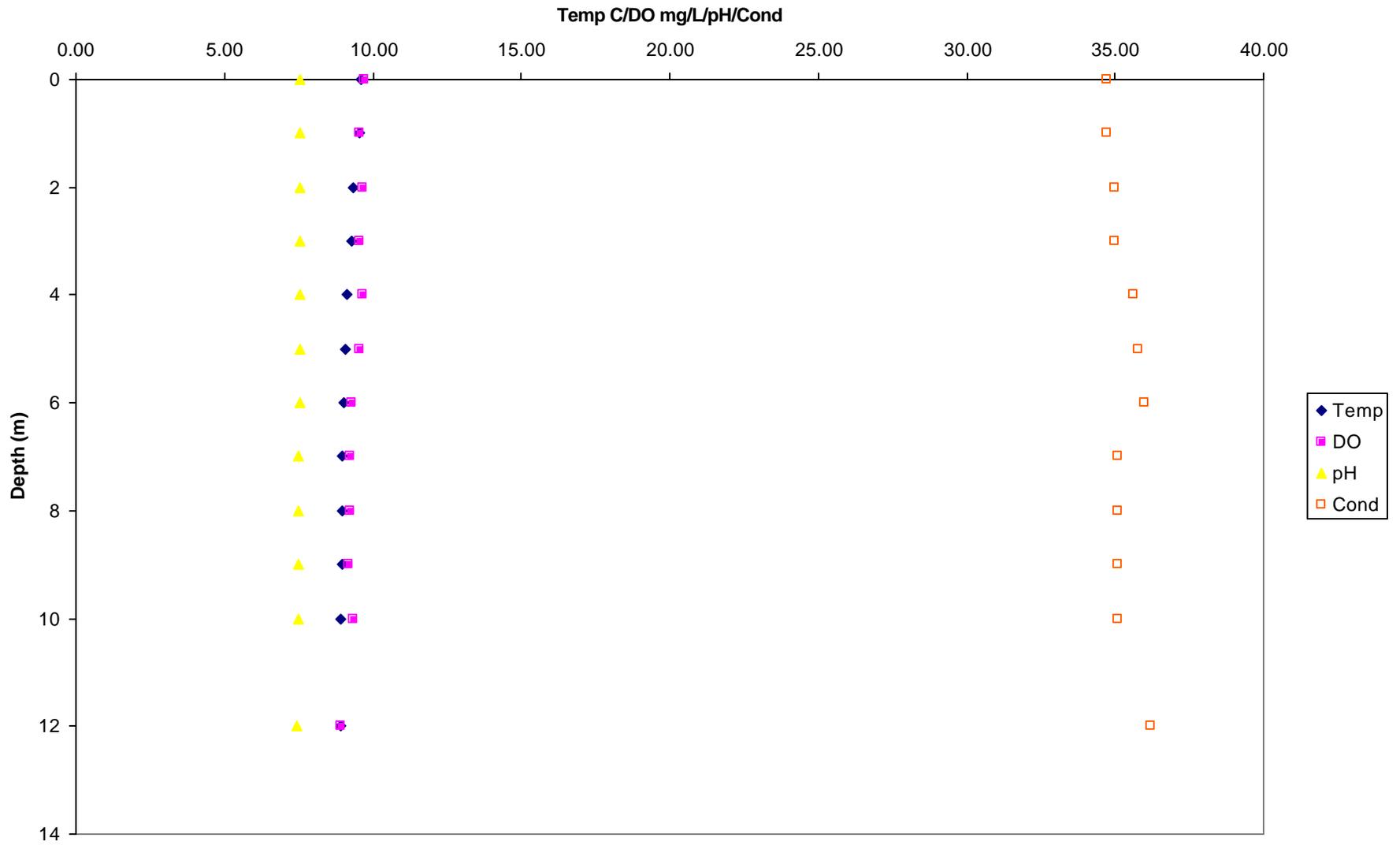


Figure 7 a. Flowery Branch Channel water quality profiles April 2001.

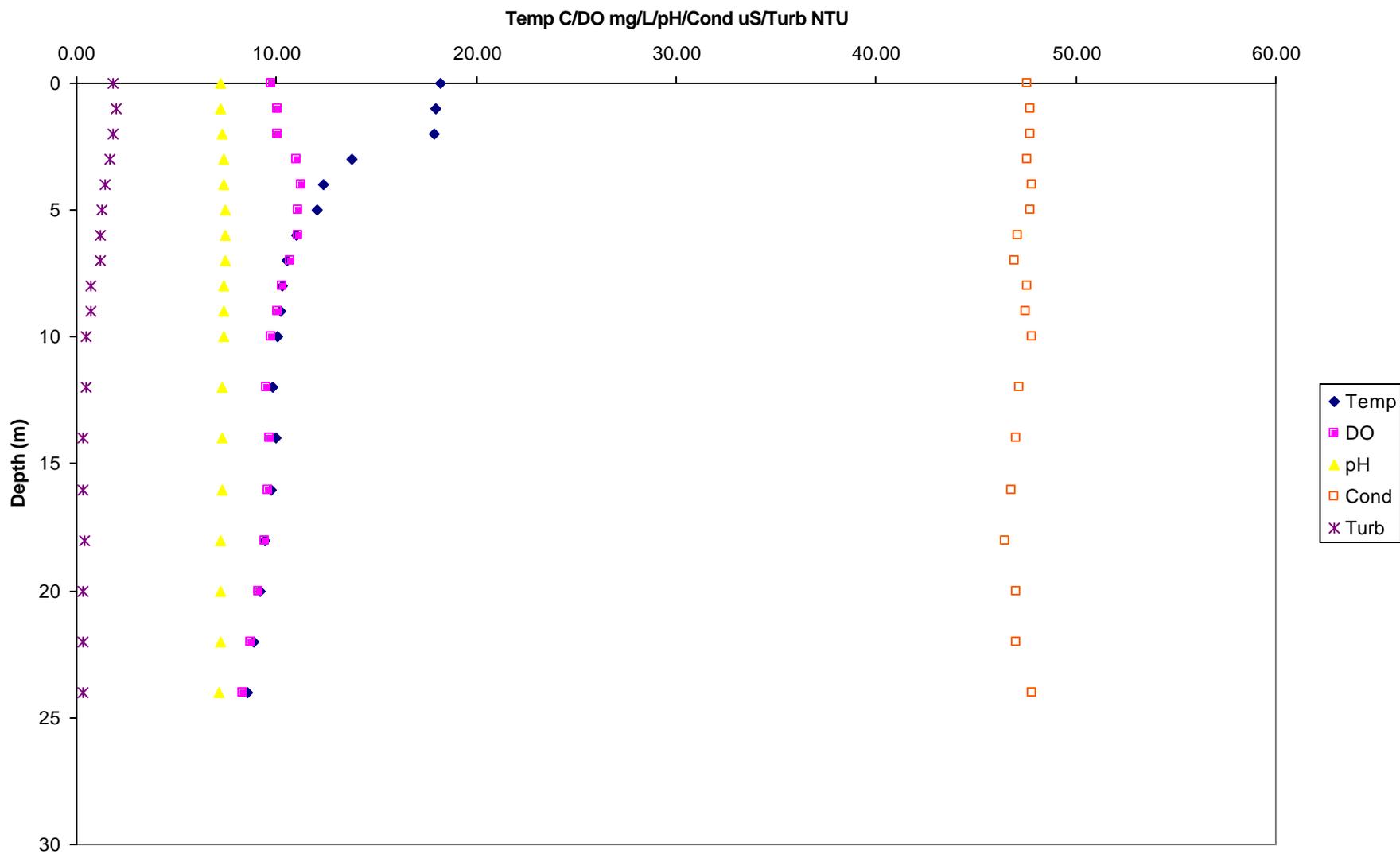


Figure 7 b. Flowery Branch Channel water quality profiles August 2001.

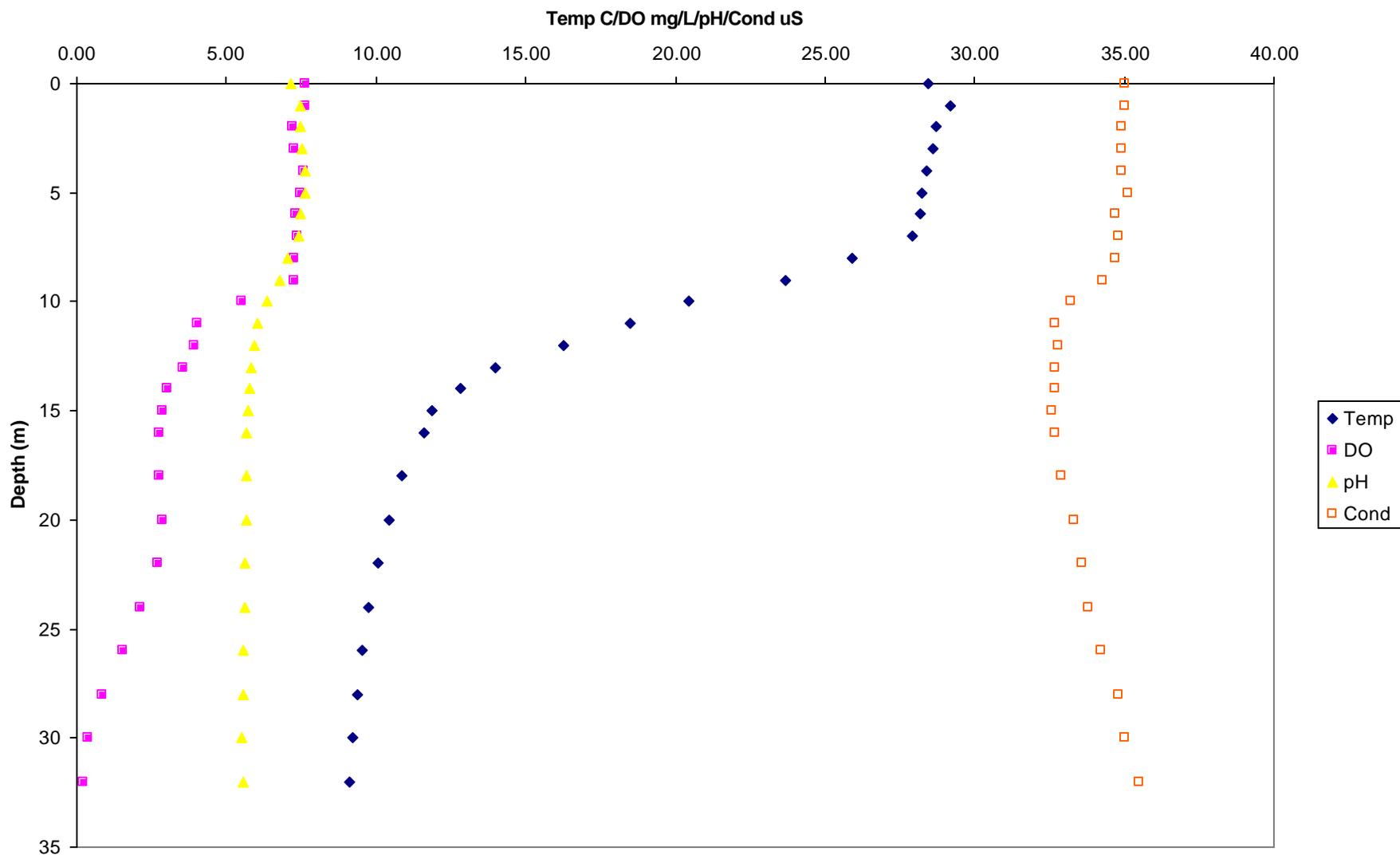


Figure 7 c. Flowery Branch Channel water quality profiles December 2001.

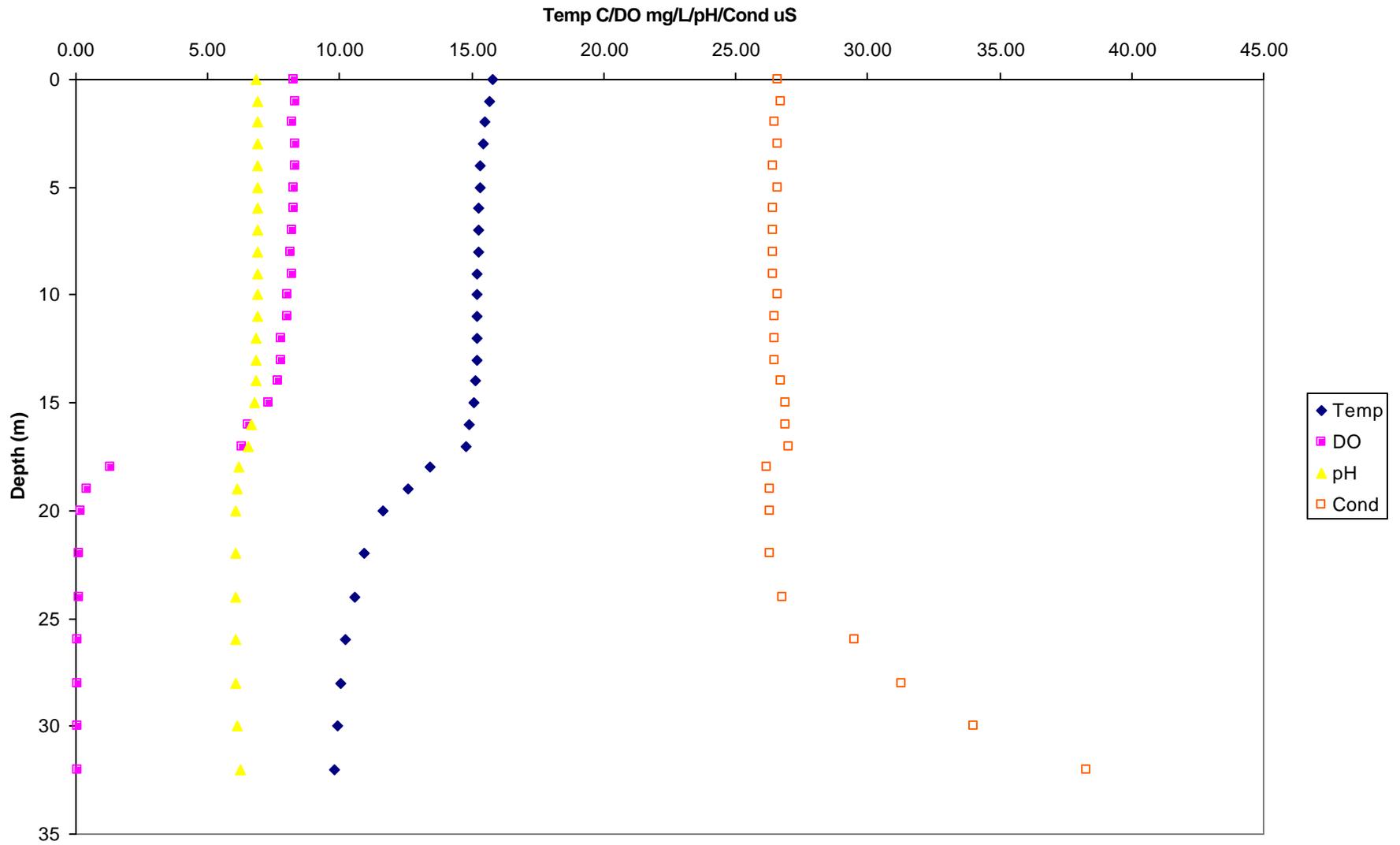


Figure 7 d. Flowery Branch Channel water quality profiles February 2002.

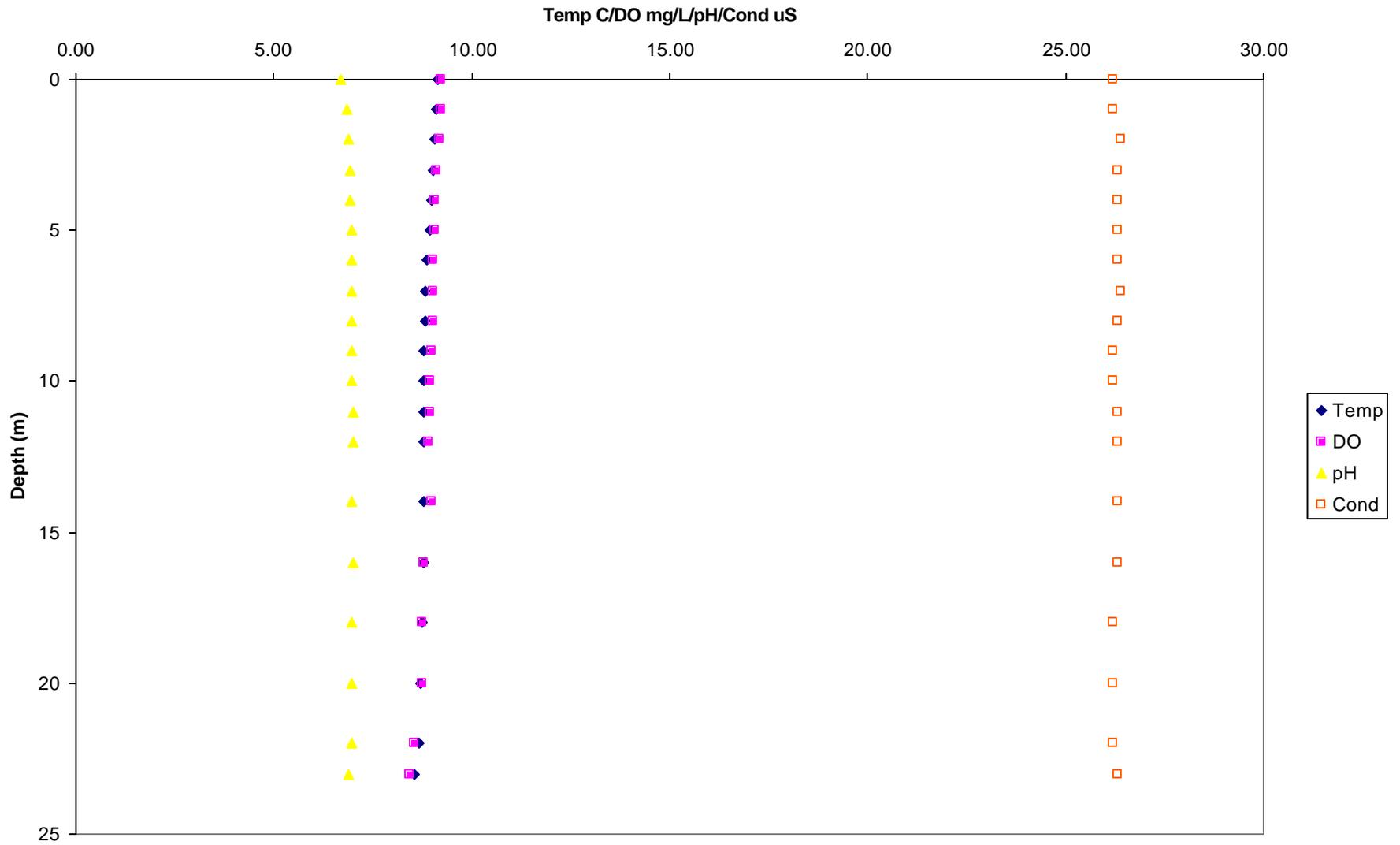


Figure 8 a. Flowery Branch Bay water quality profiles April 2001.

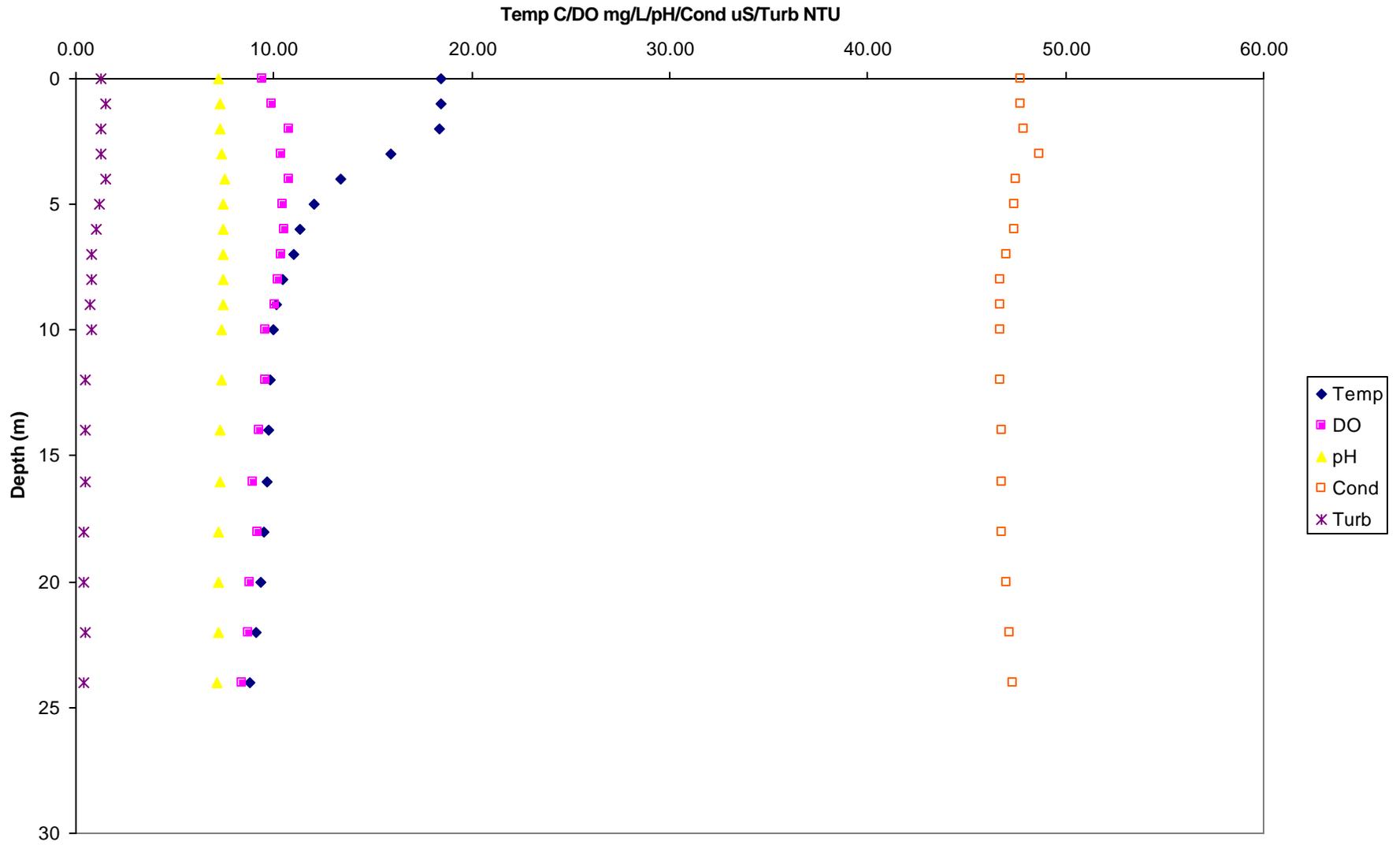


Figure 8 b. Flowery Branch Bay water quality profiles September 2001.

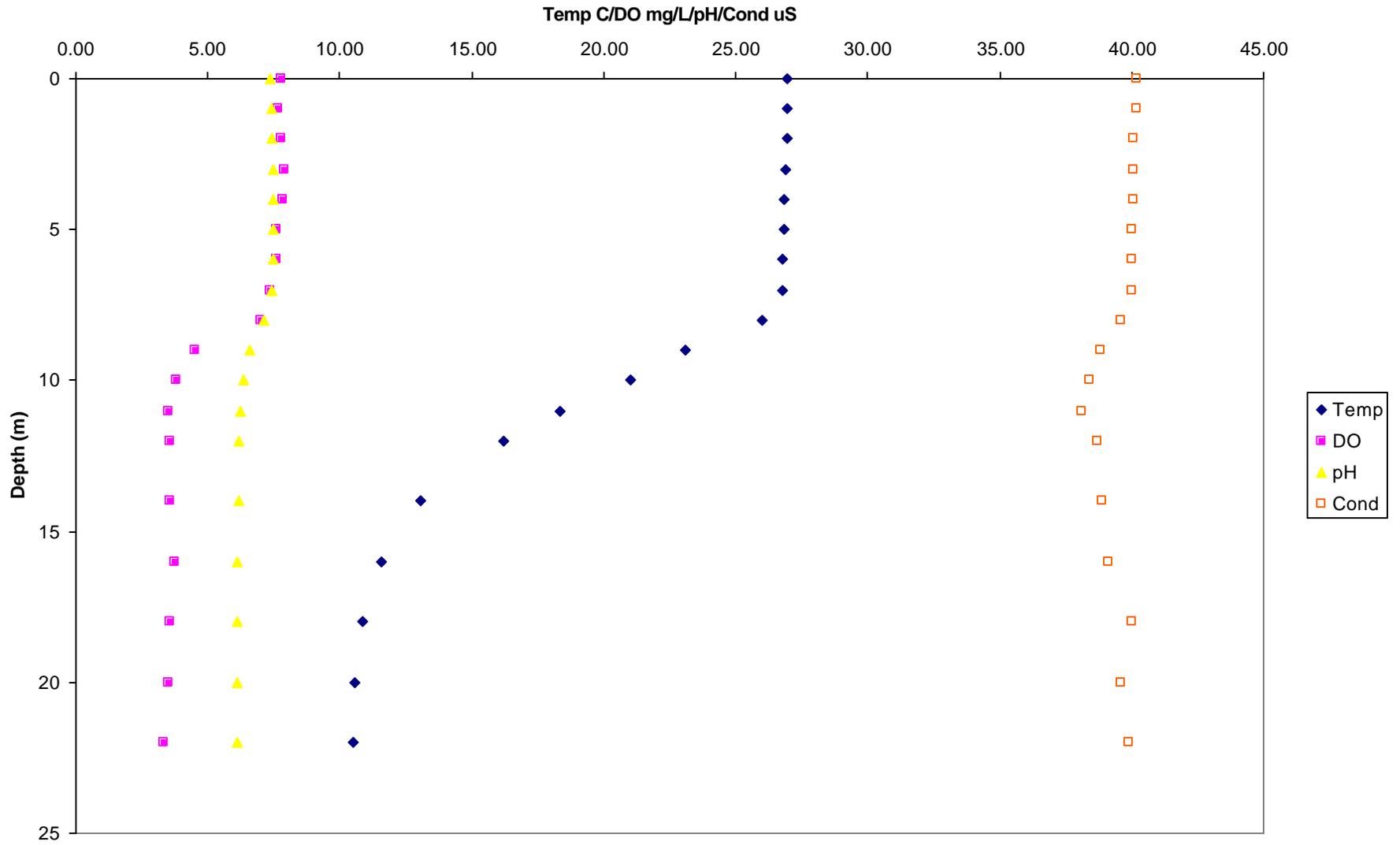


Figure 8 c. Flowery Branch Bay water quality profiles December 2001.

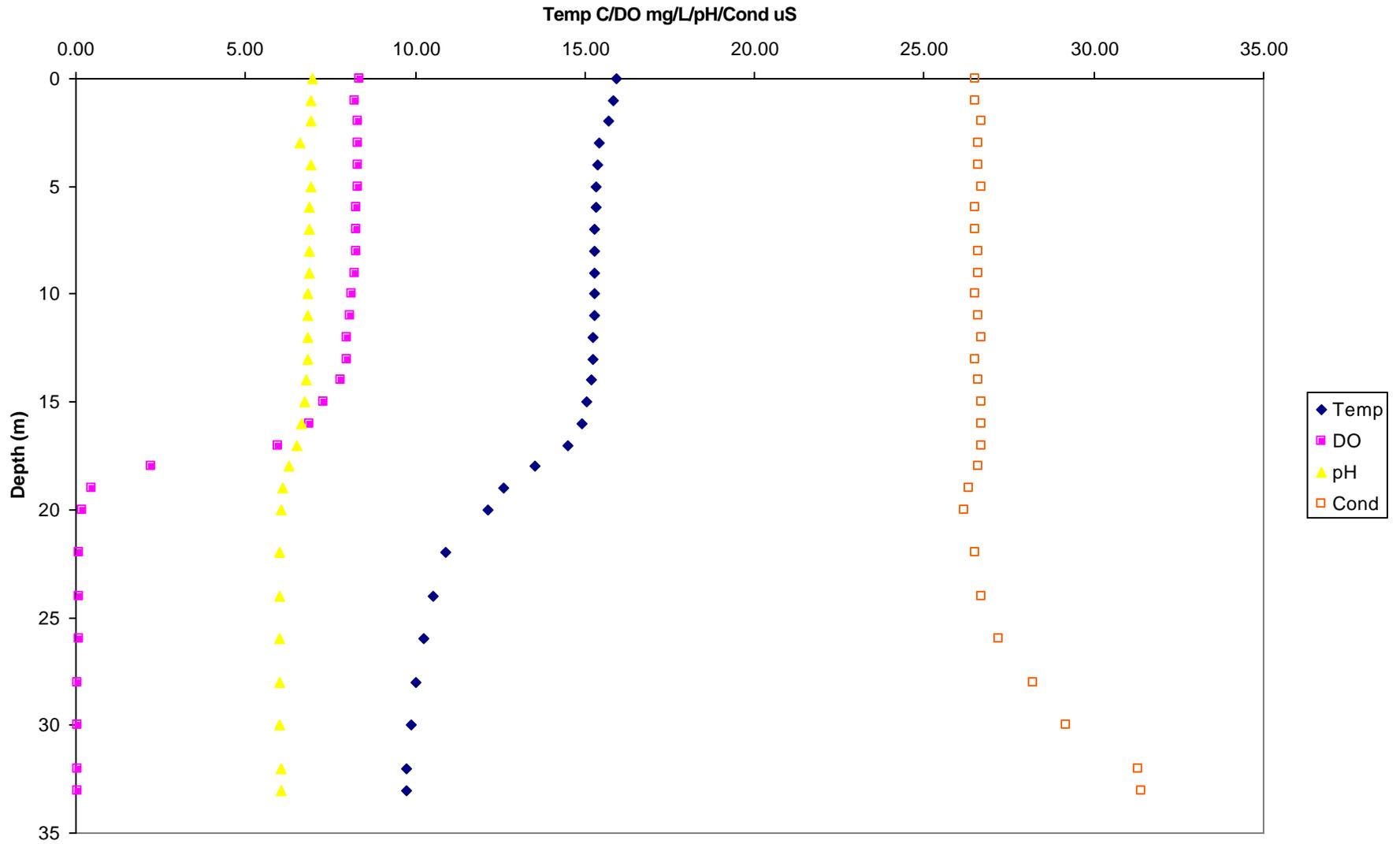


Figure 8 d. Flowery Branch Bay water quality profiles February 2002.

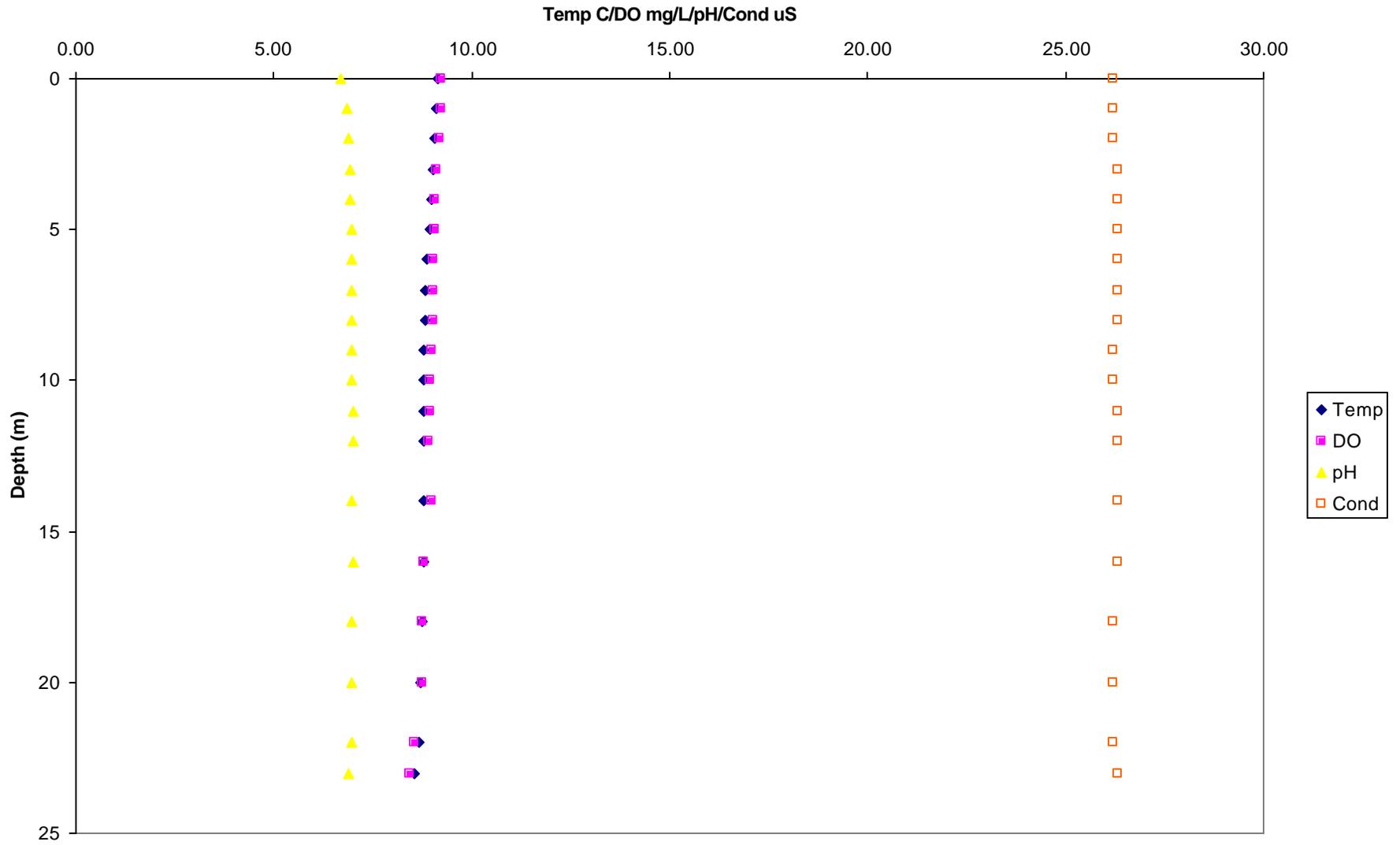


Figure 9. Flat Creek TIC and TOC during stratification.

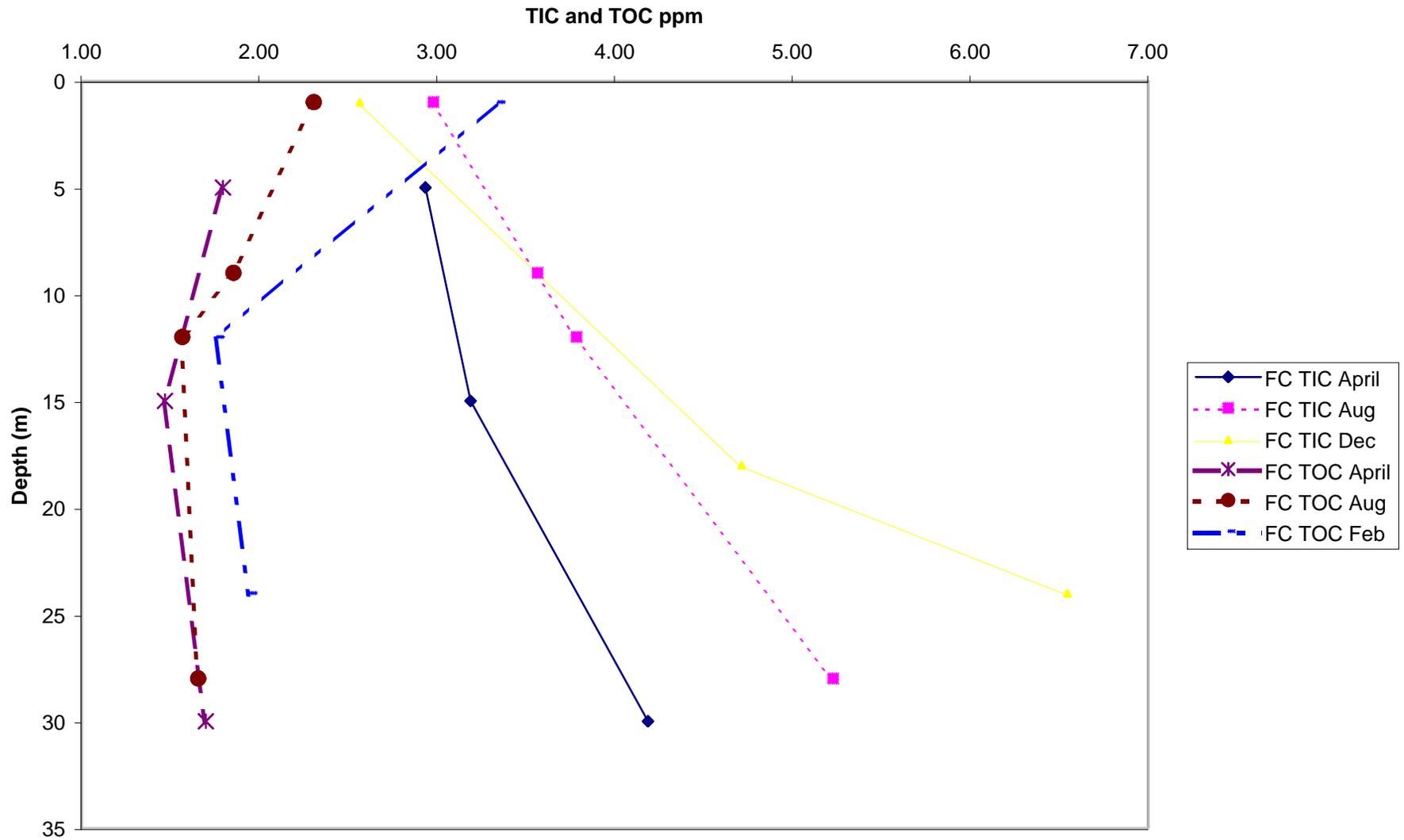


Table 1. Lake Lanier water chemical analyses four times in the annual cycle.

Date	Station	Depth m	.05-400 Al ppm		.05-600 Ca ppm		.05-600 Fe ppm		0.10-300 Mn ppm		0.02-2.0 NO2+NO3 ppm		0.02-2.0 NO2 ppm	
			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	
	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 Al ppm		.05-600 Ca ppm		.05-600 Fe ppm		0.10-300 Mn ppm		0.02-2.0 NO2+NO3 ppm		0.02-2.0 NO2 ppm	
Date	Station	Depth m	Filt	Unfilt	Filt	Unfilt	Filt	Unfilt	Filt	Unfilt	Filt	Unfilt	Filt	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 Al ppm		.05-600 Ca ppm		.05-600 Fe ppm		0.10-300 Mn ppm		0.02-2.0 NO2+NO3 ppm		0.02-2.0 NO2 ppm	
Date	Station	Depth m	Filt	Unfilt	Filt	Unfilt	Filt	Unfilt	Filt	Unfilt	Filt	Unfilt	Filt	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

Date	Station	Depth m	0.02-3.0		0.02-2.0	0.04-2.0	0.04-2.0	3.0-100	*Alk ppm		TIC ppm		TOC ppm		
			NH4 ppm		TN ppm	TP ppm	PO4 ppm	SO4 ppm	Unfilt	Filt	Unfilt	Filt	Unfilt	Filt	Unfilt
			Filt	Unfilt	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		
	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
FC		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	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

Date	Station	Depth m	Detection Range		0.02-3.0		0.02-2.0		0.04-2.0		0.04-2.0		3.0-100		*Alk ppm		TIC ppm		TOC ppm			
			Filt	Unfilt	Filt	Unfilt	Filt	Unfilt	Filt	Unfilt	Filt	Unfilt	Filt	Unfilt	Filt	Unfilt	Filt	Unfilt	Filt	Unfilt		
																					NH4 ppm	TN ppm
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		
	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

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