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Application of a Tidal Prism Water Quality Model to Virginia Small Coastal Basins: Poquoson River, Piankatank River, Cherrystone Inlet and Hungars Creek

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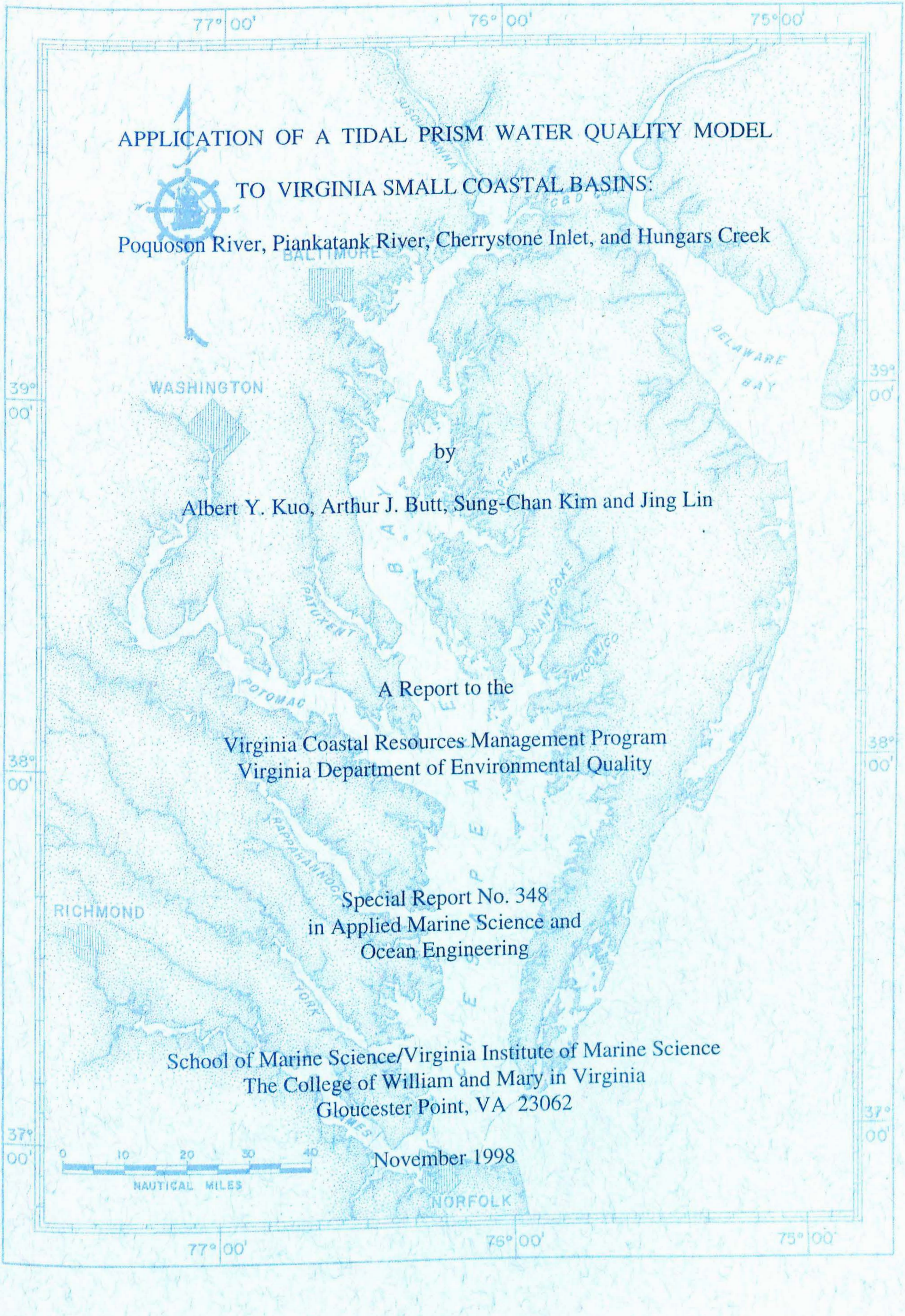

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Poquoson River, Piankatank River, Cherrystone Inlet, and Hungars Creek

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A Report to the

Virginia Coastal Resources Management Program
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Acknowledgments

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I. Introduction

Under the project entitled "Development of a Water Quality Model for Small Coastal Basins to Address Management Needs" of the FY '93 and '94 Virginia Coastal Resources Management Program Grants (VCRMPG), a tidal prism water quality model was developed (Kuo & Park, 1994). The model was applied to the Lynnhaven River, calibrated and verified with data collected by VIMS (Virginia Institute of Marine Science) and VADEQ (Virginia Department of Environmental Quality) (Park et al., 1995). The values of model parameters were determined through model calibration and confirmed through model verification.

To be used as a tool to help setting goals and developing strategies for nutrient reduction in a particular coastal basin, the model needs to be calibrated to derive a set of parameter values appropriate to that basin. In practice, it is impossible to collect field data for model calibration in all of the small coastal basins fringing the mainstem Chesapeake Bay and its major tributaries. As an alternative, VCRMPG supported a study to test the model applicability without calibration data. The study was financed through two grants: Task 84 of the 1995 Grant and Task 4.4 of the 1996 Grant. Four targeted basins were selected for testing: the Poquoson and Piankatank Rivers on the western shore and the Cherrystone Inlet and the Hungars Creek on the eastern shore. The set of model parameter values derived from the calibration of the Lynnhaven River was assumed applicable to all four basins. The model was applied to each basin to simulate the 1997 water quality conditions. Water quality data were also collected in all four basins during 1997, and used to compare with model simulation to determine the relative error for model application without calibration.

This report serves as the combined final report of the Task 84 of the 1995 Grant and the Task 4.4 of the 1996 Grant. A brief description of the tidal prism water quality model is presented in Chapter II. Chapter III describes the field monitoring program. The application of the model to the four targeted basins is presented individually in Chapter IV. Quantitative assessments and a brief summary of model results are given in Chapter V, followed by conclusions and recommendations.

II. Description of the Model

To provide a tool for water quality management of small coastal basins, VIMS (Virginia Institute of Marine Science) developed a tidal prism model in the late 1970s (Kuo & Neilson, 1988). The tidal prism model simulates the physical transport processes in terms of the concept of tidal flushing (Ketchum, 1951). The implementation of the concept in numerical computation is simple and straightforward, and thus ideal for small coastal basins including those with a high degree of branching. The model was applied to several small coastal basins in Virginia (Ho et al., 1977; Cerco and Kuo, 1981), and has been employed by Virginia Water Control Board for point source wasteload allocations and by local planning district commissions to address impacts of nonpoint source management (Kuo et al., 1982). The US Army Corps of Engineers and the City of Virginia Beach also have used the model to assess the water quality impacts of navigation channel and canal construction in the Lynnhaven Bay system (Kuo and Hyer, 1979; Hayes, Seay, Mattern and Mattern, 1982).

The tidal prism water quality model, described in Kuo & Park (1994), has been evolved from the one in Kuo & Neilson (1988). The model in Kuo & Neilson (1988) simulates the conditions in the main channel and its primary branches (those connected to the main channel) only. The model was modified to include shallow embayments connected to the primary branches, thus allowing the model to simulate the conditions in the secondary branches (those connected to the primary branches). The modified model (Kuo & Park, 1994) treats the secondary branches as storage areas, which exchange the water masses with the primary branches as the tide rises and falls. A new solution scheme (Park and Kuo, 1996), in which decoupling of the kinetic processes from the physical transport and external sources results in a simple and efficient computational procedure, was developed and used for the modified model. The kinetic portion of the model in Kuo & Neilson (1988) was expanded to describe eutrophication processes more completely and to be comparable with the modeling efforts in the Bay mainstem and major tributaries. First, the kinetic formulations used in the Chesapeake Bay three-dimensional water quality model (Cerco and Cole, 1994) were modified and used in the model reported in Kuo & Park (1994). Second, the sediment process model that was used for modeling of the Chesapeake Bay mainstem and major tributaries (DiToro & Fitzpatrick, 1993) was slightly modified and incorporated into the modified model to enhance the predictive capability of the model.

The tidal prism water quality model, described in Kuo & Park (1994), has twenty-four water column and twenty-seven sediment state variables (Table II-1). The model's capability to simulate water quality conditions in a small coastal basin has been demonstrated by its application to the Lynnhaven River (Park et al., 1995). The water column portion of the model was calibrated and verified with extensive data sets collected by VIMS and VADEQ. The values of model parameters were determined for the Lynnhaven River.

Table II-1. Model state variables[a].

WATER COLUMN:	
1) salinity	2) temperature
3) cyanobacteria (B_c)	4) diatoms (B_d)
5) green algae (B_g)	
6) refractory particulate organic C (RPOC)	7) labile particulate organic C (LPOC)
8) dissolved organic C (DOC)	
9) refractory particulate organic P (RPOP)	10) labile particulate organic P (LPOP)
11) dissolved organic P (DOP)	12) total phosphate (PO4t)
13) refractory particulate organic N (RPON)	14) labile particulate organic N (LPON)
15) dissolved organic N (DON)	16) ammonium N (NH4)
17) nitrite+nitrate N (NO3)	
18) particulate biogenic silica (SU)	19) available silica (SA)
20) dissolved oxygen (DO)	21) chemical oxygen demand (COD)
22) total suspended solid (TSS)	
23) total active metal (TAM)[b]	
24) fecal coliform bacteria (FCB)	
SEDIMENT:	
1-3) particulate organic carbon, G_1, G_2 and G_3 classes in Layer 2	
4-6) particulate organic nitrogen, G_1, G_2 and G_3 classes in Layer 2	
7-9) particulate organic phosphorus, G_1, G_2 and G_3 classes in Layer 2	
10) particulate biogenic silica in Layer 2	
11-12) sulfide/methane[c], Layer 1 and 2	
13-14) ammonium nitrogen, Layer 1 and 2	15-16) nitrate nitrogen, Layer 1 and 2
17-18) phosphate phosphorus, Layer 1 and 2	
19-20) available silica, Layer 1 and 2	
21) ammonium nitrogen flux	22) nitrate nitrogen flux
23) phosphate phosphorus flux	24) silica flux
25) sediment oxygen demand	26) release of chemical oxygen demand
27) sediment temperature	

[a] The tidal prism water quality model is described in Kuo & Park (1994).

[b] Total active metal may not be modeled by using total suspended solid as sorption site for phosphate and dissolved silica.

[c] Sulfide is modeled for saltwater while methane is modeled for freshwater.

III. Field Surveys and Data

III-1. Description of Field Surveys

Four small coastal basins, the Poquoson and Piankatank Rivers on the western shore, the Cherrystone Inlet and the Hungars Creek on the eastern shore, were monitored for water quality conditions and providing data to test model applicability without calibration to individual basin. The geographical locations of the four basins are shown in Figure III-1. The monitoring stations in each basins are shown in Figures III-2 to III-5, respectively. There are five stations in the Poquoson River, four stations each in the Piankatank River and the Cherrystone Inlet, and three stations in the Hungars Creek.

A total of six field surveys in each basin were conducted bimonthly from February to December, 1997. All surveys were conducted at high water slacks. At each station, in-situ measurements of temperature, salinity and dissolved oxygen were made every meter from 1 meter below surface to 1 m above bottom. In addition, the secchi depths were also taken. At least one water sample was collected at each station, at 1 m below surface, or at mid-depth if the total depth is less than 2 m. An additional water sample was collected at 1 m above the bottom at one selected station in each of the four basins. The water samples were analyzed for the following water quality variables:
:

dissolved oxygen, chlorophyll 'a'/pheophytin,

particulate carbon, dissolved organic carbon,

(particulate organic carbon was also analyzed for the water samples collected in February)

particulate N (nitrogen), total dissolved N, ammonium N, nitrite+nitrate N,

particulate P (phosphorus), particulate inorganic P, total dissolved P, dissolved ortho-P

total suspended sediment, fixed solid

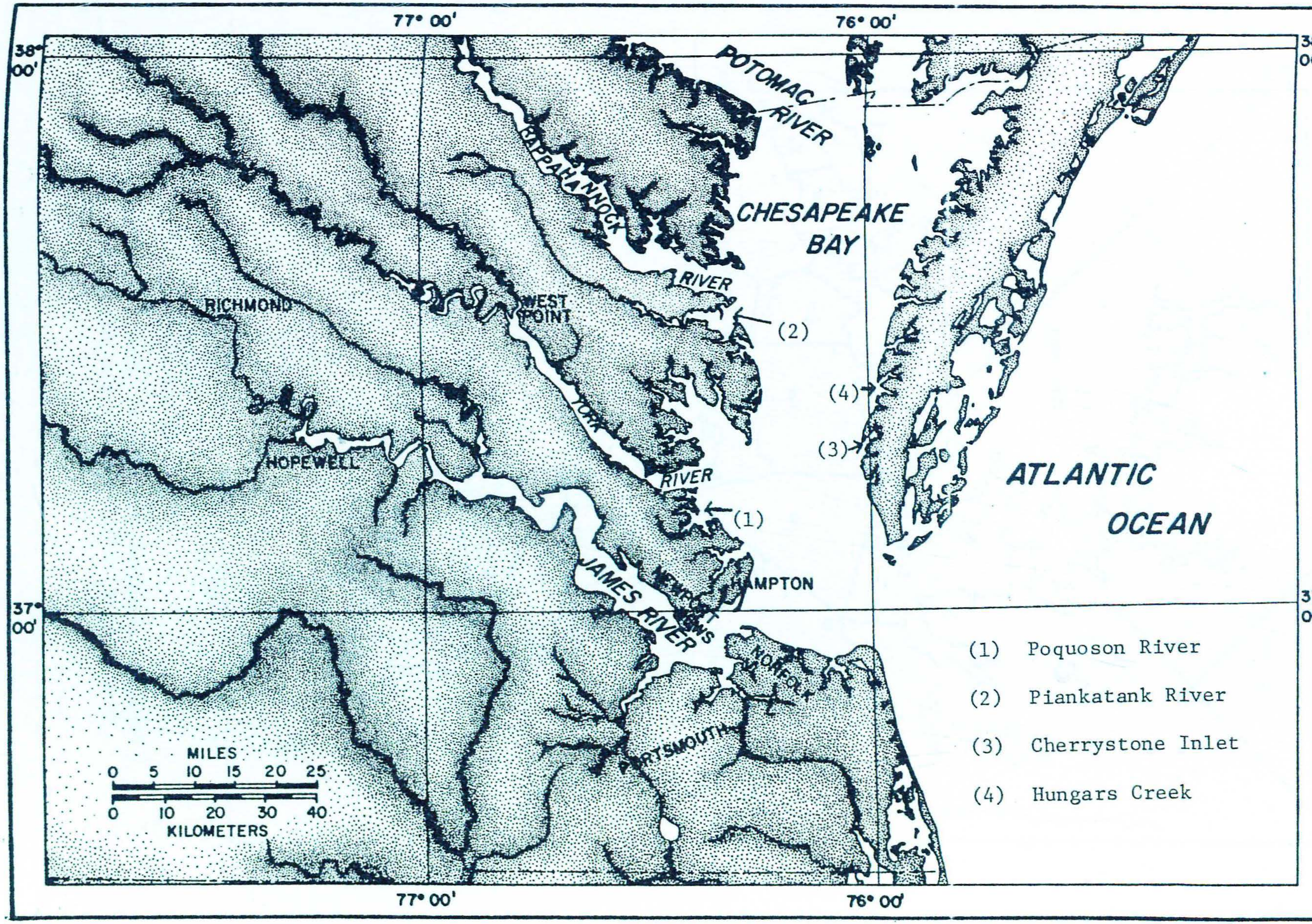

Figure III-1. Map of Tidewater, Virginia, showing locations of coastal basins surveyed in 1997.

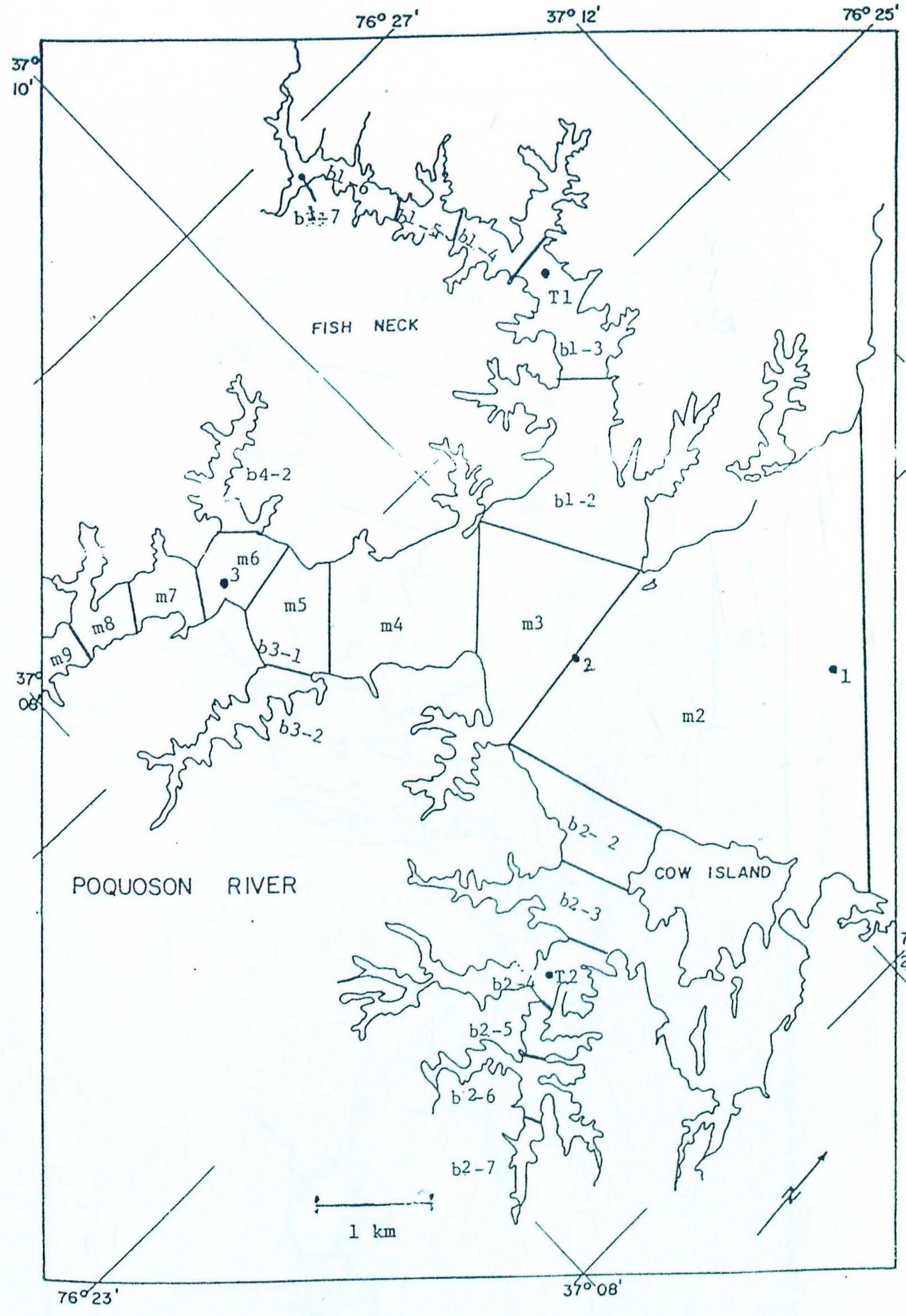

Figure III-2

The Poquoson River, showing the sampling stations for 1997 field surveys and model segmentation.

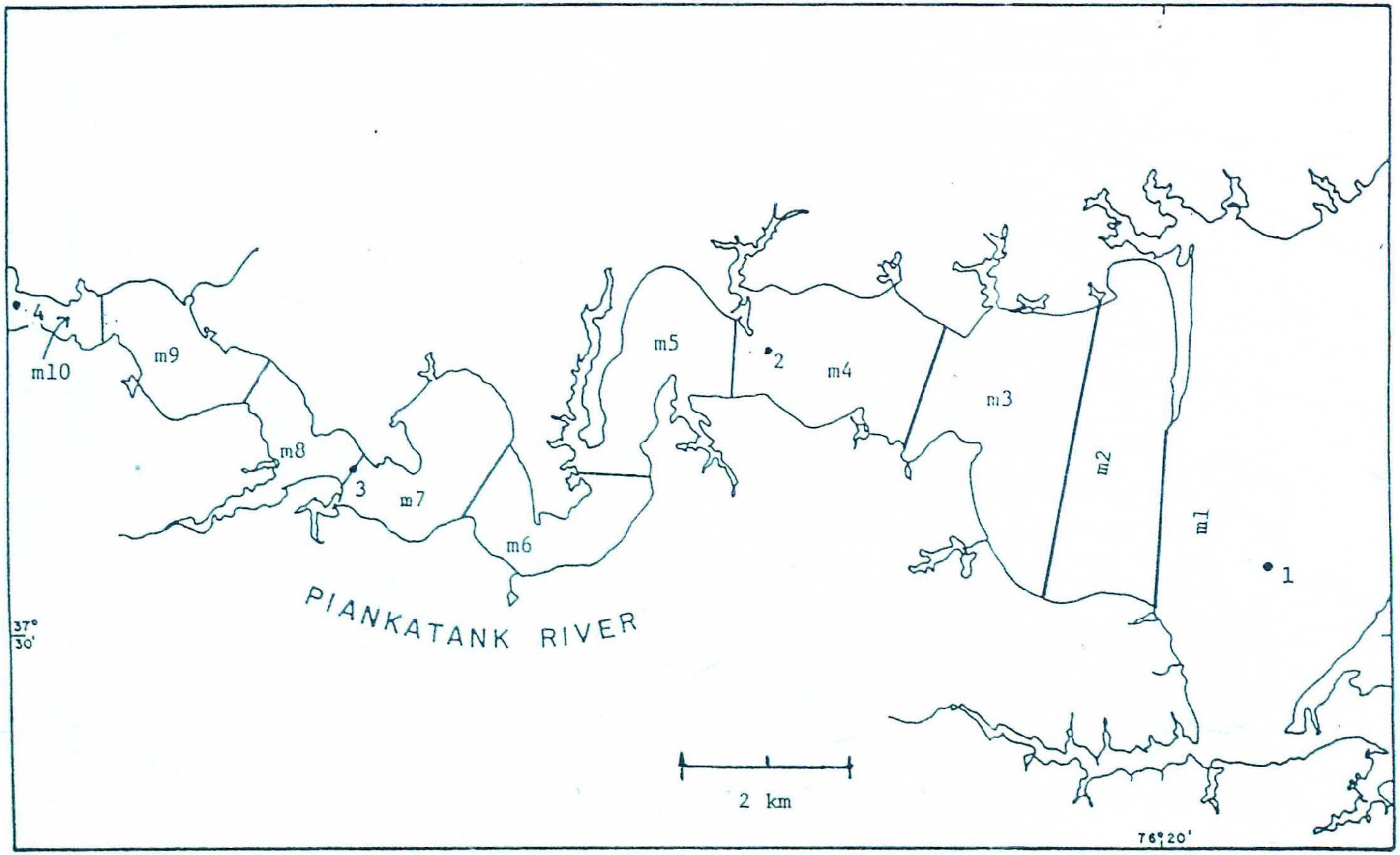

Figure III-3

The Piankatank River, showing the sampling stations for 1997 field surveys and model segmentation.

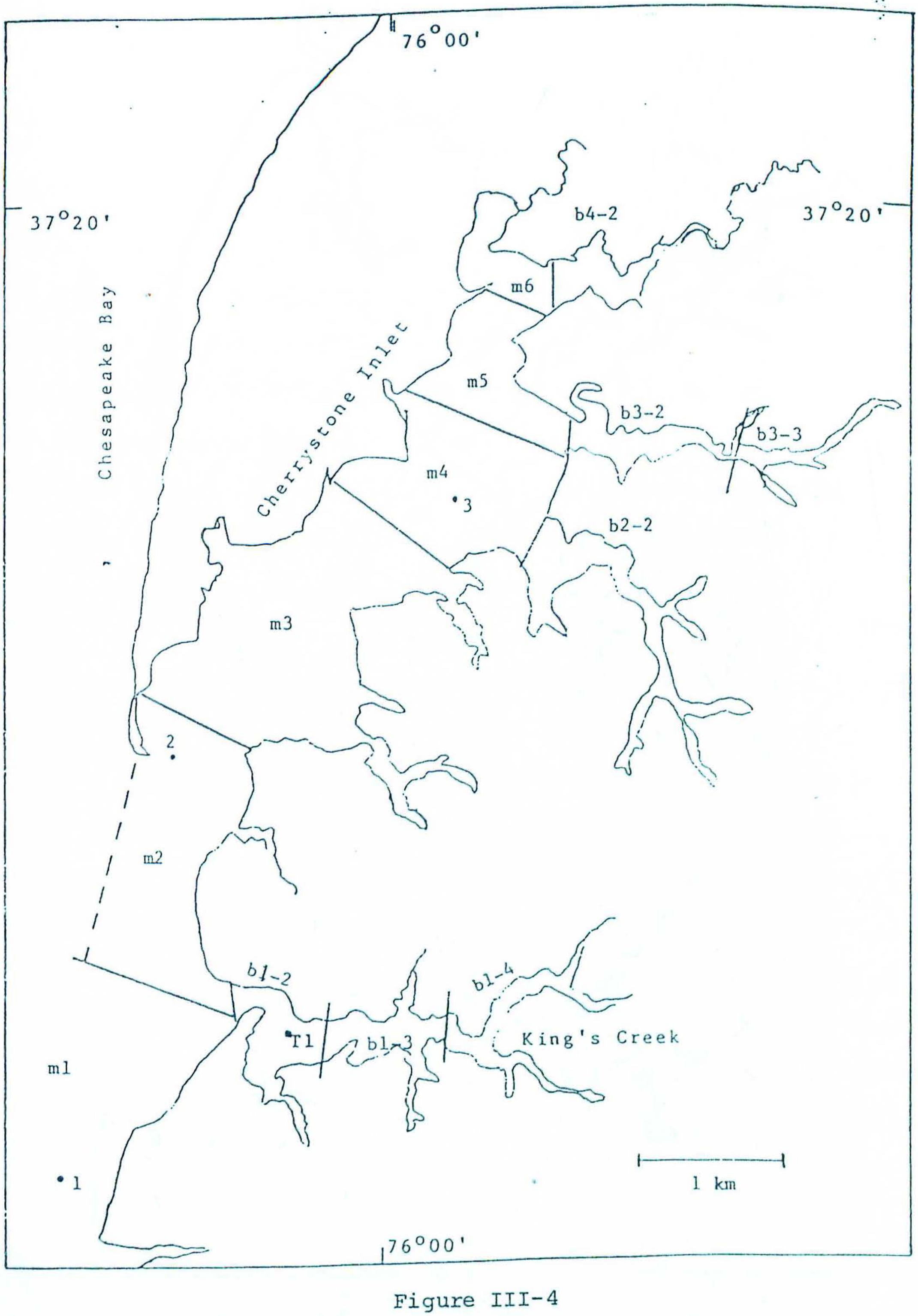

Figure III-4

The Cherrystone Inlet, showing the sampling stations for 1997 field surveys and model segmentation.

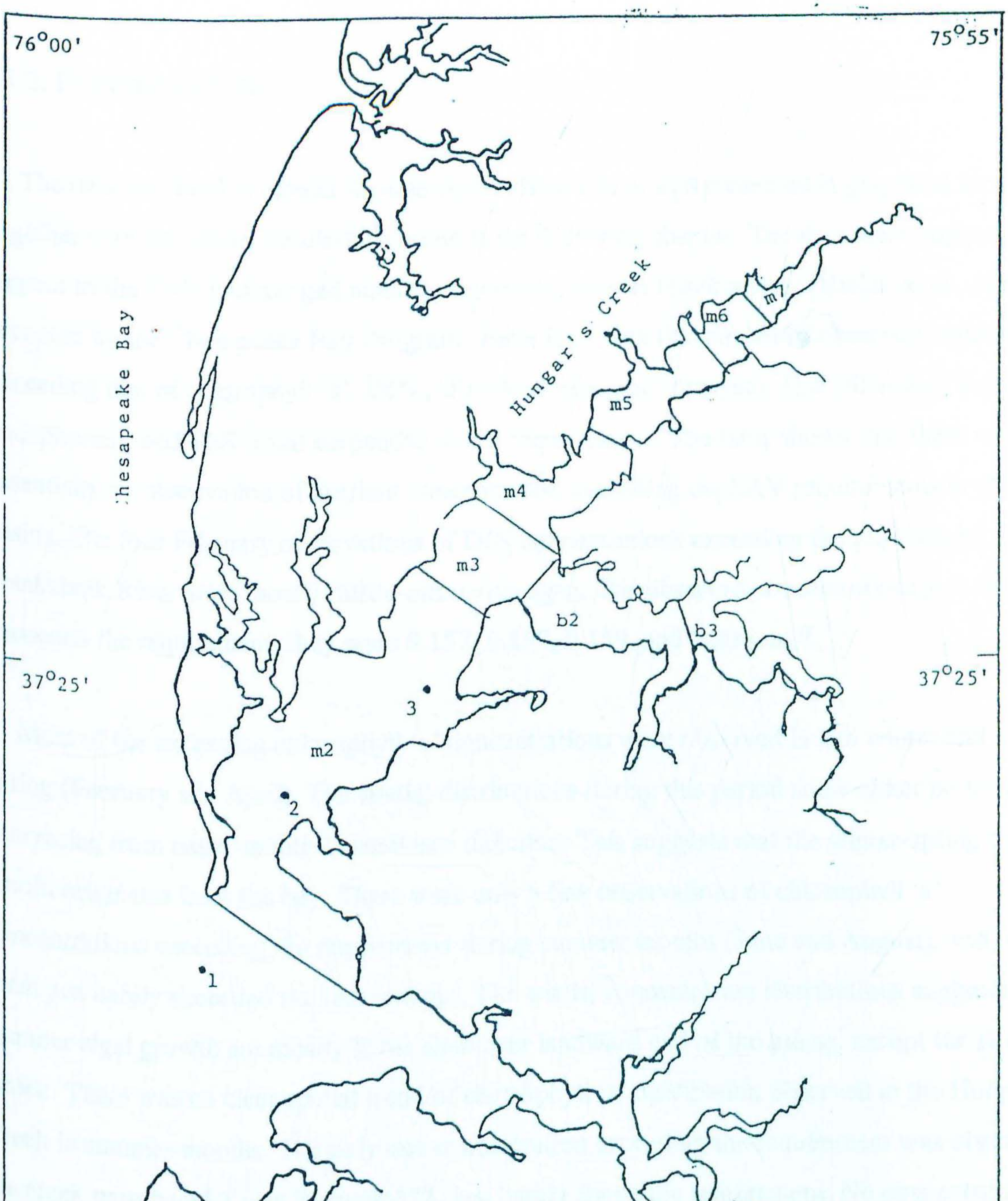

Figure III-5

The Hungars Creek, showing the sampling stations for 1997 field surveys and model segmentation.

III-2. Description of Data

The data are listed in tabular form in Appendices 1 to 4, and presented in graphical form together with the model simulation results in the following chapter. The data were analyzed with respect to the SAV (submerged aquatic vegetation) habitat requirements (Batiuk et al., 1992) accepted by the Chesapeake Bay Program. Table III-1 lists the number of observed concentrations exceeding that of chlorophyll 'a', DIN (dissolved inorganic nitrogen), DIP (dissolved inorganic phosphorus), and TSS (total suspended solid) requirements. The table shows that there was essentially no observation of nutrient concentration exceeding the SAV requirements in all four basins. The four February observations of DIN concentrations exceeding the requirement in the Piankatank River were mostly nitrite-nitrate nitrogen. The observed concentrations just barely exceeded the requirement, they were 0.157, 0.157, 0.159, and 0.206 mg/l.

Most of the exceeding chlorophyll 'a' concentrations were observed in late winter and early spring (February and April). The spatial distributions during this period show either no trend or decreasing from basin mouth in landward direction. This suggests that the winter-spring algal bloom originates from the bay. There were only a few observations of chlorophyll 'a' concentrations exceeding the requirement during summer months (June and August), and most of them just barely exceeded the requirement. The spatial concentration distributions suggests that the summer algal growth are mostly in the shallower landward end of the basins, except the Hungars Creek. There was no clear spatial trend of chlorophyll 'a' distribution observed in the Hungars Creek in summer months. The only one concentration exceeding the requirement was observed at the creek mouth and it was 16 mg/m**3, just barely above the requirement. No concentration exceeding the requirement was observed in fall and early winter (October and December).

TSS exceeding the requirement were observed in all four basins and in all seasons. Except for the Hungars Creek, the TSS concentrations show either an increasing trend or no trend landward from basin mouth. This suggests that local watershed runoff and/or shoreline erosion contribute to the excessive TSS concentrations. The observed spatial TSS distributions in the Hungars Creek were more variable. There was only one occasion for which the data indicated that local runoff

Table III-1. Number of Data Points Failing to Meet SAV Requirements

Month		Feb.	April	June	Aug.	Oct.	Dec.
Poquoson River (5 stations, 6 data points)	Chlorophyll	6	1	0	2	0	0
	DIN	0	0	0	0	0	0
	PO_4	0	0	0	0	0	0
	TSS	2	2	4	5	1	0
	DO<5	0	0	0	0	0	0
Piankatank River (4 stations, 5 data points)	Chlorophyll	1	4	1	2	0	0
	DIN	4*	0	0	0	0	0
	PO_4	0	0	0	0	0	0
	TSS	3	3	2	1	2	0
	DO<5**	0	0	3(>3.9)	3(>2.8)	1(>4.7)	0
Cherrystone Inlet (4 stations, 5 data points)	Chlorophyll	3	3	0	1	0	0
	DIN	0	0	0	0	0	0
	PO_4	0	0	0	0	0	0
	TSS	3	5	3	2	5	2
	DO<5**	0	0	1(4.9)	0	0	0
Hungars Creek (3 stations, 4 data points)	Chlorophyll	3/3	4	1	0	0	0
	DIN	0	0	0	0	0	0
	PO_4	0	0	0	0	0	0
	TSS	3/3	0	1	0	4	2
	DO<5	0	0	0	0	0	0

SAV Requirements:

Chlorophyll <15 mg/m**3
DIN <0.15 mg/l
DIP <0.01 mg/l (mesohaline), < 0.02 (polyhaline)
TSS <15 mg/l

* mostly nitrite-nitrate nitrogen, ~0.15 mg/l
** occurred only at bottom waters

and/or shoreline erosion had significant contribution to the excessive TSS concentration.

The numbers of observations that DO (dissolved oxygen) fell below 5.0 mg/l were also included in Table III-1. Since DO were measured every meter throughout the water column, there were many more observations of this than of other water quality variables. The low DO were observed only in the bottom waters and only during warmer months. All low DO observations were in the Piankatank River, except one (4.9 mg/l) in the Cherrystone Inlet.

IV. Model Applications

The tidal prism water quality model is applied to the four targeted basins: the Poquoson and Piankatank Rivers on the western shore, and the Cherrystone Inlet and Hungars Creek on the eastern shore. The model is run to simulate the period from February to December, 1997, during which monitoring data are available for comparison with model results. Since only the chlorophyll 'a' measurements are available to quantify the total algal biomass, only one algal type in the model is simulated to represent the total algal biomass. Because diatoms are not explicitly modeled, the silica cycle in the model is not activated. Total suspended sediment, which is included in the monitoring program, is simulated to quantify the sorption site for phosphate, and thus total active metal is not modeled. The sediment process model is not activated. The sediment fluxes obtained through calibration of the Lynnhaven River (Park et al., 1995) are used, as are the values of calibrated model coefficients. Preparation of input data for the model application is described in Section VI-1, and the results of the model runs are presented in Section VI-2.

IV-1. Preparation of Input Data

To facilitate the inter-comparisons among the four targeted basins, the data for all four basins are grouped together by data types. The data with values identical to those of the Lynnhaven River model (Park et al., 1995) will not be repeated.

IV-1-1. Geometry

Each basin is segmented in accordance to the segmentation scheme described in Kuo and Park (1994), except the Piankatank River. The Piankatank River has a very small tidal range (37 cm or 1.2 ft) and higher depth. If the model segmentation scheme were strictly followed, it would result in the segment length being much smaller than the river width. This would contradict the concept of a one-dimensional description of the water body. Therefore, a deviation is tolerated that allows the segment volume to be twice, instead of equal, the accumulated tidal prism upriver of it. The model segments are presented on the maps in Figures III-2 to III-5, where the letter 'm' designates mainstem and the letter 'b' designates branch. The geometric data: distance from river mouth,

Table IV-1. Geometric and hydrodynamic data, Poquoson River

Segment or transect number	Distance from mouth (km)	High tide volume (10^6 m^3)	Accumulated tidal prism (10^6 m^3)	Mean depth (m)
m1	0.000	-	9.400	-
m2	1.900	9.400	4.800	2.100
m3	2.900	4.800	3.000	2.190
m4	4.000	3.000	2.200	2.380
m5	4.750	2.200	1.400	1.798
m6	5.760	1.400	1.000	1.585
m7	6.700	1.000	0.750	1.500
m8	7.600	0.750	0.500	0.900
m9	8.500	0.500	-	0.700
b1-1	0.000	-	1.180	-
b1-2	1.250	1.180	0.770	1.768
b1-3	2.400	0.770	0.500	1.463
b1-4	3.100	0.500	0.320	1.372
b1-5	3.800	0.320	0.200	1.200
b1-6	4.450	0.200	0.100	1.097
b1-7	4.750	0.100	-	1.097
b2-1	0.000	-	1.150	-
b2-2	0.700	1.150	0.700	1.650
b2-3	1.250	0.700	0.500	0.730
b2-4	1.800	0.500	0.300	0.670
b2-5	2.120	0.300	0.200	1.340
b2-6	2.400	0.200	0.120	1.340
b2-7	2.630	0.120	-	1.340
b3-1	0.000	-	1.000	-
b3-2	1.190	1.000	-	0.760
b4-1	0.000	-	1.000	-
b4-2	1.190	1.000	-	0.760
s2-3	0.700	0.220	0.600	0.400

Table IV-2. Geometric and hydrodynamic data, Piankatank River

Segment or transect number	Distance from mouth (km)	High tide volume (10^6 m^3)	Accumulated tidal prism (10^6 m^3)	Mean depth (m)
m1	0.000	-	11.521	-
m2	1.250	21.214	9.608	3.631
m3	3.160	17.513	7.831	3.566
m4	5.510	14.410	6.526	4.040
m5	8.520	11.900	5.370	3.826
m6	11.040	10.003	4.628	5.188
m7	12.760	8.433	3.765	3.716
m8	14.410	6.730	2.952	3.145
m9	16.500	5.108	2.155	2.423
m10	18.530	3.679	1.522	2.201
m11	20.290	2.299	0.774	1.171
m12	21.710	1.032	0.258	0.618
m13	24.620	2.347	-	0.384

Table IV-3. Geometric and hydrodynamic data, Cherrystone Inlet

Segment or transect number	Distance from mouth (km)	High tide volume (10^6 m^3)	Accumulated tidal prism (10^6 m^3)	Mean depth (m)
m1	0.000	-	5.829	-
m2	2.660	5.850	3.651	1.747
m3	4.540	3.665	2.265	1.500
m4	5.720	2.284	1.010	1.110
m5	6.720	1.013	0.418	0.799
m6	7.790	0.508	-	0.547
b1-1	0.000	-	0.659	-
b1-2	1.140	0.661	0.362	1.206
b1-3	2.050	0.364	0.166	0.951
b1-4	3.500	0.274	-	0.807
b2-1	0.000	-	0.192	-
b2-2	1.390	0.226	-	0.473
b3-1	0.000	-	0.251	-
b3-2	1.370	0.252	0.075	0.655
b3-3	2.580	0.108	0.000	0.655
b4-1	0.000	-	0.180	-
b4-2	1.170	0.204	-	0.441

Table IV-4. Geometric and hydrodynamic data, Hungars Creek

Segment or transect number	Distance from mouth (km)	High tide volume (10^6 m^3)	Accumulated tidal prism (10^6 m^3)	Mean depth (m)
m1	0.000	-	2.907	-
m2	2.800	2.915	1.614	1.106
m3	3.690	1.629	0.808	0.958
m4	4.530	0.809	0.397	0.925
m5	5.480	0.398	0.195	0.925
m6	5.990	0.196	0.095	0.925
m7	6.927	0.184	-	0.925
b1	0.000	-	0.573	-
b2	1.030	0.577	0.280	0.925
b3	3.845	0.751	-	0.925

segment volume, tidal prism, and mean depth, are listed in Tables III-1 to III-4.

IV-1-2. Water temperature

The observed water temperature in each of the basins show a seasonal variation, but with little spatial variability. A sinusoidal curve that is fitted to approximate the monitoring data in each basin is used to specify the spatially uniform water temperature. The temperature is described as function of Julian day, t:

$$T = \frac{T_{max} + T_{min}}{2} + \frac{T_{max} - T_{min}}{2} \cdot \cos\left(\frac{2\pi}{T_p}(t - t_{max}) \right) \tag{4-1}$$

with T_{max} is annual maximum temperature, T_{min} is annual minimum temperature, t_{max} is number of days since January 1 to reach $_{Tmax}$, T_p = 365 days. The parameters in equation (4-1) are obtained by fitting the equation to the temperature data of each basin. It turns out that one set of parameter values can fit all four basins equally well. There a single equation is used for all four basins. The prediction by the equation is compared with the monitoring data in Figure IV-1.

IV-1-3. Solar radiation

The model requires, in order to simulate the algal growth, daily solar radiation intensity and fractional day length averaged over a time step, one tidal cycle. Hourly measurements of solar radiation at VIMS (Gloucester Point) in 1997 are used to estimate daily mean light intensity and fractional day length, which are weight-averaged over a tidal cycle to be used for the 1997 model simulation runs.

IV-1-4. Initial conditions

The monitoring data of February, 1997 are used to estimate the initial conditions. Not all model state variables (Table II-1) were measured for all model segments. Hence, some approximations are required to estimate the initial conditions for each state variable at each model segment. The procedures used in the Lynnhaven River model (Park et al., 1995) are adopted for this study.

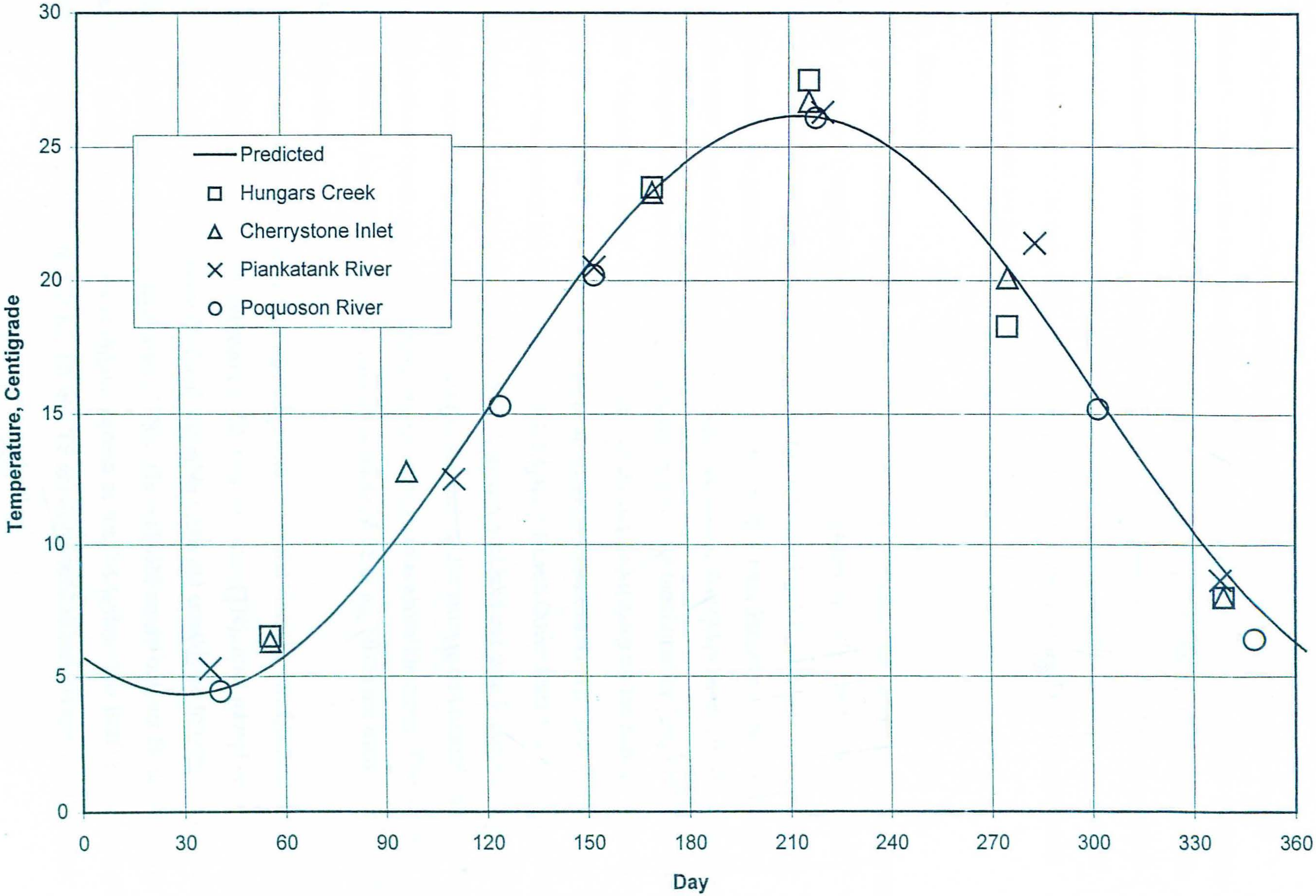

Figure IV-1
Water temperature data of 1997 surveys, with a sinusoidal curve to fit the observations.

IV-1-5. Boundary conditions

The field data at the mouth of each basin from the 1997 bi-monthly surveys are linearly interpolated to estimate the boundary conditions. The same approximations used for the initial conditions are also employed to estimate the boundary conditions for the model state variables from the measured parameters. The present model is configured such that it does not require explicit specification of the upriver boundary conditions. Rather, the flux through the upriver boundary is defined to be zero, with the upriver contributions incorporated through nonpoint source discharges and loads.

IV-1-6. External loads

There is no point source input into any of the four targeted basins. Nonpoint source inputs are estimated using the outputs from the US Army Corps of Engineers' STORM model (Abbott 1977). The STORM model uses rainfall data and land use patterns to calculate quantity and quality of runoff. To generate the nonpoint source runoffs for the Poquoson and Piankatank Rivers, the 1997 rainfall data monitored at VIMS (Gloucester Point) are used. For the Cherrystone Inlet and Hungars Creek on the eastern shore, the rainfall data monitored by Virginia Tech. Station at Painter, Virginia are used. The land use data of the two watersheds on the eastern shore are provided by the CBLAD (Chesapeake Bay Local Assistant Department). The land use data for the western shore watersheds are derived from EPA Region III Land Cover Data Set by the Resource Management and Policy Department of VIMS. A summary of land use data is presented in Table IV-5. Other input parameters for the STORM model include the storage and runoff characteristics of various land use types, unit hydrograph characteristics and evaporation rates. The input constants from the model study of the Lynnhaven River (Park et al., 1975) are used for the present model applications.

The STORM model generates daily discharge rates and total loads of biochemical oxygen demand (BOD), suspended solid, settleable solid, total nitrogen (TN), total phosphorus (TP) and fecal coliform bacteria. Both suspended and settleable solids are considered to contribute to the model state variable, total suspended solid (TSS). The STORM model outputs BOD while the Tidal Prism Model has three types of organic carbon as state variables. The BOD is converted to total organic carbon (TOC), and TOC, TN and TP are distributed to various species of organic

Table IV-5. Land Use Patterns of the Targeted Small Coastal Basins

			Hungars Creek	Cherrystone Inlet	Poquoson River	Piankatank River
Total Drainage Area (acres)			6,790	9,920	13,994	142,026
Land Use Categories (percents)	Residential	low density	11.26	5.0	13.0	0.68
		high density			3.3	0.28
	Commercial		0.01	2.0		
	Light Industry		0.00	2.0		
	Agricultural & Vacant Forest		46.22	60.0	21.6	21.19
	Forest		42.51	31.0	58.1	70.63
	Marsh				4.0	7.22
Water Surface Area (acres)			1,405	3,045	3,884	10,753

carbon, nitrogen and phosphorus, respectively, in the same manner as done in the Lynnhaven River model (Park et al., 1995).

The Tidal Prism Model also requires, for nonpoint source input, dissolved oxygen (DO) loading in terms of concentration in runoff water. The DO concentration in nonpoint source discharge is taken to be 80% of the saturated concentration. Finally, it is assumed that there is no nonpoint source input of salinity, chlorophyll ‘a’, and chemical oxygen demand.

IV-2. Results

The model is run to simulate the period from February to December, 1997 for each of the four small coastal basins, and the results are compared with the field data. Appendices 5 through 8 show the comparison for the Poquoson River, Piankatank River, Cherrystone Inlet, and Hungars Creek , respectively. Model predictions of salinity, concentrations of chlorophyll ‘a’, dissolved oxygen, total carbon, total nitrogen, total phosphorus, and total suspended sediment at selected segments are plotted as functions of time, together with the bimonthly survey data at corresponding locations.

The model has one calibration parameter for the physical transport, the returning ratio α (Kuo & Park, 1994: Chapter II). The value of the returning ratio was calibrated to be 0.3 for the Lynnhaven River. Since salinity is solely the result of physical transport processes, the excellent agreement between model results and salinity data indicate that the value 0.3 is a good number to use for the four targeted basins, and probably would be adequate for all Virginia’s small coastal basins without further calibration.

In addition to the physical transport process, the model predictions of non-conservative state variables also depend on the external loads as well as the values of biochemical rate constants. As stated in the previous section, all the values of the calibrated constants, including those in the nonpoint source model, are adopted from the Lynnhaven River without further calibration for individual basin. Appendix 8 indicates that the model predictions of the Hungars Creek agree with field data. However, the predictions for the individual species (not presented) of carbon, nitrogen, and phosphorus are not satisfactory. The nonpoint model, STORM, generates BOD, total nitrogen, and total phosphorus. The partition of the STORM model outputs into different species is adopted from the calibration of the Lynnhaven River. It is apparent that different basins require different partition factors.

Appendices 5 to 7 indicate that, for the other three basins, the general spatial and temporal trends of field observations are reproduced by the model. However, the model generally under-predicts the concentration levels of total carbon, total nitrogen, total phosphorus, and total suspended sediment. The discrepancies between the model predictions and field observations are larger in the spring and summer, and decrease toward fall and early winter, i.e., October and December. The discrepancies are most likely the results of inadequate external inputs. A better nonpoint source model than STORM should be used, and calibrated for basins with different land use characteristics. Furthermore, most nonpoint sources do not include sediment source from shoreline erosion, and therefore a separate quantitative estimate of shoreline erosion is required for an accurate prediction of the total suspended sediment concentration.

V. Summary and Conclusions

A bi-monthly water quality monitoring program was executed in 1997 for four small coastal basins: the Poquoson and Piankatank Rivers on the western shore, and the Cherrystone Inlet and Hungars Creek on the eastern shore of Virginia. The observed concentrations of dissolved inorganic nitrogen and phosphorus are all very low, satisfying the SAV (submerged aquatic vegetation) requirements. High chlorophyll 'a' concentrations were observed in all basins in late winter and early spring. Spatial distributions suggest that the winter-spring algal bloom originates from the Bay. Summer algal growth are mostly in the shallow landward end of the basins, except the Hungars Creek where the chlorophyll 'a' concentrations were low and exhibit no distinct spatial pattern. All observed dissolved oxygen (DO) concentrations were above 5.0 mg/l, except one in the Cherrystone Inlet (4.9 mg/l) and several in the Piankatank River. Low DO concentrations were restricted to the bottom waters and occurred only in summer months. Total suspended sediment (TSS) concentrations exceeding the SAV requirement were observed in all four basins and in all seasons. Except for Hungars Creek, the spatial distributions indicate that local sources, either from watershed runoff or shoreline erosion, have significant contribution to the excessive TSS concentrations. The TSS distributions in the Hungars Creek were more variable, and no conclusion regarding its source may be drawn.

The tidal prism water quality model has been applied to four small coastal basins: the Poquoson and Piankatank Rivers on the western shore, and the Cherrystone Inlet and Hungars Creek on the eastern shore. The model is run to simulate the 1997 water quality conditions in each of the basins, and the results compared with the bi-monthly survey data. The external loads of nonpoint sources are generated with the watershed model STORM, developed by US Army Corps of Engineers. Values of all model calibration parameters are adopted from the previous calibration of the models to the Lynnhaven River of Virginia Beach.

Salinity distributions are well simulated by the tidal prism model in all four basins. It may be concluded that the value of 0.3 for the returning ratio (the only calibration parameter for physical transport process) is adequate for most small coastal basins of Chesapeake Bay system without the need of further calibration. The models, with the values of calibration constants adopted from the Lynnhaven River for both the tidal prism model and STORM, are acceptable to the Hungars Creek. However, the differentiation of individual species of carbon, nitrogen, and phosphorus requires more accurate partition of these nutrients, or application of a more sophisticated watershed model. The model result of nutrients and total suspended sediment concentrations in the other three basins are generally lower than field data, even though the prediction of dissolved oxygen and chlorophyll 'a' concentrations agree with field observations. Better characterization of nonpoint source loadings is required prior to usage of the tidal prism model for scenario runs. Monitoring of nonpoint source loadings and application of a more sophisticated watershed model for small coastal basins are recommended.

Both the model simulation and field data indicate that the water quality in the lower portions of small basins are dominated by the conditions at the mouth in the Bay or major tributaries. Water quality data at the mouth are required for model application. These data may be obtained through monitoring or three-dimensional water quality model of the bay and major tributaries. The upper portions of the basins may be temporarily dominated by nonpoint source loadings during and immediately following runoff events. The use of a watershed model to generate loading inputs is required.

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Appendix A-1. 1997 Field Survey Data, Poquoson River

POQUOSON RIVER
February 11, 1997

Station 1

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	4.5		13.6
2.0	4.5		13.6
3.0	4.5		13.6
4.0	4.4		13.6
5.0	4.4		13.6
6.0	4.4		13.5

Station 2

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	4.6	13.6	12.7
2.0	4.5	13.6	12.7
3.0	4.4	13.7	12.6
4.0	4.4	13.7	12.6

Station 3

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	5.0	12.9	12.0
2.0	5.0	12.9	12.0

Station T1

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	5.0	13.1	12.7
2.0	4.9	13.1	12.7

Station T2

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	3.9	13.3	12.7
2.0	3.9	13.3	12.7
3.0	3.9	13.3	12.5

POQUOSON RIVER: February 11, 1997

	1	2 Top	2 Bottom	3	T1	T2
Secchi Disk, m	1.2	1.0		1.0	1.0	0.9
Chlorophyll	25	22	19	21	20	17
DOC	3.2	3.2	3.1	3.5	3.8	3.1
PC	2.0	2.2	2.3	2.1	2.4	2.3
POC	1.9	2.1	2.1	2.0	2.2	2.2
TDN	0.32	0.30	0.29	0.30	0.22	0.27
NH4	0.011	0.007	0.007	0.008	0.007	0.007
NO2+NO3	0.071	0.054	0.052	0.001	0.003	0.033
DON*	0.24	0.24	0.23	0.29	0.21	0.23
PN	0.22	0.24	0.25	0.26	0.25	0.25
TDP	0.010	0.012	0.008	0.007	0.011	0.006
PO4	0.002	0.004	0.002	0.001	0.003	0.002
DOP*	0.008	0.008	0.006	0.006	0.008	0.004
PPhos	0.017	0.017	0.018	0.017	0.017	0.017
PIP	0.008	0.006	0.007	0.007	0.007	0.007
POP*	0.009	0.011	0.011	0.011	0.010	0.010
TSS	13	12	15	11	12	15
FS	7	6	8	5	5	8
VS*	6	6	7	6	7	7

Note: Chlorophyll is in mg/m^3, all others in g/m^3 unless noted otherwise.
* indicates calculated value.

POQUOSON RIVER
May 5, 1997

Station 1

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	15.5	16.2	9.0
2.0	15.2	16.3	8.9
3.0	15.3	16.3	8.9
4.0	15.3	16.3	8.8
5.0	15.2	16.4	8.7
6.0	15.1	16.4	8.4

Station 2

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	16.5	15.5	8.6
2.0	16.1	15.9	8.9
3.0	15.6	16.2	8.8
4.0	15.3	16.3	8.6

Station 3

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	16.8	14.3	6.6
2.0	17.4	15.0	6.2

Station T1

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	17.6	14.5	6.5
2.0	17.4	15.2	6.4

Station T2

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	15.8	15.4	8.1
2.0	16.1	15.3	8.0
3.0	16.2	15.3	7.7

POQUOSON RIVER: May 5, 1997

	1	2 Top	2 Bottom	3	T1	T2
Secchi Disk, m	1.5	1.0		0.5	0.5	1.0
Chlorophyll	6	8	7	7	7	22
DOC	3.4	3.5	3.6	3.8	4.2	3.6
PC	1.0	0.9	1.0	1.2	1.2	1.1
POC						
TDN	0.31	0.34	0.31	0.40	0.41	0.34
NH4	0.019	0.039	0.002	0.102	0.099	0.026
NO2+NO3	0.042	0.036	0.041	0.050	0.038	0.024
DON*	0.25	0.26	0.27	0.25	0.27	0.29
PN	0.15	0.12	0.14	0.18	0.19	0.16
TDP	0.014	0.012	0.010	0.010	0.014	0.013
PO4	0.002	0.001	0.002	0.002	0.004	0.002
DOP*	0.012	0.011	0.008	0.008	0.010	0.011
PPhos		0.016	0.020	0.028	0.025	0.019
PIP	0.003	0.003	0.003	0.005	0.008	0.007
POP*		0.013	0.017	0.023	0.017	0.012
TSS	11	10	10	19	17	13
FS	7	7	7	15	13	10
VS*	4	3	3	4	4	3

Note: Chlorophyll is in mg/m^3, all others in g/m^3 unless noted otherwise.
* indicates calculated value.

POQUOSON RIVER
June 3, 1997

Station 1				Station 2			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l	Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	20.2	19.7	8.1	1.0	19.9	19.4	8.1
2.0	20.2	19.7	8.1	2.0	19.9	19.4	8.1
3.0	20.2	19.8	8.1	3.0	19.9	19.4	8.0
4.0	20.2	19.8	8.0	4.0	19.9	19.4	7.6
5.0	20.3	19.9	8.0	5.0	20.0	19.7	6.7
				6.0	20.1	19.8	6.8

Station 3				Station T1			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l	Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	21.3	20.0	6.4	1.0	21.9	20.1	5.7
2.0	21.3	20.0	6.1	2.0	21.9	20.1	5.7
3.0	21.1	19.5	6.3	3.0	21.9	20.1	5.7

Station T2			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	20.6	20.3	6.3
2.0	20.6	20.4	6.4
3.0	20.6	20.4	6.7

POQUOSON RIVER: June 3, 1997

	1	2 Top	2 Bottom	3	T1	T2
Secchi Disk, m	1.3	1.0		0.7	0.7	0.5
Chlorophyll	8	13	9	6	5	6
DOC	3.4	3.2	3.5	3.8	3.4	3.4
PC	1.3	1.6	1.6	1.9	1.5	1.5
POC						
TDN	0.26	0.27	0.27	0.34	0.32	0.30
NH4	0.017	0.016	0.018	0.073	0.048	0.013
NO2+NO3	0.001	0.001	0.000	0.006	0.003	0.000
DON*	0.24	0.25	0.25	0.26	0.27	0.29
PN	0.12	0.14	0.15	0.15	0.14	0.11
TDP	0.013	0.015	0.012	0.009	0.012	0.012
PO4	0.003	0.003	0.003	0.002	0.003	0.003
DOP*	0.010	0.012	0.009	0.007	0.009	0.009
PPhos	0.016		0.025	0.037	0.026	0.024
PIP	0.005		0.007	0.009	0.006	0.006
POP*	0.011		0.018	0.028	0.020	0.018
TSS	10		27	35	19	21
FS	7		20	29	14	16
VS*	3		7	6	5	5

Note: Chlorophyll is in mg/m^3, all others in g/m^3 unless noted otherwise.
* indicates calculated value.

POQUOSON RIVER
August 7, 1997

Station 1				Station 2			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l	Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	26.2	22.1	7.0	1.0	26.2	22.2	6.9
2.0	26.2	22.1	7.0	2.0	26.2	22.2	6.8
3.0	26.1	22.1	7.0	3.0	26.2	22.2	6.7
4.0	26.0	22.1	6.8	4.0	26.0	22.2	6.6
5.0	26.0	22.1	6.4	5.0	25.9	22.2	6.4

Station 3				Station T1			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l	Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	26.8	22.2	6.9	1.0	26.9	22.1	6.4
2.0	26.8	22.2	6.8	2.0	26.7	22.1	5.9

Station T2			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	26.0	22.3	6.6
2.0	25.9	22.3	6.3

POQUOSON RIVER: August 7, 1997

	1	2 Top	2 Bottom	3	T1	T2
Secchi Disk, m	1.0	1.0		0.6	0.6	1.0
Chlorophyll	11	10	10	18	11	33
DOC	3.4	3.6	3.6	4.5	4.1	3.8
PC	1.3	1.3	1.4	2.5	1.9	1.3
POC						
TDN	0.26	0.30	0.31	0.35	0.34	0.33
NH4	0.007	0.008	0.012	0.008	0.008	0.010
NO2+NO3	0.001	0.001	0.002	0.001	0.002	0.002
DON*	0.25	0.29	0.30	0.34	0.33	0.32
PN	0.19	0.20	0.23	0.36	0.29	0.20
TDP	0.012	0.011	0.012	0.013	0.011	0.014
PO4	0.003	0.002	0.002	0.003	0.002	0.002
DOP*	0.009	0.009	0.010	0.010	0.009	0.012
PPhos	0.026	0.025	0.029	0.042	0.033	0.026
PIP	0.005	0.004	0.006	0.008	0.006	0.005
POP*	0.021	0.021	0.023	0.034	0.027	0.021
TSS	16	15	17	27	20	13
FS	10	10	12	17	13	8
VS*	6	5	5	10	7	5

Note: Chlorophyll is in mg/m^3, all others in g/m^3 unless noted otherwise.
* indicates calculated value.

POQUOSON RIVER
October 30, 1997

Station 1

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	15.2	25.3	8.1
2.0	15.2	25.3	8.1
3.0	15.2	25.3	8.1
4.0	15.2	25.3	8.1
5.0	15.2	25.3	8.1

Station 2

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	14.5	25.0	8.8
2.0	14.5	25.0	8.7
3.0	14.6	25.1	8.6
4.0	14.6	25.1	8.6

Station 3

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	13.4	24.1	9.4
2.0	13.7	24.4	9.3

Station T1

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	13.7	24.2	9.1
2.0	13.8	24.3	9.0

Station T2

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	13.0	24.4	8.9
2.0	13.2	24.5	8.8

POQUOSON RIVER: October 30, 1997

	1	2 Top	2 Bottom	3	T1	T2
Secchi Disk, m	1.2	1.1		0.8	0.9	1.7
Chlorophyll	7	10	8	12	7	
DOC	3.4	3.5	3.8	3.7	4.0	3.9
PC	0.5	0.7	0.7	1.3	1.1	0.5
POC						
TDN	0.36	0.34	0.35	0.29	0.30	0.34
NH4	0.059	0.016	0.022	0.007	0.006	0.028
NO2+NO3	0.049	0.043	0.046	0.003	0.001	0.019
DON*	0.25	0.28	0.28	0.28	0.29	0.29
PN	0.10	0.14	0.14	0.20	0.17	0.09
TDP	0.022	0.018	0.021	0.018	0.018	0.019
PO4	0.006	0.002	0.003	0.002	0.002	0.002
DOP*	0.016	0.016	0.018	0.016	0.016	0.017
Pphos	0.015	0.015	0.017	0.019	0.018	0.011
PIP	0.004	0.003	0.004	0.004	0.004	0.002
POP*	0.011	0.012	0.013	0.015	0.014	0.009
TSS	16	10	13	13	13	9
FS	12	6	10	9	9	6
VS*	4	4	3	4	4	3

Note: Chlorophyll is in mg/m^3, all others in g/m^3 unless noted otherwise.
* indicates calculated value.

POQUOSON RIVER
December 15, 1997

Station 1				Station 2			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l	Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	6.4	21.1	10.3	1.0	6.3	21.2	10.4
2.0	6.4	21.1	10.4	2.0	6.3	21.2	10.4
3.0	6.4	21.2	10.4	3.0	6.5	21.3	10.5
4.0	6.4	21.2	10.4	4.0	6.6	21.3	10.6
5.0	6.5	21.2	10.6				

Station 3				Station T1			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l	Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	5.7	20.6	11.0	1.0	6.0	20.8	10.7
2.0	5.7	20.6	11.0	2.0	6.0	20.8	10.8
				3.0	6.0	20.8	10.9

Station T2			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	5.6	21.1	10.4
2.0	5.8	21.1	10.6

POQUOSON RIVER December 15, 1997

	1	2 Top	2 Bottom	3	T1	T2
Secchi Disk, m	1.9	2.0		1.7	1.7	1.7
Chlorophyll	3	3	2	3	4	3
DOC	3.1	3.3	3.7	3.6	3.3	3.7
PC	0.5	0.5	0.5	0.8	0.7	0.6
POC						
TDN	0.31	0.29	0.29	0.28	0.28	0.27
NH4	0.012	0.011	0.012	0.007	0.005	0.007
NO2+NO3	0.013	0.011	0.017	0.002	0.001	0.004
DON*	0.28	0.27	0.26	0.27	0.27	0.26
PN	0.11	0.11	0.10	0.12	0.12	0.10
TDP	0.024	0.020	0.016	0.019	0.018	0.019
PO4	0.006	0.005	0.005	0.003	0.003	0.003
DOP*	0.018	0.015	0.011	0.016	0.015	0.016
Pphos	0.010	0.009	0.009	0.011	0.011	0.010
PIP	0.002	0.002	0.002	0.002	0.002	0.002
POP*	0.008	0.007	0.007	0.009	0.009	0.008
TSS	11	8	7	10	11	9
FS	8	5	4	7	8	5
VS*	3	3	3	3	3	4

Note: Chlorophyll is in mg/m^3, all others in g/m^3 unless noted otherwise.
* indicates calculated value.

Appendix A-2. 1997 Field Survey Data, Piankatank River

PIANKATANK RIVER
February 7, 1997

Station 1				Station 2			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l	Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	5.3		13.3	1.0	5.7	9.2	12.3
2.0	5.3		13.3	2.0	5.6	9.5	12.3
3.0	5.3		13.3	3.0	5.6	9.7	12.3
4.0	5.3		13.3	4.0	5.6	9.7	12.3
5.0	5.3		13.3	5.0	5.6	9.8	12.1
6.0	5.3		13.3	6.0	5.5	9.9	12.1
7.0	5.3		13.3	7.0	5.5	10.0	12.1
8.0	5.3		13.3	8.0	5.4	9.8	12.2

Station 3				Station 4			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l	Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	6.1	7.9	11.1	1.0	6.7	5.7	10.2
2.0	6.1	8.2	11.0	2.0	6.6	6.2	10.3
3.0	6.0	8.5	11.0	3.0	6.6	6.4	10.3
4.0	6.0	8.5	11.0	4.0	6.6	6.5	10.2
5.0	6.0	8.5	11.0	5.0	6.6	6.4	10.2
6.0	6.0	8.7	11.0				

PIANKATANK RIVER: February 7, 1997

	1	2 Top	2 Bottom	3	4
Secchi Disk, m	1.6	1.3		1.1	0.9
Chlorophyll	13	31	15	15	10
DOC	3.2	3.4	3.5	3.7	3.6
PC	2.5	1.8	3.7	1.7	1.4
POC	2.2	1.7	3.6	1.6	1.3
TDN	0.48	0.42	0.45	0.44	0.45
NH4	0.018	0.023	0.020	0.055	0.052
NO2+NO3	0.198	0.124	0.137	0.104	0.105
DON*	0.26	0.27	0.29	0.28	0.30
PN	0.22	0.20	0.46	0.23	0.21
TDP	0.018	0.010	0.010	0.010	0.007
PO4	0.004	0.003	0.002	0.002	0.001
DOP*	0.014	0.007	0.008	0.008	0.006
PPhos	0.016	0.016	0.060	0.025	0.040
PIP		0.005	0.027	0.012	0.018
POP*		0.011	0.033	0.013	0.022
TSS	15	9	43	9	15
FS	8	6	32	4	9
VS*	7	3	11	5	6

Note: Chlorophyll is in mg/m^3, all others in g/m^3 unless noted otherwise.
* indicates calculated value.

PIANKATANK RIVER
April 21, 1997

Station 1				Station 2			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l	Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	12.6	11.5	11.4	1.0	13.0	11.0	11.0
2.0	12.5	11.5		2.0	13.0	11.0	10.9
3.0	12.5	11.5	10.8	3.0	12.8	11.3	8.9
4.0	12.4	11.7		4.0	12.1	11.7	8.6
5.0	12.1	12.0	10.4	5.0	12.0	11.8	8.6
6.0	11.9	12.5	9.0				
7.0	11.8	12.4	8.8				

Station 3				Station 4			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l	Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	13.2	9.4	8.7	1.0	13.6	7.7	9.0
2.0	13.2	9.8	7.9	2.0	13.7	8.2	8.4
3.0	13.2	10.2	7.9	3.0	13.7	8.4	8.4
4.0	13.1	10.6	7.8	4.0	13.6	8.6	8.2
5.0	12.7	10.9	6.9				
6.0	12.6	10.8	6.9				

PIANKATANK RIVER: April 21, 1997

	1	2 Top	2 Bottom	3	4
Secchi Disk, m	1.6	1.1		1.3	1.0
Chlorophyll	30	16	34	21	11
DOC	3.7	3.6	3.9	4.4	4.5
PC	3.1	2.6	4.1	2.4	2.6
POC					
TDN	0.30	0.28	0.26	0.28	0.28
NH4	0.007	0.007	0.008	0.007	0.005
NO2+NO3	0.003	0.001	0.003	0.002	0.001
DON*	0.29	0.27	0.25	0.27	0.27
PN	0.38	0.32	0.54	0.36	0.31
TDP	0.014	0.008	0.008	0.009	0.013
PO4	0.005	0.001	0.002	0.002	0.003
DOP*	0.009	0.007	0.006	0.007	0.010
PPhos	0.023	0.022	0.037	0.033	0.040
PIP	0.006	0.004	0.011	0.008	0.008
POP*	0.017	0.018	0.026	0.025	0.032
TSS	14	12	22	16	16
FS	8	6	12	8	7
VS*	6	6	10	8	9

Note: Chlorophyll is in mg/m^3, all others in g/m^3 unless noted otherwise.
* indicates calculated value.

PIANKATANK RIVER
June 2, 1997

Station 1				Station 2			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l	Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	20.8	15.0	9.4	1.0	21.6	13.8	7.4
2.0	20.7	15.0	9.2	2.0	21.6	13.8	7.5
3.0	20.6	15.0	9.0	3.0	21.6	13.9	7.3
4.0	20.6	15.0	8.7	4.0	21.5	13.9	7.0
5.0	20.5	15.0	8.6	5.0	20.9	14.1	6.0
6.0	20.1	15.1	6.7	6.0	20.1	14.4	4.5
7.0	19.3	15.2	5.7	7.0	19.4	14.7	3.8
8.0	19.2	14.6	5.7	8.0	19.2	14.0	3.9

Station 3				Station 4			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l	Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	22.2	12.0	5.4	1.0	23.2	10.0	4.8
2.0	22.0	12.3	5.5	2.0	23.1	10.2	4.4
3.0	22.0	12.5	5.3	3.0	23.0	10.6	4.6
4.0	21.8	12.7	4.9	4.0	22.9	10.5	4.2
5.0	21.6	12.8	4.7				
6.0	21.5	12.9	4.3				
7.0	21.5	12.3	4.0				

PIANKATANK RIVER: June 2, 1997

	1	2 Top	2 Bottom	3	4
Secchi Disk, m	1.8	1.2		0.7	0.6
Chlorophyll	6	10	9	9	16
DOC	3.2	3.4	3.3	3.7	4.1
PC	1.3	1.3	1.3	1.4	2.0
POC					
TDN	0.28	0.30	0.51	0.31	0.30
NH4	0.018	0.016	0.116	0.057	0.024
NO2+NO3	0.005	0.001	0.002	0.001	0.002
DON*	0.26	0.28	0.39	0.25	0.27
PN	0.13	0.18	0.22	0.21	0.22
TDP	0.011	0.015	0.030	0.013	0.014
PO4	0.002	0.002	0.004	0.002	0.002
DOP*	0.009	0.013	0.026	0.011	0.012
PPhos	0.013	0.020	0.024	0.032	0.048
PIP	0.003	0.003	0.004	0.006	0.012
POP*	0.010	0.017	0.020	0.026	0.036
TSS	6	8	11	16	23
FS	3	4	7	11	16
VS*	3	4	4	5	7

Note: Chlorophyll is in mg/m^3, all others in g/m^3 unless noted otherwise.
* indicates calculated value.

PIANKATANK RIVER
August 8, 1997

Station 1				Station 2			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l	Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	26.8	17.3	7.4	1.0	26.9	16.7	7.5
2.0	26.5	17.4	7.3	2.0	26.8	16.8	6.8
3.0	26.3	17.4	7.2	3.0	26.7	17.0	5.5
4.0	26.2	17.4	7.0	4.0	26.6	17.1	5.1
5.0	26.2	17.4	7.0	5.0	26.4	17.2	3.6
6.0	26.1	17.4	7.0	6.0	26.4	17.2	3.4
7.0	26.1	17.4	6.8	7.0	26.4	17.2	3.4
8.0	26.1	17.4	6.7				

Station 3				Station 4			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l	Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	28.1	14.9	7.2	1.0	28.0	13.2	7.5
2.0	27.4	15.5	6.5	2.0	27.4	13.5	6.0
3.0	26.9	15.7	5.9	3.0	27.2	13.9	5.1
4.0	26.6	15.9	4.6	4.0	27.0	14.2	4.6
5.0	26.6	16.1	3.0	5.0	27.0	14.3	4.3
6.0	26.6	14.8	2.8				

PIANKATANK RIVER: August 8, 1997

	1	2 Top	2 Bottom	3	4
Secchi Disk, m		1.0		0.7	0.6
Chlorophyll	8	14	9	16	16
DOC	4.0	4.6	3.8	4.4	6.0
PC	1.3	1.9	1.3	2.0	2.7
POC					
TDN	0.30	0.31	0.34	0.34	0.37
NH4	0.006	0.005	0.025	0.005	0.005
NO2+NO3	0.001	0.000	0.002	0.000	0.000
DON*	0.29	0.31	0.31	0.34	0.36
PN	0.18	0.25	0.21	0.29	0.39
TDP	0.011	0.014	0.014	0.017	0.020
PO4	0.003	0.004	0.004	0.005	0.006
DOP*	0.008	0.010	0.010	0.012	0.014
PPhos	0.024	0.029	0.027	0.034	0.054
PIP	0.004	0.004	0.006	0.006	0.013
POP*	0.020	0.025	0.021	0.028	0.041
TSS	9	7	8	10	19
FS	4	1	4	4	11
VS*	5	6	4	6	8

Note: Chlorophyll is in mg/m^3, all others in g/m^3 unless noted otherwise.
* indicates calculated value.

PIANKATANK RIVER
October 10, 1997

Station 1				Station 2			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l	Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	21.4	19.3	7.5	1.0	21.7	18.5	6.6
2.0	21.4	19.3	7.5	2.0	21.7	18.5	6.4
3.0	21.4	19.3	7.3	3.0	21.7	18.5	6.2
4.0	21.4	19.3	7.2	4.0	21.7	18.5	6.1
5.0	21.4	19.3	7.1	5.0	21.7	18.6	6.1
6.0	21.4	19.4	7.1	6.0	21.8	18.6	6.0
7.0	21.4	19.4	7.1	7.0	21.7	18.6	6.0
8.0	21.4	19.4	7.1				
9.0	21.4	19.4	7.0				
10.0	21.4	19.4	6.9				

Station 3				Station 4			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l	Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	22.1	17.5	6.1	1.0	22.3	16.4	5.3
2.0	22.0	17.6	6.1	2.0	22.1	16.6	4.9
3.0	22.0	17.6	6.1	3.0	22.0	16.5	4.7
4.0	21.9	17.7	5.8	4.0	22.0	16.7	4.7
5.0	21.9	17.7	5.7	5.0	22.0	16.8	4.7

PIANKATANK RIVER: October 10, 1997

	1	2 Top	2 Bottom	3	4
Secchi Disk, m	1.3	1.4		1.0	0.7
Chlorophyll	6	8	8	9	9
DOC	3.5	4.0	4.1	4.3	4.4
PC	1.1	1.0	1.2	1.1	1.4
POC					
TDN	0.32	0.34	0.31	0.33	0.33
NH4	0.009	0.009	0.016	0.005	0.005
NO2+NO3	0.001	0.000	0.002	0.001	0.001
DON*	0.31	0.33	0.29	0.32	0.32
PN	0.18	0.17	0.19	0.20	0.24
TDP	0.049	0.020	0.017	0.022	0.022
PO4	0.029	0.003	0.003	0.005	0.005
DOP*	0.020	0.017	0.014	0.017	0.017
Pphos	0.022	0.024	0.029	0.032	0.046
PIP	0.005	0.006	0.008	0.007	0.014
POP*	0.017	0.018	0.021	0.025	0.032
TSS	12	10	15	14	17
FS	8	6	10	9	12
VS*	4	4	5	5	5

Note: Chlorophyll is in mg/m^3, all others in g/m^3 unless noted otherwise.
* indicates calculated value.

PIANKATANK RIVER
December 4, 1997

Station 1

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	8.7	17.6	10.4
2.0	8.7	17.6	10.4
3.0	8.6	17.7	10.2
4.0	8.6	17.7	10.2
5.0	8.6	17.7	10.2
6.0	8.6	17.7	10.2
7.0	8.6	17.7	

Station 2

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	9.1	16.7	10.5
2.0	8.9		
3.0	8.8		
4.0	8.9		
5.0	8.8		
6.0	8.8		
7.0	8.8	17.3	10.0

Station 3

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	9.3		
2.0	9.2	15.6	9.2
3.0	8.9		
4.0	8.9		
5.0	8.9		

Station 4

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	9.5		
2.0	9.1	12.4	8.7
3.0	9.0		
4.0	8.9		

PIANKATANK RIVER: December 4, 1997

	1	2 Top	2 Bottom	3	4
Secchi Disk, m	3.3	2.1		1.2	1.1
Chlorophyll	3	4	5	8	6
DOC	3.0	3.5	3.2	3.4	3.8
PC	0.5	0.6	0.6	1.1	1.0
POC					
TDN	0.28	0.27	0.29	0.28	0.25
NH4	0.005	0.005	0.006	0.008	0.004
NO2+NO3	0.001	0.001	0.001	0.003	0.001
DON*	0.27	0.26	0.28	0.27	0.25
PN	0.08	0.10	0.10	0.17	0.17
TDP	0.013	0.010	0.017	0.018	0.013
PO4	0.002	0.002	0.002	0.005	0.003
DOP*	0.011	0.008	0.015	0.013	0.010
Pphos	0.007	0.008	0.008	0.016	0.018
PIP	0.000	0.001	0.001	0.003	0.005
POP*	0.007	0.007	0.007	0.013	0.013
TSS	9	8	7	14	12
FS	6	6	5	10	8
VS*	3	2	2	4	4

Note: Chlorophyll is in mg/m^3, all others in g/m^3 unless noted otherwise.
* indicates calculated value.

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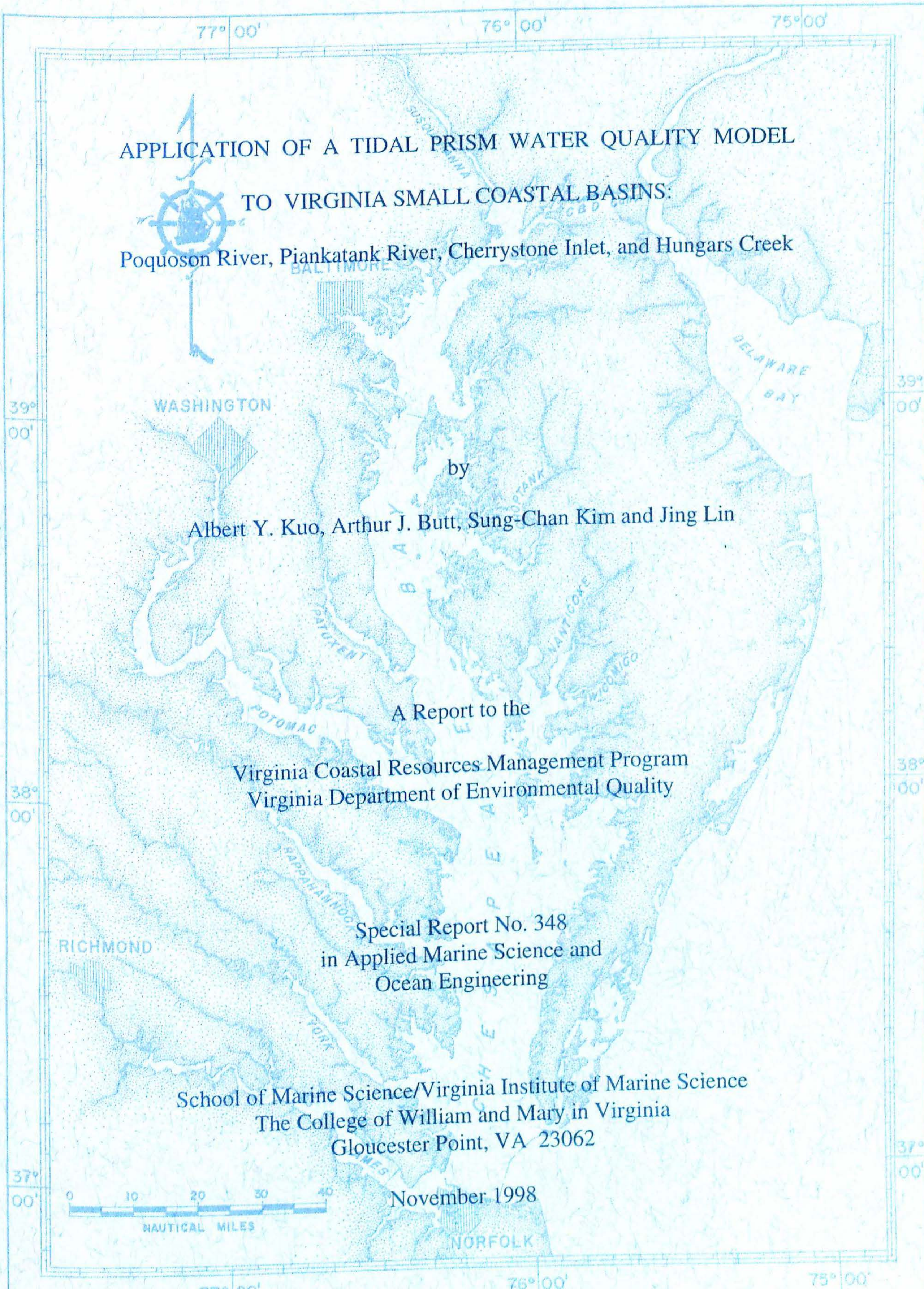

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Acknowledgments

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We would like to thank Shawn Smith of the Virginia Chesapeake Bay Local Assistance Department, and Julie Glover of the VIMS Department of Resource Management and Policy for compiling the land use data of the four targeted small coastal basins.

I. Introduction

Under the project entitled "Development of a Water Quality Model for Small Coastal Basins to Address Management Needs" of the FY '93 and '94 Virginia Coastal Resources Management Program Grants (VCRMPG), a tidal prism water quality model was developed (Kuo & Park, 1994). The model was applied to the Lynnhaven River, calibrated and verified with data collected by VIMS (Virginia Institute of Marine Science) and VADEQ (Virginia Department of Environmental Quality) (Park et al., 1995). The values of model parameters were determined through model calibration and confirmed through model verification.

To be used as a tool to help setting goals and developing strategies for nutrient reduction in a particular coastal basin, the model needs to be calibrated to derive a set of parameter values appropriate to that basin. In practice, it is impossible to collect field data for model calibration in all of the small coastal basins fringing the mainstem Chesapeake Bay and its major tributaries. As an alternative, VCRMPG supported a study to test the model applicability without calibration data. The study was financed through two grants: Task 84 of the 1995 Grant and Task 4.4 of the 1996 Grant. Four targeted basins were selected for testing: the Poquoson and Piankatank Rivers on the western shore and the Cherrystone Inlet and the Hungars Creek on the eastern shore. The set of model parameter values derived from the calibration of the Lynnhaven River was assumed applicable to all four basins. The model was applied to each basin to simulate the 1997 water quality conditions. Water quality data were also collected in all four basins during 1997, and used to compare with model simulation to determine the relative error for model application without calibration.

This report serves as the combined final report of the Task 84 of the 1995 Grant and the Task 4.4 of the 1996 Grant. A brief description of the tidal prism water quality model is presented in Chapter II. Chapter III describes the field monitoring program. The application of the model to the four targeted basins is presented individually in Chapter IV. Quantitative assessments and a brief summary of model results are given in Chapter V, followed by conclusions and recommendations.

II. Description of the Model

To provide a tool for water quality management of small coastal basins, VIMS (Virginia Institute of Marine Science) developed a tidal prism model in the late 1970s (Kuo & Neilson, 1988). The tidal prism model simulates the physical transport processes in terms of the concept of tidal flushing (Ketchum, 1951). The implementation of the concept in numerical computation is simple and straightforward, and thus ideal for small coastal basins including those with a high degree of branching. The model was applied to several small coastal basins in Virginia (Ho et al., 1977; Cerco and Kuo, 1981), and has been employed by Virginia Water Control Board for point source wasteload allocations and by local planning district commissions to address impacts of nonpoint source management (Kuo et al., 1982). The US Army Corps of Engineers and the City of Virginia Beach also have used the model to assess the water quality impacts of navigation channel and canal construction in the Lynnhaven Bay system (Kuo and Hyer, 1979; Hayes, Seay, Mattern and Mattern, 1982).

The tidal prism water quality model, described in Kuo & Park (1994), has been evolved from the one in Kuo & Neilson (1988). The model in Kuo & Neilson (1988) simulates the conditions in the main channel and its primary branches (those connected to the main channel) only. The model was modified to include shallow embayments connected to the primary branches, thus allowing the model to simulate the conditions in the secondary branches (those connected to the primary branches). The modified model (Kuo & Park, 1994) treats the secondary branches as storage areas, which exchange the water masses with the primary branches as the tide rises and falls. A new solution scheme (Park and Kuo, 1996), in which decoupling of the kinetic processes from the physical transport and external sources results in a simple and efficient computational procedure, was developed and used for the modified model. The kinetic portion of the model in Kuo & Neilson (1988) was expanded to describe eutrophication processes more completely and to be comparable with the modeling efforts in the Bay mainstem and major tributaries. First, the kinetic formulations used in the Chesapeake Bay three-dimensional water quality model (Cerco and Cole, 1994) were modified and used in the model reported in Kuo & Park (1994). Second, the sediment process model that was used for modeling of the Chesapeake Bay mainstem and major tributaries (DiToro & Fitzpatrick, 1993) was slightly modified and incorporated into the modified model to enhance the predictive capability of the model.

The tidal prism water quality model, described in Kuo & Park (1994), has twenty-four water column and twenty-seven sediment state variables (Table II-1). The model's capability to simulate water quality conditions in a small coastal basin has been demonstrated by its application to the Lynnhaven River (Park et al., 1995). The water column portion of the model was calibrated and verified with extensive data sets collected by VIMS and VADEQ. The values of model parameters were determined for the Lynnhaven River.

Table II-1. Model state variables[a].

WATER COLUMN:

1) salinity
2) temperature
3) cyanobacteria (B_c)
4) diatoms (B_d)
5) green algae (B_g)
6) refractory particulate organic C (RPOC)
7) labile particulate organic C (LPOC)
8) dissolved organic C (DOC)
9) refractory particulate organic P (RPOP)
10) labile particulate organic P (LPOP)
11) dissolved organic P (DOP)
12) total phosphate (PO4t)
13) refractory particulate organic N (RPON)
14) labile particulate organic N (LPON)
15) dissolved organic N (DON)
16) ammonium N (NH4)
17) nitrite+nitrate N (NO3)
18) particulate biogenic silica (SU)
19) available silica (SA)
20) dissolved oxygen (DO)
21) chemical oxygen demand (COD)
22) total suspended solid (TSS)
23) total active metal (TAM)[b]
24) fecal coliform bacteria (FCB)

SEDIMENT:

1-3) particulate organic carbon, G_1, G_2 and G_3 classes in Layer 2
4-6) particulate organic nitrogen, G_1, G_2 and G_3 classes in Layer 2
7-9) particulate organic phosphorus, G_1, G_2 and G_3 classes in Layer 2
10) particulate biogenic silica in Layer 2
11-12) sulfide/methane[c], Layer 1 and 2
13-14) ammonium nitrogen, Layer 1 and 2
15-16) nitrate nitrogen, Layer 1 and 2
17-18) phosphate phosphorus, Layer 1 and 2
19-20) available silica, Layer 1 and 2
21) ammonium nitrogen flux
22) nitrate nitrogen flux
23) phosphate phosphorus flux
24) silica flux
25) sediment oxygen demand
26) release of chemical oxygen demand
27) sediment temperature

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[a] The tidal prism water quality model is described in Kuo & Park (1994).
[b] Total active metal may not be modeled by using total suspended solid as sorption site for phosphate and dissolved silica.
[c] Sulfide is modeled for saltwater while methane is modeled for freshwater.

III. Field Surveys and Data

III-1. Description of Field Surveys

Four small coastal basins, the Poquoson and Piankatank Rivers on the western shore, the Cherrystone Inlet and the Hungars Creek on the eastern shore, were monitored for water quality conditions and providing data to test model applicability without calibration to individual basin. The geographical locations of the four basins are shown in Figure III-1. The monitoring stations in each basins are shown in Figures III-2 to III-5, respectively. There are five stations in the Poquoson River, four stations each in the Piankatank River and the Cherrystone Inlet, and three stations in the Hungars Creek.

A total of six field surveys in each basin were conducted bimonthly from February to December, 1997. All surveys were conducted at high water slacks. At each station, in-situ measurements of temperature, salinity and dissolved oxygen were made every meter from 1 meter below surface to 1 m above bottom. In addition, the secchi depths were also taken. At least one water sample was collected at each station, at 1 m below surface, or at mid-depth if the total depth is less than 2 m. An additional water sample was collected at 1 m above the bottom at one selected station in each of the four basins. The water samples were analyzed for the following water quality variables:

:

dissolved oxygen, chlorophyll 'a'/pheophytin,

particulate carbon, dissolved organic carbon,

(particulate organic carbon was also analyzed for the water samples collected in February)

particulate N (nitrogen), total dissolved N, ammonium N, nitrite+nitrate N,

particulate P (phosphorus), particulate inorganic P, total dissolved P, dissolved ortho-P

total suspended sediment, fixed solid

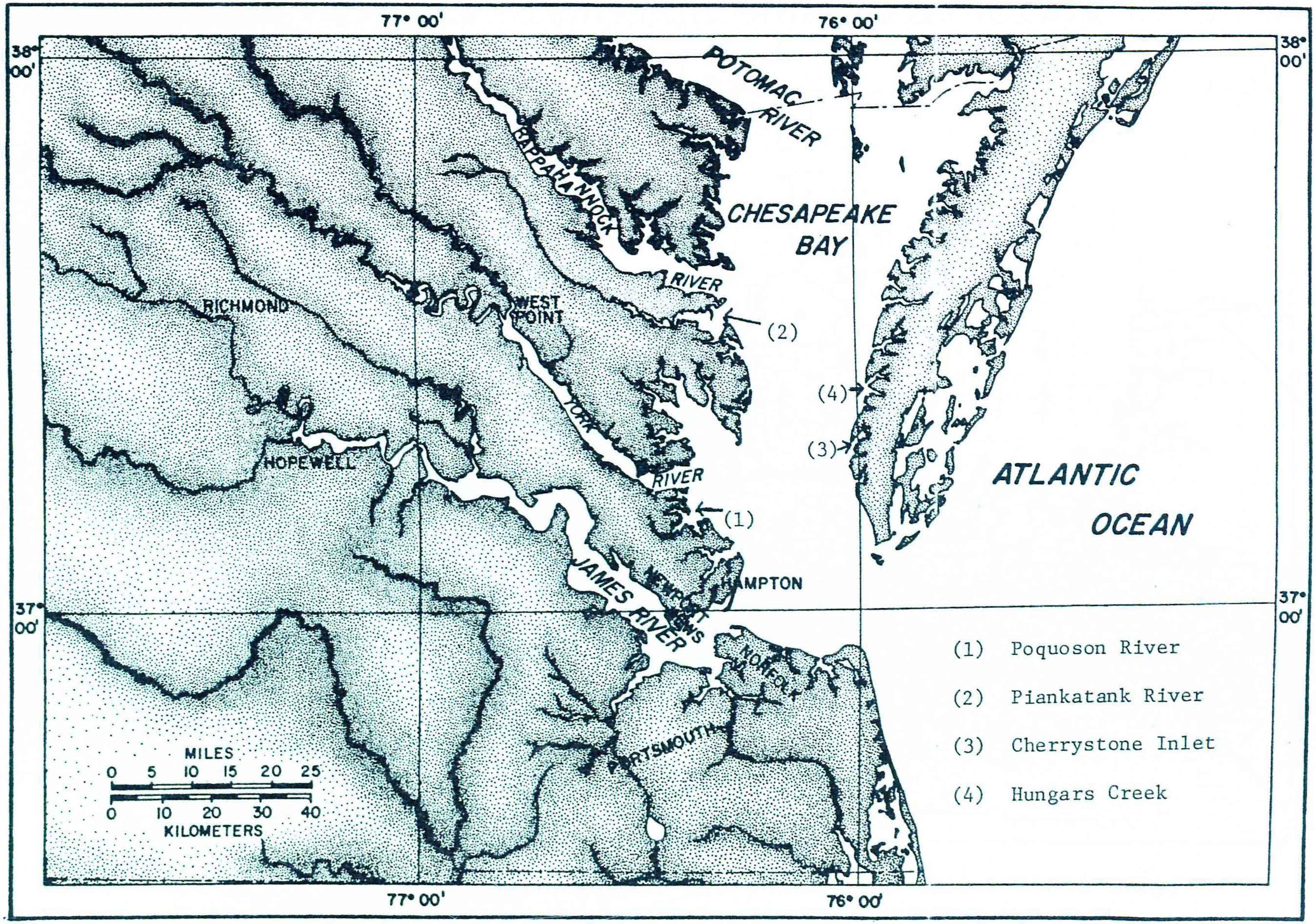

Figure III-1. Map of Tidewater, Virginia, showing locations of coastal basins surveyed in 1997.

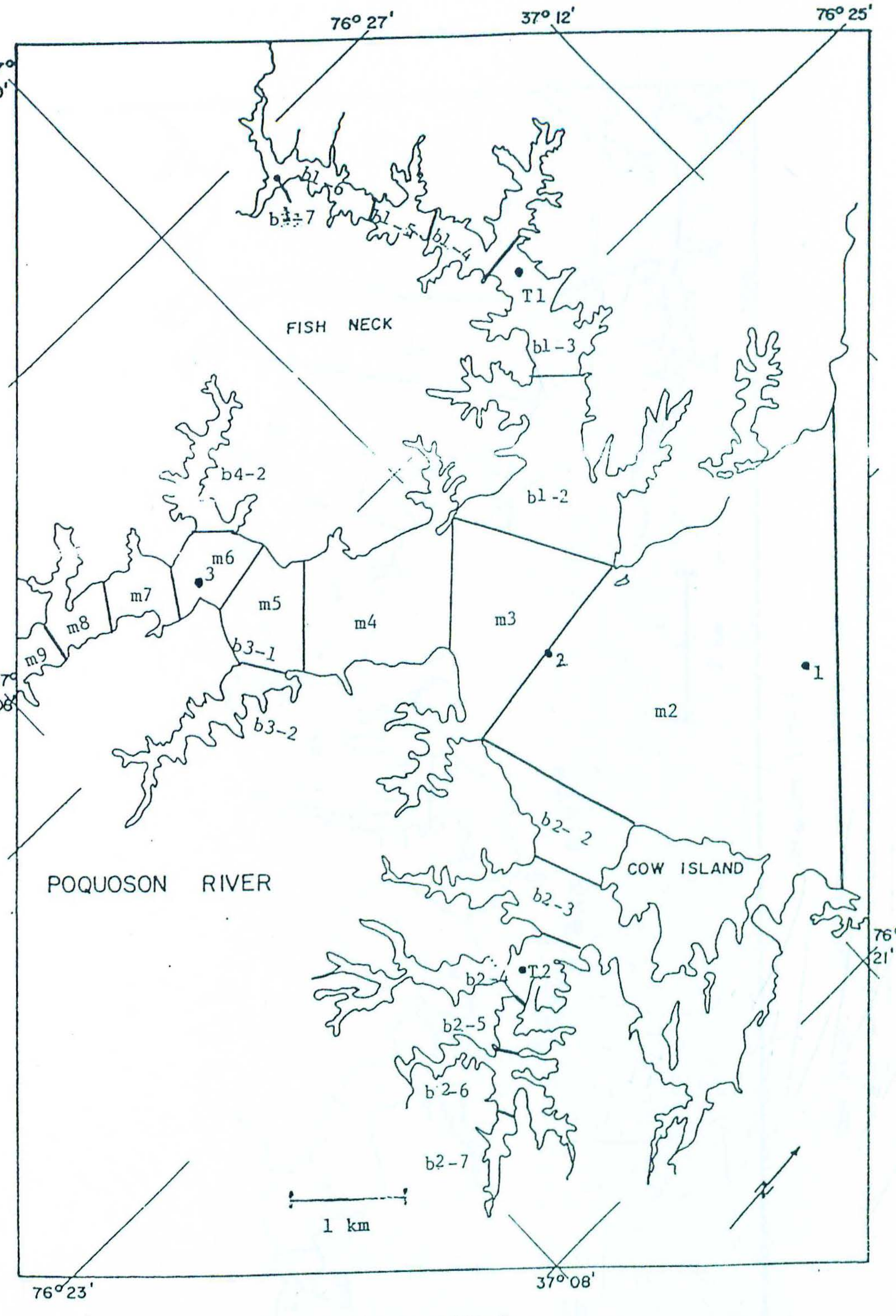

Figure III-2

The Poquoson River, showing the sampling stations for 1997 field surveys and model segmentation.

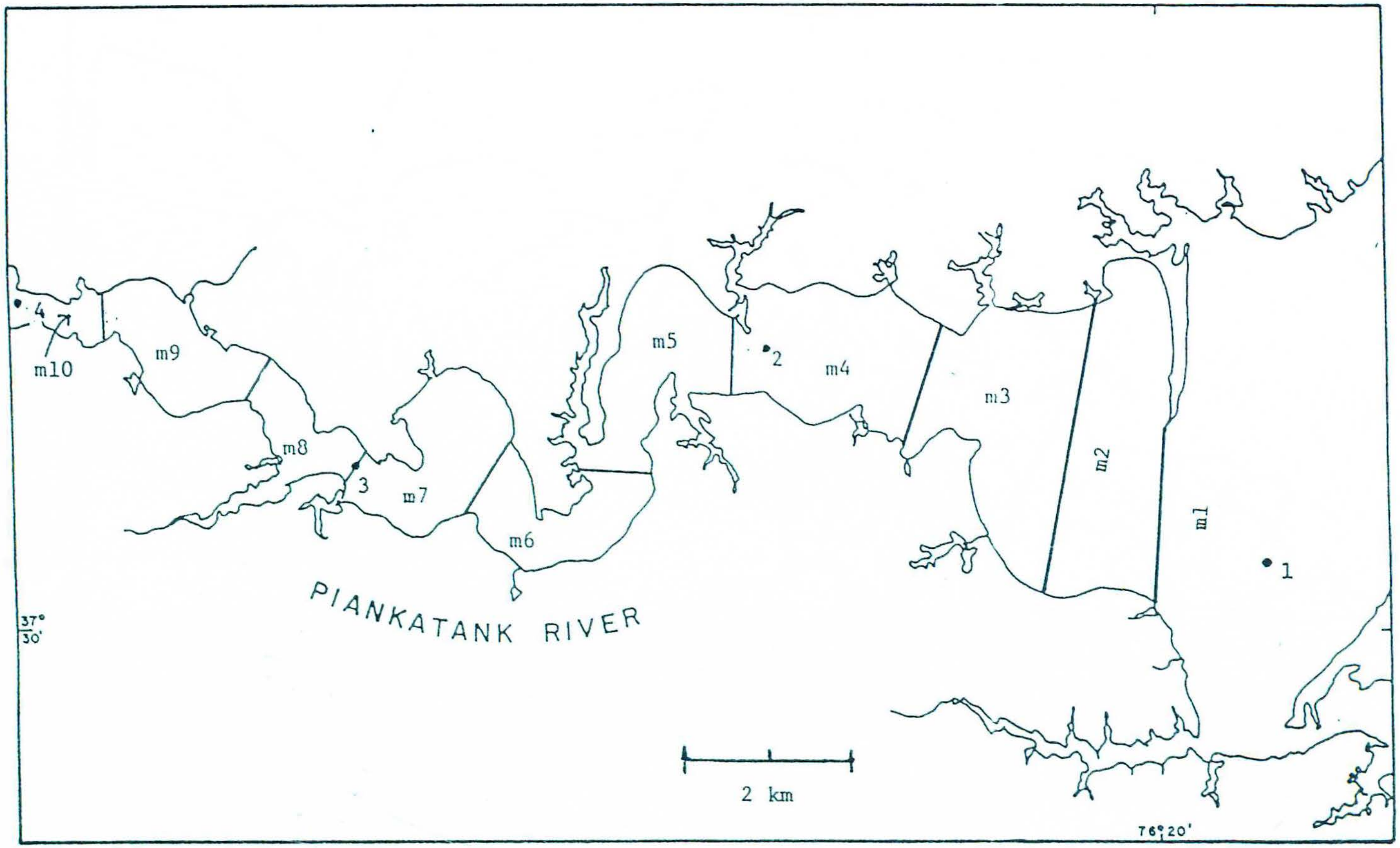

Figure III-3

The Piankatank River, showing the sampling stations for 1997 field surveys and model segmentation.

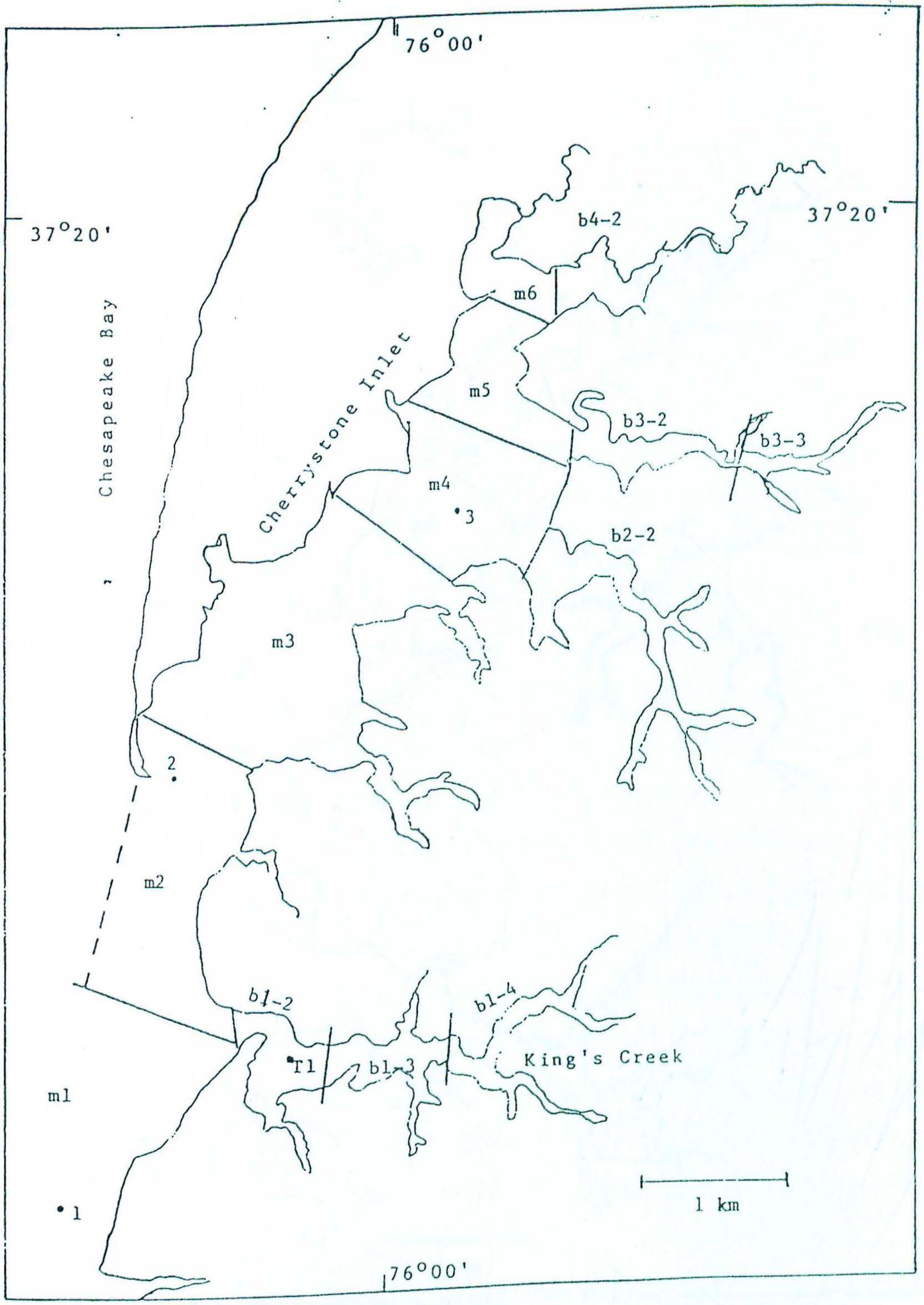

Figure III-4

The Cherrystone Inlet, showing the sampling stations for 1997 field surveys and model segmentation.

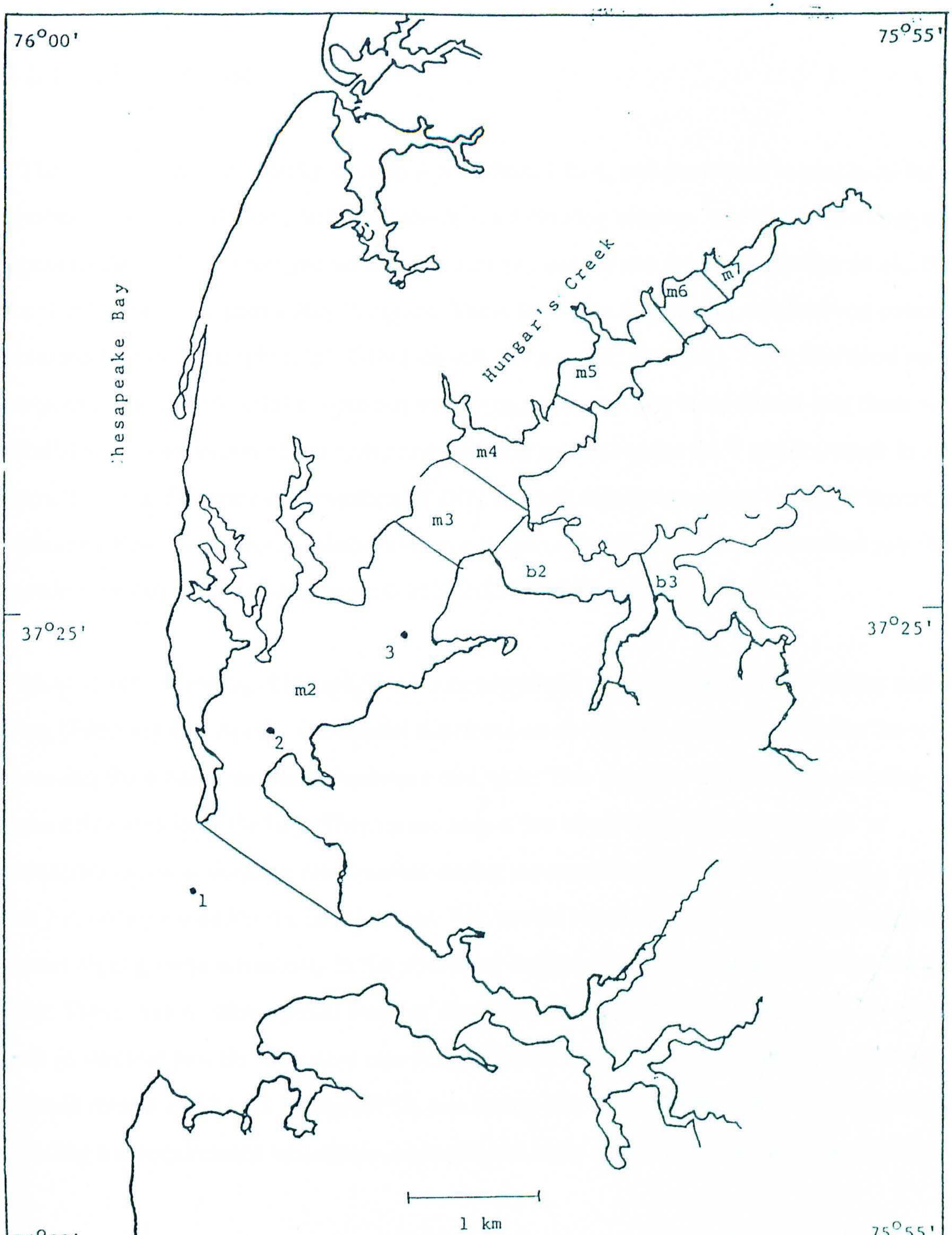

Figure III-5

The Hungars Creek, showing the sampling stations for 1997 field surveys and model segmentation.

III-2. Description of Data

The data are listed in tabular form in Appendices 1 to 4, and presented in graphical form together with the model simulation results in the following chapter. The data were analyzed with respect to the SAV (submerged aquatic vegetation) habitat requirements (Batiuk et al., 1992) accepted by the Chesapeake Bay Program. Table III-1 lists the number of observed concentrations exceeding that of chlorophyll 'a', DIN (dissolved inorganic nitrogen), DIP (dissolved inorganic phosphorus), and TSS (total suspended solid) requirements. The table shows that there was essentially no observation of nutrient concentration exceeding the SAV requirements in all four basins. The four February observations of DIN concentrations exceeding the requirement in the Piankatank River were mostly nitrite-nitrate nitrogen. The observed concentrations just barely exceeded the requirement, they were 0.157, 0.157, 0.159, and 0.206 mg/l.

Most of the exceeding chlorophyll 'a' concentrations were observed in late winter and early spring (February and April). The spatial distributions during this period show either no trend or decreasing from basin mouth in landward direction. This suggests that the winter-spring algal bloom originates from the bay. There were only a few observations of chlorophyll 'a' concentrations exceeding the requirement during summer months (June and August), and most of them just barely exceeded the requirement. The spatial concentration distributions suggests that the summer algal growth are mostly in the shallower landward end of the basins, except the Hungars Creek. There was no clear spatial trend of chlorophyll 'a' distribution observed in the Hungars Creek in summer months. The only one concentration exceeding the requirement was observed at the creek mouth and it was 16 mg/m**3, just barely above the requirement. No concentration exceeding the requirement was observed in fall and early winter (October and December).

TSS exceeding the requirement were observed in all four basins and in all seasons. Except for the Hungars Creek, the TSS concentrations show either an increasing trend or no trend landward from basin mouth. This suggests that local watershed runoff and/or shoreline erosion contribute to the excessive TSS concentrations. The observed spatial TSS distributions in the Hungars Creek were more variable. There was only one occasion for which the data indicated that local runoff

Table III-1. Number of Data Points Failing to Meet SAV Requirements

Month		Feb.	April	June	Aug.	Oct.	Dec.
Poquoson River (5 stations, 6 data points)	Chlorophyll	6	1	0	2	0	0
	DIN	0	0	0	0	0	0
	PO_4	0	0	0	0	0	0
	TSS	2	2	4	5	1	0
	DO<5	0	0	0	0	0	0
Piankatank River (4 stations, 5 data points)	Chlorophyll	1	4	1	2	0	0
	DIN	4*	0	0	0	0	0
	PO_4	0	0	0	0	0	0
	TSS	3	3	2	1	2	0
	DO<5**	0	0	3(>3.9)	3(>2.8)	1(>4.7)	0
Cherrystone Inlet (4 stations, 5 data points)	Chlorophyll	3	3	0	1	0	0
	DIN	0	0	0	0	0	0
	PO_4	0	0	0	0	0	0
	TSS	3	5	3	2	5	2
	DO<5**	0	0	1(4.9)	0	0	0
Hungars Creek (3 stations, 4 data points)	Chlorophyll	3/3	4	1	0	0	0
	DIN	0	0	0	0	0	0
	PO_4	0	0	0	0	0	0
	TSS	3/3	0	1	0	4	2
	DO<5	0	0	0	0	0	0

SAV Requirements:

Chlorophyll <15 mg/m**3

DIN <0.15 mg/l

DIP <0.01 mg/l (mesohaline), < 0.02 (polyhaline)

TSS <15 mg/l

* mostly nitrite-nitrate nitrogen, ~0.15 mg/l

** occurred only at bottom waters

and/or shoreline erosion had significant contribution to the excessive TSS concentration.

The numbers of observations that DO (dissolved oxygen) fell below 5.0 mg/l were also included in Table III-1. Since DO were measured every meter throughout the water column, there were many more observations of this than of other water quality variables. The low DO were observed only in the bottom waters and only during warmer months. All low DO observations were in the Piankatank River, except one (4.9 mg/l) in the Cherrystone Inlet.

IV. Model Applications

The tidal prism water quality model is applied to the four targeted basins: the Poquoson and Piankatank Rivers on the western shore, and the Cherrystone Inlet and Hungars Creek on the eastern shore. The model is run to simulate the period from February to December, 1997, during which monitoring data are available for comparison with model results. Since only the chlorophyll 'a' measurements are available to quantify the total algal biomass, only one algal type in the model is simulated to represent the total algal biomass. Because diatoms are not explicitly modeled, the silica cycle in the model is not activated. Total suspended sediment, which is included in the monitoring program, is simulated to quantify the sorption site for phosphate, and thus total active metal is not modeled. The sediment process model is not activated. The sediment fluxes obtained through calibration of the Lynnhaven River (Park et al., 1995) are used, as are the values of calibrated model coefficients. Preparation of input data for the model application is described in Section VI-1, and the results of the model runs are presented in Section VI-2.

IV-1. Preparation of Input Data

To facilitate the inter-comparisons among the four targeted basins, the data for all four basins are grouped together by data types. The data with values identical to those of the Lynnhaven River model (Park et al., 1995) will not be repeated.

IV-1-1. Geometry

Each basin is segmented in accordance to the segmentation scheme described in Kuo and Park (1994), except the Piankatank River. The Piankatank River has a very small tidal range (37 cm or 1.2 ft) and higher depth. If the model segmentation scheme were strictly followed, it would result in the segment length being much smaller than the river width. This would contradict the concept of a one-dimensional description of the water body. Therefore, a deviation is tolerated that allows the segment volume to be twice, instead of equal, the accumulated tidal prism upriver of it. The model segments are presented on the maps in Figures III-2 to III-5, where the letter 'm' designates mainstem and the letter 'b' designates branch. The geometric data: distance from river mouth,

Table IV-1. Geometric and hydrodynamic data, Poquoson River

Segment or transect number	Distance from mouth (km)	High tide volume (10^6 m^3)	Accumulated tidal prism (10^6 m^3)	Mean depth (m)
m1	0.000	-	9.400	-
m2	1.900	9.400	4.800	2.100
m3	2.900	4.800	3.000	2.190
m4	4.000	3.000	2.200	2.380
m5	4.750	2.200	1.400	1.798
m6	5.760	1.400	1.000	1.585
m7	6.700	1.000	0.750	1.500
m8	7.600	0.750	0.500	0.900
m9	8.500	0.500	-	0.700
b1-1	0.000	-	1.180	-
b1-2	1.250	1.180	0.770	1.768
b1-3	2.400	0.770	0.500	1.463
b1-4	3.100	0.500	0.320	1.372
b1-5	3.800	0.320	0.200	1.200
b1-6	4.450	0.200	0.100	1.097
b1-7	4.750	0.100	-	1.097
b2-1	0.000	-	1.150	-
b2-2	0.700	1.150	0.700	1.650
b2-3	1.250	0.700	0.500	0.730
b2-4	1.800	0.500	0.300	0.670
b2-5	2.120	0.300	0.200	1.340
b2-6	2.400	0.200	0.120	1.340
b2-7	2.630	0.120	-	1.340
b3-1	0.000	-	1.000	-
b3-2	1.190	1.000	-	0.760
b4-1	0.000	-	1.000	-
b4-2	1.190	1.000	-	0.760
s2-3	0.700	0.220	0.600	0.400

Table IV-2. Geometric and hydrodynamic data, Piankatank River

Segment or transect number	Distance from mouth (km)	High tide volume (10^6 m^3)	Accumulated tidal prism (10^6 m^3)	Mean depth (m)
m1	0.000	-	11.521	-
m2	1.250	21.214	9.608	3.631
m3	3.160	17.513	7.831	3.566
m4	5.510	14.410	6.526	4.040
m5	8.520	11.900	5.370	3.826
m6	11.040	10.003	4.628	5.188
m7	12.760	8.433	3.765	3.716
m8	14.410	6.730	2.952	3.145
m9	16.500	5.108	2.155	2.423
m10	18.530	3.679	1.522	2.201
m11	20.290	2.299	0.774	1.171
m12	21.710	1.032	0.258	0.618
m13	24.620	2.347	-	0.384

Table IV-3. Geometric and hydrodynamic data, Cherrystone Inlet

Segment or transect number	Distance from mouth (km)	High tide volume (10^6 m^3)	Accumulated tidal prism (10^6 m^3)	Mean depth (m)
m1	0.000	-	5.829	-
m2	2.660	5.850	3.651	1.747
m3	4.540	3.665	2.265	1.500
m4	5.720	2.284	1.010	1.110
m5	6.720	1.013	0.418	0.799
m6	7.790	0.508	-	0.547
b1-1	0.000	-	0.659	-
b1-2	1.140	0.661	0.362	1.206
b1-3	2.050	0.364	0.166	0.951
b1-4	3.500	0.274	-	0.807
b2-1	0.000	-	0.192	-
b2-2	1.390	0.226	-	0.473
b3-1	0.000	-	0.251	-
b3-2	1.370	0.252	0.075	0.655
b3-3	2.580	0.108	0.000	0.655
b4-1	0.000	-	0.180	-
b4-2	1.170	0.204	-	0.441

Table IV-4. Geometric and hydrodynamic data, Hungars Creek

Segment or transect number	Distance from mouth (km)	High tide volume (10^6 m^3)	Accumulated tidal prism (10^6 m^3)	Mean depth (m)
m1	0.000	-	2.907	-
m2	2.800	2.915	1.614	1.106
m3	3.690	1.629	0.808	0.958
m4	4.530	0.809	0.397	0.925
m5	5.480	0.398	0.195	0.925
m6	5.990	0.196	0.095	0.925
m7	6.927	0.184	-	0.925
b1	0.000	-	0.573	-
b2	1.030	0.577	0.280	0.925
b3	3.845	0.751	-	0.925

segment volume, tidal prism, and mean depth, are listed in Tables III-1 to III-4.

IV-1-2. Water temperature

The observed water temperature in each of the basins show a seasonal variation, but with little spatial variability. A sinusoidal curve that is fitted to approximate the monitoring data in each basin is used to specify the spatially uniform water temperature. The temperature is described as function of Julian day, t:

$$T = \frac{T_{max} + T_{min}}{2} + \frac{T_{max} - T_{min}}{2} \cdot \cos\left(\frac{2\pi}{T_p}(t - t_{max}) \right) \tag{4-1}$$

with T_{max} is annual maximum temperature, T_{min} is annual minimum temperature, t_{max} is number of days since January 1 to reach $_{Tmax}$, T_p = 365 days. The parameters in equation (4-1) are obtained by fitting the equation to the temperature data of each basin. It turns out that one set of parameter values can fit all four basins equally well. There a single equation is used for all four basins. The prediction by the equation is compared with the monitoring data in Figure IV-1.

IV-1-3. Solar radiation

The model requires, in order to simulate the algal growth, daily solar radiation intensity and fractional day length averaged over a time step, one tidal cycle. Hourly measurements of solar radiation at VIMS (Gloucester Point) in 1997 are used to estimate daily mean light intensity and fractional day length, which are weight-averaged over a tidal cycle to be used for the 1997 model simulation runs.

IV-1-4. Initial conditions

The monitoring data of February, 1997 are used to estimate the initial conditions. Not all model state variables (Table II-1) were measured for all model segments. Hence, some approximations are required to estimate the initial conditions for each state variable at each model segment. The procedures used in the Lynnhaven River model (Park et al., 1995) are adopted for this study.

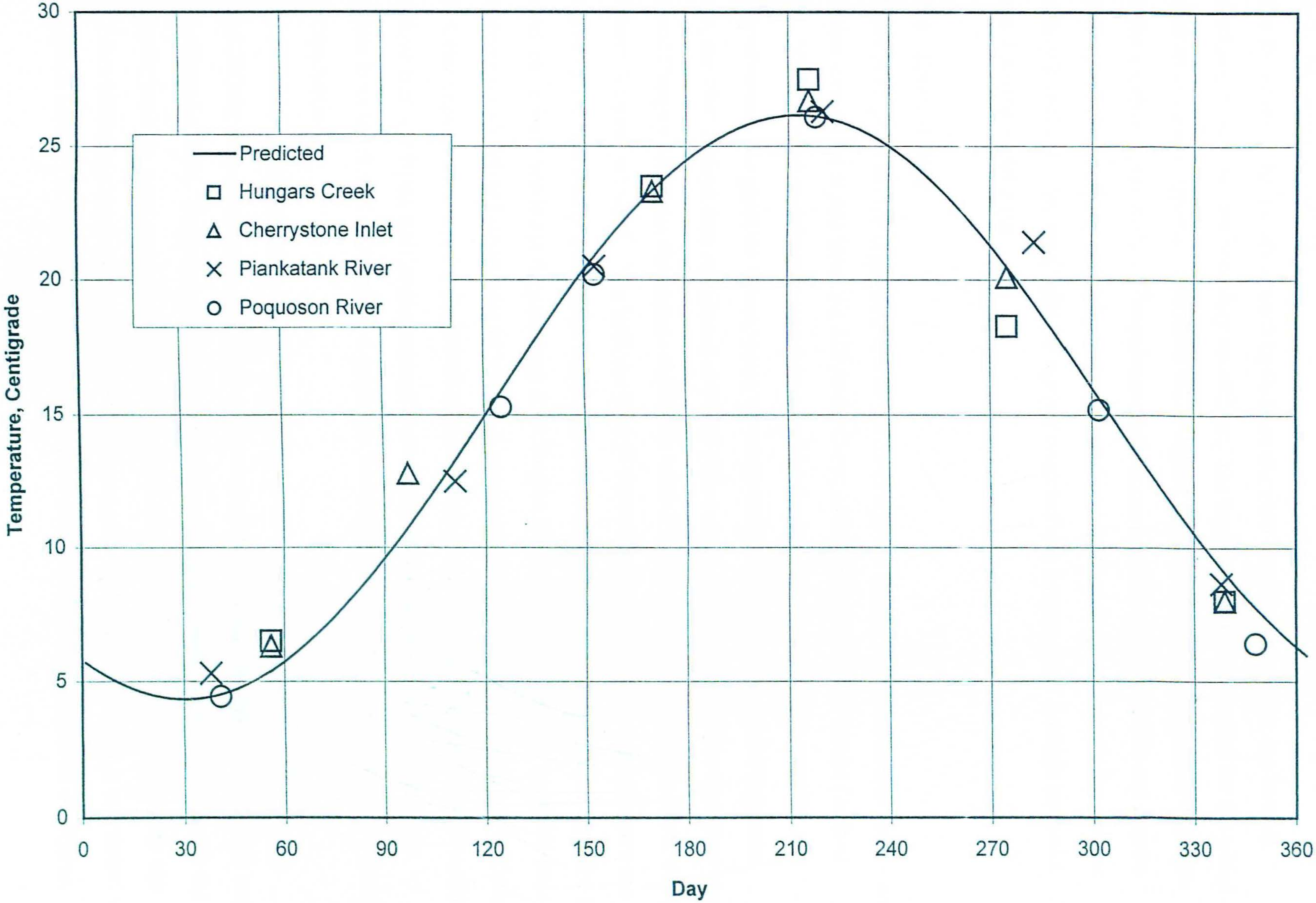

Figure IV-1
Water temperature data of 1997 surveys, with a sinusoidal curve to fit the observations.

IV-1-5. Boundary conditions

The field data at the mouth of each basin from the 1997 bi-monthly surveys are linearly interpolated to estimate the boundary conditions. The same approximations used for the initial conditions are also employed to estimate the boundary conditions for the model state variables from the measured parameters. The present model is configured such that it does not require explicit specification of the upriver boundary conditions. Rather, the flux through the upriver boundary is defined to be zero, with the upriver contributions incorporated through nonpoint source discharges and loads.

IV-1-6. External loads

There is no point source input into any of the four targeted basins. Nonpoint source inputs are estimated using the outputs from the US Army Corps of Engineers' STORM model (Abbott 1977). The STORM model uses rainfall data and land use patterns to calculate quantity and quality of runoff. To generate the nonpoint source runoffs for the Poquoson and Piankatank Rivers, the 1997 rainfall data monitored at VIMS (Gloucester Point) are used. For the Cherrystone Inlet and Hungars Creek on the eastern shore, the rainfall data monitored by Virginia Tech. Station at Painter, Virginia are used. The land use data of the two watersheds on the eastern shore are provided by the CBLAD (Chesapeake Bay Local Assistant Department). The land use data for the western shore watersheds are derived from EPA Region III Land Cover Data Set by the Resource Management and Policy Department of VIMS. A summary of land use data is presented in Table IV-5. Other input parameters for the STORM model include the storage and runoff characteristics of various land use types, unit hydrograph characteristics and evaporation rates. The input constants from the model study of the Lynnhaven River (Park et al., 1975) are used for the present model applications.

The STORM model generates daily discharge rates and total loads of biochemical oxygen demand (BOD), suspended solid, settleable solid, total nitrogen (TN), total phosphorus (TP) and fecal coliform bacteria. Both suspended and settleable solids are considered to contribute to the model state variable, total suspended solid (TSS). The STORM model outputs BOD while the Tidal Prism Model has three types of organic carbon as state variables. The BOD is converted to total organic carbon (TOC), and TOC, TN and TP are distributed to various species of organic

Table IV-5. Land Use Patterns of the Targeted Small Coastal Basins

			Hungars Creek	Cherrystone Inlet	Poquoson River	Piankatank River
Total Drainage Area (acres)			6,790	9,920	13,994	142,026
Land Use Categories (percents)	Residential	low density	11.26	5.0	13.0	0.68
		high density			3.3	0.28
	Commercial		0.01	2.0		
	Light Industry		0.00	2.0		
	Agricultural & Vacant Forest		46.22	60.0	21.6	21.19
	Forest		42.51	31.0	58.1	70.63
	Marsh				4.0	7.22
Water Surface Area (acres)			1,405	3,045	3,884	10,753

carbon, nitrogen and phosphorus, respectively, in the same manner as done in the Lynnhaven River model (Park et al., 1995).

The Tidal Prism Model also requires, for nonpoint source input, dissolved oxygen (DO) loading in terms of concentration in runoff water. The DO concentration in nonpoint source discharge is taken to be 80% of the saturated concentration. Finally, it is assumed that there is no nonpoint source input of salinity, chlorophyll 'a', and chemical oxygen demand.

IV-2. Results

The model is run to simulate the period from February to December, 1997 for each of the four small coastal basins, and the results are compared with the field data. Appendices 5 through 8 show the comparison for the Poquoson River, Piankatank River, Cherrystone Inlet, and Hungars Creek , respectively. Model predictions of salinity, concentrations of chlorophyll 'a', dissolved oxygen, total carbon, total nitrogen, total phosphorus, and total suspended sediment at selected segments are plotted as functions of time, together with the bimonthly survey data at corresponding locations.

The model has one calibration parameter for the physical transport, the returning ratio α (Kuo & Park, 1994: Chapter II). The value of the returning ratio was calibrated to be 0.3 for the Lynnhaven River. Since salinity is solely the result of physical transport processes, the excellent agreement between model results and salinity data indicate that the value 0.3 is a good number to use for the four targeted basins, and probably would be adequate for all Virginia's small coastal basins without further calibration.

In addition to the physical transport process, the model predictions of non-conservative state variables also depend on the external loads as well as the values of biochemical rate constants. As stated in the previous section, all the values of the calibrated constants, including those in the nonpoint source model, are adopted from the Lynnhaven River without further calibration for individual basin. Appendix 8 indicates that the model predictions of the Hungars Creek agree with field data. However, the predictions for the individual species (not presented) of carbon, nitrogen, and phosphorus are not satisfactory. The nonpoint model, STORM, generates BOD, total nitrogen, and total phosphorus. The partition of the STORM model outputs into different species is adopted from the calibration of the Lynnhaven River. It is apparent that different basins require different partition factors.

Appendices 5 to 7 indicate that, for the other three basins, the general spatial and temporal trends of field observations are reproduced by the model. However, the model generally under-predicts the concentration levels of total carbon, total nitrogen, total phosphorus, and total suspended sediment. The discrepancies between the model predictions and field observations are larger in the spring and summer, and decrease toward fall and early winter, i.e., October and December. The discrepancies are most likely the results of inadequate external inputs. A better nonpoint source model than STORM should be used, and calibrated for basins with different land use characteristics. Furthermore, most nonpoint sources do not include sediment source from shoreline erosion, and therefore a separate quantitative estimate of shoreline erosion is required for an accurate prediction of the total suspended sediment concentration.

V. Summary and Conclusions

A bi-monthly water quality monitoring program was executed in 1997 for four small coastal basins: the Poquoson and Piankatank Rivers on the western shore, and the Cherrystone Inlet and Hungars Creek on the eastern shore of Virginia. The observed concentrations of dissolved inorganic nitrogen and phosphorus are all very low, satisfying the SAV (submerged aquatic vegetation) requirements. High chlorophyll 'a' concentrations were observed in all basins in late winter and early spring. Spatial distributions suggest that the winter-spring algal bloom originates from the Bay. Summer algal growth are mostly in the shallow landward end of the basins, except the Hungars Creek where the chlorophyll 'a' concentrations were low and exhibit no distinct spatial pattern. All observed dissolved oxygen (DO) concentrations were above 5.0 mg/l, except one in the Cherrystone Inlet (4.9 mg/l) and several in the Piankatank River. Low DO concentrations were restricted to the bottom waters and occurred only in summer months. Total suspended sediment (TSS) concentrations exceeding the SAV requirement were observed in all four basins and in all seasons. Except for Hungars Creek, the spatial distributions indicate that local sources, either from watershed runoff or shoreline erosion, have significant contribution to the excessive TSS concentrations. The TSS distributions in the Hungars Creek were more variable, and no conclusion regarding its source may be drawn.

The tidal prism water quality model has been applied to four small coastal basins: the Poquoson and Piankatank Rivers on the western shore, and the Cherrystone Inlet and Hungars Creek on the eastern shore. The model is run to simulate the 1997 water quality conditions in each of the basins, and the results compared with the bi-monthly survey data. The external loads of nonpoint sources are generated with the watershed model STORM, developed by US Army Corps of Engineers. Values of all model calibration parameters are adopted from the previous calibration of the models to the Lynnhaven River of Virginia Beach.

Salinity distributions are well simulated by the tidal prism model in all four basins. It may be concluded that the value of 0.3 for the returning ratio (the only calibration parameter for physical transport process) is adequate for most small coastal basins of Chesapeake Bay system without the need of further calibration. The models, with the values of calibration constants adopted from the Lynnhaven River for both the tidal prism model and STORM, are acceptable to the Hungars Creek. However, the differentiation of individual species of carbon, nitrogen, and phosphorus requires more accurate partition of these nutrients, or application of a more sophisticated watershed model. The model result of nutrients and total suspended sediment concentrations in the other three basins are generally lower than field data, even though the prediction of dissolved oxygen and chlorophyll 'a' concentrations agree with field observations. Better characterization of nonpoint source loadings is required prior to usage of the tidal prism model for scenario runs. Monitoring of nonpoint source loadings and application of a more sophisticated watershed model for small coastal basins are recommended.

Both the model simulation and field data indicate that the water quality in the lower portions of small basins are dominated by the conditions at the mouth in the Bay or major tributaries. Water quality data at the mouth are required for model application. These data may be obtained through monitoring or three-dimensional water quality model of the bay and major tributaries. The upper portions of the basins may be temporarily dominated by nonpoint source loadings during and immediately following runoff events. The use of a watershed model to generate loading inputs is required.

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Appendix A-1. 1997 Field Survey Data, Poquoson River

POQUOSON RIVER
February 11, 1997

Station 1

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	4.5		13.6
2.0	4.5		13.6
3.0	4.5		13.6
4.0	4.4		13.6
5.0	4.4		13.6
6.0	4.4		13.5

Station 2

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	4.6	13.6	12.7
2.0	4.5	13.6	12.7
3.0	4.4	13.7	12.6
4.0	4.4	13.7	12.6

Station 3

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	5.0	12.9	12.0
2.0	5.0	12.9	12.0

Station T1

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	5.0	13.1	12.7
2.0	4.9	13.1	12.7

Station T2

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	3.9	13.3	12.7
2.0	3.9	13.3	12.7
3.0	3.9	13.3	12.5

POQUOSON RIVER: February 11, 1997

	1	2 Top	2 Bottom	3	T1	T2
Secchi Disk, m	1.2	1.0		1.0	1.0	0.9
Chlorophyll	25	22	19	21	20	17
DOC	3.2	3.2	3.1	3.5	3.8	3.1
PC	2.0	2.2	2.3	2.1	2.4	2.3
POC	1.9	2.1	2.1	2.0	2.2	2.2
TDN	0.32	0.30	0.29	0.30	0.22	0.27
NH4	0.011	0.007	0.007	0.008	0.007	0.007
NO2+NO3	0.071	0.054	0.052	0.001	0.003	0.033
DON*	0.24	0.24	0.23	0.29	0.21	0.23
PN	0.22	0.24	0.25	0.26	0.25	0.25
TDP	0.010	0.012	0.008	0.007	0.011	0.006
PO4	0.002	0.004	0.002	0.001	0.003	0.002
DOP*	0.008	0.008	0.006	0.006	0.008	0.004
PPhos	0.017	0.017	0.018	0.017	0.017	0.017
PIP	0.008	0.006	0.007	0.007	0.007	0.007
POP*	0.009	0.011	0.011	0.011	0.010	0.010
TSS	13	12	15	11	12	15
FS	7	6	8	5	5	8
VS*	6	6	7	6	7	7

Note: Chlorophyll is in mg/m^3, all others in g/m^3 unless noted otherwise.
* indicates calculated value.

POQUOSON RIVER
May 5, 1997

Station 1

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	15.5	16.2	9.0
2.0	15.2	16.3	8.9
3.0	15.3	16.3	8.9
4.0	15.3	16.3	8.8
5.0	15.2	16.4	8.7
6.0	15.1	16.4	8.4

Station 2

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	16.5	15.5	8.6
2.0	16.1	15.9	8.9
3.0	15.6	16.2	8.8
4.0	15.3	16.3	8.6

Station 3

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	16.8	14.3	6.6
2.0	17.4	15.0	6.2

Station T1

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	17.6	14.5	6.5
2.0	17.4	15.2	6.4

Station T2

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	15.8	15.4	8.1
2.0	16.1	15.3	8.0
3.0	16.2	15.3	7.7

POQUOSON RIVER: May 5, 1997

	1	2 Top	2 Bottom	3	T1	T2
Secchi Disk, m	1.5	1.0		0.5	0.5	1.0
Chlorophyll	6	8	7	7	7	22
DOC	3.4	3.5	3.6	3.8	4.2	3.6
PC	1.0	0.9	1.0	1.2	1.2	1.1
POC						
TDN	0.31	0.34	0.31	0.40	0.41	0.34
NH4	0.019	0.039	0.002	0.102	0.099	0.026
NO2+NO3	0.042	0.036	0.041	0.050	0.038	0.024
DON*	0.25	0.26	0.27	0.25	0.27	0.29
PN	0.15	0.12	0.14	0.18	0.19	0.16
TDP	0.014	0.012	0.010	0.010	0.014	0.013
PO4	0.002	0.001	0.002	0.002	0.004	0.002
DOP*	0.012	0.011	0.008	0.008	0.010	0.011
PPhos		0.016	0.020	0.028	0.025	0.019
PIP	0.003	0.003	0.003	0.005	0.008	0.007
POP*		0.013	0.017	0.023	0.017	0.012
TSS	11	10	10	19	17	13
FS	7	7	7	15	13	10
VS*	4	3	3	4	4	3

Note: Chlorophyll is in mg/m^3, all others in g/m^3 unless noted otherwise.
* indicates calculated value.

POQUOSON RIVER
June 3, 1997

Station 1

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	20.2	19.7	8.1
2.0	20.2	19.7	8.1
3.0	20.2	19.8	8.1
4.0	20.2	19.8	8.0
5.0	20.3	19.9	8.0

Station 2

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	19.9	19.4	8.1
2.0	19.9	19.4	8.1
3.0	19.9	19.4	8.0
4.0	19.9	19.4	7.6
5.0	20.0	19.7	6.7
6.0	20.1	19.8	6.8

Station 3

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	21.3	20.0	6.4
2.0	21.3	20.0	6.1
3.0	21.1	19.5	6.3

Station T1

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	21.9	20.1	5.7
2.0	21.9	20.1	5.7
3.0	21.9	20.1	5.7

Station T2

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	20.6	20.3	6.3
2.0	20.6	20.4	6.4
3.0	20.6	20.4	6.7

POQUOSON RIVER: June 3, 1997

	1	2 Top	2 Bottom	3	T1	T2
Secchi Disk, m	1.3	1.0		0.7	0.7	0.5
Chlorophyll	8	13	9	6	5	6
DOC	3.4	3.2	3.5	3.8	3.4	3.4
PC	1.3	1.6	1.6	1.9	1.5	1.5
POC						
TDN	0.26	0.27	0.27	0.34	0.32	0.30
NH4	0.017	0.016	0.018	0.073	0.048	0.013
NO2+NO3	0.001	0.001	0.000	0.006	0.003	0.000
DON*	0.24	0.25	0.25	0.26	0.27	0.29
PN	0.12	0.14	0.15	0.15	0.14	0.11
TDP	0.013	0.015	0.012	0.009	0.012	0.012
PO4	0.003	0.003	0.003	0.002	0.003	0.003
DOP*	0.010	0.012	0.009	0.007	0.009	0.009
PPhos	0.016		0.025	0.037	0.026	0.024
PIP	0.005		0.007	0.009	0.006	0.006
POP*	0.011		0.018	0.028	0.020	0.018
TSS	10		27	35	19	21
FS	7		20	29	14	16
VS*	3		7	6	5	5

Note: Chlorophyll is in mg/m^3, all others in g/m^3 unless noted otherwise.
* indicates calculated value.

POQUOSON RIVER
August 7, 1997

Station 1

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	26.2	22.1	7.0
2.0	26.2	22.1	7.0
3.0	26.1	22.1	7.0
4.0	26.0	22.1	6.8
5.0	26.0	22.1	6.4

Station 2

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	26.2	22.2	6.9
2.0	26.2	22.2	6.8
3.0	26.2	22.2	6.7
4.0	26.0	22.2	6.6
5.0	25.9	22.2	6.4

Station 3

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	26.8	22.2	6.9
2.0	26.8	22.2	6.8

Station T1

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	26.9	22.1	6.4
2.0	26.7	22.1	5.9

Station T2

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	26.0	22.3	6.6
2.0	25.9	22.3	6.3

POQUOSON RIVER: August 7, 1997

	1	2 Top	2 Bottom	3	T1	T2
Secchi Disk, m	1.0	1.0		0.6	0.6	1.0
Chlorophyll	11	10	10	18	11	33
DOC	3.4	3.6	3.6	4.5	4.1	3.8
PC	1.3	1.3	1.4	2.5	1.9	1.3
POC						
TDN	0.26	0.30	0.31	0.35	0.34	0.33
NH4	0.007	0.008	0.012	0.008	0.008	0.010
NO2+NO3	0.001	0.001	0.002	0.001	0.002	0.002
DON*	0.25	0.29	0.30	0.34	0.33	0.32
PN	0.19	0.20	0.23	0.36	0.29	0.20
TDP	0.012	0.011	0.012	0.013	0.011	0.014
PO4	0.003	0.002	0.002	0.003	0.002	0.002
DOP*	0.009	0.009	0.010	0.010	0.009	0.012
PPhos	0.026	0.025	0.029	0.042	0.033	0.026
PIP	0.005	0.004	0.006	0.008	0.006	0.005
POP*	0.021	0.021	0.023	0.034	0.027	0.021
TSS	16	15	17	27	20	13
FS	10	10	12	17	13	8
VS*	6	5	5	10	7	5

Note: Chlorophyll is in mg/m^3, all others in g/m^3 unless noted otherwise.
* indicates calculated value.

POQUOSON RIVER
October 30, 1997

Station 1

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	15.2	25.3	8.1
2.0	15.2	25.3	8.1
3.0	15.2	25.3	8.1
4.0	15.2	25.3	8.1
5.0	15.2	25.3	8.1

Station 2

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	14.5	25.0	8.8
2.0	14.5	25.0	8.7
3.0	14.6	25.1	8.6
4.0	14.6	25.1	8.6

Station 3

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	13.4	24.1	9.4
2.0	13.7	24.4	9.3

Station T1

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	13.7	24.2	9.1
2.0	13.8	24.3	9.0

Station T2

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	13.0	24.4	8.9
2.0	13.2	24.5	8.8

POQUOSON RIVER: October 30, 1997

	1	2 Top	2 Bottom	3	T1	T2
Secchi Disk, m	1.2	1.1		0.8	0.9	1.7
Chlorophyll	7	10	8	12	7	
DOC	3.4	3.5	3.8	3.7	4.0	3.9
PC	0.5	0.7	0.7	1.3	1.1	0.5
POC						
TDN	0.36	0.34	0.35	0.29	0.30	0.34
NH4	0.059	0.016	0.022	0.007	0.006	0.028
NO2+NO3	0.049	0.043	0.046	0.003	0.001	0.019
DON*	0.25	0.28	0.28	0.28	0.29	0.29
PN	0.10	0.14	0.14	0.20	0.17	0.09
TDP	0.022	0.018	0.021	0.018	0.018	0.019
PO4	0.006	0.002	0.003	0.002	0.002	0.002
DOP*	0.016	0.016	0.018	0.016	0.016	0.017
Pphos	0.015	0.015	0.017	0.019	0.018	0.011
PIP	0.004	0.003	0.004	0.004	0.004	0.002
POP*	0.011	0.012	0.013	0.015	0.014	0.009
TSS	16	10	13	13	13	9
FS	12	6	10	9	9	6
VS*	4	4	3	4	4	3

Note: Chlorophyll is in mg/m^3, all others in g/m^3 unless noted otherwise.
* indicates calculated value.

POQUOSON RIVER
December 15, 1997

Station 1				Station 2			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l	Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	6.4	21.1	10.3	1.0	6.3	21.2	10.4
2.0	6.4	21.1	10.4	2.0	6.3	21.2	10.4
3.0	6.4	21.2	10.4	3.0	6.5	21.3	10.5
4.0	6.4	21.2	10.4	4.0	6.6	21.3	10.6
5.0	6.5	21.2	10.6				

Station 3				Station T1			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l	Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	5.7	20.6	11.0	1.0	6.0	20.8	10.7
2.0	5.7	20.6	11.0	2.0	6.0	20.8	10.8
				3.0	6.0	20.8	10.9

Station T2			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	5.6	21.1	10.4
2.0	5.8	21.1	10.6

POQUOSON RIVER December 15, 1997

	1	2 Top	2 Bottom	3	T1	T2
Secchi Disk, m	1.9	2.0		1.7	1.7	1.7
Chlorophyll	3	3	2	3	4	3
DOC	3.1	3.3	3.7	3.6	3.3	3.7
PC	0.5	0.5	0.5	0.8	0.7	0.6
POC						
TDN	0.31	0.29	0.29	0.28	0.28	0.27
NH4	0.012	0.011	0.012	0.007	0.005	0.007
NO2+NO3	0.013	0.011	0.017	0.002	0.001	0.004
DON*	0.28	0.27	0.26	0.27	0.27	0.26
PN	0.11	0.11	0.10	0.12	0.12	0.10
TDP	0.024	0.020	0.016	0.019	0.018	0.019
PO4	0.006	0.005	0.005	0.003	0.003	0.003
DOP*	0.018	0.015	0.011	0.016	0.015	0.016
Pphos	0.010	0.009	0.009	0.011	0.011	0.010
PIP	0.002	0.002	0.002	0.002	0.002	0.002
POP*	0.008	0.007	0.007	0.009	0.009	0.008
TSS	11	8	7	10	11	9
FS	8	5	4	7	8	5
VS*	3	3	3	3	3	4

Note: Chlorophyll is in mg/m^3, all others in g/m^3 unless noted otherwise.
* indicates calculated value.

Appendix A-2. 1997 Field Survey Data, Piankatank River

PIANKATANK RIVER
February 7, 1997

Station 1				Station 2			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l	Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	5.3		13.3	1.0	5.7	9.2	12.3
2.0	5.3		13.3	2.0	5.6	9.5	12.3
3.0	5.3		13.3	3.0	5.6	9.7	12.3
4.0	5.3		13.3	4.0	5.6	9.7	12.3
5.0	5.3		13.3	5.0	5.6	9.8	12.1
6.0	5.3		13.3	6.0	5.5	9.9	12.1
7.0	5.3		13.3	7.0	5.5	10.0	12.1
8.0	5.3		13.3	8.0	5.4	9.8	12.2

Station 3				Station 4			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l	Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	6.1	7.9	11.1	1.0	6.7	5.7	10.2
2.0	6.1	8.2	11.0	2.0	6.6	6.2	10.3
3.0	6.0	8.5	11.0	3.0	6.6	6.4	10.3
4.0	6.0	8.5	11.0	4.0	6.6	6.5	10.2
5.0	6.0	8.5	11.0	5.0	6.6	6.4	10.2
6.0	6.0	8.7	11.0				

PIANKATANK RIVER: February 7, 1997

	1	2 Top	2 Bottom	3	4
Secchi Disk, m	1.6	1.3		1.1	0.9
Chlorophyll	13	31	15	15	10
DOC	3.2	3.4	3.5	3.7	3.6
PC	2.5	1.8	3.7	1.7	1.4
POC	2.2	1.7	3.6	1.6	1.3
TDN	0.48	0.42	0.45	0.44	0.45
NH4	0.018	0.023	0.020	0.055	0.052
NO2+NO3	0.198	0.124	0.137	0.104	0.105
DON*	0.26	0.27	0.29	0.28	0.30
PN	0.22	0.20	0.46	0.23	0.21
TDP	0.018	0.010	0.010	0.010	0.007
PO4	0.004	0.003	0.002	0.002	0.001
DOP*	0.014	0.007	0.008	0.008	0.006
PPhos	0.016	0.016	0.060	0.025	0.040
PIP		0.005	0.027	0.012	0.018
POP*		0.011	0.033	0.013	0.022
TSS	15	9	43	9	15
FS	8	6	32	4	9
VS*	7	3	11	5	6

Note: Chlorophyll is in mg/m^3, all others in g/m^3 unless noted otherwise.
* indicates calculated value.

PIANKATANK RIVER
April 21, 1997

Station 1				Station 2			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l	Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	12.6	11.5	11.4	1.0	13.0	11.0	11.0
2.0	12.5	11.5		2.0	13.0	11.0	10.9
3.0	12.5	11.5	10.8	3.0	12.8	11.3	8.9
4.0	12.4	11.7		4.0	12.1	11.7	8.6
5.0	12.1	12.0	10.4	5.0	12.0	11.8	8.6
6.0	11.9	12.5	9.0				
7.0	11.8	12.4	8.8				

Station 3				Station 4			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l	Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	13.2	9.4	8.7	1.0	13.6	7.7	9.0
2.0	13.2	9.8	7.9	2.0	13.7	8.2	8.4
3.0	13.2	10.2	7.9	3.0	13.7	8.4	8.4
4.0	13.1	10.6	7.8	4.0	13.6	8.6	8.2
5.0	12.7	10.9	6.9				
6.0	12.6	10.8	6.9				

PIANKATANK RIVER: April 21, 1997

	1	2 Top	2 Bottom	3	4
Secchi Disk, m	1.6	1.1		1.3	1.0
Chlorophyll	30	16	34	21	11
DOC	3.7	3.6	3.9	4.4	4.5
PC	3.1	2.6	4.1	2.4	2.6
POC					
TDN	0.30	0.28	0.26	0.28	0.28
NH4	0.007	0.007	0.008	0.007	0.005
NO2+NO3	0.003	0.001	0.003	0.002	0.001
DON*	0.29	0.27	0.25	0.27	0.27
PN	0.38	0.32	0.54	0.36	0.31
TDP	0.014	0.008	0.008	0.009	0.013
PO4	0.005	0.001	0.002	0.002	0.003
DOP*	0.009	0.007	0.006	0.007	0.010
PPhos	0.023	0.022	0.037	0.033	0.040
PIP	0.006	0.004	0.011	0.008	0.008
POP*	0.017	0.018	0.026	0.025	0.032
TSS	14	12	22	16	16
FS	8	6	12	8	7
VS*	6	6	10	8	9

Note: Chlorophyll is in mg/m^3, all others in g/m^3 unless noted otherwise.
* indicates calculated value.

PIANKATANK RIVER
June 2, 1997

Station 1				Station 2			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l	Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	20.8	15.0	9.4	1.0	21.6	13.8	7.4
2.0	20.7	15.0	9.2	2.0	21.6	13.8	7.5
3.0	20.6	15.0	9.0	3.0	21.6	13.9	7.3
4.0	20.6	15.0	8.7	4.0	21.5	13.9	7.0
5.0	20.5	15.0	8.6	5.0	20.9	14.1	6.0
6.0	20.1	15.1	6.7	6.0	20.1	14.4	4.5
7.0	19.3	15.2	5.7	7.0	19.4	14.7	3.8
8.0	19.2	14.6	5.7	8.0	19.2	14.0	3.9

Station 3				Station 4			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l	Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	22.2	12.0	5.4	1.0	23.2	10.0	4.8
2.0	22.0	12.3	5.5	2.0	23.1	10.2	4.4
3.0	22.0	12.5	5.3	3.0	23.0	10.6	4.6
4.0	21.8	12.7	4.9	4.0	22.9	10.5	4.2
5.0	21.6	12.8	4.7				
6.0	21.5	12.9	4.3				
7.0	21.5	12.3	4.0				

	1	2 Top	2 Bottom	3	4
Secchi Disk, m	1.8	1.2		0.7	0.6
Chlorophyll	6	10	9	9	16
DOC	3.2	3.4	3.3	3.7	4.1
PC	1.3	1.3	1.3	1.4	2.0
POC					
TDN	0.28	0.30	0.51	0.31	0.30
NH4	0.018	0.016	0.116	0.057	0.024
NO2+NO3	0.005	0.001	0.002	0.001	0.002
DON*	0.26	0.28	0.39	0.25	0.27
PN	0.13	0.18	0.22	0.21	0.22
TDP	0.011	0.015	0.030	0.013	0.014
PO4	0.002	0.002	0.004	0.002	0.002
DOP*	0.009	0.013	0.026	0.011	0.012
PPhos	0.013	0.020	0.024	0.032	0.048
PIP	0.003	0.003	0.004	0.006	0.012
POP*	0.010	0.017	0.020	0.026	0.036
TSS	6	8	11	16	23
FS	3	4	7	11	16
VS*	3	4	4	5	7

Note: Chlorophyll is in mg/m^3, all others in g/m^3 unless noted otherwise.
* indicates calculated value.

PIANKATANK RIVER
August 8, 1997

Station 1				Station 2			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l	Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	26.8	17.3	7.4	1.0	26.9	16.7	7.5
2.0	26.5	17.4	7.3	2.0	26.8	16.8	6.8
3.0	26.3	17.4	7.2	3.0	26.7	17.0	5.5
4.0	26.2	17.4	7.0	4.0	26.6	17.1	5.1
5.0	26.2	17.4	7.0	5.0	26.4	17.2	3.6
6.0	26.1	17.4	7.0	6.0	26.4	17.2	3.4
7.0	26.1	17.4	6.8	7.0	26.4	17.2	3.4
8.0	26.1	17.4	6.7				

Station 3				Station 4			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l	Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	28.1	14.9	7.2	1.0	28.0	13.2	7.5
2.0	27.4	15.5	6.5	2.0	27.4	13.5	6.0
3.0	26.9	15.7	5.9	3.0	27.2	13.9	5.1
4.0	26.6	15.9	4.6	4.0	27.0	14.2	4.6
5.0	26.6	16.1	3.0	5.0	27.0	14.3	4.3
6.0	26.6	14.8	2.8				

PIANKATANK RIVER: August 8, 1997

	1	2 Top	2 Bottom	3	4
Secchi Disk, m		1.0		0.7	0.6
Chlorophyll	8	14	9	16	16
DOC	4.0	4.6	3.8	4.4	6.0
PC	1.3	1.9	1.3	2.0	2.7
POC					
TDN	0.30	0.31	0.34	0.34	0.37
NH4	0.006	0.005	0.025	0.005	0.005
NO2+NO3	0.001	0.000	0.002	0.000	0.000
DON*	0.29	0.31	0.31	0.34	0.36
PN	0.18	0.25	0.21	0.29	0.39
TDP	0.011	0.014	0.014	0.017	0.020
PO4	0.003	0.004	0.004	0.005	0.006
DOP*	0.008	0.010	0.010	0.012	0.014
PPhos	0.024	0.029	0.027	0.034	0.054
PIP	0.004	0.004	0.006	0.006	0.013
POP*	0.020	0.025	0.021	0.028	0.041
TSS	9	7	8	10	19
FS	4	1	4	4	11
VS*	5	6	4	6	8

Note: Chlorophyll is in mg/m^3, all others in g/m^3 unless noted otherwise.
* indicates calculated value.

PIANKATANK RIVER
October 10, 1997

Station 1

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	21.4	19.3	7.5
2.0	21.4	19.3	7.5
3.0	21.4	19.3	7.3
4.0	21.4	19.3	7.2
5.0	21.4	19.3	7.1
6.0	21.4	19.4	7.1
7.0	21.4	19.4	7.1
8.0	21.4	19.4	7.1
9.0	21.4	19.4	7.0
10.0	21.4	19.4	6.9

Station 2

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	21.7	18.5	6.6
2.0	21.7	18.5	6.4
3.0	21.7	18.5	6.2
4.0	21.7	18.5	6.1
5.0	21.7	18.6	6.1
6.0	21.8	18.6	6.0
7.0	21.7	18.6	6.0

Station 3

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	22.1	17.5	6.1
2.0	22.0	17.6	6.1
3.0	22.0	17.6	6.1
4.0	21.9	17.7	5.8
5.0	21.9	17.7	5.7

Station 4

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	22.3	16.4	5.3
2.0	22.1	16.6	4.9
3.0	22.0	16.5	4.7
4.0	22.0	16.7	4.7
5.0	22.0	16.8	4.7

PIANKATANK RIVER: October 10, 1997

	1	2 Top	2 Bottom	3	4
Secchi Disk, m	1.3	1.4		1.0	0.7
Chlorophyll	6	8	8	9	9
DOC	3.5	4.0	4.1	4.3	4.4
PC	1.1	1.0	1.2	1.1	1.4
POC					
TDN	0.32	0.34	0.31	0.33	0.33
NH4	0.009	0.009	0.016	0.005	0.005
NO2+NO3	0.001	0.000	0.002	0.001	0.001
DON*	0.31	0.33	0.29	0.32	0.32
PN	0.18	0.17	0.19	0.20	0.24
TDP	0.049	0.020	0.017	0.022	0.022
PO4	0.029	0.003	0.003	0.005	0.005
DOP*	0.020	0.017	0.014	0.017	0.017
Pphos	0.022	0.024	0.029	0.032	0.046
PIP	0.005	0.006	0.008	0.007	0.014
POP*	0.017	0.018	0.021	0.025	0.032
TSS	12	10	15	14	17
FS	8	6	10	9	12
VS*	4	4	5	5	5

Note: Chlorophyll is in mg/m^3, all others in g/m^3 unless noted otherwise.
* indicates calculated value.

PIANKATANK RIVER
December 4, 1997

Station 1

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	8.7	17.6	10.4
2.0	8.7	17.6	10.4
3.0	8.6	17.7	10.2
4.0	8.6	17.7	10.2
5.0	8.6	17.7	10.2
6.0	8.6	17.7	10.2
7.0	8.6	17.7	

Station 2

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	9.1	16.7	10.5
2.0	8.9		
3.0	8.8		
4.0	8.9		
5.0	8.8		
6.0	8.8		
7.0	8.8	17.3	10.0

Station 3

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	9.3		
2.0	9.2	15.6	9.2
3.0	8.9		
4.0	8.9		
5.0	8.9		

Station 4

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	9.5		
2.0	9.1	12.4	8.7
3.0	9.0		
4.0	8.9		

PIANKATANK RIVER: December 4, 1997

	1	2 Top	2 Bottom	3	4
Secchi Disk, m	3.3	2.1		1.2	1.1
Chlorophyll	3	4	5	8	6
DOC	3.0	3.5	3.2	3.4	3.8
PC	0.5	0.6	0.6	1.1	1.0
POC					
TDN	0.28	0.27	0.29	0.28	0.25
NH4	0.005	0.005	0.006	0.008	0.004
NO2+NO3	0.001	0.001	0.001	0.003	0.001
DON*	0.27	0.26	0.28	0.27	0.25
PN	0.08	0.10	0.10	0.17	0.17
TDP	0.013	0.010	0.017	0.018	0.013
PO4	0.002	0.002	0.002	0.005	0.003
DOP*	0.011	0.008	0.015	0.013	0.010
Pphos	0.007	0.008	0.008	0.016	0.018
PIP	0.000	0.001	0.001	0.003	0.005
POP*	0.007	0.007	0.007	0.013	0.013
TSS	9	8	7	14	12
FS	6	6	5	10	8
VS*	3	2	2	4	4

Note: Chlorophyll is in mg/m^3, all others in g/m^3 unless noted otherwise.
* indicates calculated value.

Appendix A-3. 1997 Field Survey Data, Cherrystone Inlet

CHERRYSTONE INLET
February 25, 1997

Station 1				Station 2			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l	Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	6.3	18.1	14.4	1.0	6.1	16.5	13.1
2.0	6.3		14.6	2.0	6.4		13.1
3.0	6.3	18.1	14.4				

Station 3				Station T1			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l	Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	7.7	16.2	13.6	1.0	7.9	16.4	14.1

CHERRYSTONE INLET: February 25, 1997

	1 Top	1 Bottom	2	3	T1
Secchi Disk, m	1.3		1.0	1.0	1.2
Chlorophyll	20	12	9	20	23
DOC	2.7	2.9	2.8	3.1	3.2
PC	1.8	1.9	2.0	2.6	2.3
POC	1.7	1.7	1.9	2.5	2.0
TDN	0.26	0.24	0.22	0.25	0.24
NH4	0.010	0.010	0.009	0.008	0.008
NO2+NO3	0.042	0.042	0.042	0.017	0.015
DON*	0.21	0.19	0.17	0.22	0.22
PN	0.23	0.24	0.26	0.32	0.27
TDP	0.009	0.012	0.013	0.017	0.009
PO4	0.003	0.003	0.001	0.002	0.002
DOP*	0.006	0.009	0.012	0.015	0.007
PPhos	0.017	0.018	0.021	0.022	0.018
PIP	0.007	0.007	0.008	0.008	0.005
POP*	0.010	0.011	0.013	0.014	0.013
TSS	16	13	15	15	9
FS	11	7	10	9	4
VS*	5	6	5	6	5

Note: Chlorophyll is in mg/m^3, all others in g/m^3 unless noted otherwise.
* indicates calculated value.

CHERRYSTONE INLET
April 7, 1997

Station 1

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	12.9	20.0	8.5
2.0	12.8	20.4	8.2
3.0	12.7	20.5	8.2
4.0	12.7	20.5	8.2

Station 2

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	12.9	20.0	8.5
2.0	12.8	20.4	8.7
3.0	12.7	20.5	8.5

Station 3

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l

Station T1

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	15.8	19.9	9.3

CHERRYSTONE INLET: April 7, 1997

	1 Top	1 Bottom	2	3	T1
Secchi Disk, m	1.1		1.1	1.0	1.9
Chlorophyll	28	14	21	26	
DOC	2.6	2.8	2.8	3.2	3.4
PC	1.5	1.6	2.4	2.1	2.1
POC					
TDN	0.21	0.21	0.23	0.22	0.22
NH4	0.010	0.008	0.008	0.006	0.007
NO2+NO3	0.003	0.002	0.003	0.001	0.001
DON*	0.20	0.20	0.22	0.21	0.21
PN	0.26	0.22	0.43	0.37	0.34
TDP	0.013	0.013	0.014	0.012	0.017
PO4	0.003	0.002	0.001	0.002	0.002
DOP*	0.010	0.011	0.013	0.010	0.015
PPhos	0.020	0.021	0.025	0.022	0.023
PIP	0.006	0.006	0.007	0.006	0.006
POP*	0.014	0.015	0.018	0.016	0.017
TSS	18	18	19	18	17
FS	13	14	13	13	12
VS*	5	4	6	5	5

Note: Chlorophyll is in mg/m^3, all others in g/m^3 unless noted otherwise.
* indicates calculated value.

CHERRYSTONE INLET
June 19, 1997

Station 1				Station 2			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l	Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	23.4	19.2	8.0	1.0	24.6	19.1	6.4
2.0	23.3	20.0	7.3	2.0	24.6	19.3	6.3
3.0	22.8	20.8	7.4				

Station 3				Station T1			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l	Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	26.6	19.3	4.9	1.0	25.9	19.5	5.6

CHERRYSTONE INLET
August 4, 1997

Station 1				Station 2			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l	Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	26.7	22.1	6.7	1.0	28.4	21.6	6.5
2.0	26.7	22.2	6.6	2.0	28.1	21.6	6.3
3.0	26.7	22.2	6.7				

Station 3				Station T1			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l	Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	28.7	21.6	7.4	1.0	28.7	21.7	6.1

CHERRYSTONE INLET: June 19, 1997

	1 Top	1 Bottom	2	3	T1
Secchi Disk, m	1.9		0.8	0.5	0.7
Chlorophyll	6	9	6	13	5
DOC	2.6	2.6	2.8	3.5	3.1
PC	0.9	1.0	1.4	1.2	1.3
POC					
TDN	0.26	0.26	0.32	0.44	0.31
NH4	0.017	0.018	0.063	0.099	0.040
NO2+NO3	0.003	0.002	0.009	0.006	0.009
DON*	0.24	0.24	0.25	0.33	0.26
PN	0.13	0.16	0.21	0.17	0.18
TDP	0.012	0.013	0.015	0.018	0.013
PO4	0.004	0.005	0.005	0.005	0.003
DOP*	0.008	0.008	0.010	0.013	0.010
PPhos	0.017	0.020	0.030	0.051	0.030
PIP	0.004	0.005	0.007	0.012	0.007
POP*	0.013	0.015	0.023	0.039	0.023
TSS	11	12	19	42	17
FS	7	8	15	33	12
VS*	4	4	4	9	5

Note: Chlorophyll is in mg/m^3, all others in g/m^3 unless noted otherwise.
* indicates calculated value.

CHERRYSTONE INLET: August 4, 1997

	1 Top	1 Bottom	2	3	T1
Secchi Disk, m	1.4		0.9	0.6	0.7
Chlorophyll	5	5	8	30	13
DOC	2.8	2.8	2.9	3.4	3.3
PC	0.8	1.0	1.2	2.9	1.8
POC					
TDN	0.19	0.24	0.27	0.27	0.30
NH4	0.008	0.008	0.008	0.007	0.009
NO2+NO3	0.000	0.001	0.000	0.002	0.002
DON*	0.18	0.23	0.26	0.26	0.29
PN	0.12	0.15	0.19	0.39	0.27
TDP	0.014	0.017	0.015	0.018	0.018
PO4	0.006	0.007	0.003	0.004	0.003
DOP*	0.008	0.010	0.012	0.014	0.015
PPhos	0.017	0.018	0.026	0.061	0.035
PIP	0.004	0.004	0.005	0.009	0.007
POP*	0.013	0.014	0.021	0.052	0.028
TSS	14	12	14	61	18
FS	10	8	9	47	11
VS*	4	4	5	14	7

Note: Chlorophyll is in mg/m^3, all others in g/m^3 unless noted otherwise.
* indicates calculated value.

CHERRYSTONE INLET
October 2, 1997

Station 1				Station 2			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l	Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	20.2	24.1	6.7	1.0	18.7	23.2	6.2
2.0	20.1	24.1	6.9	2.0	18.6	23.4	6.2
3.0	20.1	24.1	7.8				

Station 3				Station T1			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l	Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	18.8	23.8	6.4	1.0	18.8	24.0	6.3

CHERRYSTONE INLET: October 2, 1997

	1 Top	1 Bottom	2	3	T1
Secchi Disk, m	1.1		0.9	0.6	0.7
Chlorophyll	5	6	8	8	7
DOC	2.9	2.8	3.1	3.5	3.3
PC	0.9	1.2	1.1	1.6	1.2
POC					
TDN	0.25	0.25	0.26	0.28	0.26
NH4	0.008	0.007	0.007	0.008	0.006
NO2+NO3	0.001	0.000	0.002	0.003	0.001
DON*	0.24	0.24	0.25	0.27	0.25
PN	0.11	0.15	0.15	0.22	0.16
TDP	0.020	0.021	0.021	0.020	0.018
PO4	0.003	0.003	0.002	0.002	0.001
DOP*	0.017	0.018	0.019	0.018	0.017
Pphos	0.023	0.024	0.023	0.030	0.025
PIP	0.006	0.006	0.005	0.007	0.005
POP*	0.017	0.018	0.018	0.023	0.020
TSS	20	18	15	24	15
FS	16	14	11	18	11
VS*	4	4	4	6	4

Note: Chlorophyll is in mg/m^3, all others in g/m^3 unless noted otherwise.
* indicates calculated value.

CHERRYSTONE INLET
December 5, 1997

Station 1				Station 2			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l	Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	8.0	23.0	9.5	2.0	8.5	22.3	10.1
3.0	8.0	23.0	9.4				

Station 3				Station T1			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l	Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	8.5	21.6	10.1	1.0	8.5	21.6	9.7

CHERRYSTONE INLET: December 5, 1997

	1 Top	1 Bottom	2	3	T1
Secchi Disk, m	2.0		1.2	1.2	1.1
Chlorophyll	3	3	5	6	8
DOC	3.0	2.5	2.7	3.0	3.0
PC	0.5	0.5	0.8	1.1	2.4
POC					
TDN	0.28	0.28	0.26	0.29	0.27
NH4	0.016	0.018	0.011	0.008	0.008
NO2+NO3	0.018	0.019	0.006	0.006	0.018
DON*	0.25	0.24	0.24	0.28	0.24
PN	0.10	0.11	0.15	0.19	0.35
TDP	0.020	0.022	0.018	0.019	0.016
PO4	0.004	0.005	0.003	0.003	0.002
DOP*	0.016	0.017	0.015	0.016	0.014
Pphos	0.012	0.013	0.016	0.025	0.047
PIP	0.003	0.003	0.003	0.006	0.016
POP*	0.009	0.010	0.013	0.019	0.031
TSS	9	10	14	23	54
FS	7	8	11	19	47
VS*	2	2	3	4	7

Note: Chlorophyll is in mg/m^3, all others in g/m^3 unless noted otherwise.
* indicates calculated value.

Appendix A-4. 1997 Field Survey Data, Hungars Creek

HUNGARS CREEK
February 25, 1997

Station 1				Station 2			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l	Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	6.5	16.2	12.1	1.0	6.5		13.3
				2.0	6.5	16.1	13.3

Station 3			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	6.5	16.2	12.1

HUNGARS CREEK: February 25, 1997

	1	2	3
Secchi Disk, m	0.8	0.9	1.0
Chlorophyll	26	30	21
DOC	3.3	3.2	3.2
PC	1.7	3.1	3.1
POC	1.6	2.9	2.8
TDN	0.31	0.33	0.24
NH4	0.011	0.010	0.008
NO2+NO3	0.043	0.037	0.019
DON*	0.26	0.28	0.21
PN	0.22	0.44	0.43
TDP	0.015	0.015	0.010
PO4	0.004	0.006	0.002
DOP*	0.011	0.009	0.008
PPhos	0.032	0.030	0.026
PIP	0.013	0.010	0.009
POP*	0.019	0.020	0.017
TSS	24	18	16
FS	17	12	10
VS*	7	6	6

Note: Chlorophyll is in mg/m^3, all others in g/m^3 unless noted otherwise.
* indicates calculated value.

HUNGARS CREEK
April 7, 1997

Station 1				Station 2			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l	Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0		16.9	10.4	1.0		17.6	10.6
4.0		17.0	10.7				

Station 3			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0		18.0	10.3

HUNGARS CREEK: Arpil 7, 1997

	1 Top	1 Bottom	2	3
Secchi Disk, m	1.1		1.4	1.4
Chlorophyll	37	17	19	16
DOC	3.0	3.1	2.9	3.1
PC	1.6	1.7	1.7	1.6
POC				
TDN	0.24	0.25	0.24	0.23
NH4	0.010	0.010	0.008	0.007
NO2+NO3	0.003	0.006	0.003	0.001
DON*	0.23	0.23	0.23	0.22
PN	1.46	1.74	1.73	1.64
TDP	0.012	0.008	0.011	0.012
PO4	0.003	0.003	0.002	0.002
DOP*	0.009	0.005	0.009	0.010
PPhos	0.016	0.015	0.016	0.017
PIP	0.004	0.004	0.004	0.004
POP*	0.012	0.011	0.012	0.013
TSS	13	13	14	12
FS	9	9	9	8
VS*	4	4	5	4

Note: Chlorophyll is in mg/m^3, all others in g/m^3 unless noted otherwise.
* indicates calculated value.

HUNGARS CREEK
June 19, 1997

Station 1				Station 2			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l	Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	23.5	14.9	8.7	1.0	24.1	15.5	7.4
2.0	23.5	14.9		2.0	24.1	15.6	
3.0	23.5	15.0	8.7	3.0	24.1	15.7	
4.0	23.6	15.0					

Station 3

Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	24.9	16.4	6.7

HUNGARS CREEK: June 19, 1997

	1 Top	1 Bottom	2	3
Secchi Disk, m	2.3			
Chlorophyll	16	5	4	13
DOC	3.0	2.9	3.0	3.1
PC	0.9	1.0	1.0	1.3
POC				
TDN	0.30	0.31	0.31	0.30
NH4	0.018	0.020	0.026	0.020
NO2+NO3	0.051	0.050	0.038	0.022
DON*	0.23	0.24	0.25	0.26
PN	0.06	0.11	0.13	0.21
TDP	0.008	0.009	0.009	0.010
PO4	0.002	0.003	0.002	0.002
DOP*	0.006	0.006	0.007	0.008
PPhos	0.015	0.018	0.022	0.030
PIP	0.005	0.004	0.005	0.006
POP*	0.010	0.014	0.017	0.024
TSS	8	9	8	16
FS	4	5	5	11
VS*	4	4	3	5

Note: Chlorophyll is in mg/m^3, all others in g/m^3 unless noted otherwise.
* indicates calculated value.

HUNGARS CREEK
August 4, 1997

Station 1				Station 2			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l	Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
2.0	27.5	18.6	7.0	1.0	27.5	18.6	6.9
				2.0	27.0	18.8	7.3

Station 3			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	28.0	18.7	6.4

HUNGARS CREEK: August 4, 1997

	1 Mid	2 Top	2 Bottom	3
Secchi Disk, m	1.6	1.5		0.9
Chlorophyll	7	3	4	8
DOC	3.1	3.0	2.8	3.0
PC	1.1	1.0	0.8	1.2
POC				
TDN	0.26	0.24	0.24	0.28
NH4	0.007	0.007	0.006	0.006
NO2+NO3	0.002	0.001	0.000	0.000
DON*	0.25	0.23	0.23	0.27
PN	0.15	0.15	0.13	0.18
TDP	0.015	0.013	0.013	0.013
PO4	0.004	0.004	0.004	0.002
DOP*	0.011	0.009	0.009	0.011
PPhos	0.023	0.019	0.019	0.022
PIP	0.005	0.004	0.003	0.004
POP*	0.018	0.015	0.016	0.018
TSS	11	8	8	8
FS	7	5	5	5
VS*	4	3	3	3

Note: Chlorophyll is in mg/m^3, all others in g/m^3 unless noted otherwise.
* indicates calculated value.

HUNGARS CREEK
October 2, 1997

Station 1				Station 2			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l	Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	18.3	21.8	7.7	1.0	18.9	21.5	7.6
4.0	18.3	20.5	7.6				

Station 3			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	17.8	22.0	7.7

HUNGARS CREEK: October 2, 1997

	1 Top	1 Bottom	2	3
Secchi Disk, m	0.7		0.9	0.7
Chlorophyll	6	8	9	9
DOC	2.9	2.9	2.7	3.0
PC	1.4	1.4	1.1	1.3
POC				
TDN	0.26	0.26	0.26	0.27
NH4	0.008	0.008	0.009	0.008
NO2+NO3	0.001	0.003	0.001	0.002
DON*	0.25	0.25	0.25	0.26
PN	0.19	0.20	0.15	0.18
TDP	0.018	0.019	0.020	0.019
PO4	0.002	0.002	0.002	0.001
DOP*	0.016	0.017	0.018	0.018
Pphos	0.029	0.031	0.025	0.027
PIP	0.008	0.009	0.006	0.006
POP*	0.021	0.022	0.019	0.021
TSS	23	22	20	19
FS	18	17	14	14
VS*	5	5	6	5

Note: Chlorophyll is in mg/m^3, all others in g/m^3 unless noted otherwise.
* indicates calculated value.

HUNGARS CREEK
December 5, 1997

Station 1				Station 2			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l	Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	8.0	21.7	10.0	1.0	8.5	21.4	9.9
3.0	8.0	21.8	9.7				

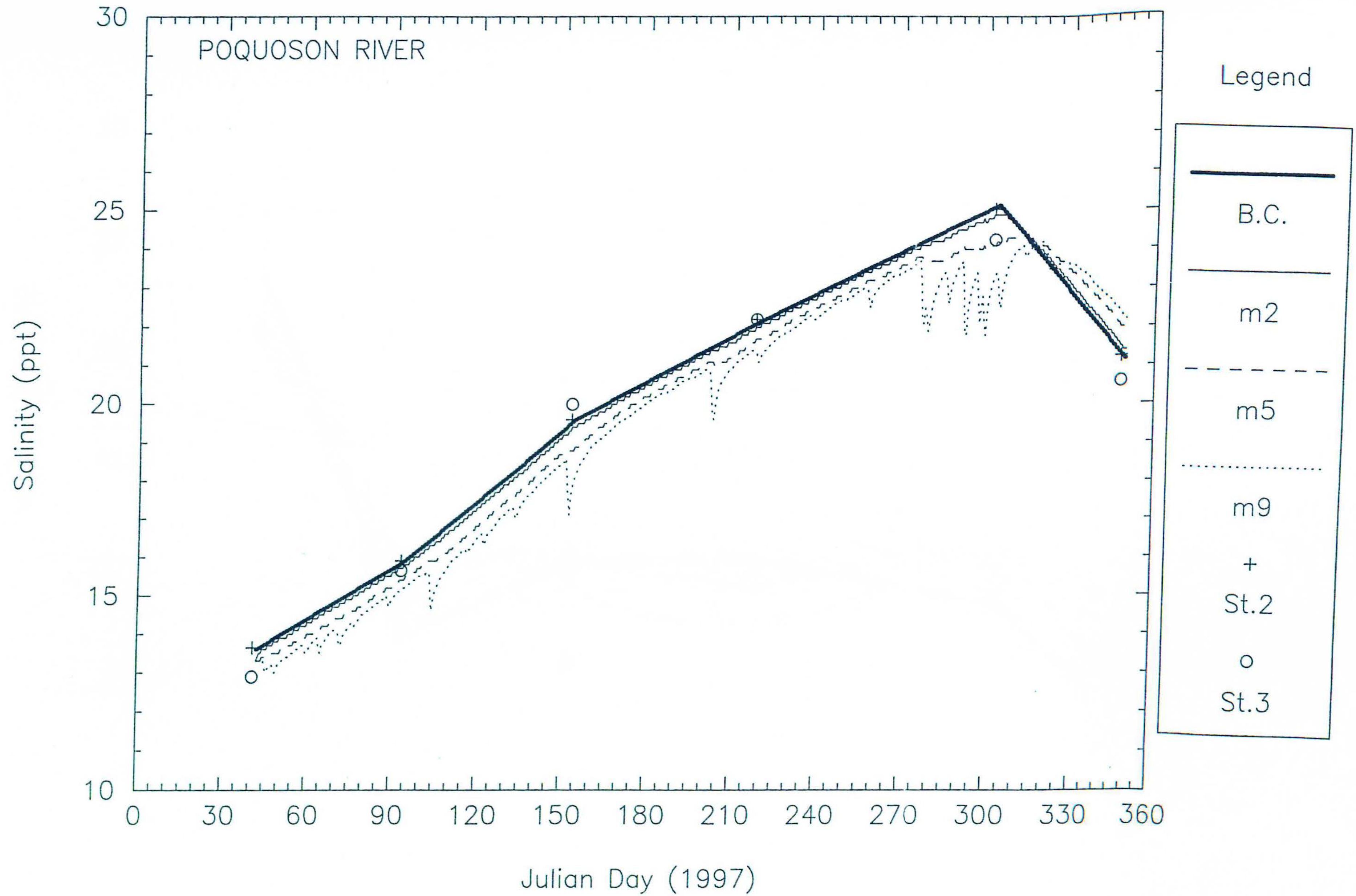
Station 3			
Depth, m	Temp, C	Salinity	Dissolved Oxygen, mg/l
1.0	8.5	21.5	10.3

HUNGARS CREEK: December 5, 1997

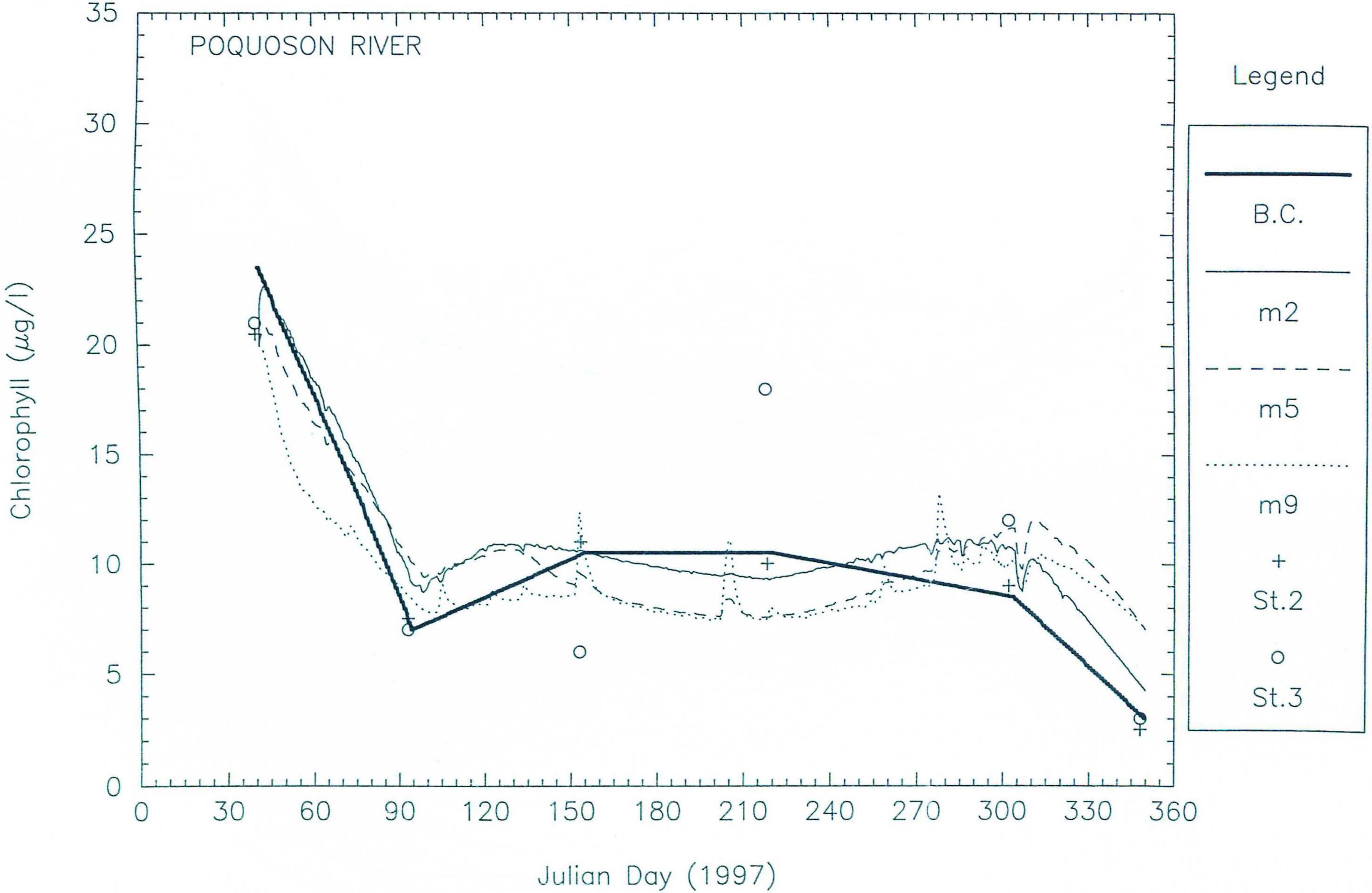
	1 Top	1 Bottom	2	3
Secchi Disk, m	1.3		1.5	1.5
Chlorophyll	4	6	5	5
DOC	2.9	2.9	2.9	3.0
PC	0.8	0.8	0.9	0.8
POC				
TDN	0.30	0.29	0.27	0.28
NH4	0.026	0.012	0.007	0.007
NO2+NO3	0.018	0.012	0.003	0.005
DON*	0.26	0.27	0.26	0.27
PN	0.14	0.13	0.14	0.13
TDP	0.016	0.018	0.014	0.016
PO4	0.003	0.004	0.003	0.004
DOP*	0.013	0.014	0.011	0.012
Pphos		0.015	0.015	0.013
PIP	0.003	0.003	0.003	0.003
POP*		0.012	0.012	0.010
TSS	15	22	12	9
FS	12	18	9	6
VS*	3	4	3	3

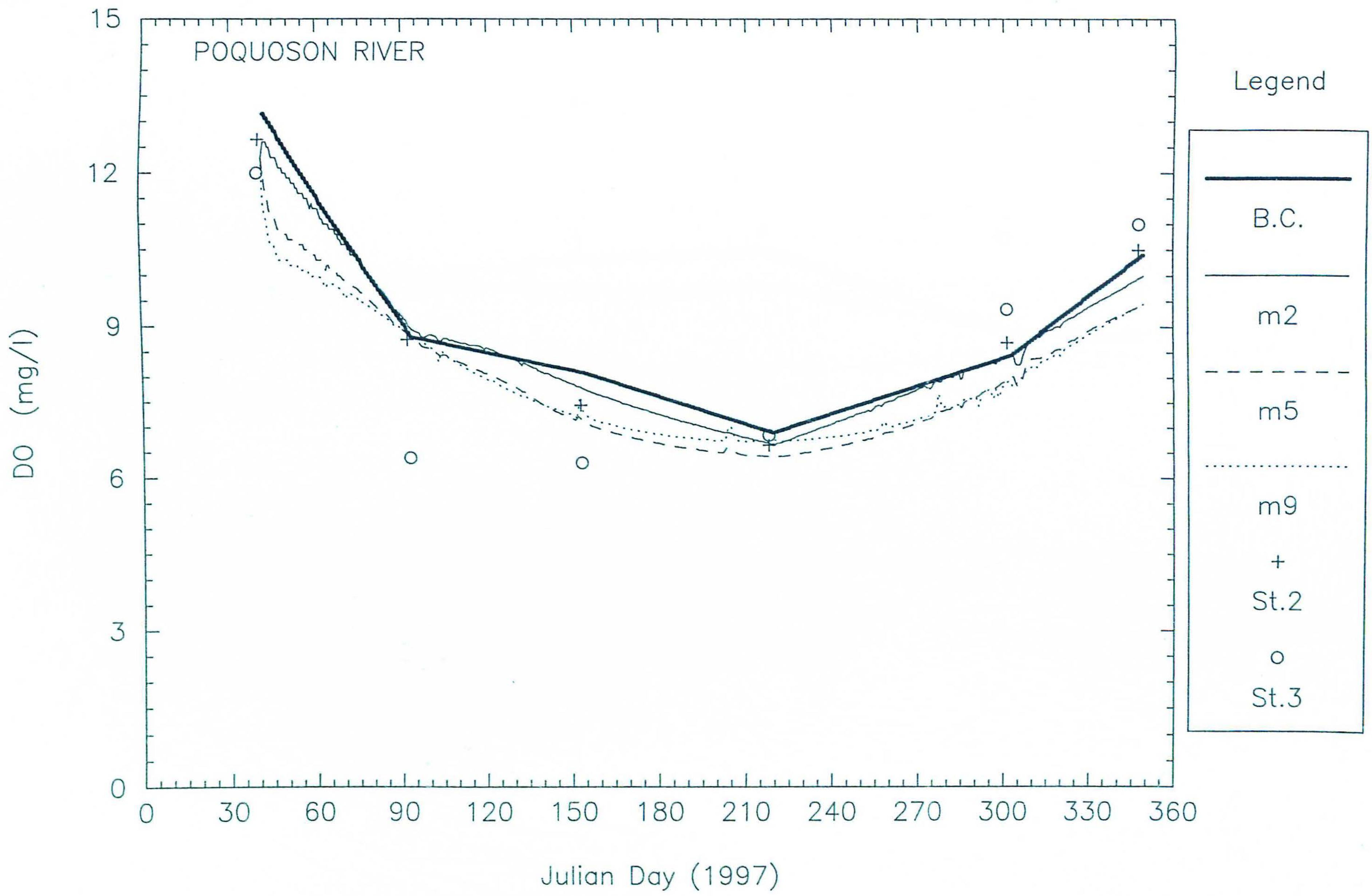
Note: Chlorophyll is in mg/m^3, all others in g/m^3 unless noted otherwise.
* indicates calculated value.

Appendix B-1. Comparisons of Model Results with Field Observations, Poquoson River

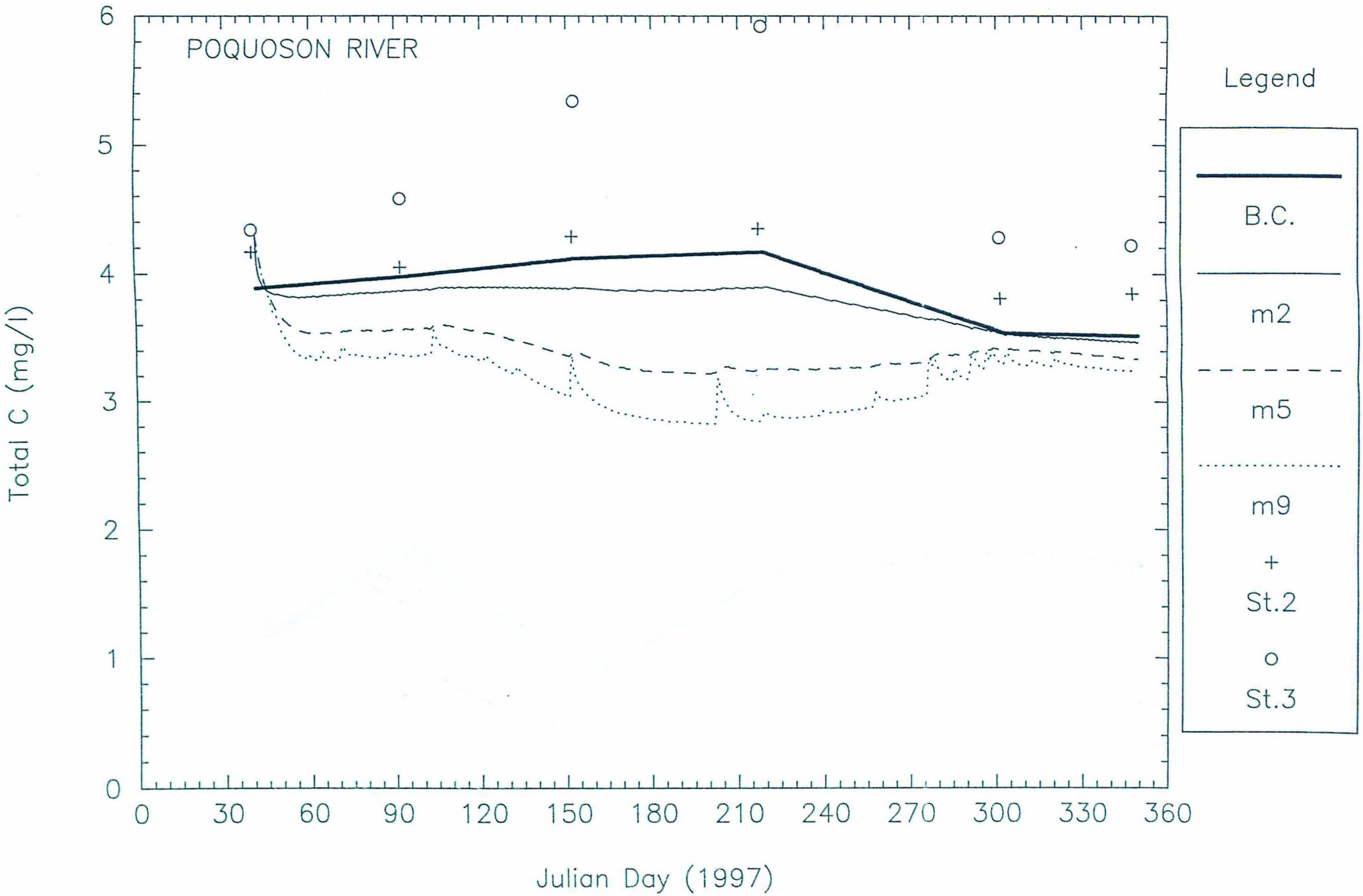


POQUOSON RIVER
Salinity (ppt)
Julian Day (1997)
30
25
20
15
10
0
30
60
90
120
150
180
210
240
270
300
330
360
Legend
B.C.
m2
m5
m9
+
St.2
o
St.3

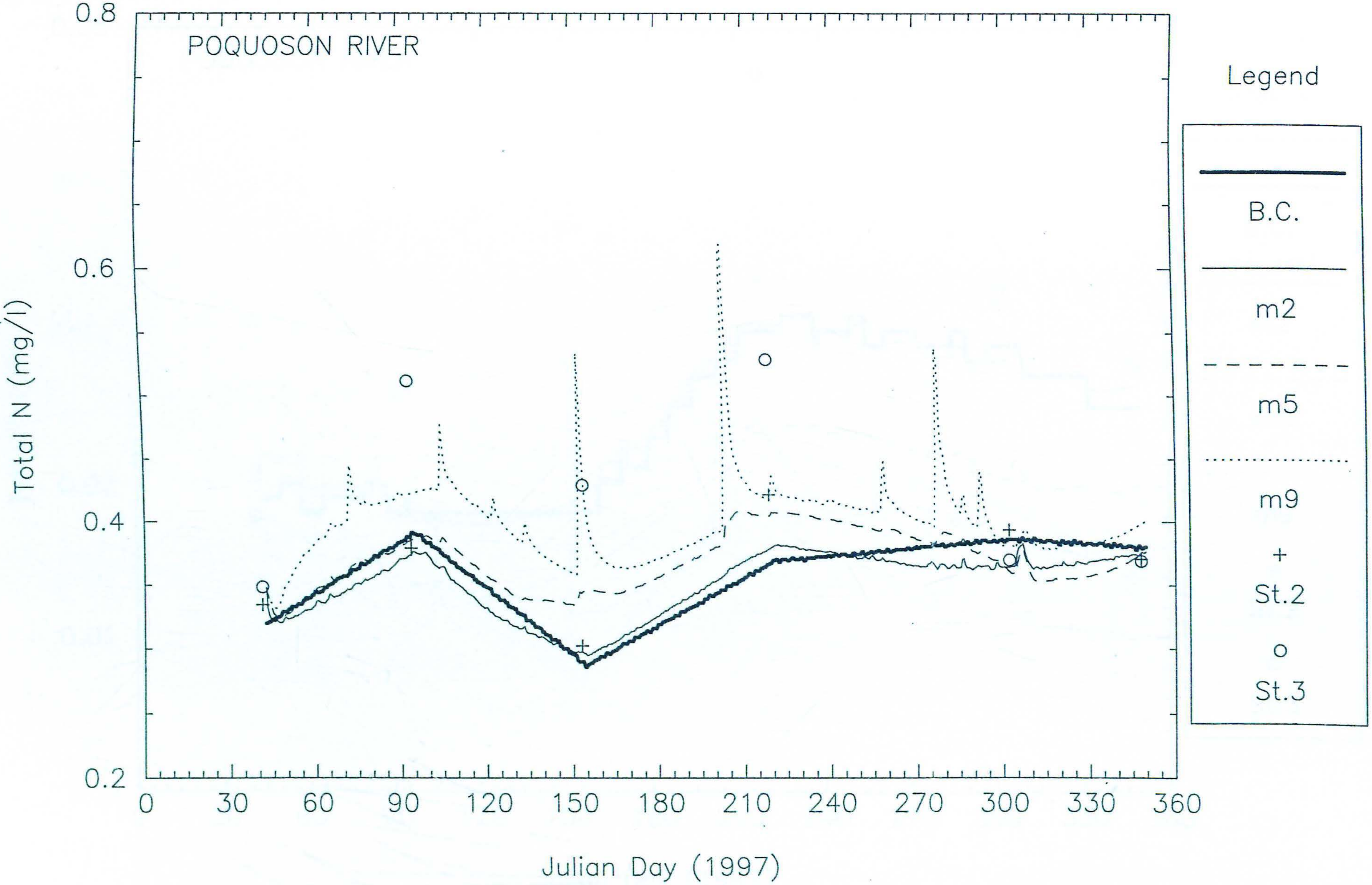

POQUOSON RIVER
Chlorophyll (µg/l)
Julian Day (1997)
0
5
10
15
20
25
30
35
0
30
60
90
120
150
180
210
240
270
300
330
360
Legend
B.C.
m2
m5
m9
St.2
St.3



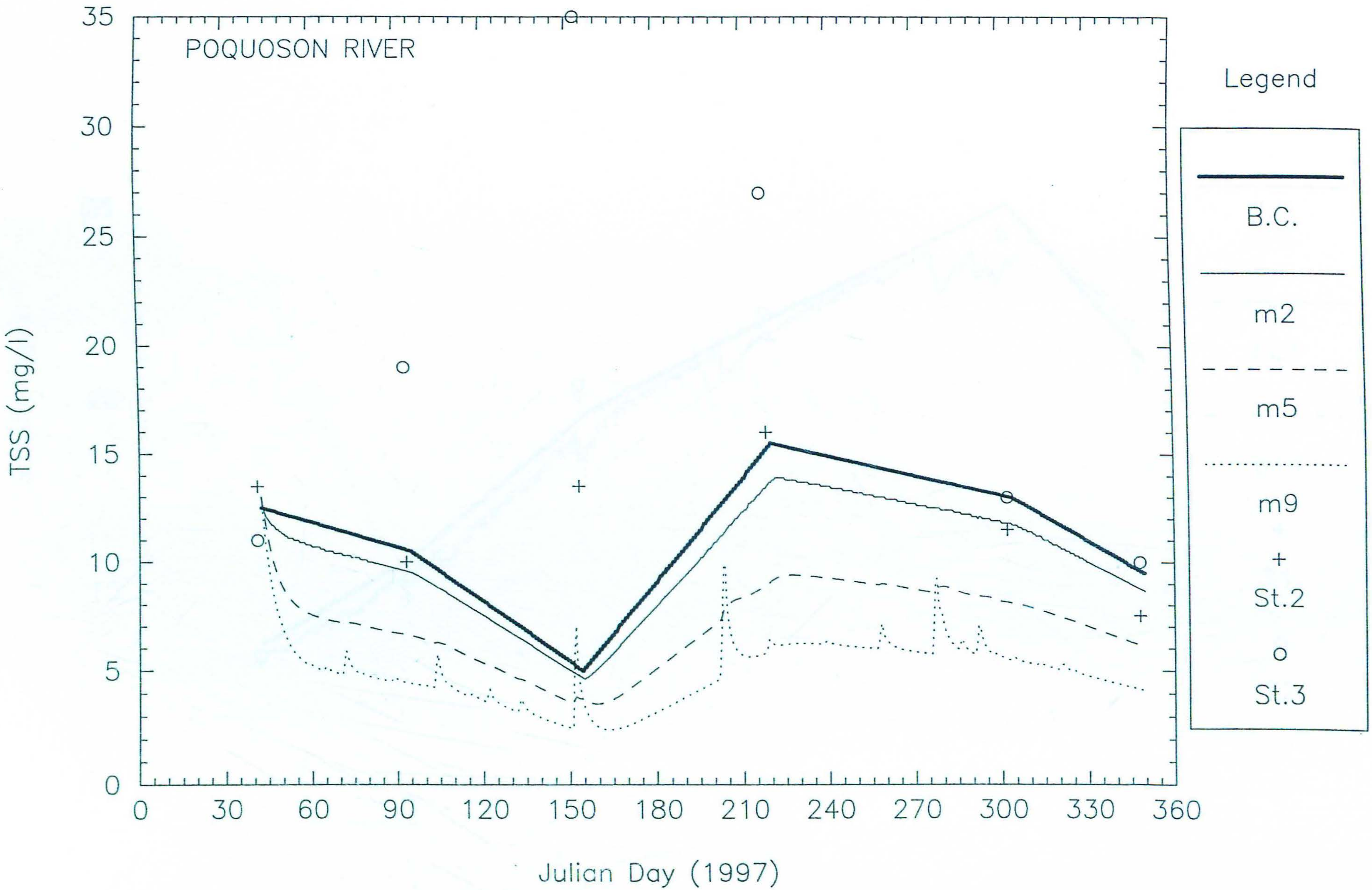
POQUOSON RIVER
Legend
B.C.
m2
m5
m9
St.2
St.3
DO (mg/l)
15
12
9
6
3
0
0
30
60
90
120
150
180
210
240
270
300
330
360
Julian Day (1997)



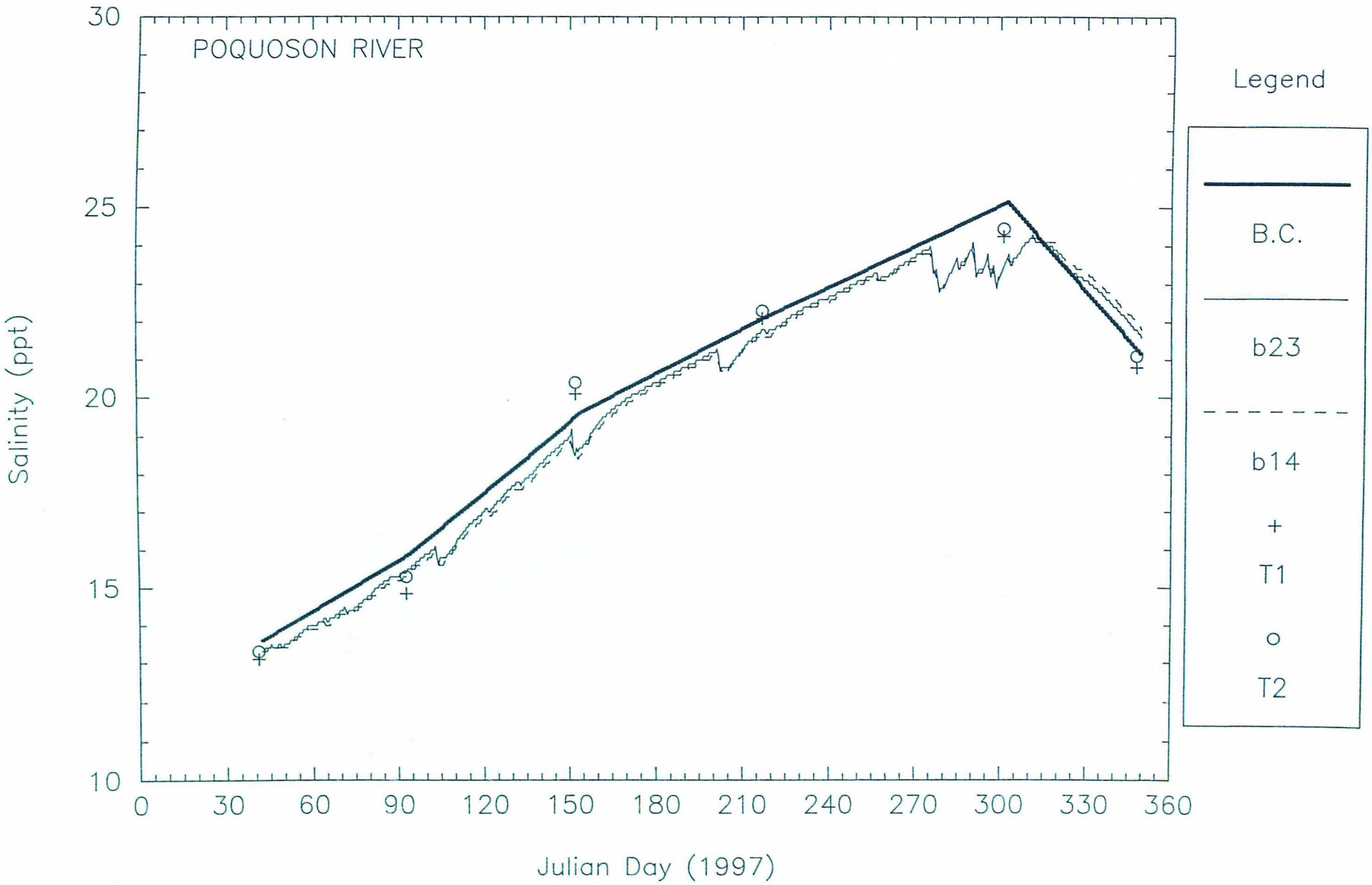
POQUOSON RIVER
Total C (mg/l)
Julian Day (1997)
0
1
2
3
4
5
6
0 30 60 90 120 150 180 210 240 270 300 330 360
Legend
B.C.
m2
m5
m9
+
St.2
o
St.3


POQUOSON RIVER
Total N (mg/l)
0.8
0.6
0.4
0.2
0
30
60
90
120
150
180
210
240
270
300
330
360
Julian Day (1997)
Legend
B.C.
m2
m5
m9
+
St.2
o
St.3

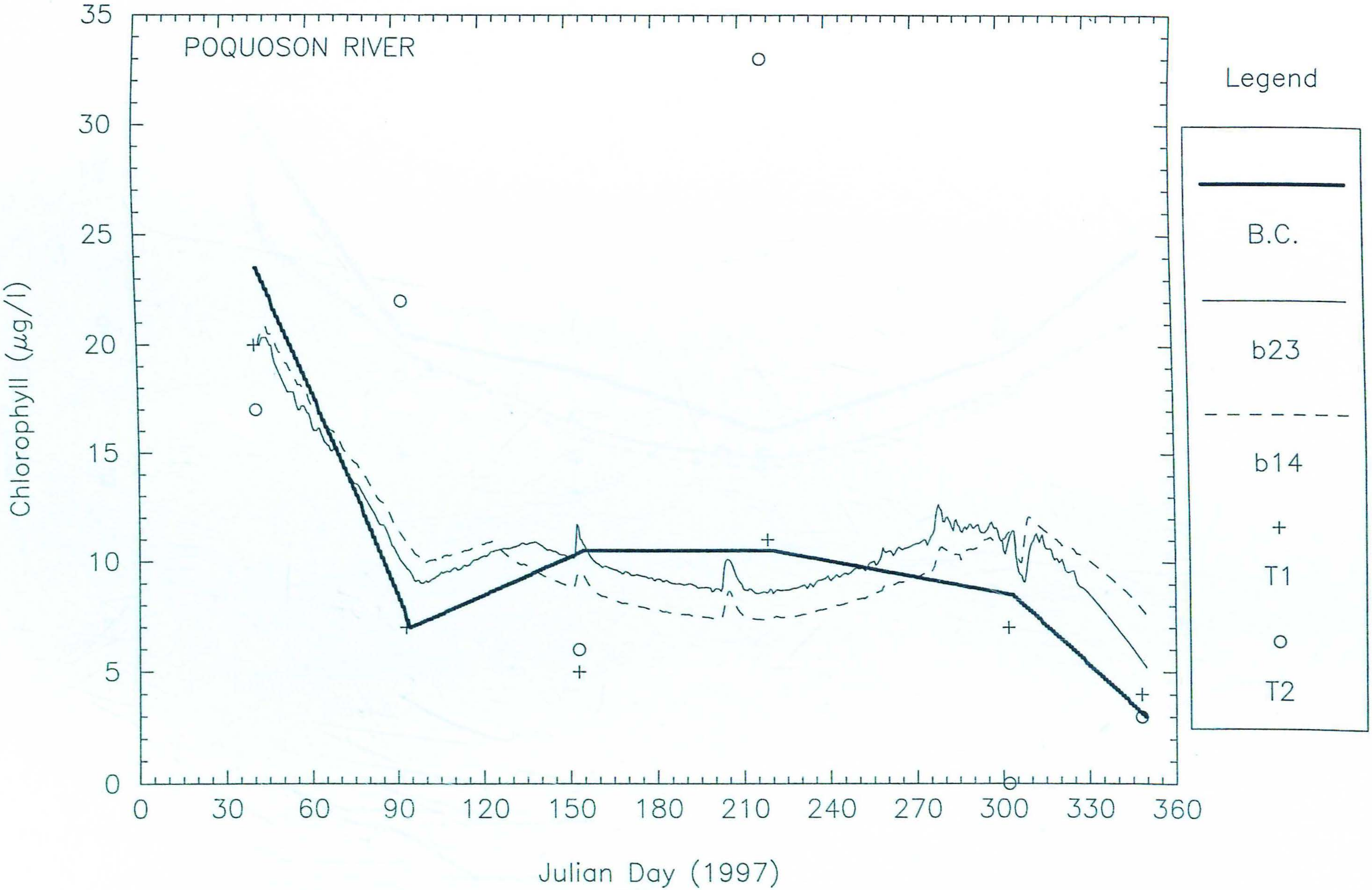

POQUOSON RIVER
Total P (mg/l)
0.05
0.04
0.03
0.02
0.01
0
0
30
60
90
120
150
180
210
240
270
300
330
360
Julian Day (1997)
Legend
B.C.
m2
m5
m9
St.2
St.3

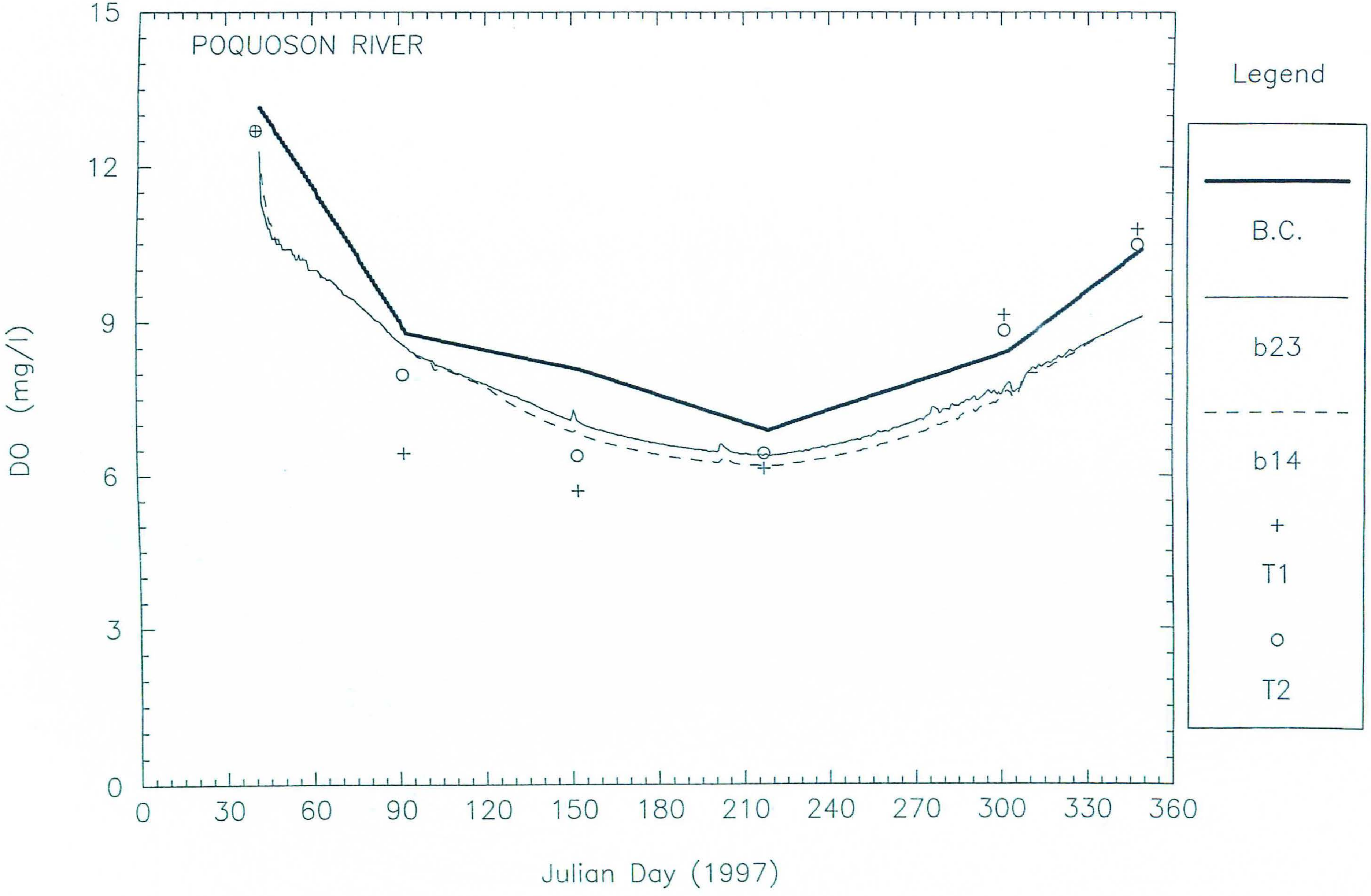


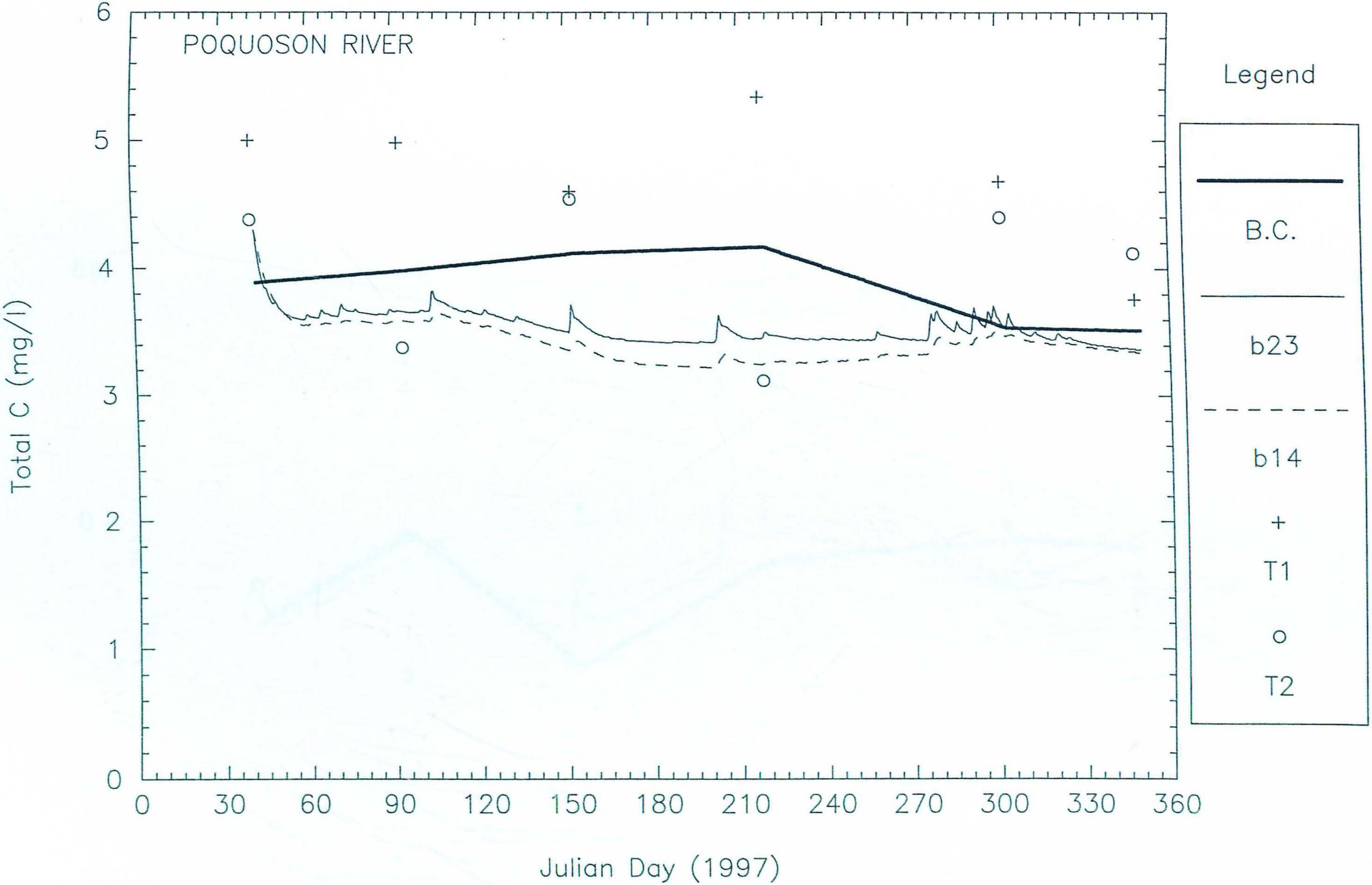
POQUOSON RIVER
TSS (mg/l)
Julian Day (1997)
0
5
10
15
20
25
30
35
0
30
60
90
120
150
180
210
240
270
300
330
360
Legend
B.C.
m2
m5
m9
+
St.2
o
St.3

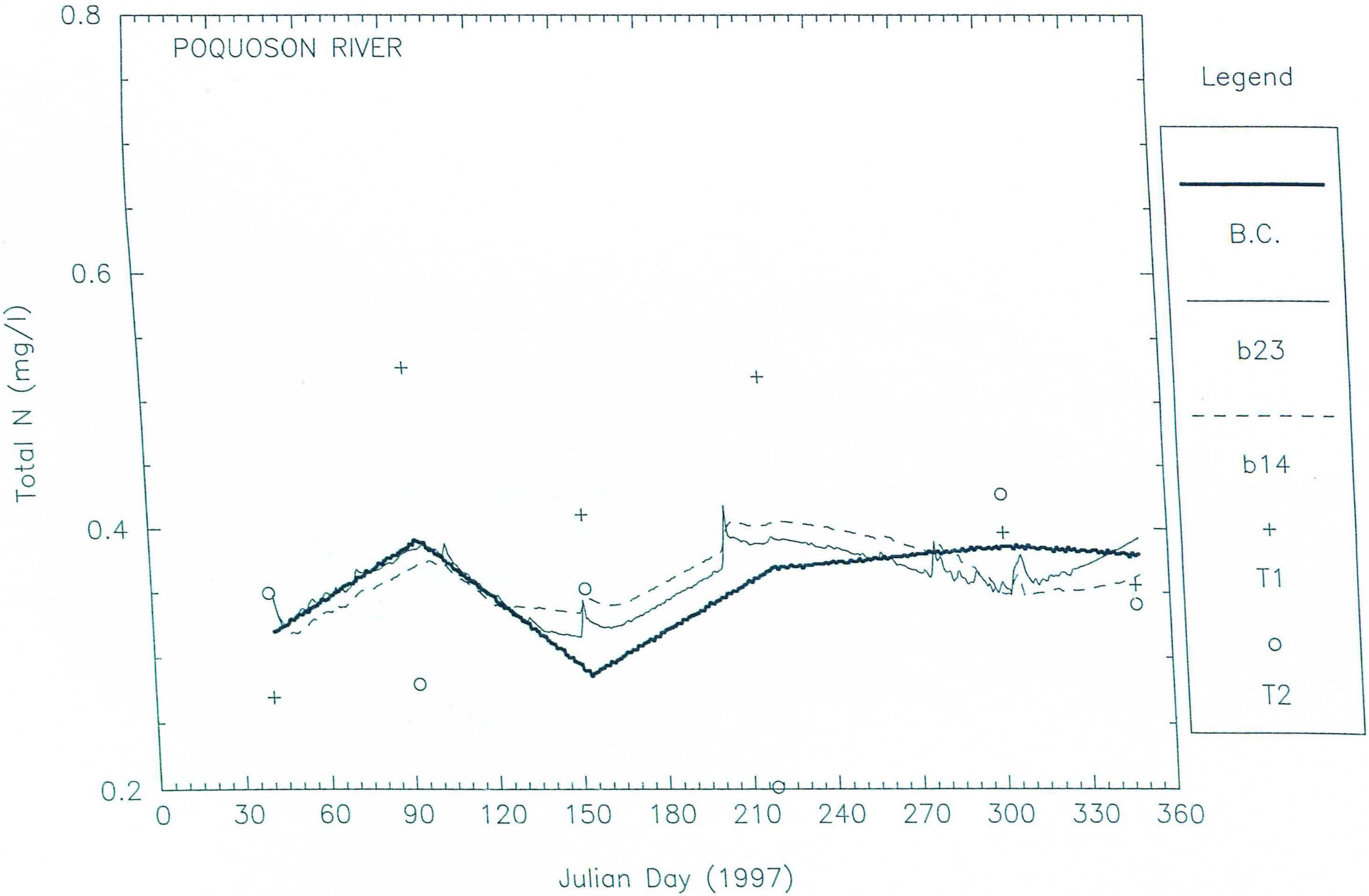


POQUOSON RIVER
Salinity (ppt)
Julian Day (1997)
30
25
20
15
10
0
30
60
90
120
150
180
210
240
270
300
330
360
Legend
B.C.
b23
b14
+
T1
o
T2


POQUOSON RIVER
Chlorophyll (μg/l)
Julian Day (1997)
0
5
10
15
20
25
30
35
0
30
60
90
120
150
180
210
240
270
300
330
360
Legend
B.C.
b23
b14
+
T1
o
T2

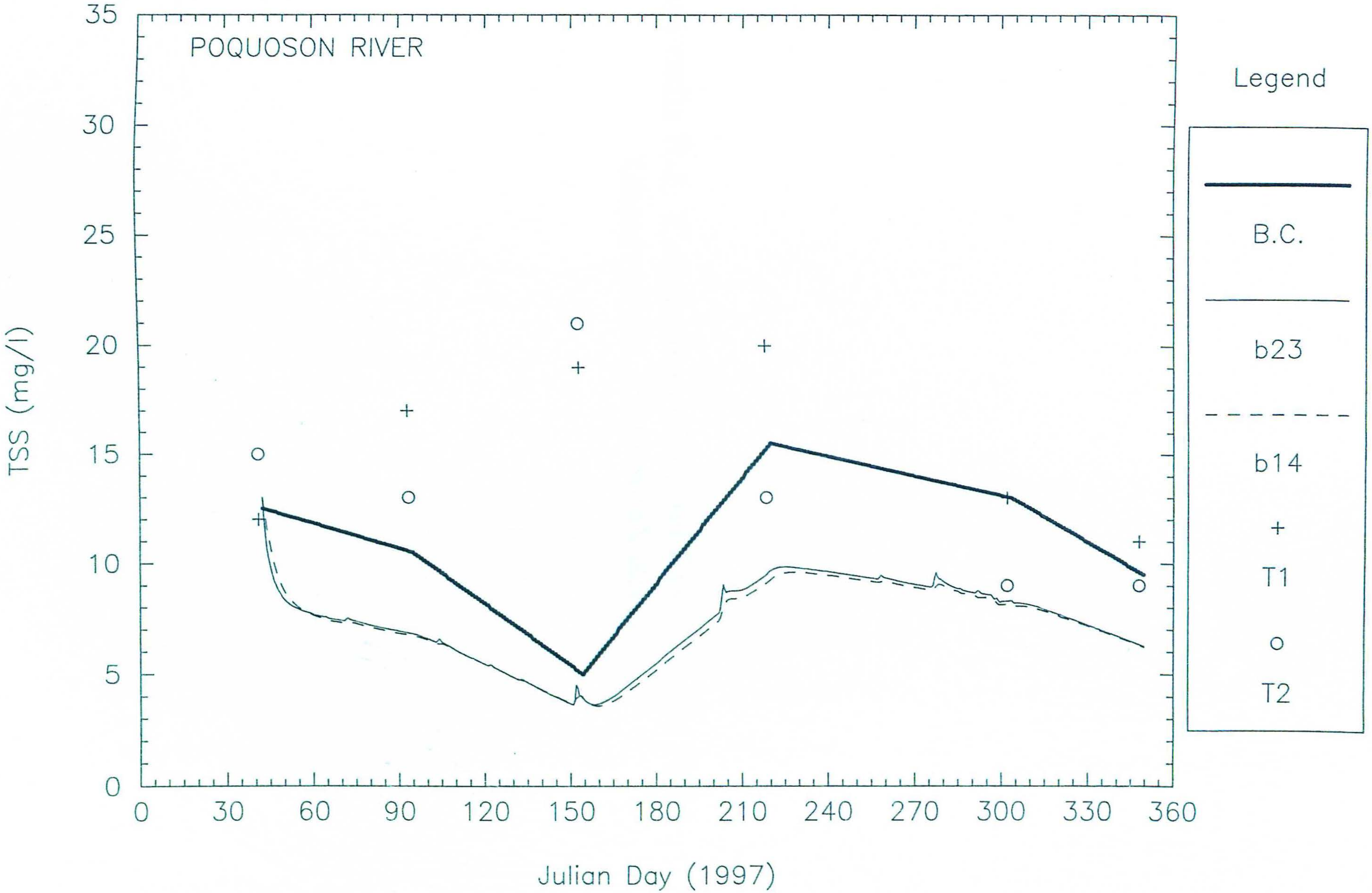

POQUOSON RIVER
DO (mg/l)
15
12
9
6
3
0
0
30
60
90
120
150
180
210
240
270
300
330
360
Julian Day (1997)
Legend
B.C.
b23
b14
+
T1
o
T2


POQUOSON RIVER
Total C (mg/l)
Julian Day (1997)
0
1
2
3
4
5
6
0
30
60
90
120
150
180
210
240
270
300
330
360
Legend
B.C.
b23
b14
+
T1
o
T2

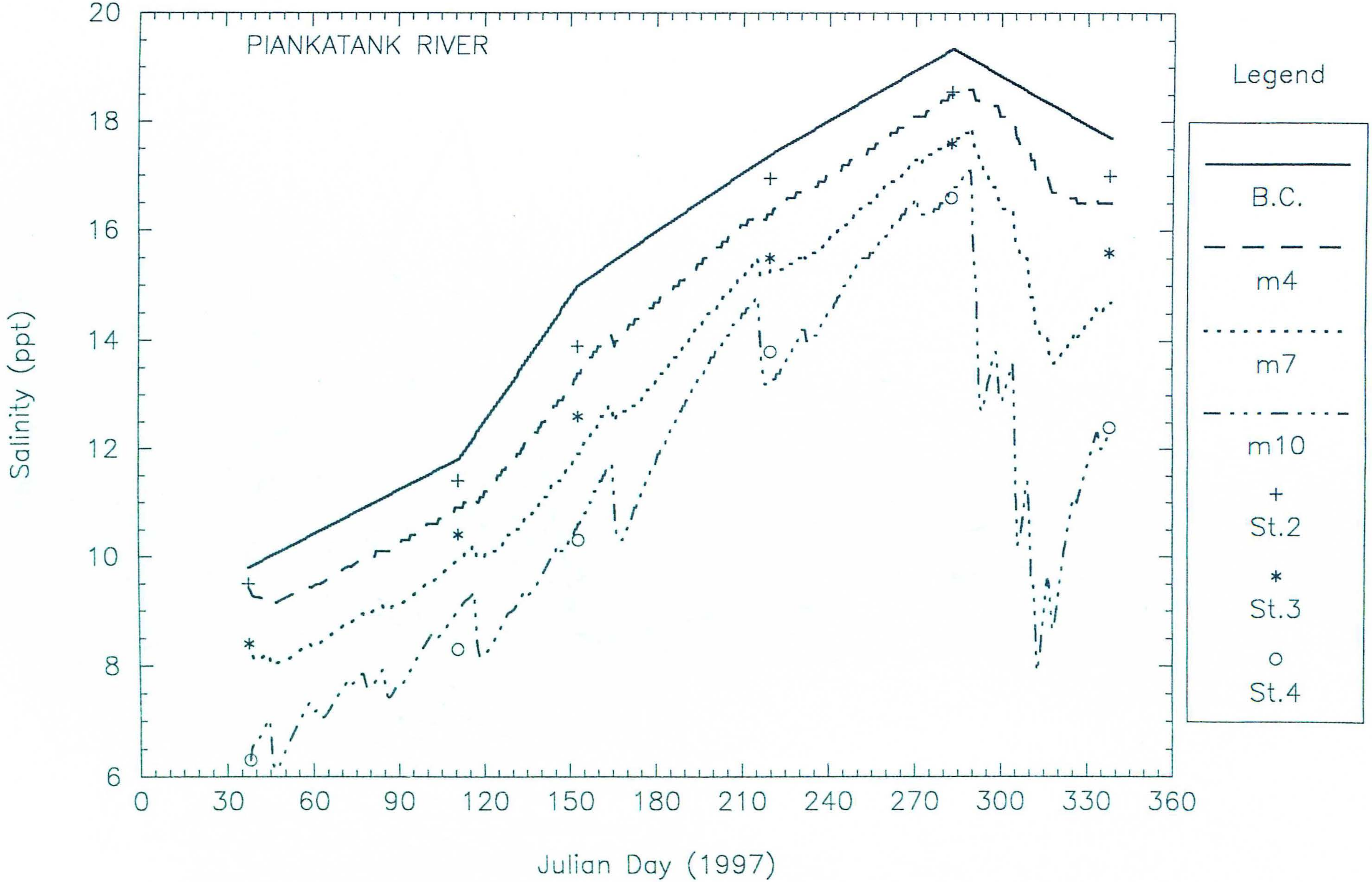


POQUOSON RIVER
Total N (mg/l)
0.8
0.6
0.4
0.2
0
30
60
90
120
150
180
210
240
270
300
330
360
Julian Day (1997)
Legend
B.C.
b23
b14
+
T1
o
T2

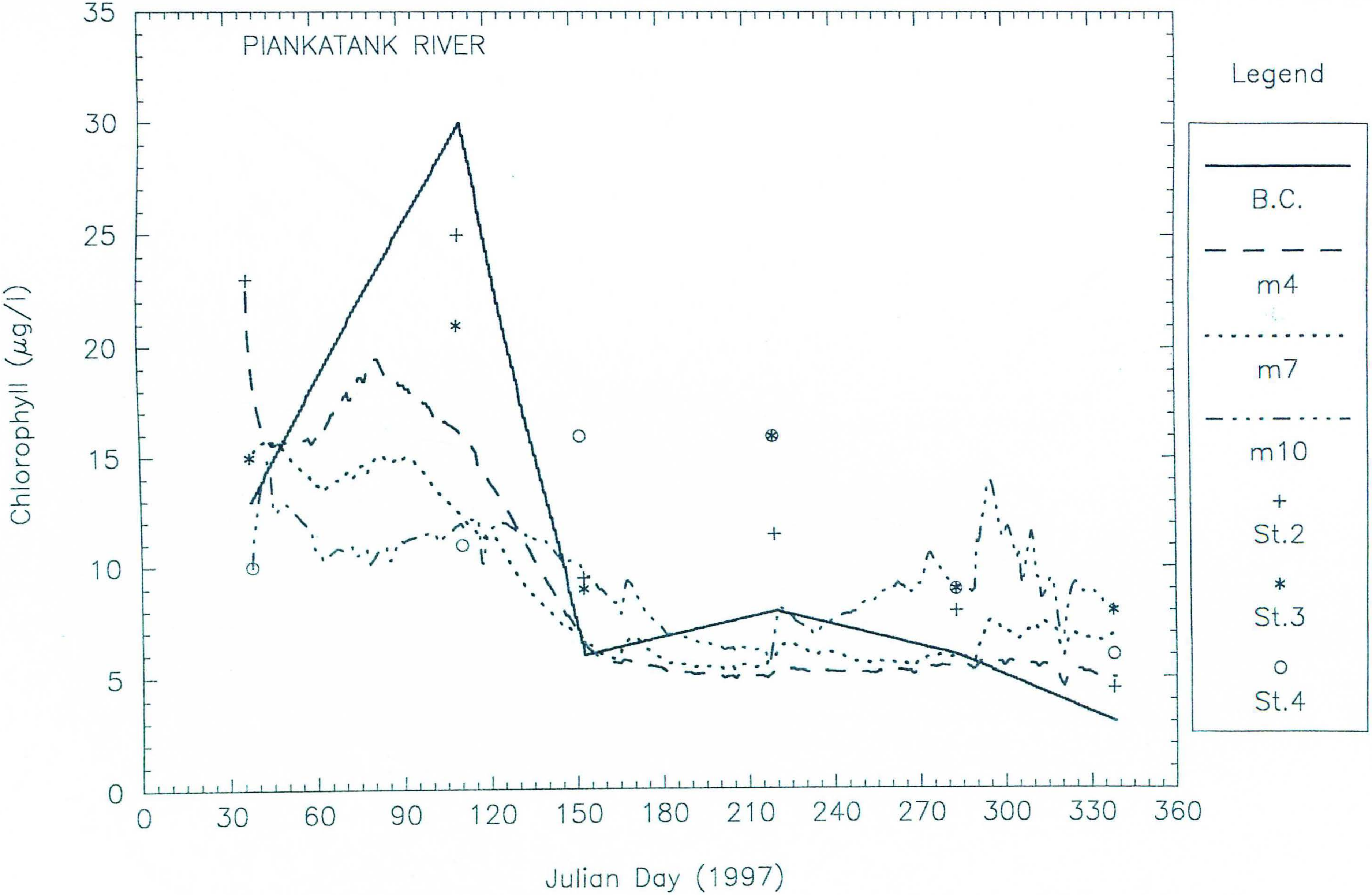
POQUOSON RIVER
Total P (mg/l)
0.05
0.04
0.03
0.02
0.01
0
0
30
60
90
120
150
180
210
240
270
300
330
360
Julian Day (1997)
Legend
B.C.
b23
b14
T1
T2

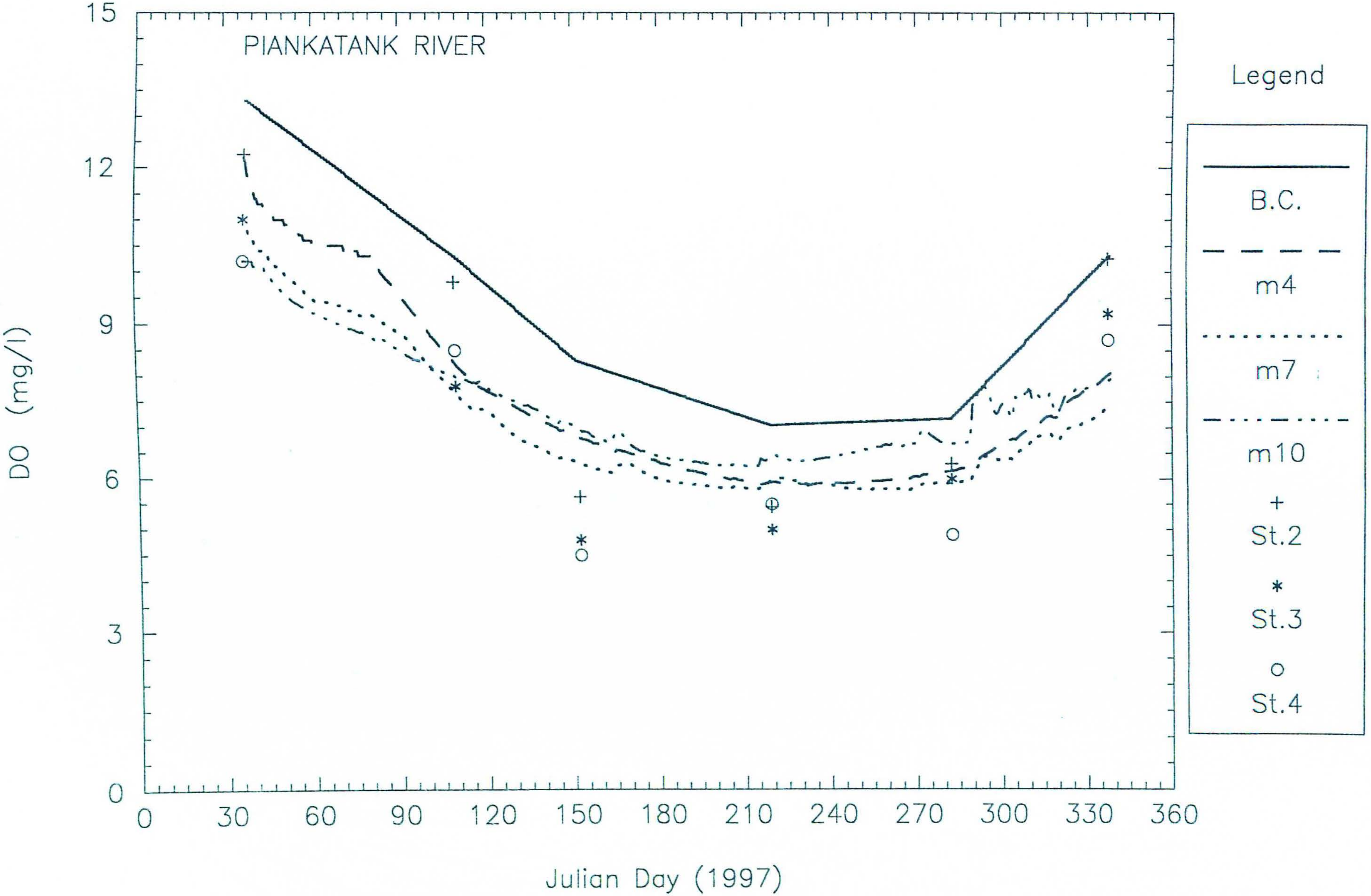

POQUOSON RIVER
TSS (mg/l)
Julian Day (1997)
0
5
10
15
20
25
30
35
0
30
60
90
120
150
180
210
240
270
300
330
360
Legend
B.C.
b23
b14
+
T1
o
T2

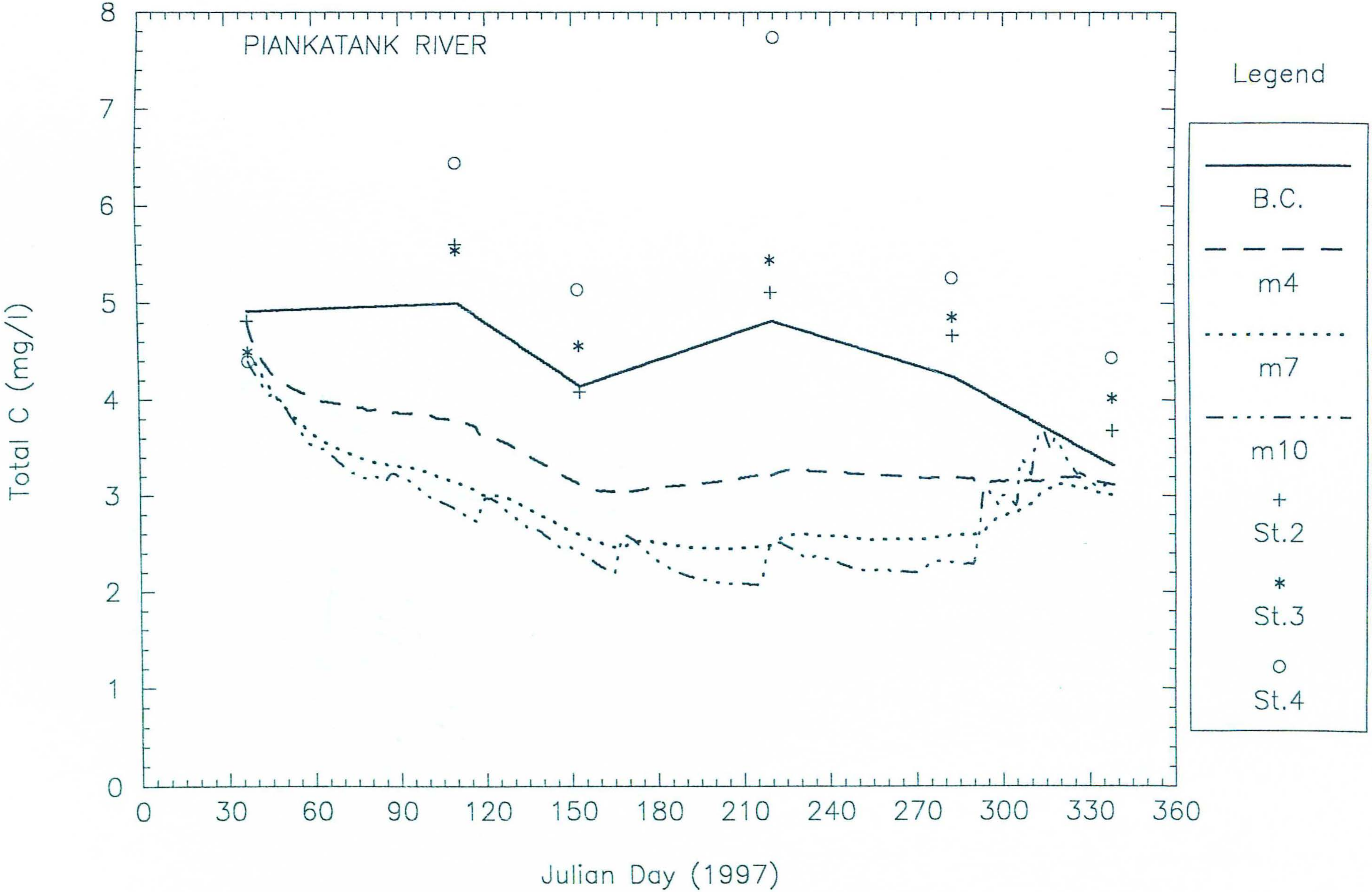
Appendix B-2. Comparison of Model Results with Field Observations, Piankatank River

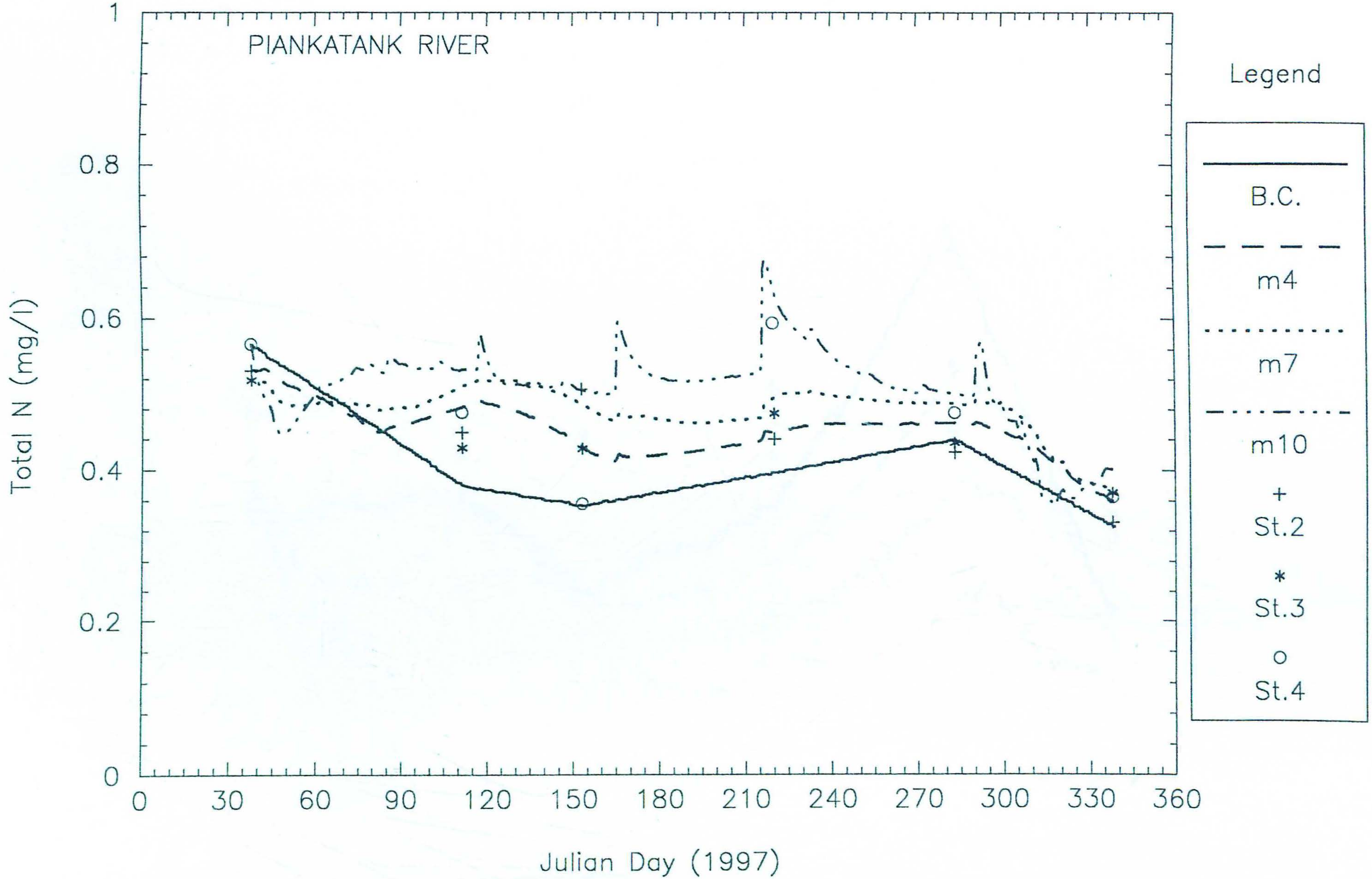


PIANKATANK RIVER
Salinity (ppt)
20
18
16
14
12
10
8
6
0
30
60
90
120
150
180
210
240
270
300
330
360
Julian Day (1997)
Legend
B.C.
m4
m7
m10
+
St.2
*
St.3
o
St.4

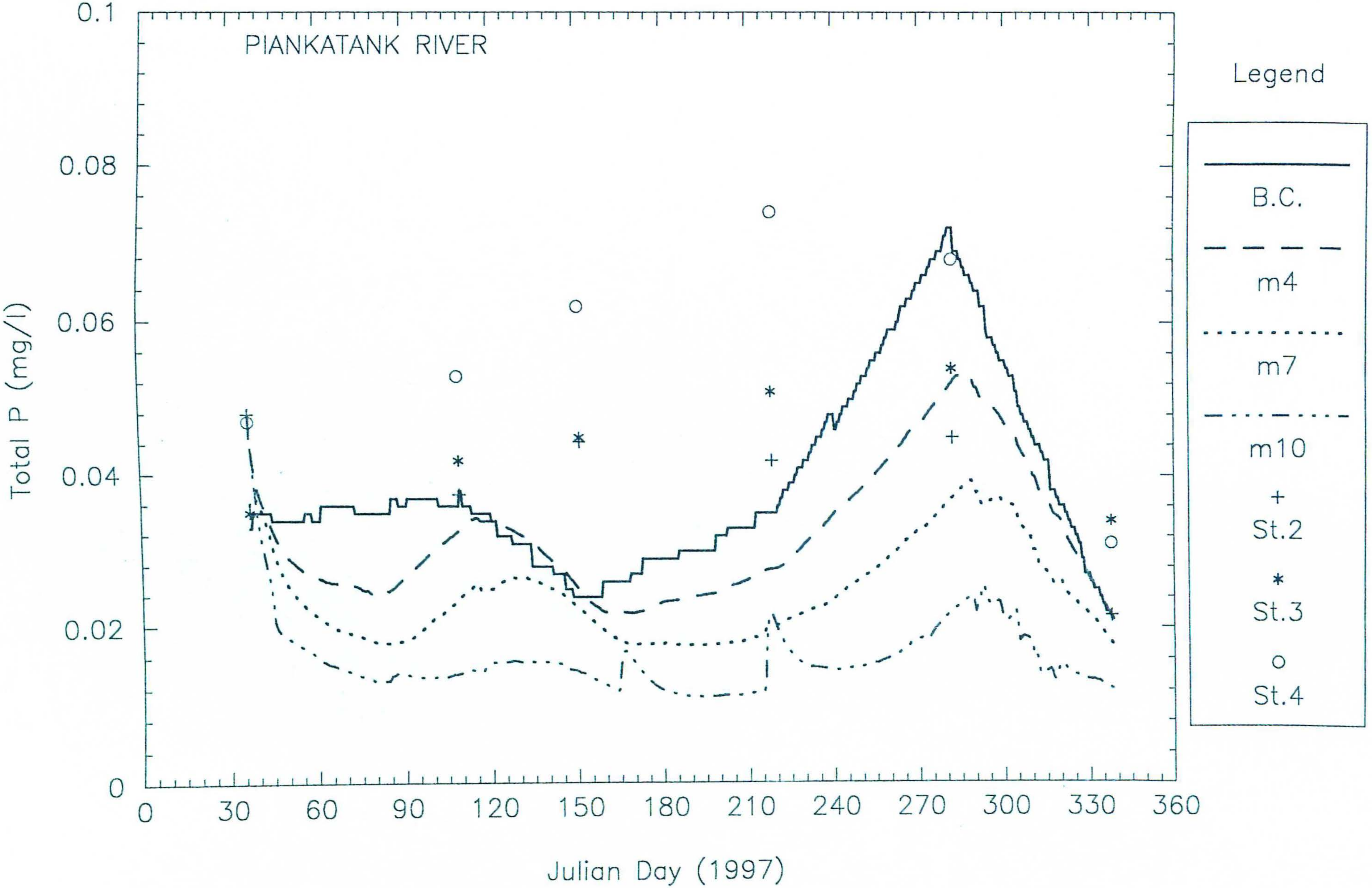

PIANKATANK RIVER
Chlorophyll (μg/l)
Julian Day (1997)
Legend
B.C.
m4
m7
m10
St.2
St.3
St.4
0
5
10
15
20
25
30
35
0
30
60
90
120
150
180
210
240
270
300
330
360


PIANKATANK RIVER
Legend
B.C.
m4
m7
m10
St.2
St.3
St.4
DO (mg/l)
Julian Day (1997)
0
3
6
9
12
15
0
30
60
90
120
150
180
210
240
270
300
330
360

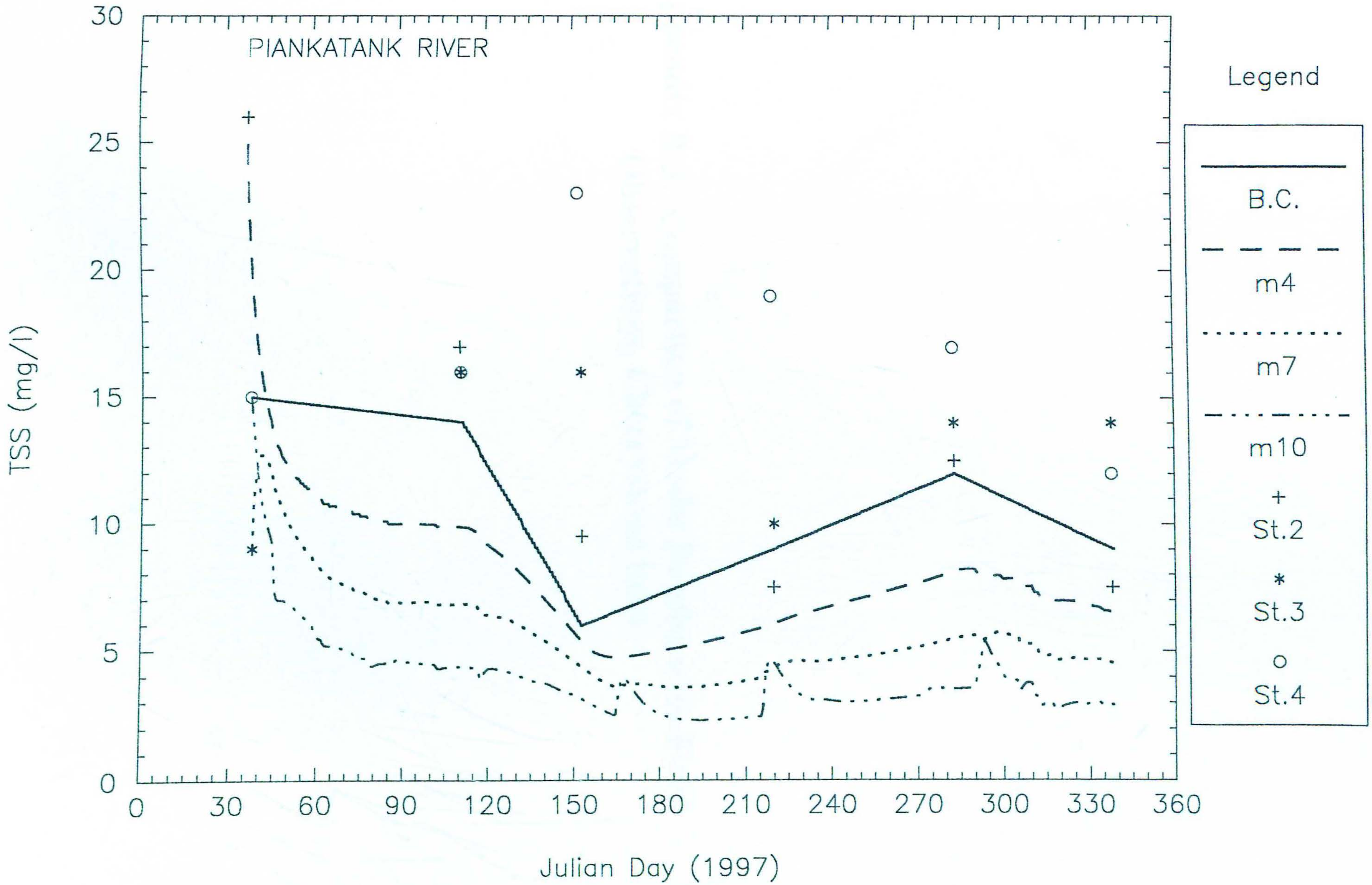

PIANKATANK RIVER
Total C (mg/l)
Julian Day (1997)
0
1
2
3
4
5
6
7
8
0
30
60
90
120
150
180
210
240
270
300
330
360
Legend
B.C.
m4
m7
m10
+
St.2
*
St.3
o
St.4



PIANKATANK RIVER
Legend
B.C.
m4
m7
m10
+
St.2
*
St.3
o
St.4
Total N (mg/l)
Julian Day (1997)
0
0.2
0.4
0.6
0.8
1
0
30
60
90
120
150
180
210
240
270
300
330
360

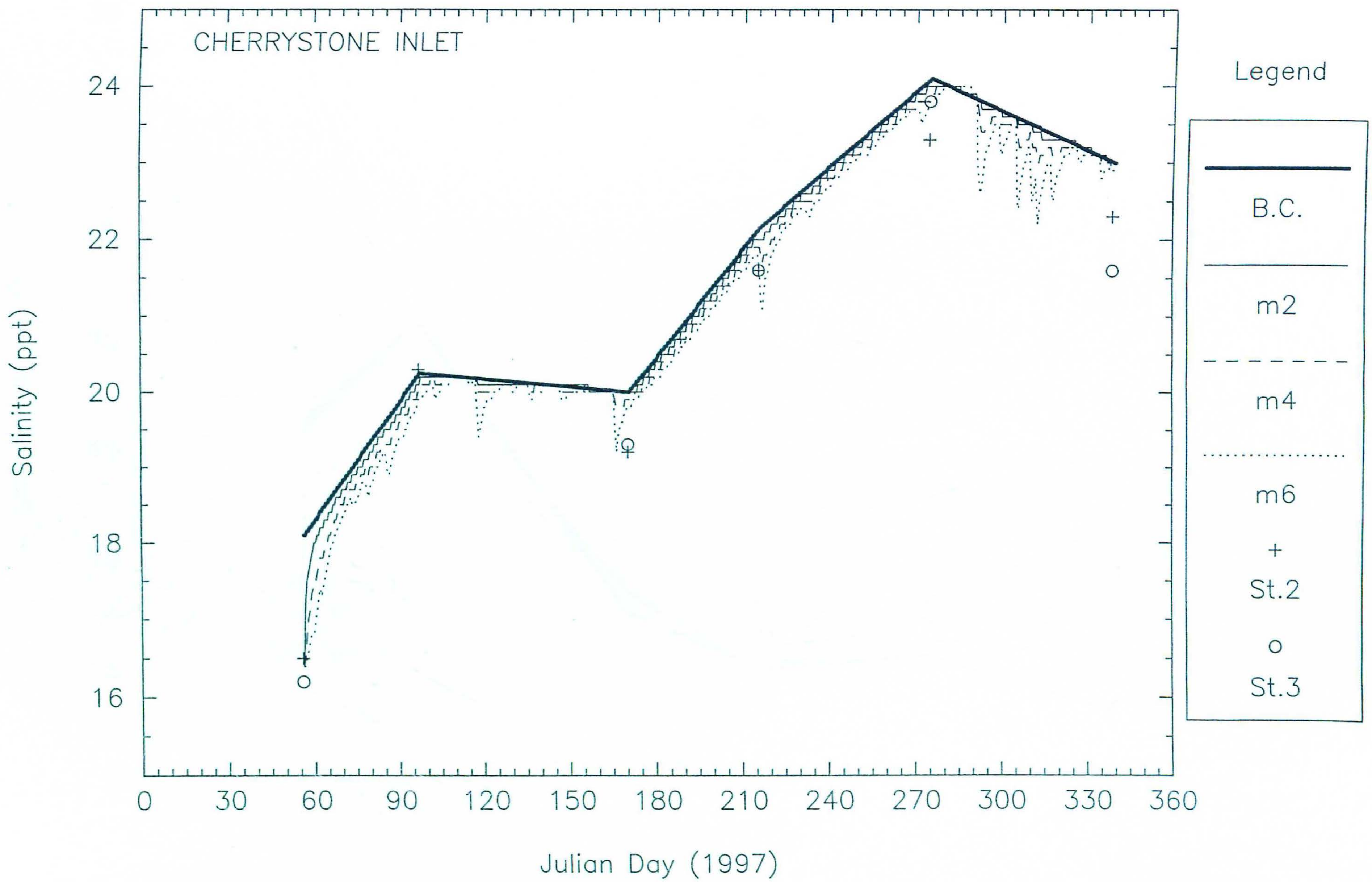


PIANKATANK RIVER
Total P (mg/l)
0.1
0.08
0.06
0.04
0.02
0
0
30
60
90
120
150
180
210
240
270
300
330
360
Julian Day (1997)
Legend
B.C.
m4
m7
m10
+
St.2
*
St.3
o
St.4

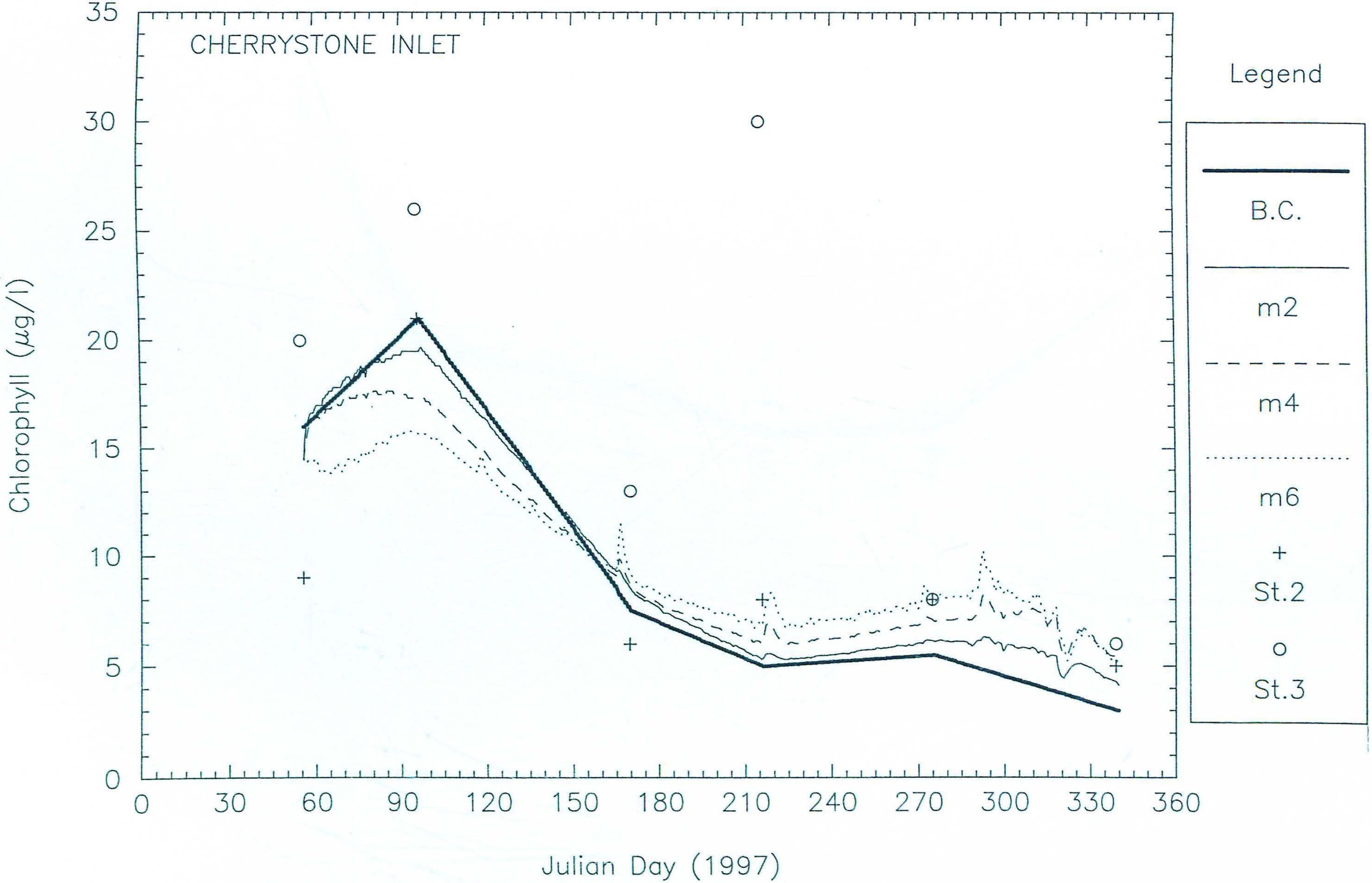


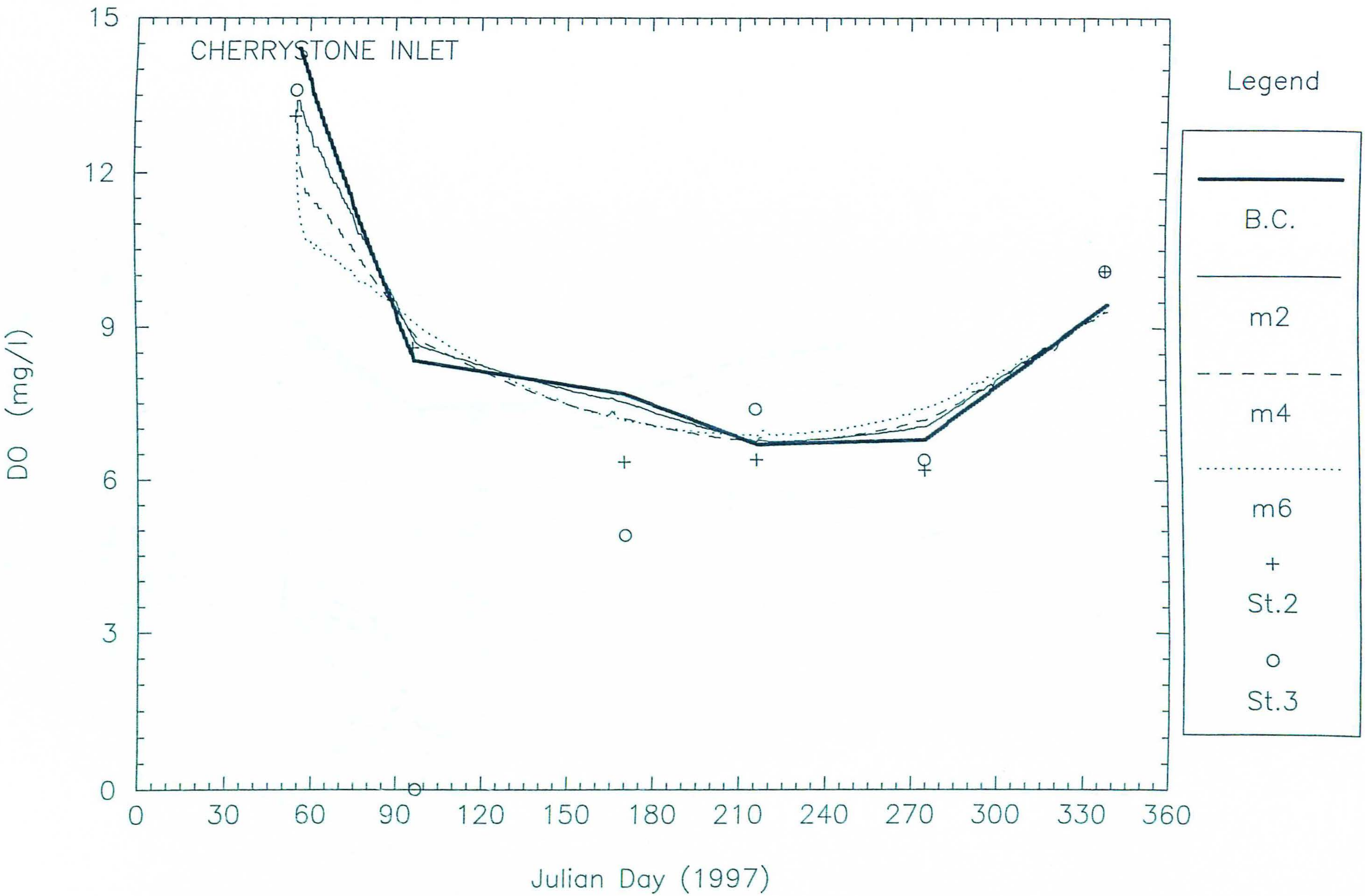
PIANKATANK RIVER
TSS (mg/l)
Julian Day (1997)
0
5
10
15
20
25
30
0
30
60
90
120
150
180
210
240
270
300
330
360
Legend
B.C.
m4
m7
m10
St.2
St.3
St.4

Appendix B-3. Comparison of Model Results with Field Observations, Cherrystone Inlet

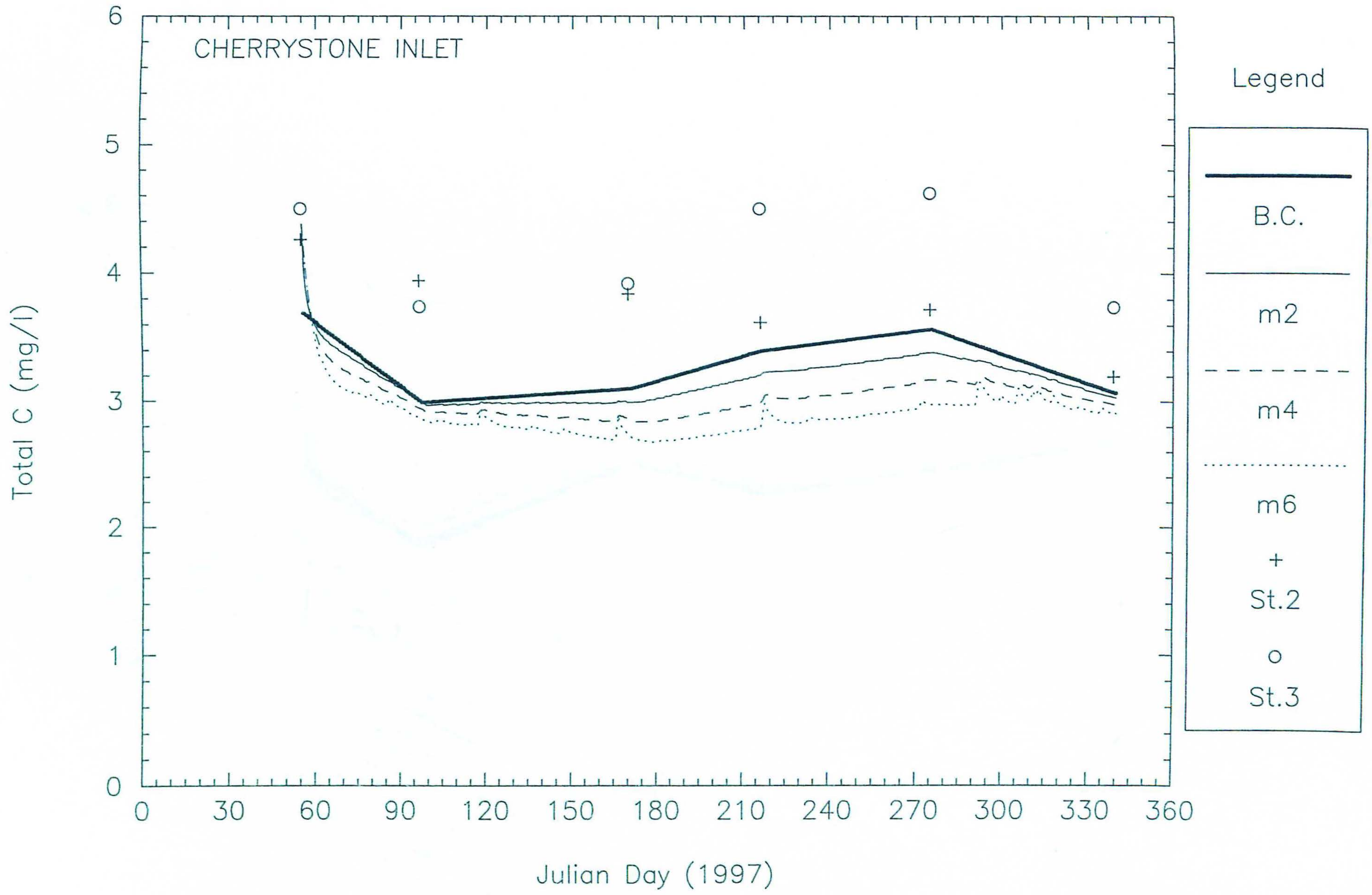


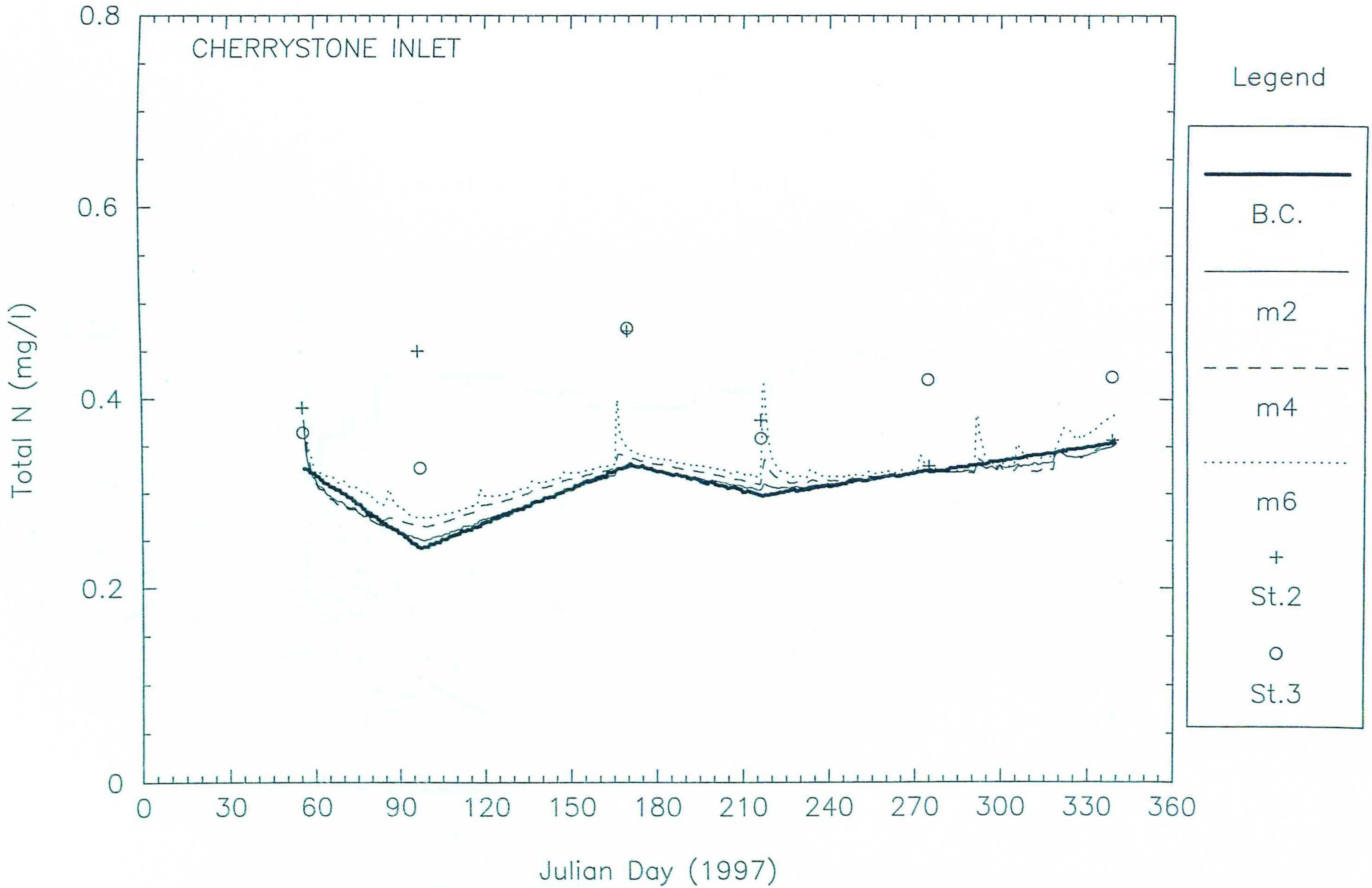
CHERRYSTONE INLET
Legend
B.C.
m2
m4
m6
St.2
St.3
Salinity (ppt)
Julian Day (1997)
16
18
20
22
24
0
30
60
90
120
150
180
210
240
270
300
330
360

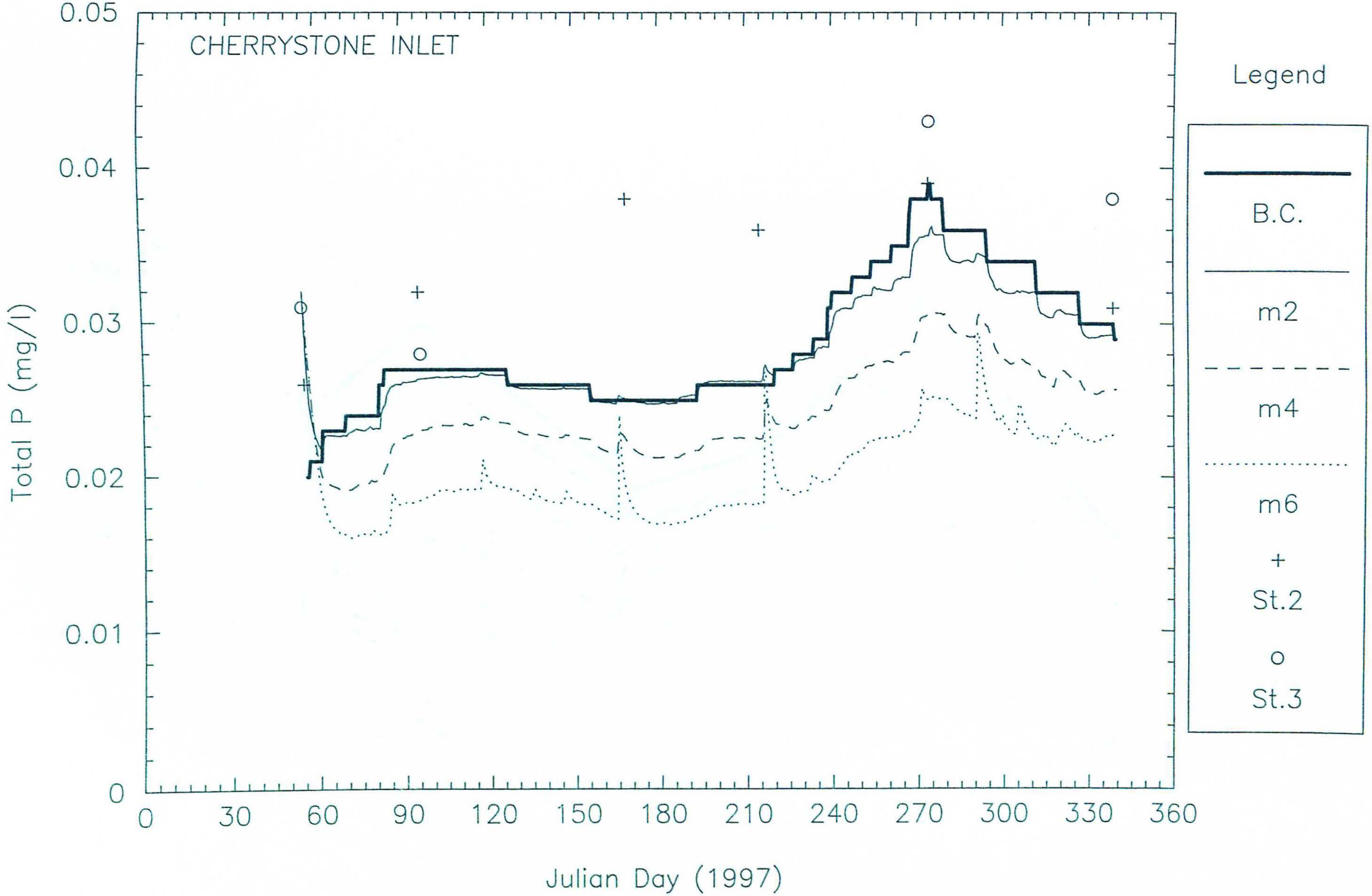

CHERRYSTONE INLET
Chlorophyll (μg/l)
Julian Day (1997)
0
5
10
15
20
25
30
35
0
30
60
90
120
150
180
210
240
270
300
330
360
Legend
B.C.
m2
m4
m6
+
St.2
o
St.3



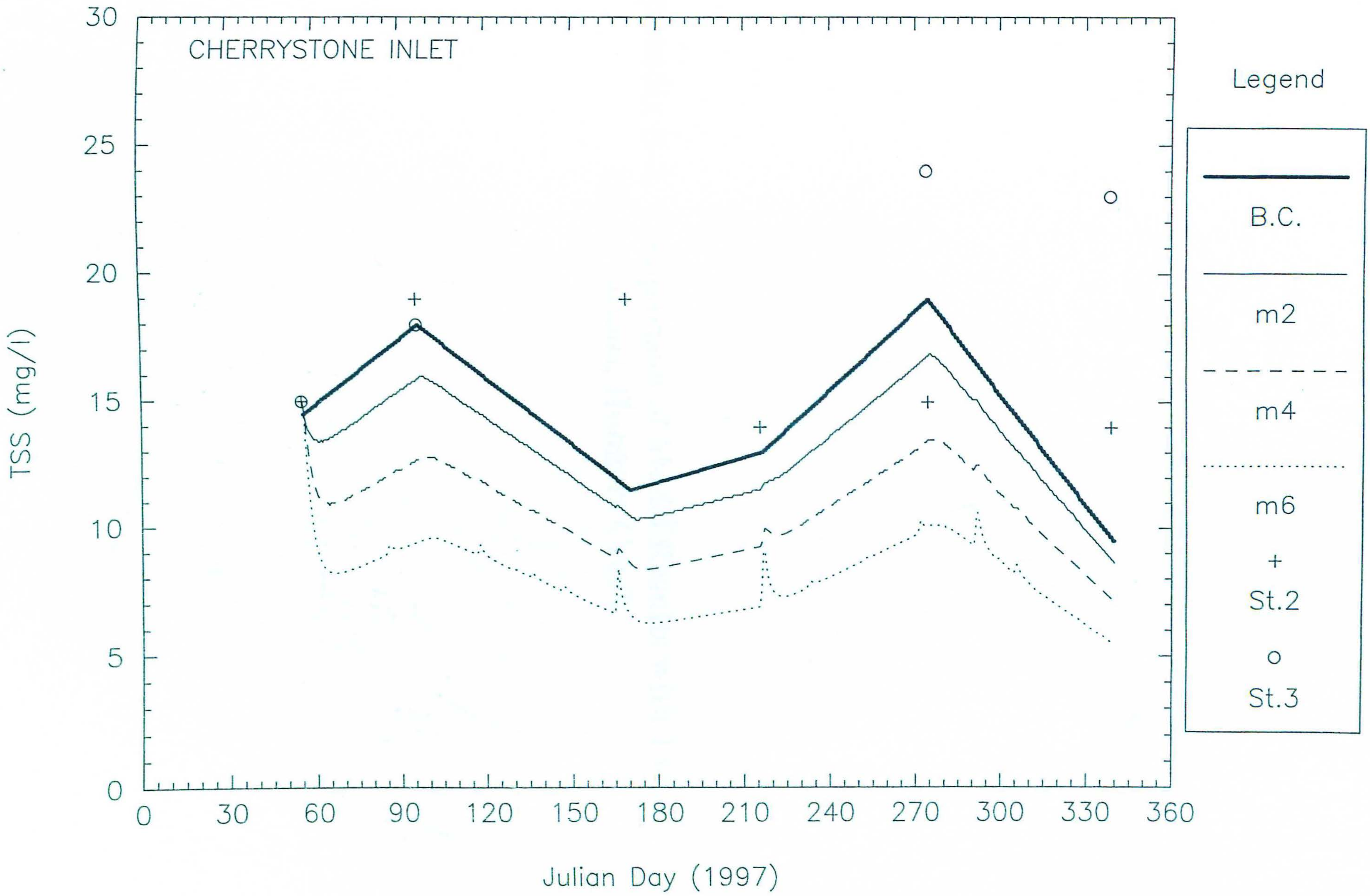
CHERRYSTONE INLET
DO (mg/l)
15
12
9
6
3
0
0
30
60
90
120
150
180
210
240
270
300
330
360
Julian Day (1997)
Legend
B.C.
m2
m4
m6
St.2
St.3


CHERRYSTONE INLET
Total C (mg/l)
Julian Day (1997)
0
1
2
3
4
5
6
0
30
60
90
120
150
180
210
240
270
300
330
360
Legend
B.C.
m2
m4
m6
St.2
St.3

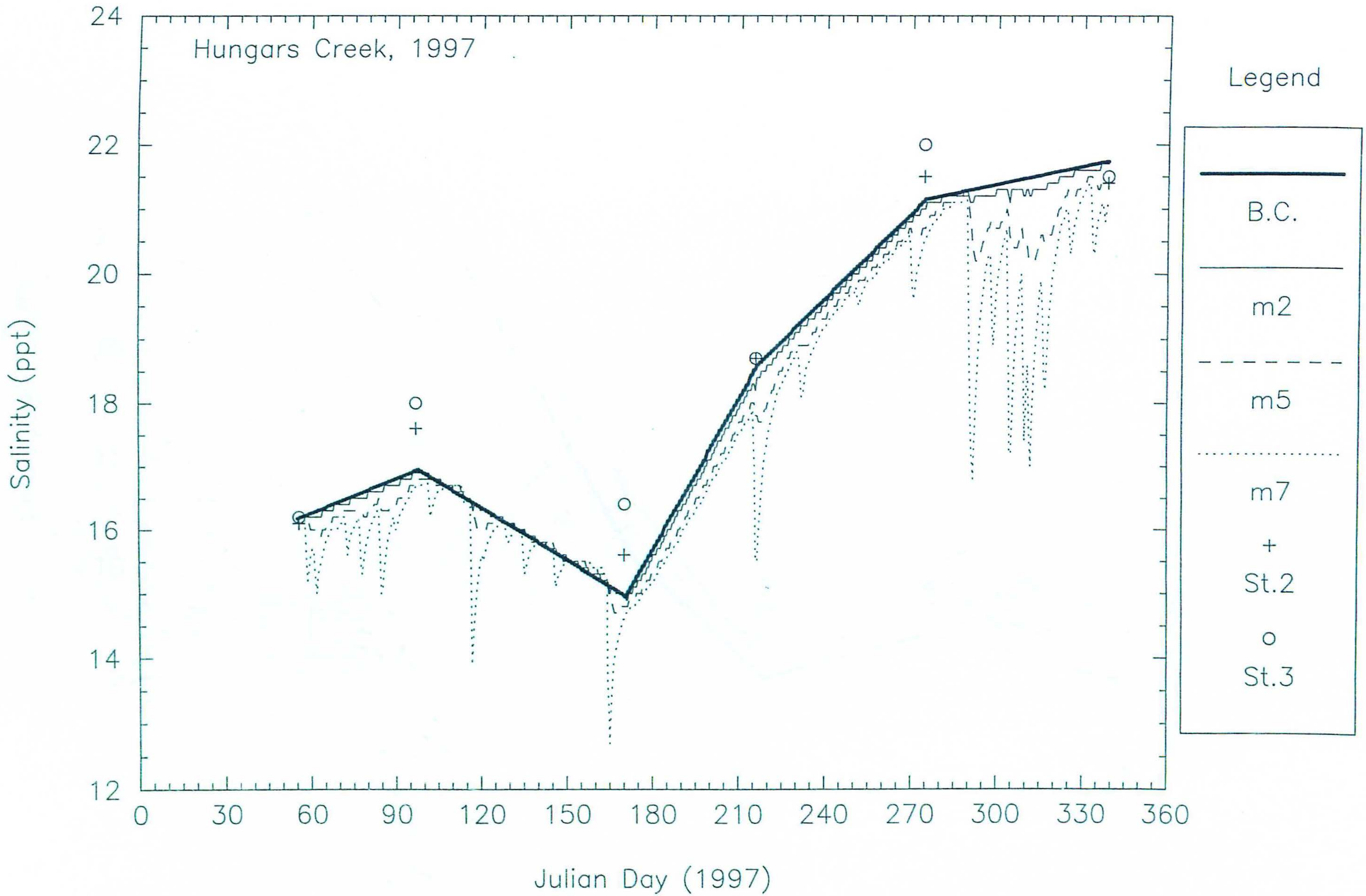

CHERRYSTONE INLET
Total N (mg/l)
0.8
0.6
0.4
0.2
0
0
30
60
90
120
150
180
210
240
270
300
330
360
Julian Day (1997)
Legend
B.C.
m2
m4
m6
St.2
St.3

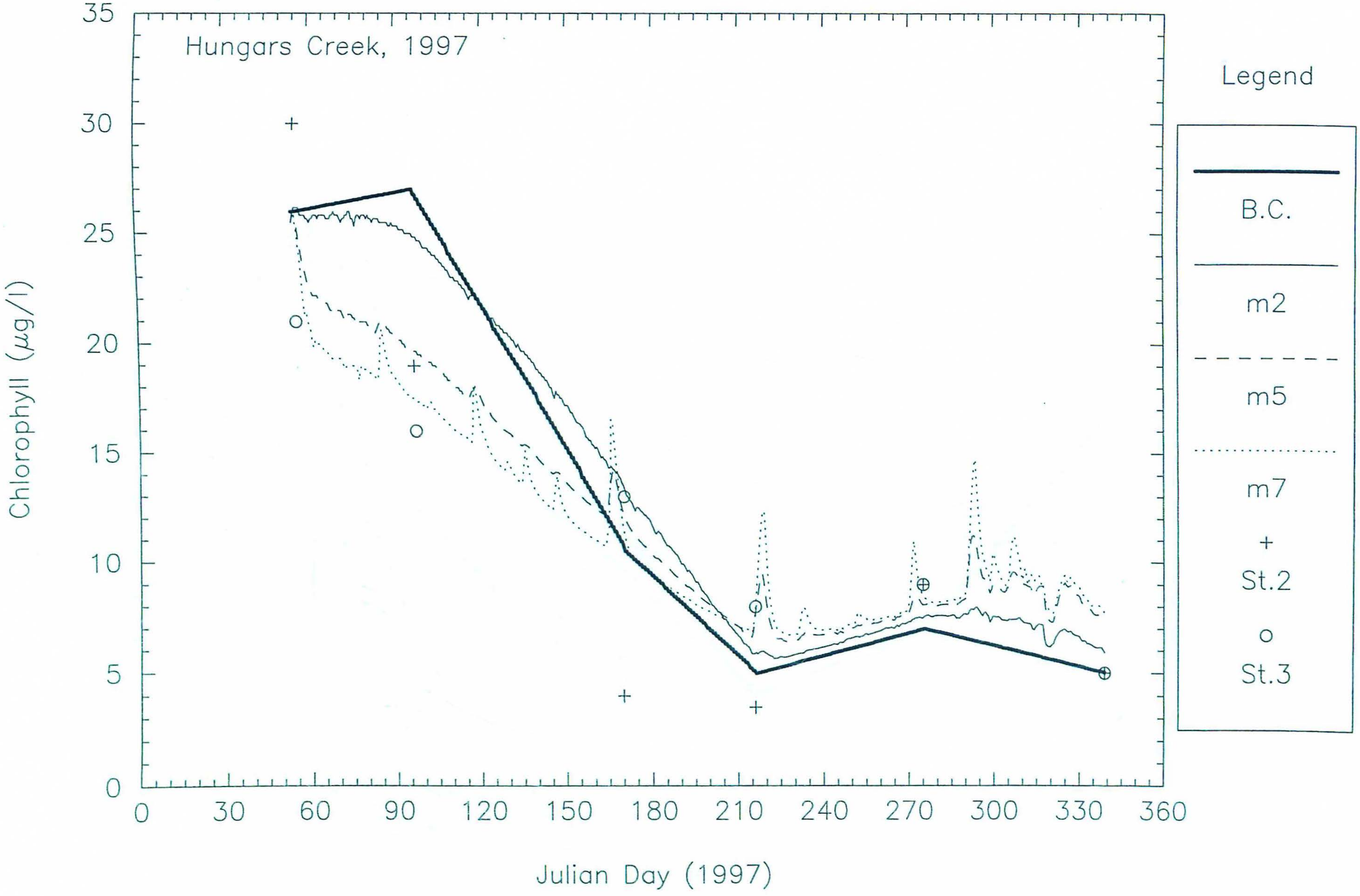


CHERRYSTONE INLET
Total P (mg/l)
0.05
0.04
0.03
0.02
0.01
0
0
30
60
90
120
150
180
210
240
270
300
330
360
Julian Day (1997)
Legend
B.C.
m2
m4
m6
+
St.2
o
St.3

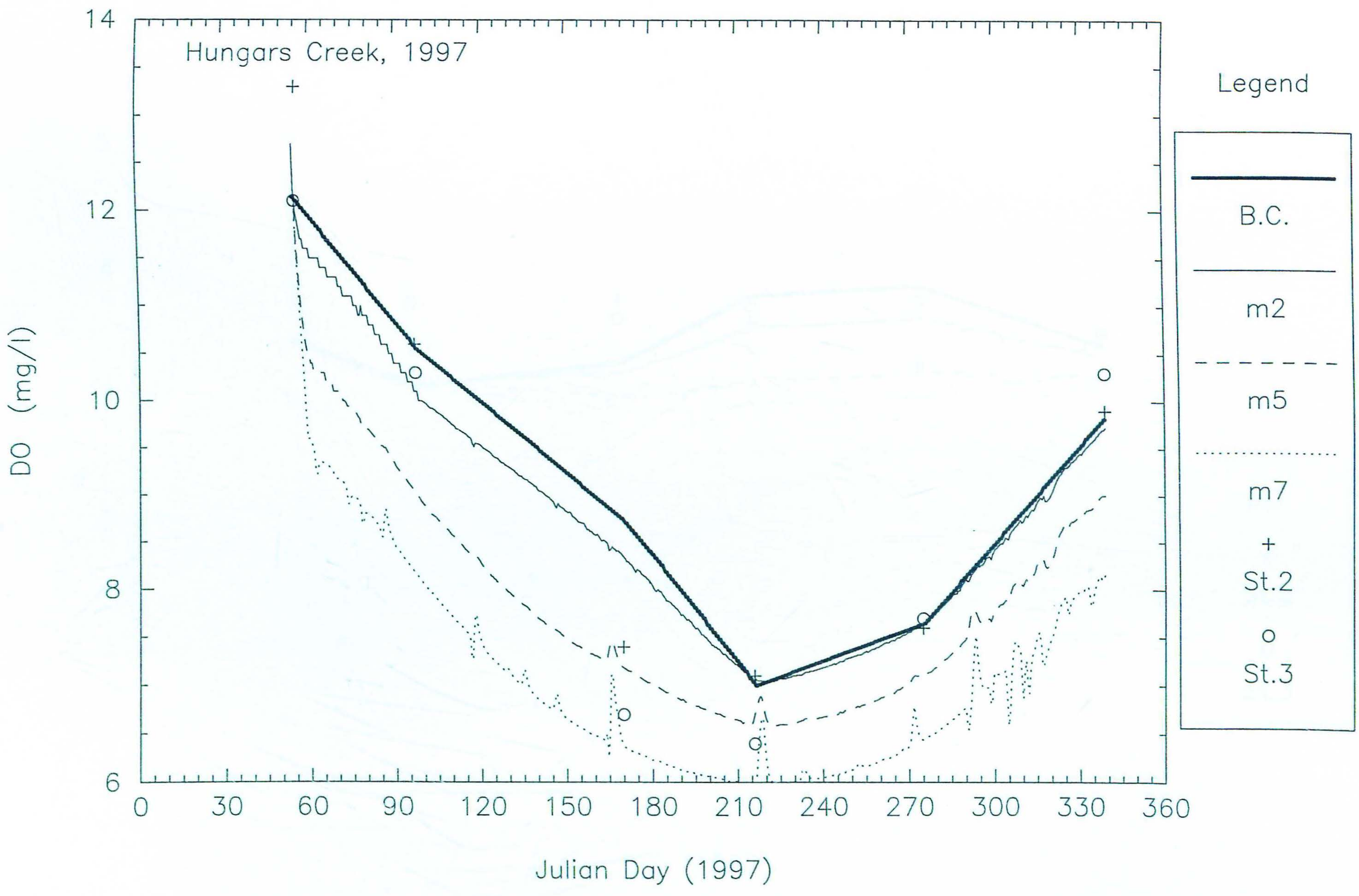

CHERRYSTONE INLET
TSS (mg/l)
Julian Day (1997)
0
5
10
15
20
25
30
0
30
60
90
120
150
180
210
240
270
300
330
360
Legend
B.C.
m2
m4
m6
+
St.2
o
St.3

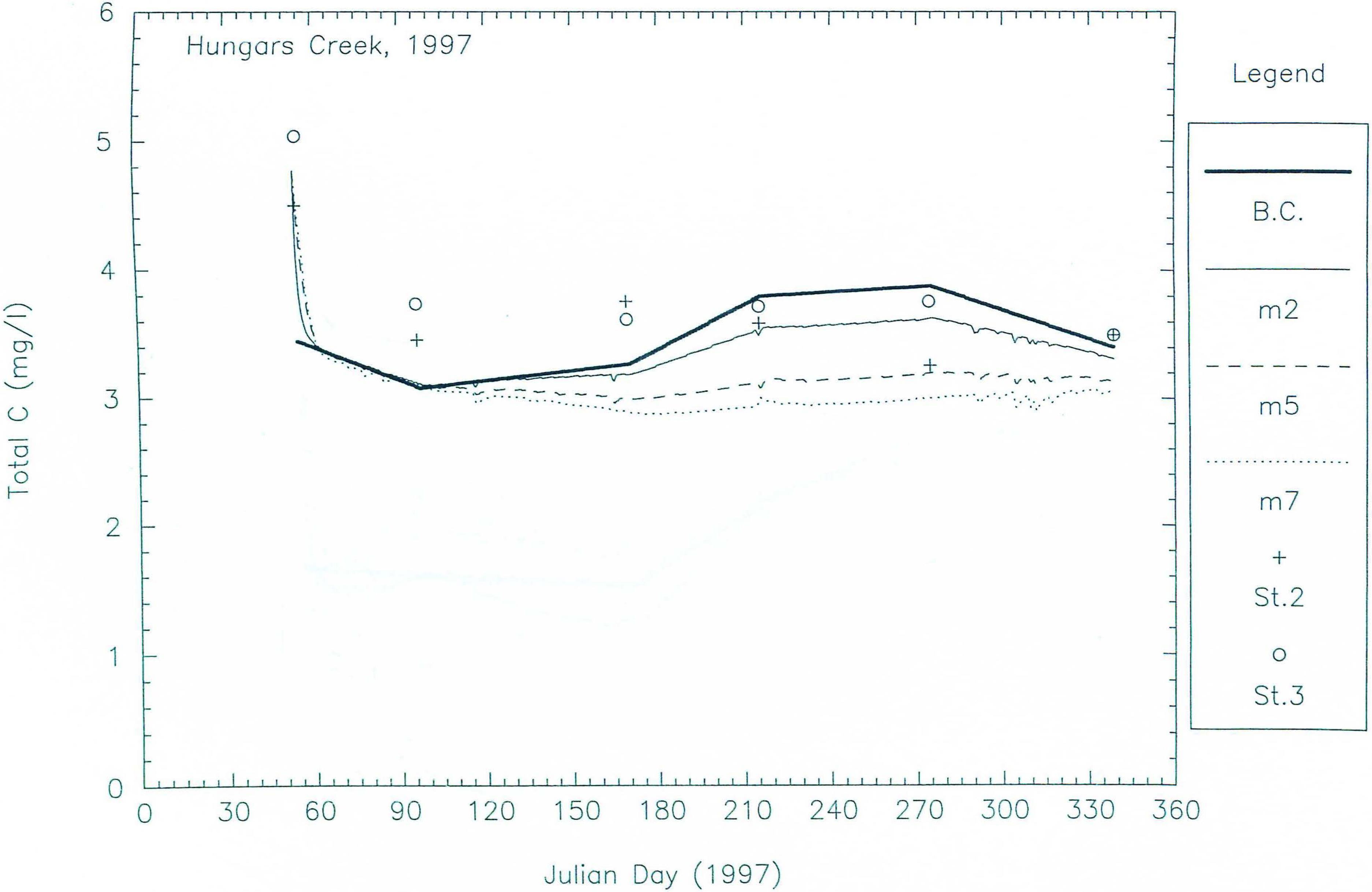
Appendix B-4. Comparison of Model Results with Field Observations, Hungars Creek


Hungars Creek, 1997
Salinity (ppt)
24
22
20
18
16
14
12
0
30
60
90
120
150
180
210
240
270
300
330
360
Julian Day (1997)
Legend
B.C.
m2
m5
m7
+
St.2
o
St.3

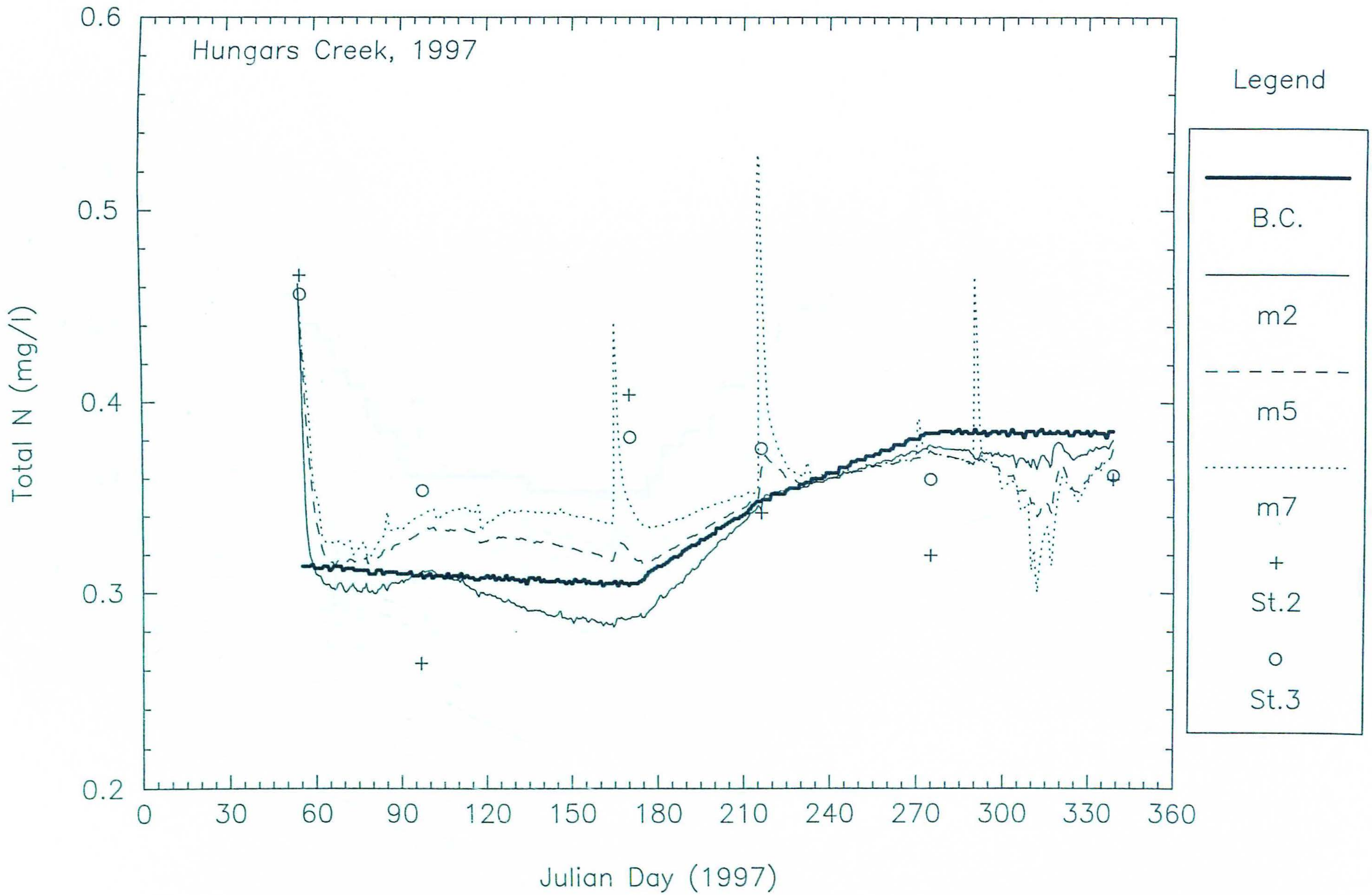


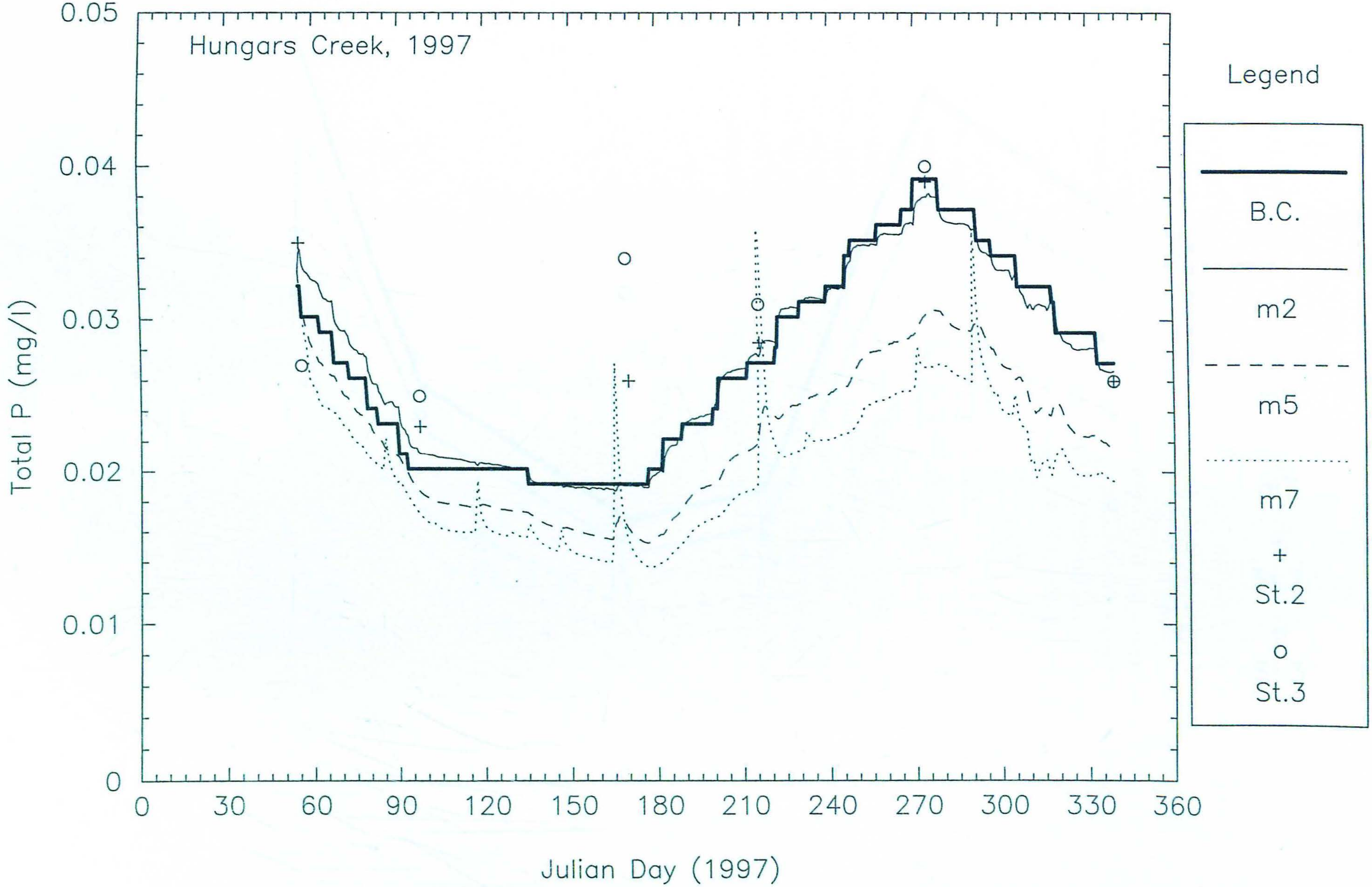
Hungars Creek, 1997
Chlorophyll (μg/l)
Julian Day (1997)
0
5
10
15
20
25
30
35
0
30
60
90
120
150
180
210
240
270
300
330
360
Legend
B.C.
m2
m5
m7
+
St.2
o
St.3


Hungars Creek, 1997
DO (mg/l)
14
12
10
8
6
0
30
60
90
120
150
180
210
240
270
300
330
360
Julian Day (1997)
Legend
B.C.
m2
m5
m7
+
St.2
o
St.3

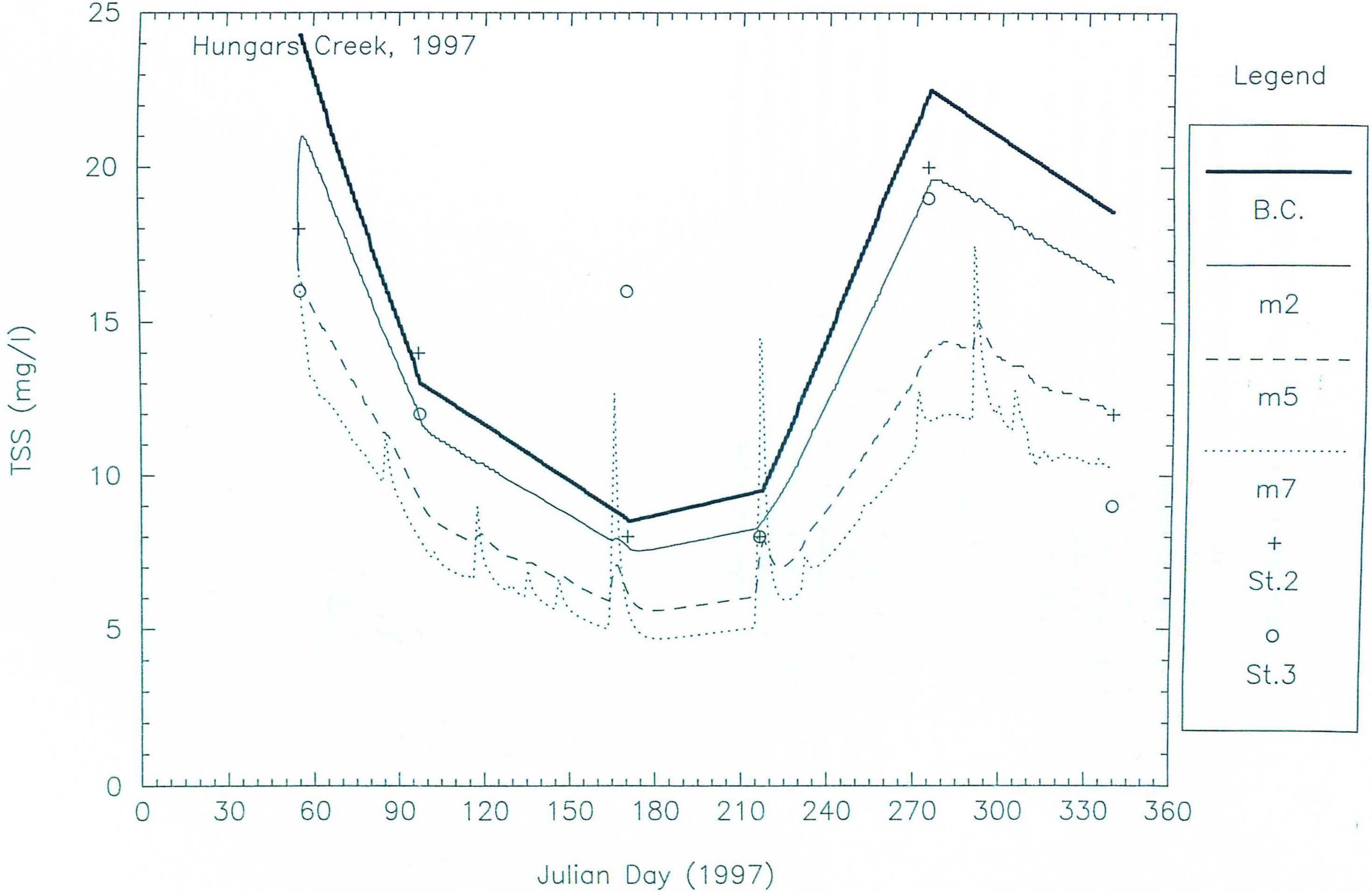


Hungars Creek, 1997
Total C (mg/l)
Julian Day (1997)
0
1
2
3
4
5
6
0
30
60
90
120
150
180
210
240
270
300
330
360
Legend
B.C.
m2
m5
m7
+
St.2
o
St.3


Hungars Creek, 1997
Total N (mg/l)
0.2
0.3
0.4
0.5
0.6
0
30
60
90
120
150
180
210
240
270
300
330
360
Julian Day (1997)
Legend
B.C.
m2
m5
m7
St.2
St.3



Hungars Creek, 1997
Total P (mg/l)
0.05
0.04
0.03
0.02
0.01
0
0
30
60
90
120
150
180
210
240
270
300
330
360
Julian Day (1997)
Legend
B.C.
m2
m5
m7
+
St.2
o
St.3



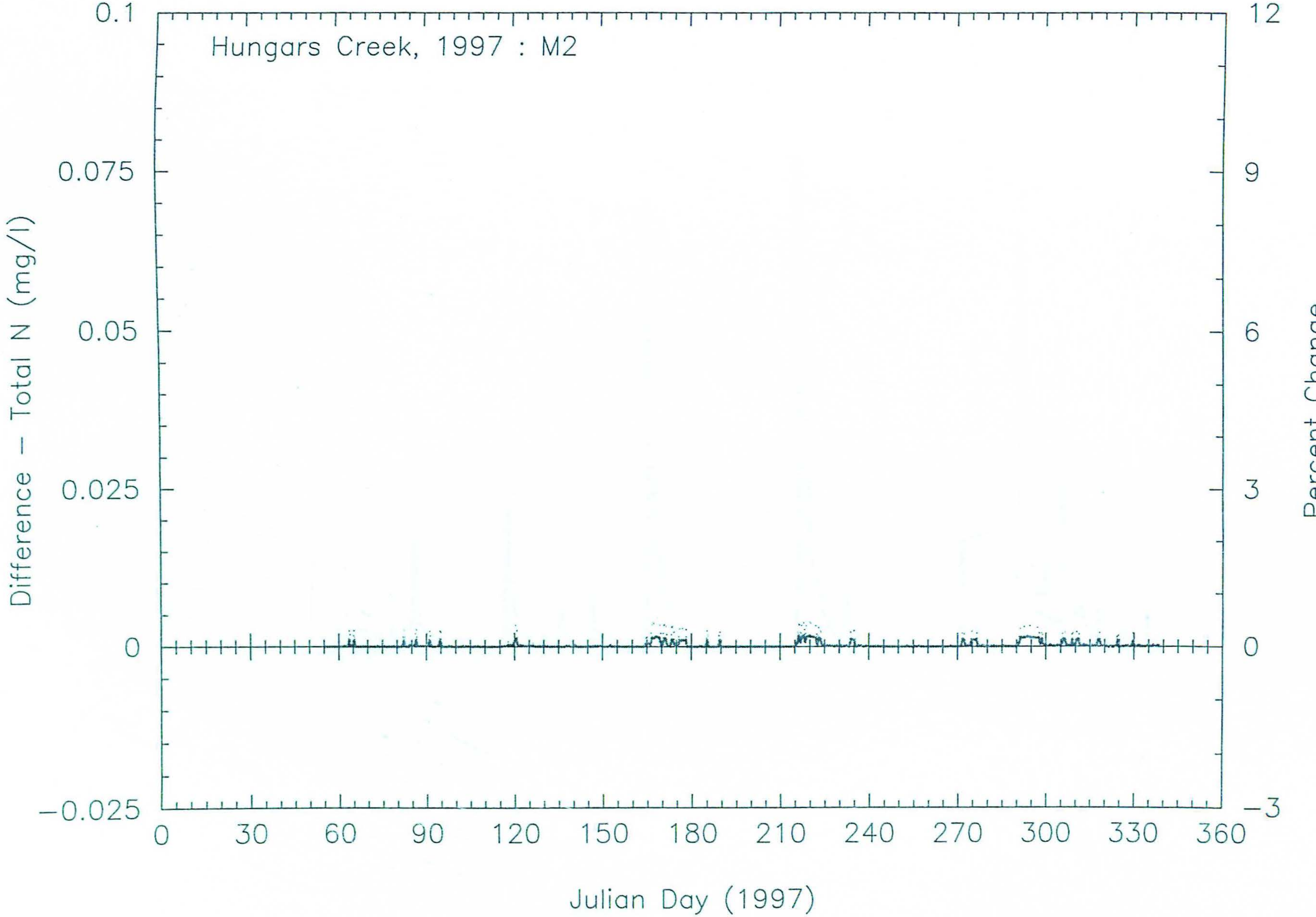
Hungars Creek, 1997
TSS (mg/l)
25
20
15
10
5
0
0
30
60
90
120
150
180
210
240
270
300
330
360
Julian Day (1997)
Legend
B.C.
m2
m5
m7
+
St.2
o
St.3

Appendix C. Hungars Creek Scenario Run

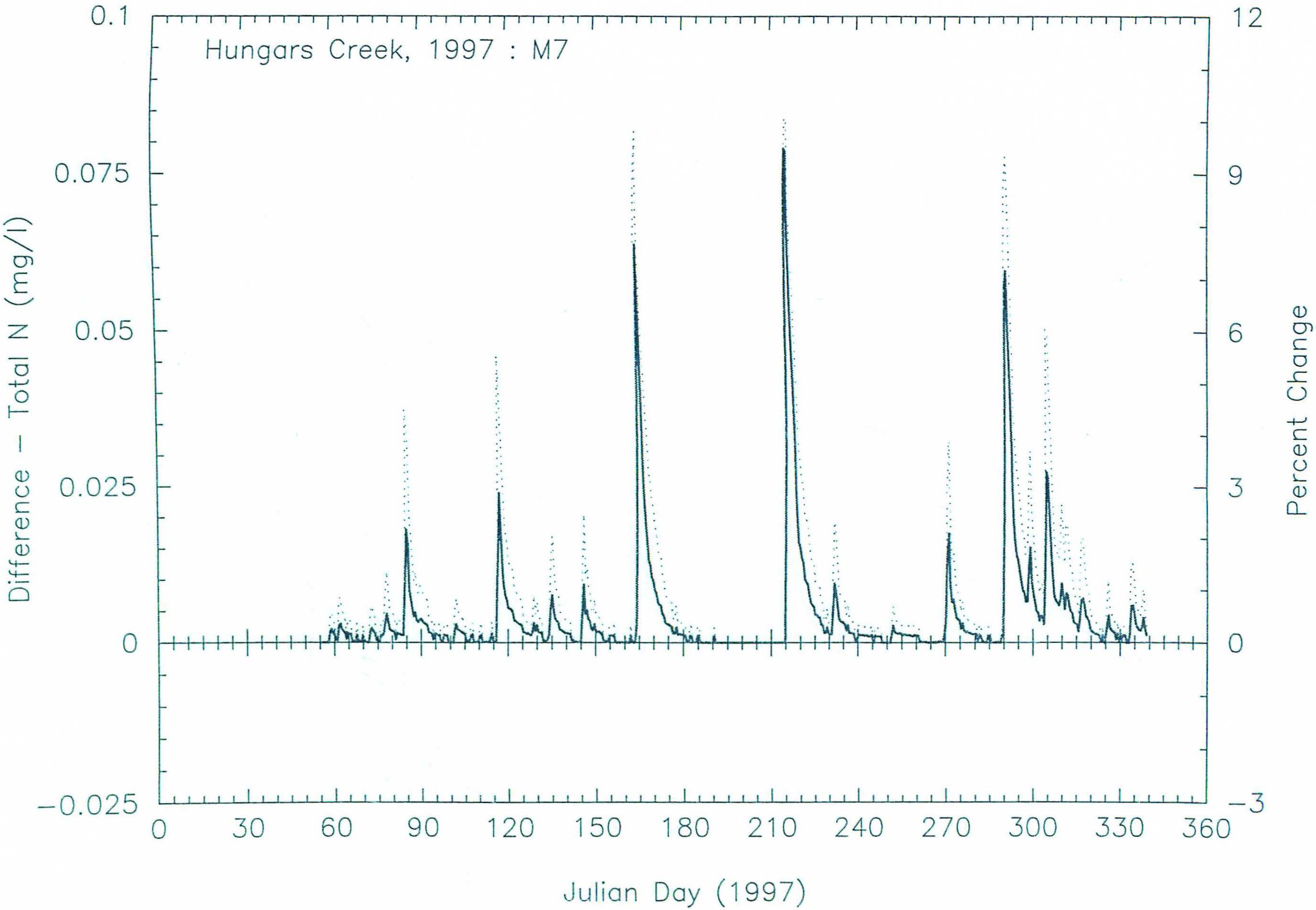
Since the Hungars Creek model simulation results agree well with field observations as it is, i.e., without further model calibration, a scenario run was conducted for the Hungars Creek. The scenario was based on the implementation of current BMP (Best Management Practice) for Accomack County. The nonpoint source loadings of nitrogen was reduced by 15.9%, phosphorus by 20.2%, and total suspended sediment by 24.9%. Results are presented in the following pages as difference (base case with 1997 conditions - scenario run with loading reductions) in concentrations (solid lines), and in percent changes (dot lines) for three model segments:

M2, the most downstream segment,
M7, the most upstream segment in main stem,
B3, the most upstream segment in side branch.

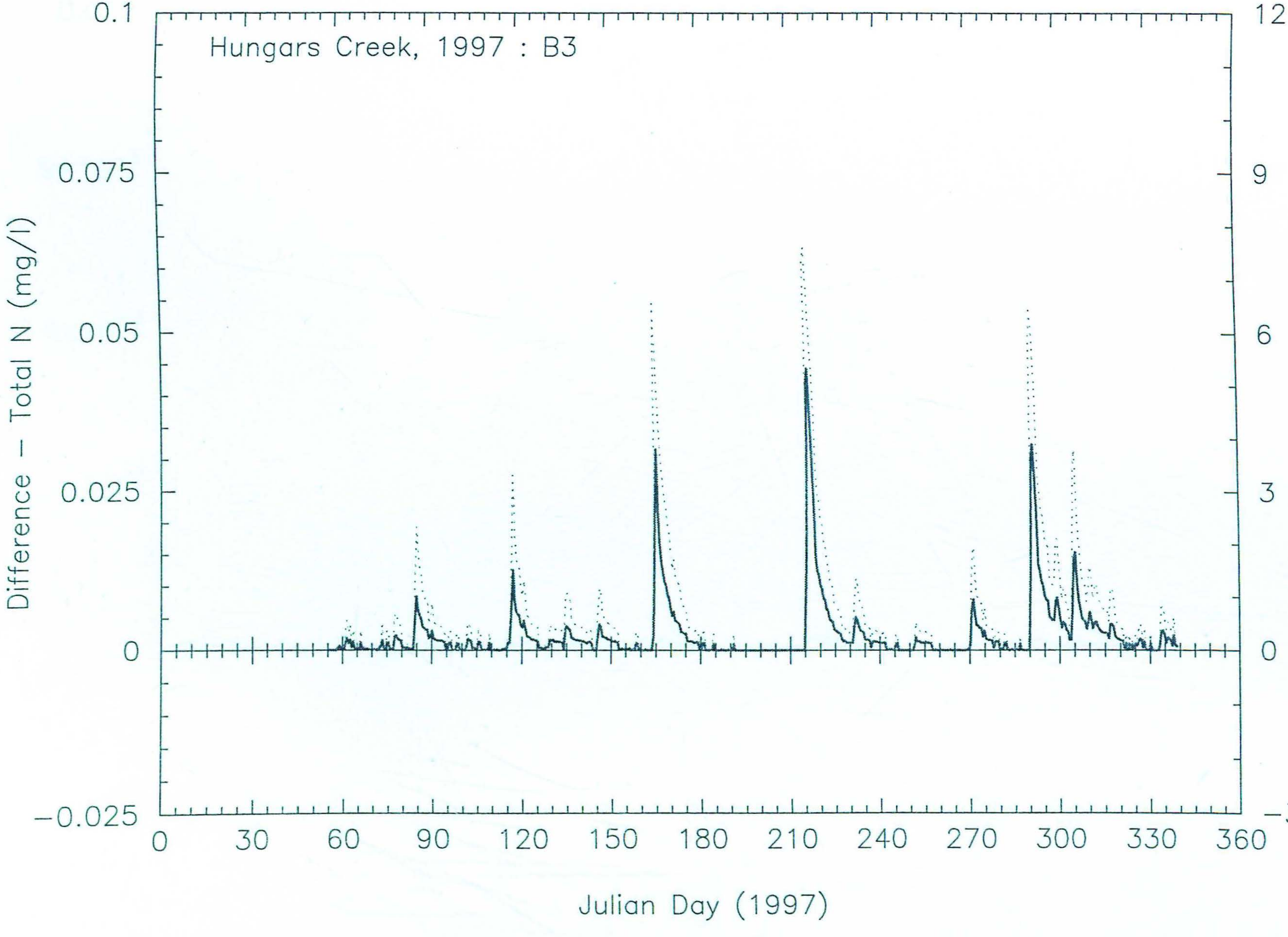
The model results indicate negligible changes for all water quality variables in segment M2, where the water quality conditions are dominated by the conditions in the Bay. For the upstream segments, M7 and B3, all noticeable changes in nutrient and sediment concentrations are transient, associated with runoff events. Dissolved oxygen decreases slightly because of decrease in chlorophyll 'a' concentration as a result of nutrient reduction. Changes of total carbon in all segments are negligible because no reduction in non-point source loadings of carbon



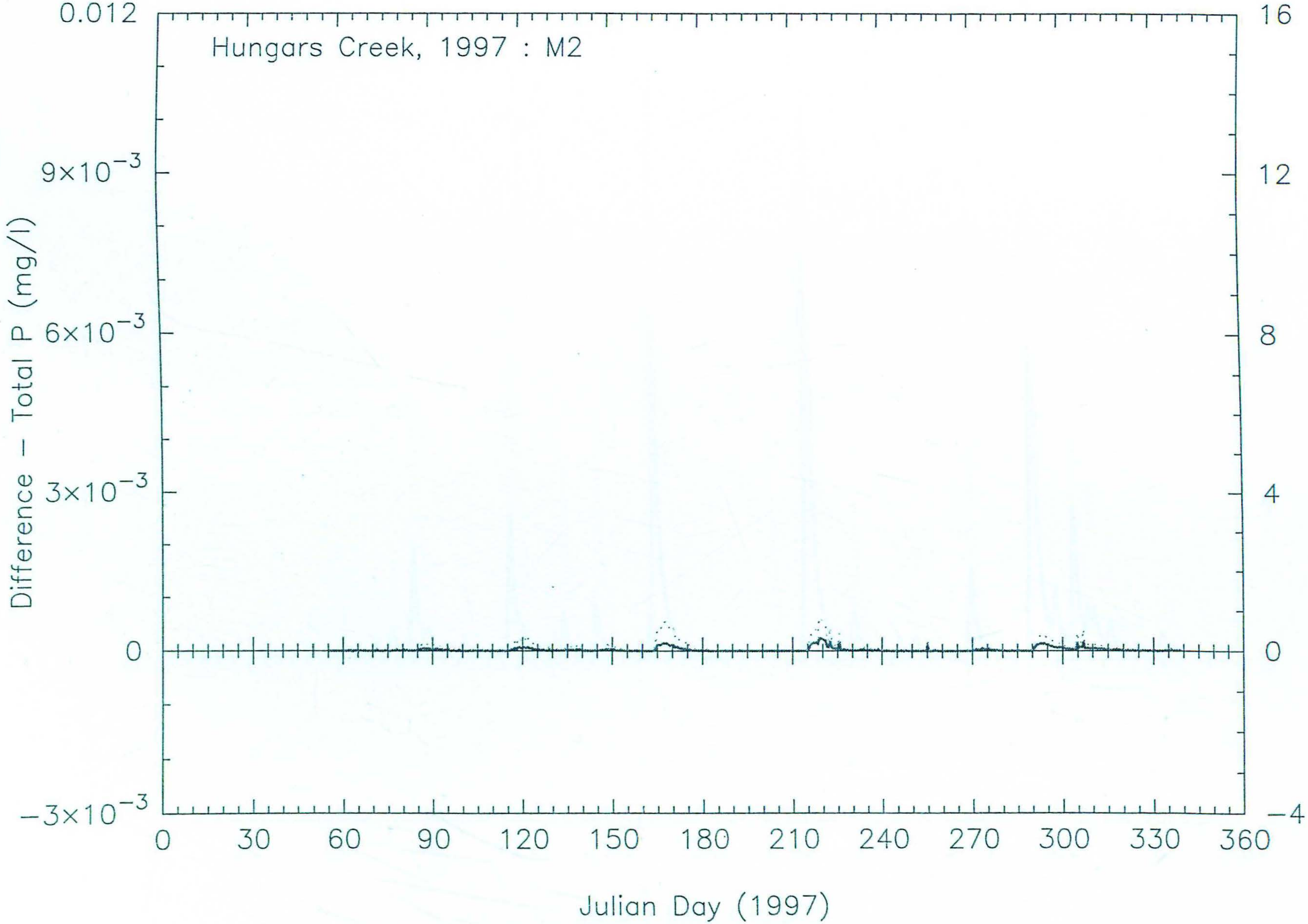
Hungars Creek, 1997 : M2
0.1
0.075
0.05
0.025
0
−0.025
Difference − Total N (mg/l)
12
9
6
3
0
−3
Percent Change
0
30
60
90
120
150
180
210
240
270
300
330
360
Julian Day (1997)



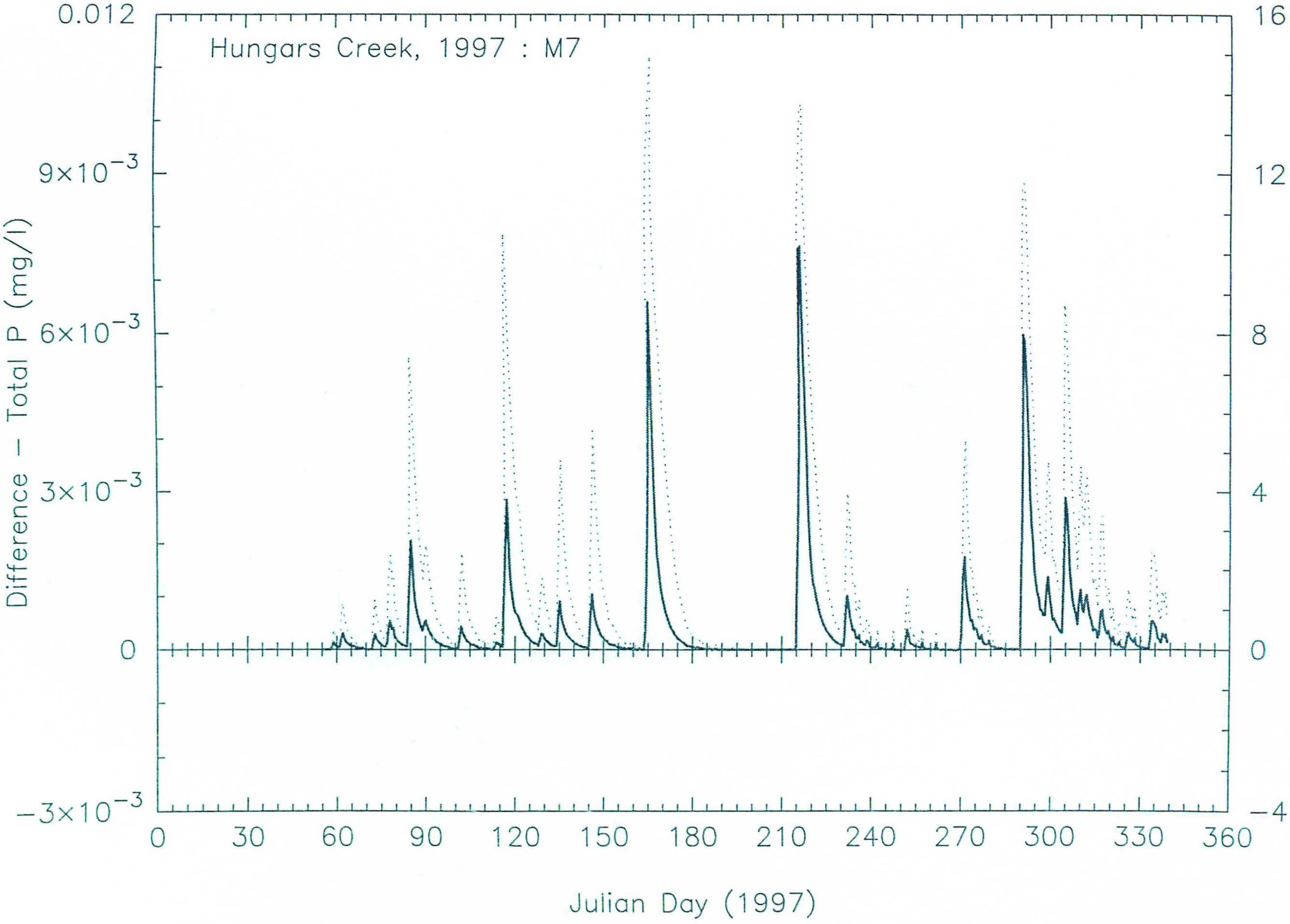
Hungars Creek, 1997 : M7
0.1
0.075
0.05
0.025
0
−0.025
Difference − Total N (mg/l)
12
9
6
3
0
−3
Percent Change
0
30
60
90
120
150
180
210
240
270
300
330
360
Julian Day (1997)



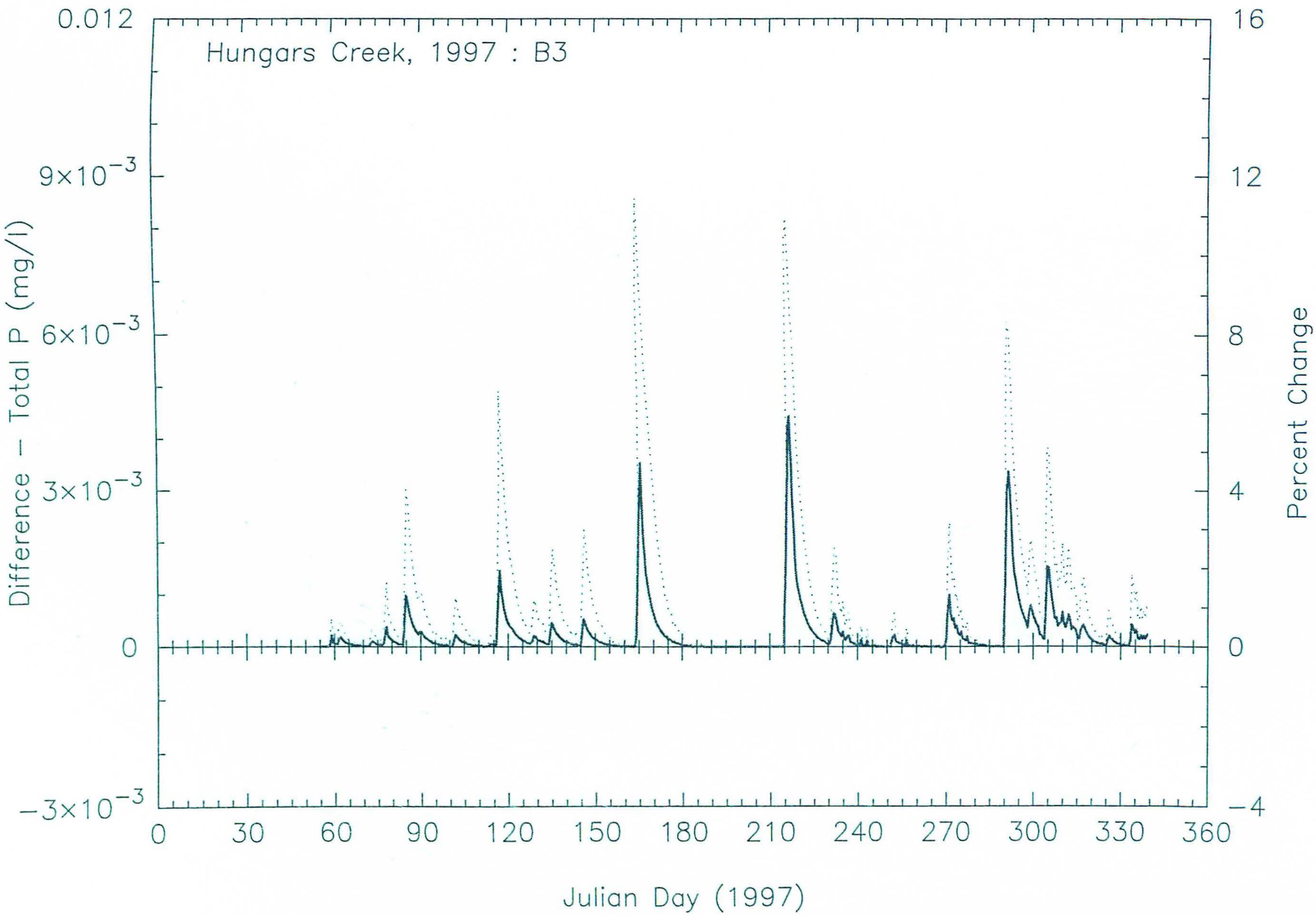
Hungars Creek, 1997 : B3
Difference – Total N (mg/l)
Percent Change
Julian Day (1997)
0.1
0.075
0.05
0.025
0
−0.025
12
9
6
3
0
−3
0
30
60
90
120
150
180
210
240
270
300
330
360

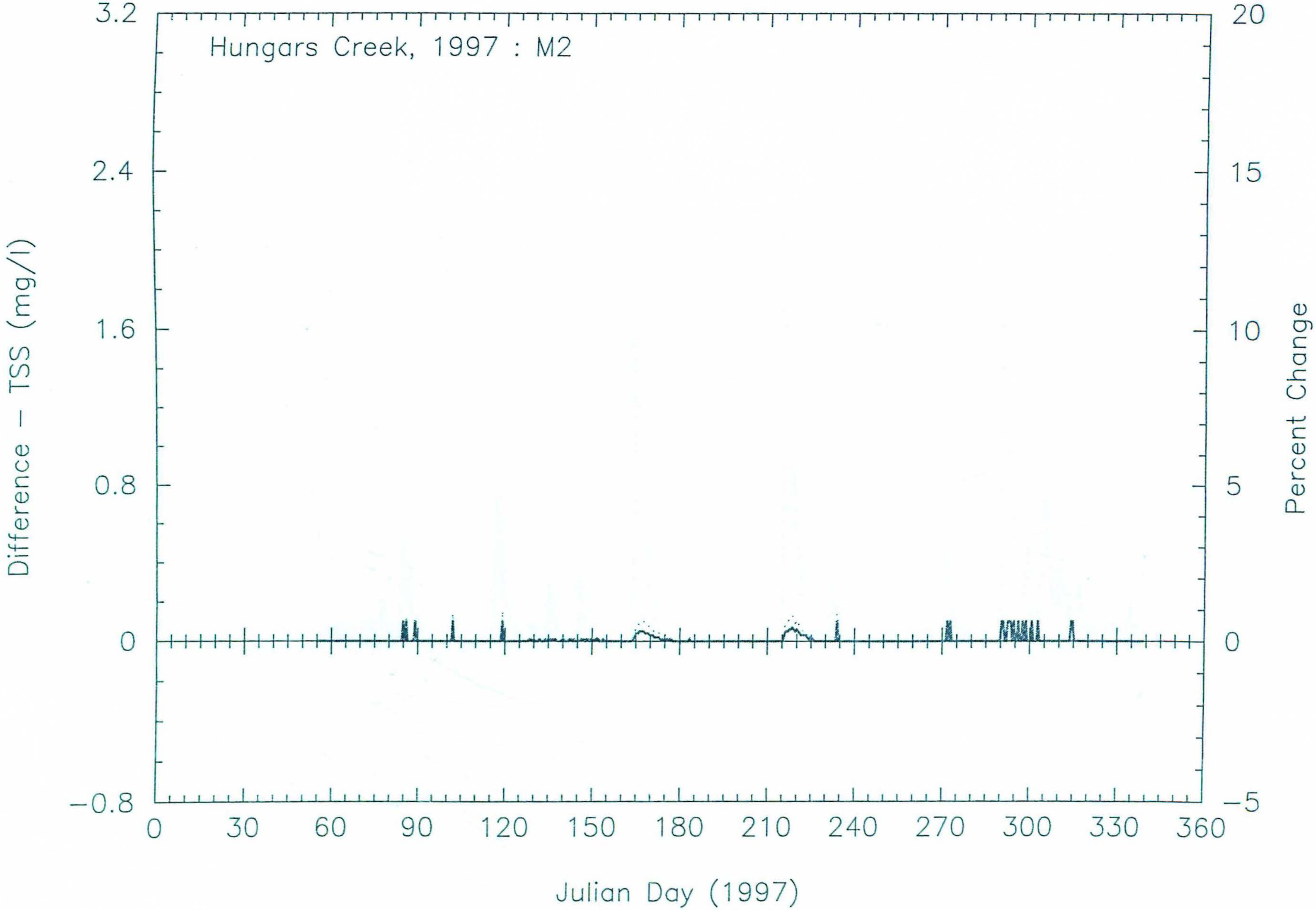


Hungars Creek, 1997 : M2
0.012
9×10−3
6×10−3
3×10−3
0
−3×10−3
Difference − Total P (mg/l)
16
12
8
4
0
−4
Percent Change
0
30
60
90
120
150
180
210
240
270
300
330
360
Julian Day (1997)

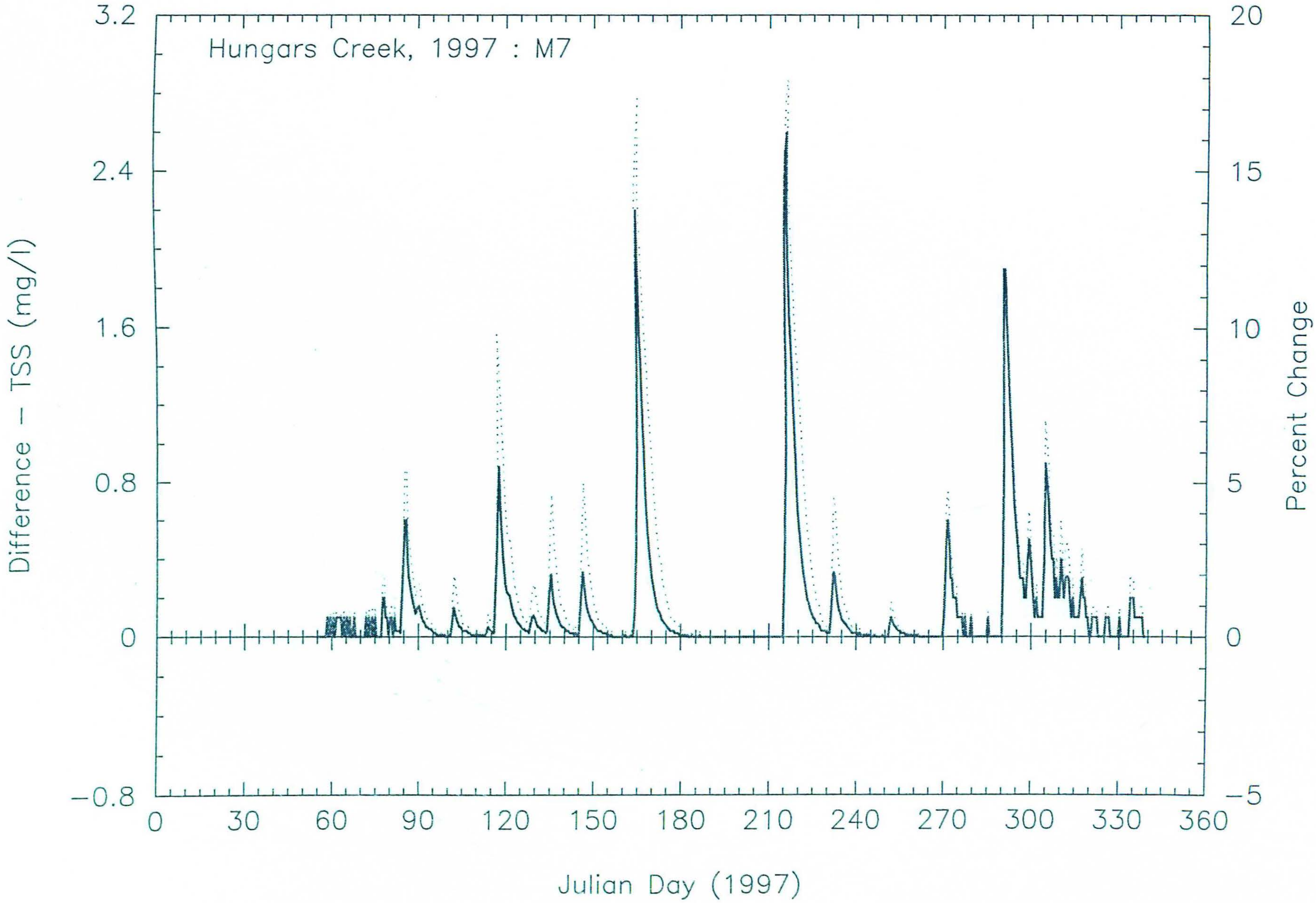


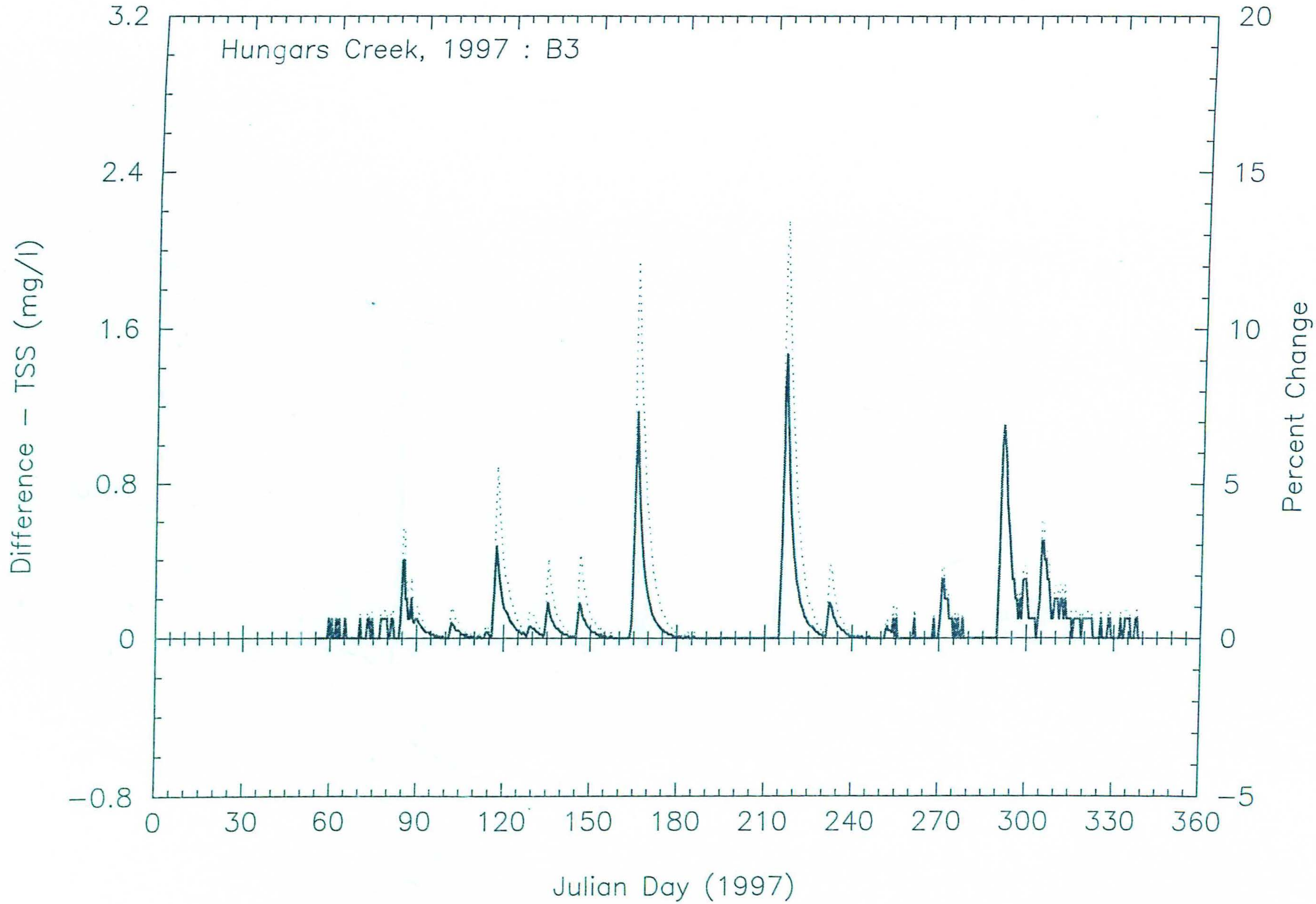
Hungars Creek, 1997 : M7
0.012
9×10^−3
6×10^−3
3×10^−3
0
−3×10^−3
Difference – Total P (mg/l)
16
12
8
4
0
−4
Percent Change
0
30
60
90
120
150
180
210
240
270
300
330
360
Julian Day (1997)


Hungars Creek, 1997 : B3
0.012
9×10⁻³
6×10⁻³
3×10⁻³
0
−3×10⁻³
16
12
8
4
0
−4
0
30
60
90
120
150
180
210
240
270
300
330
360
Difference − Total P (mg/l)
Percent Change
Julian Day (1997)

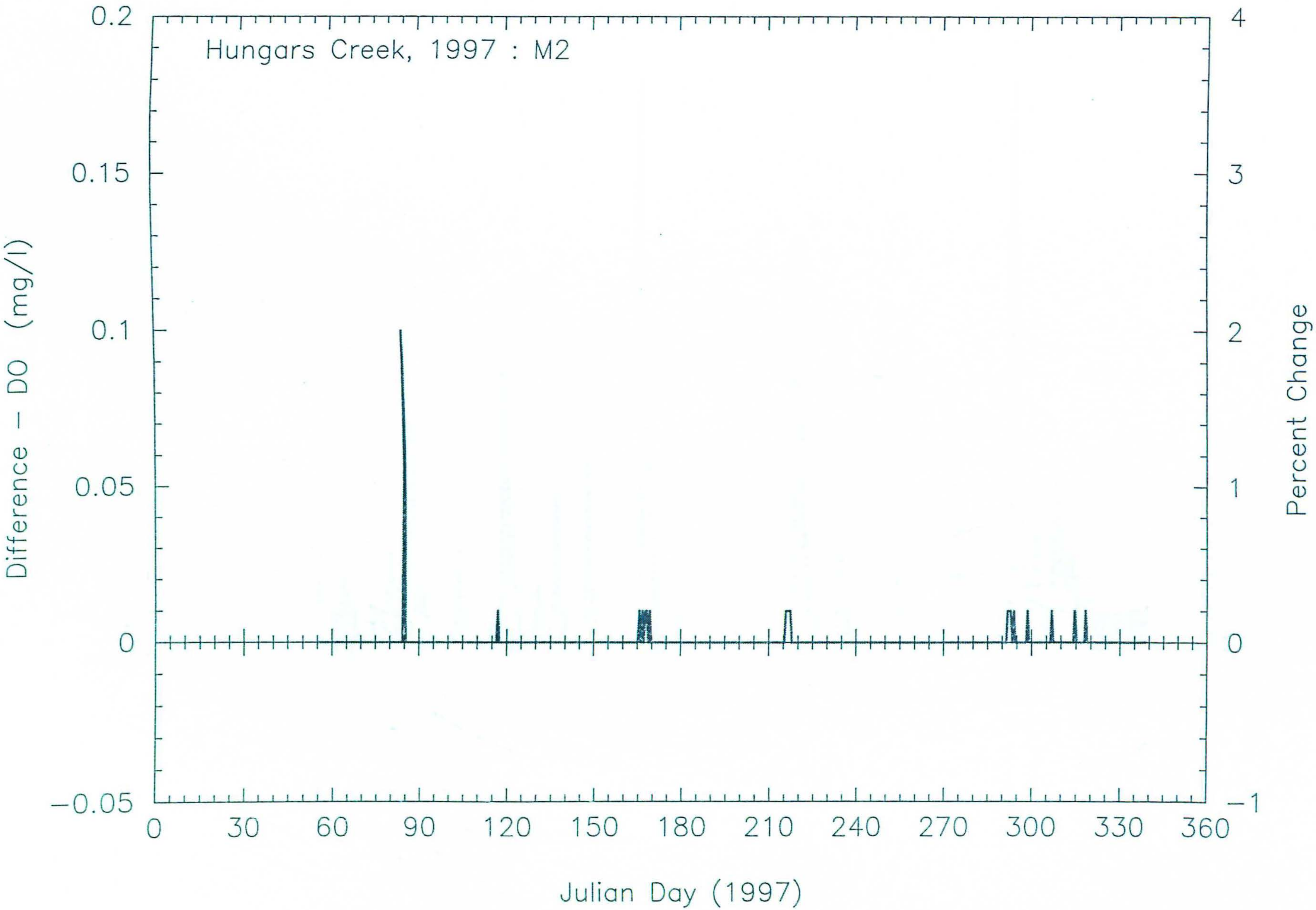


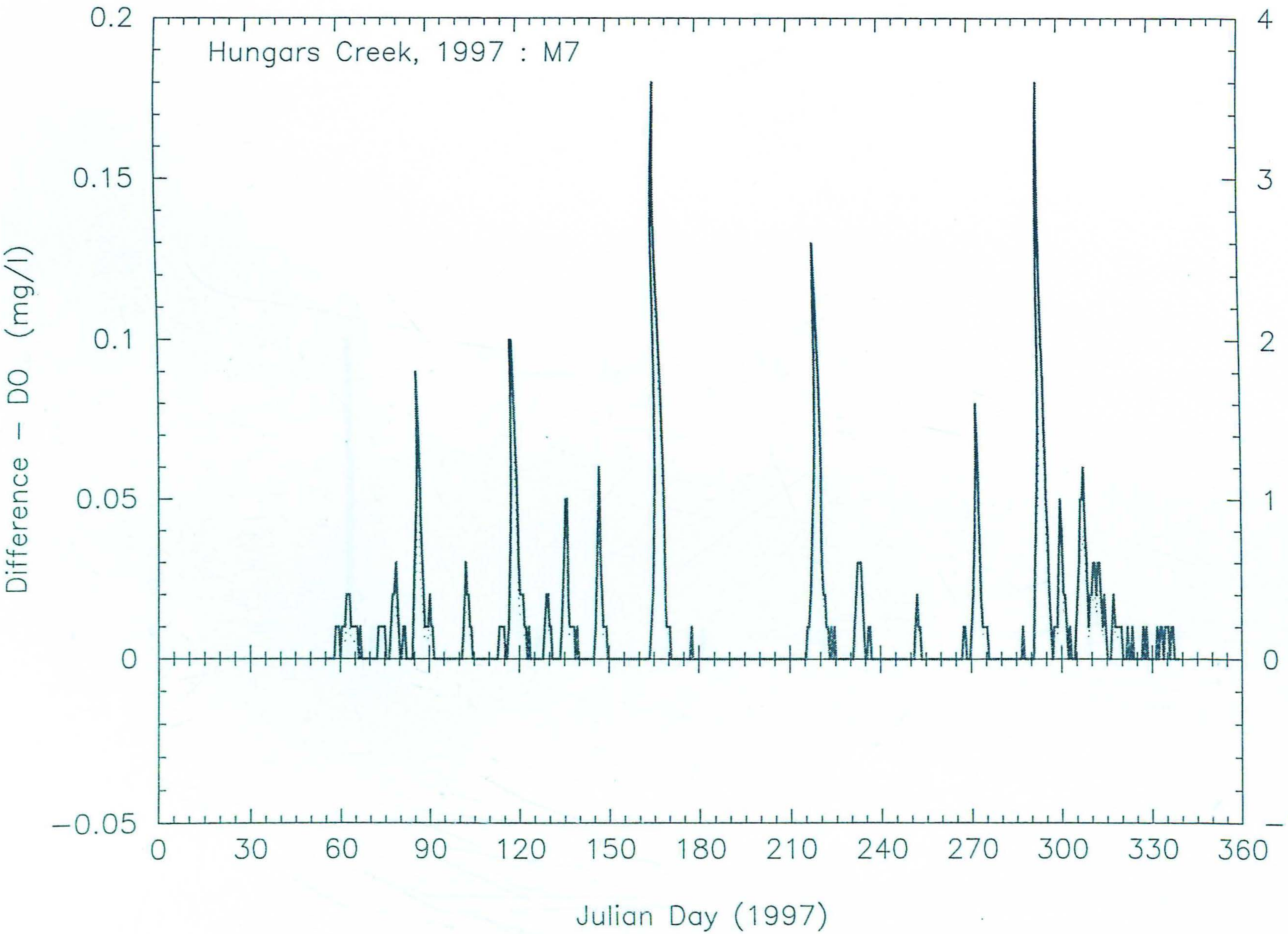
Hungars Creek, 1997 : M2
Difference – TSS (mg/l)
Percent Change
Julian Day (1997)
3.2
2.4
1.6
0.8
0
−0.8
20
15
10
5
0
−5
0
30
60
90
120
150
180
210
240
270
300
330
360


Hungars Creek, 1997 : M7
3.2
2.4
1.6
0.8
0
−0.8
Difference − TSS (mg/l)
20
15
10
5
0
−5
Percent Change
0 30 60 90 120 150 180 210 240 270 300 330 360
Julian Day (1997)

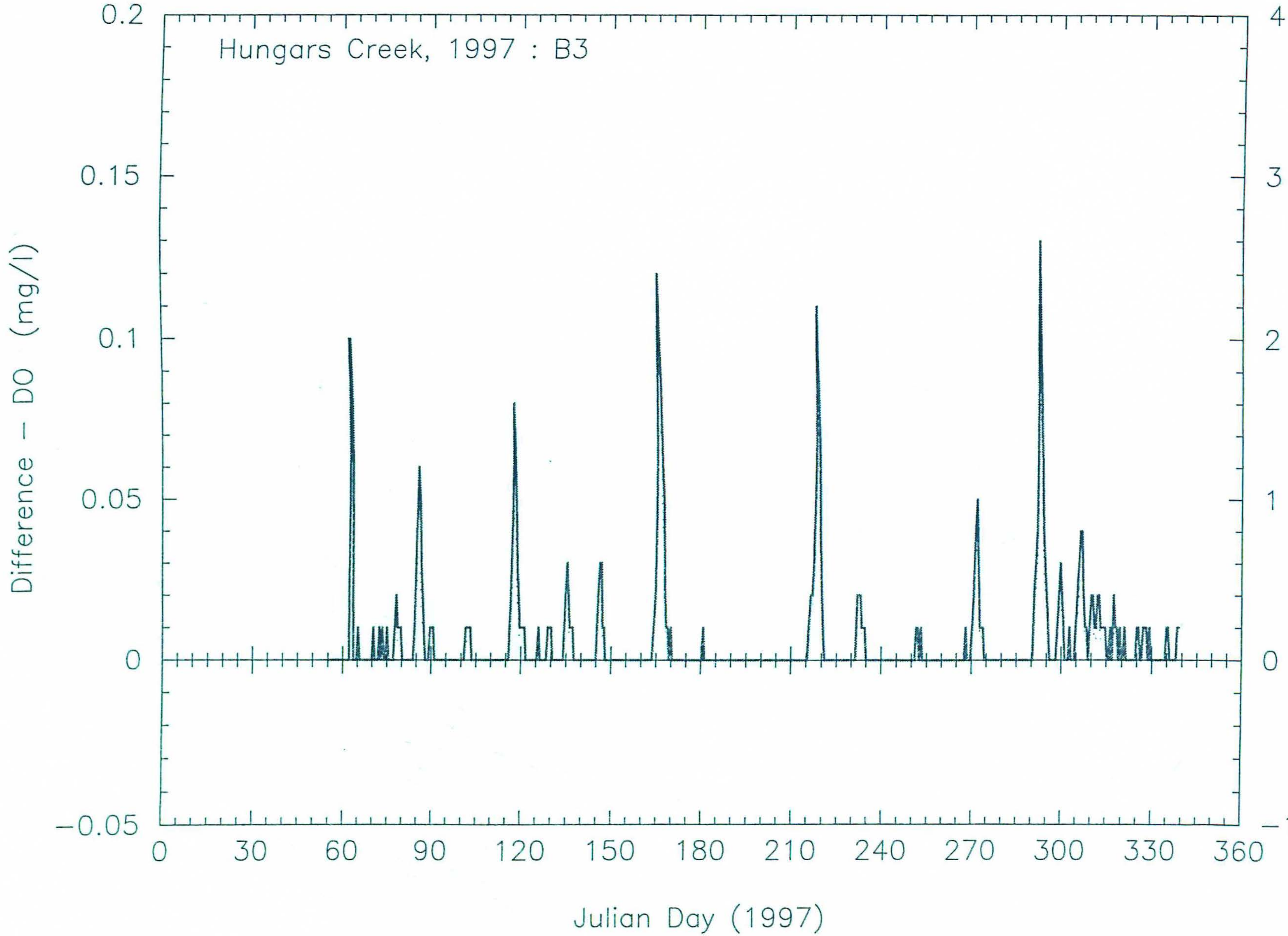


Hungars Creek, 1997 : B3
Difference – TSS (mg/l)
Percent Change
Julian Day (1997)
3.2
2.4
1.6
0.8
0
−0.8
20
15
10
5
0
−5
0
30
60
90
120
150
180
210
240
270
300
330
360

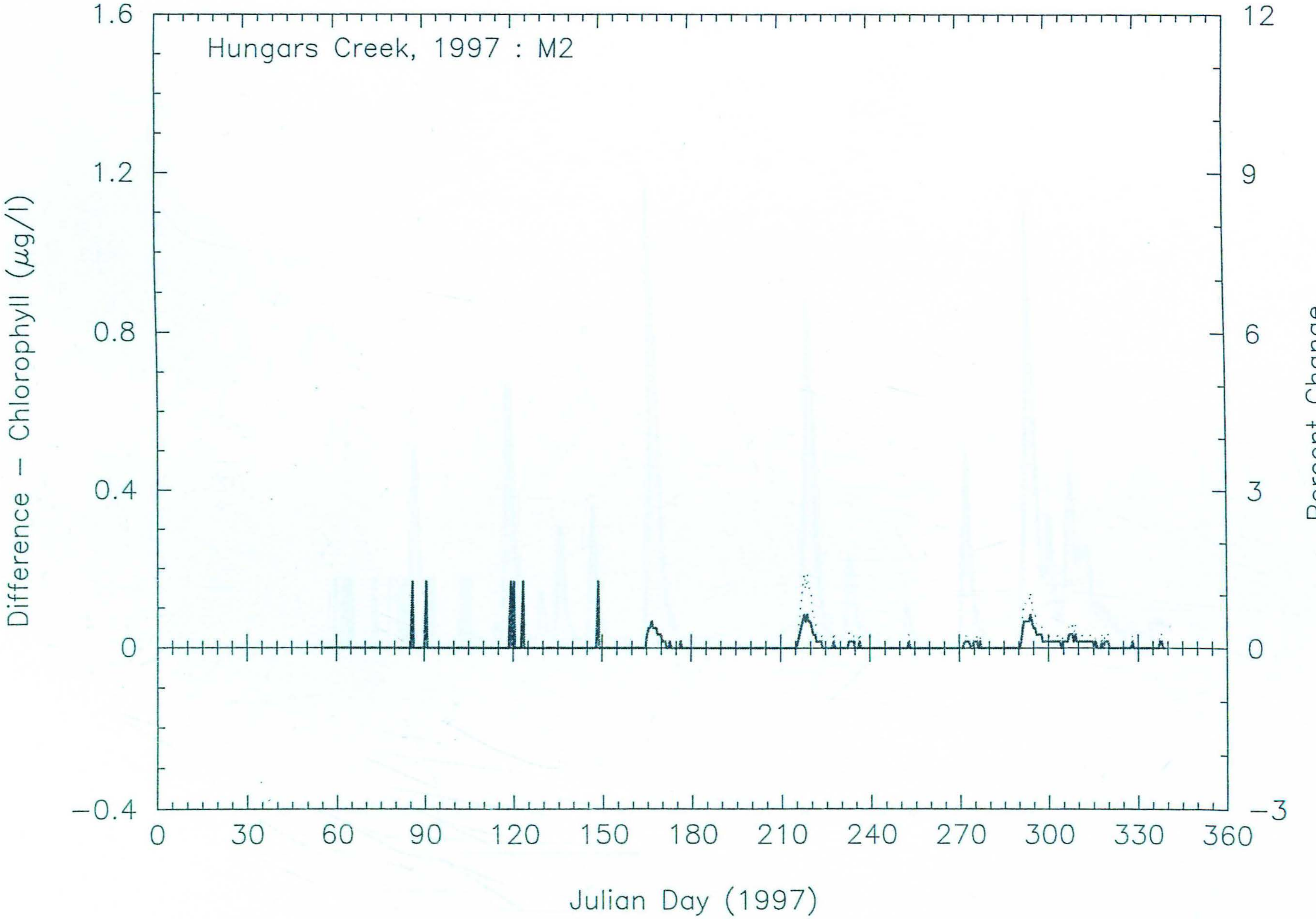

Hungars Creek, 1997 : M2
Difference - DO (mg/l)
Percent Change
Julian Day (1997)
0.2
0.15
0.1
0.05
0
-0.05
4
3
2
1
0
-1
0
30
60
90
120
150
180
210
240
270
300
330
360



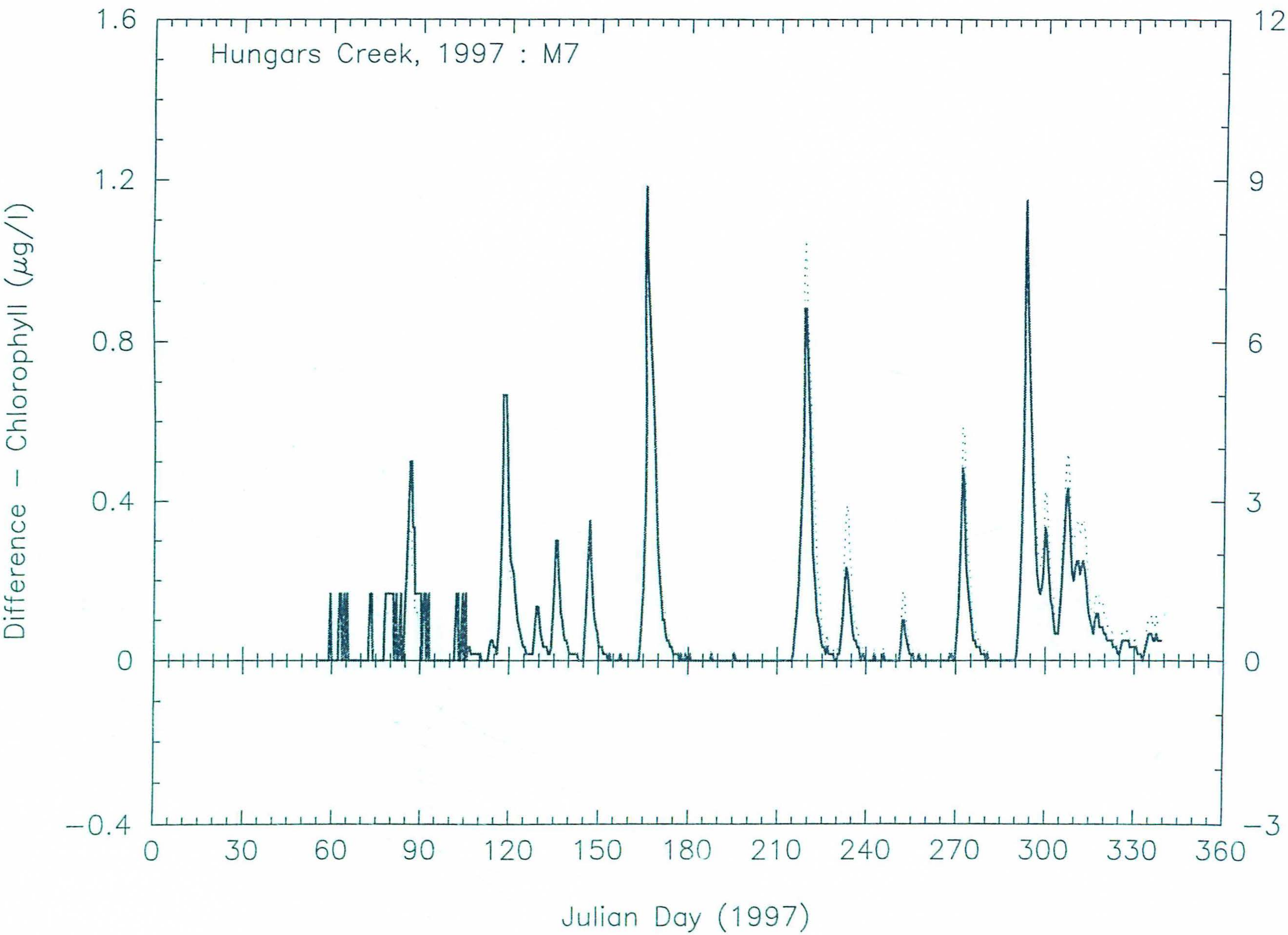
Hungars Creek, 1997 : M7
Difference - DO (mg/l)
Percent Change
Julian Day (1997)
0.2
0.15
0.1
0.05
0
−0.05
4
3
2
1
0
−1
0
30
60
90
120
150
180
210
240
270
300
330
360

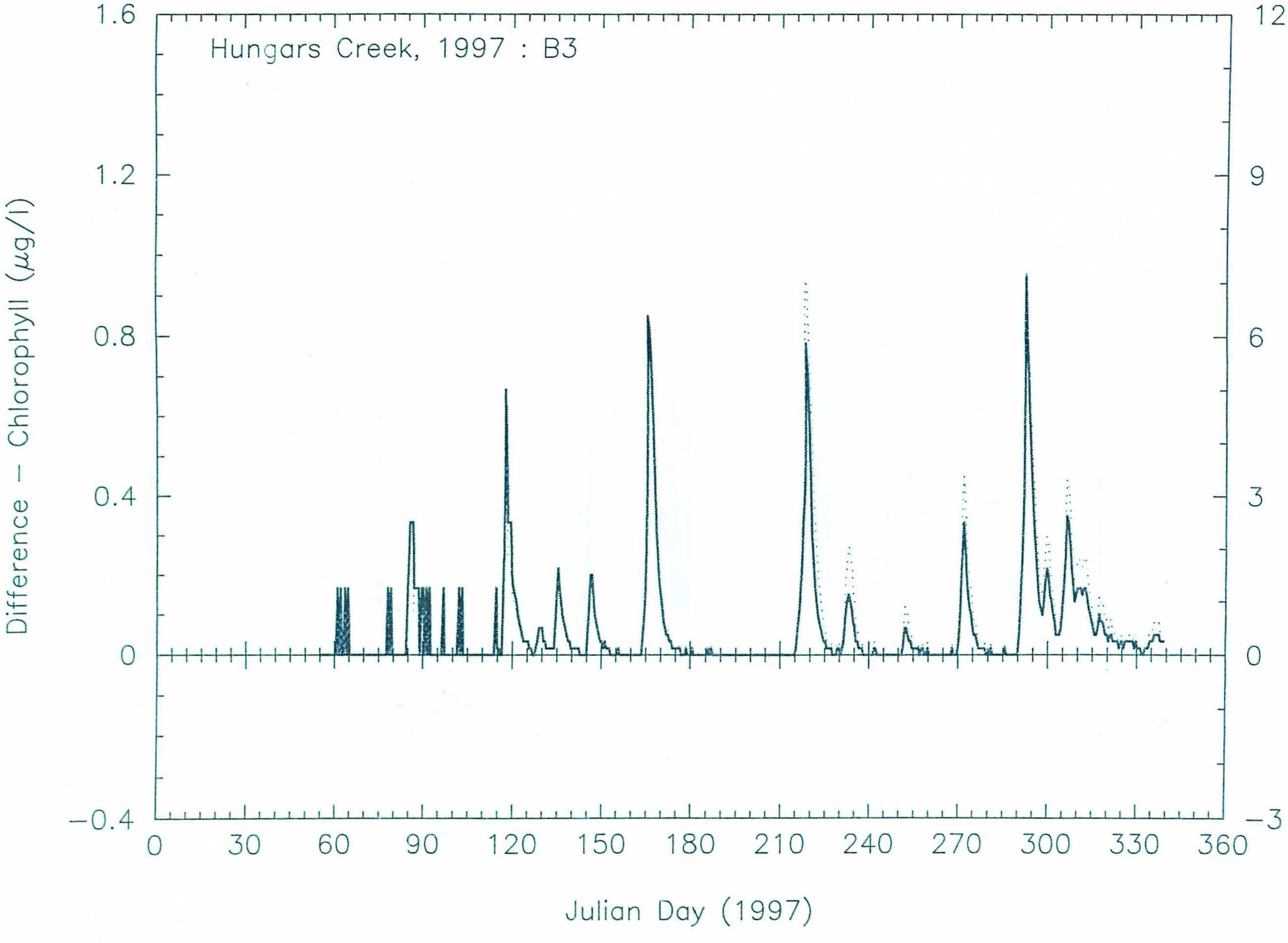


Hungars Creek, 1997 : B3
0.2
0.15
0.1
0.05
0
−0.05
Difference − DO (mg/l)
4
3
2
1
0
−1
Percent Change
0
30
60
90
120
150
180
210
240
270
300
330
360
Julian Day (1997)

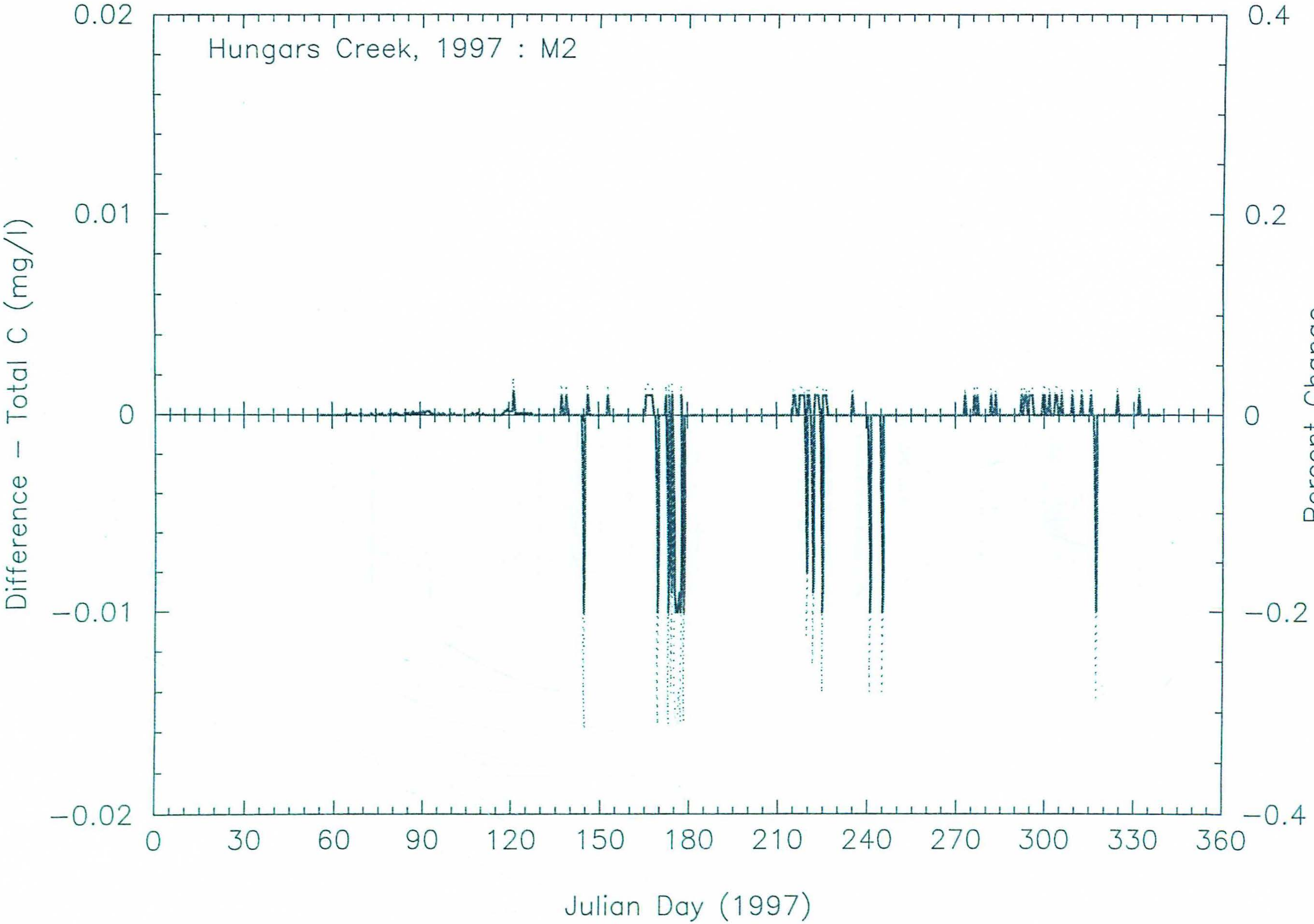


Hungars Creek, 1997 : M2
1.6
1.2
0.8
0.4
0
−0.4
Difference – Chlorophyll (μg/l)
12
9
6
3
0
−3
Percent Change
0
30
60
90
120
150
180
210
240
270
300
330
360
Julian Day (1997)

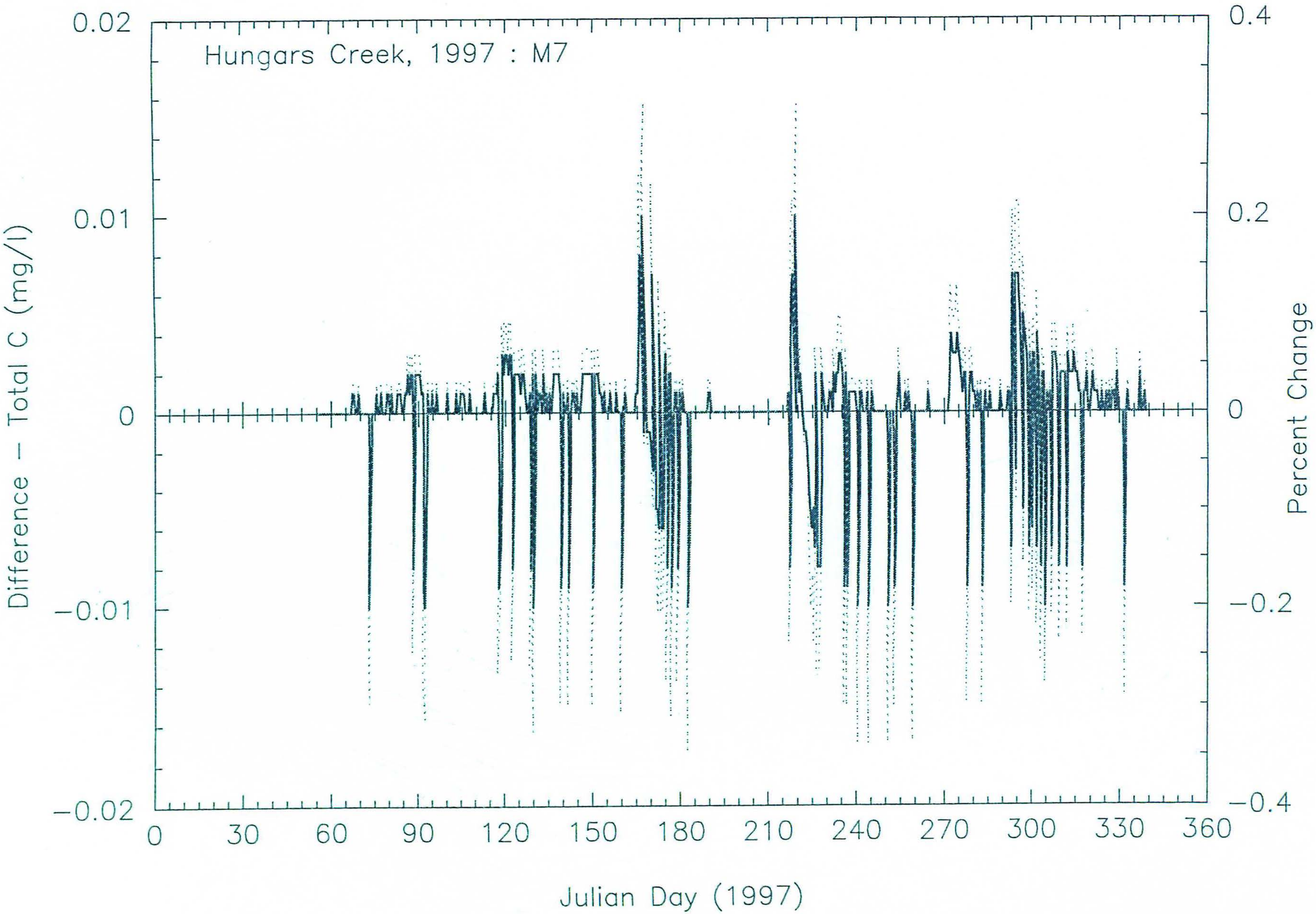

Hungars Creek, 1997 : M7
1.6
1.2
0.8
0.4
0
−0.4
12
9
6
3
0
−3
0
30
60
90
120
150
180
210
240
270
300
330
360
Difference − Chlorophyll (µg/l)
Percent Change
Julian Day (1997)



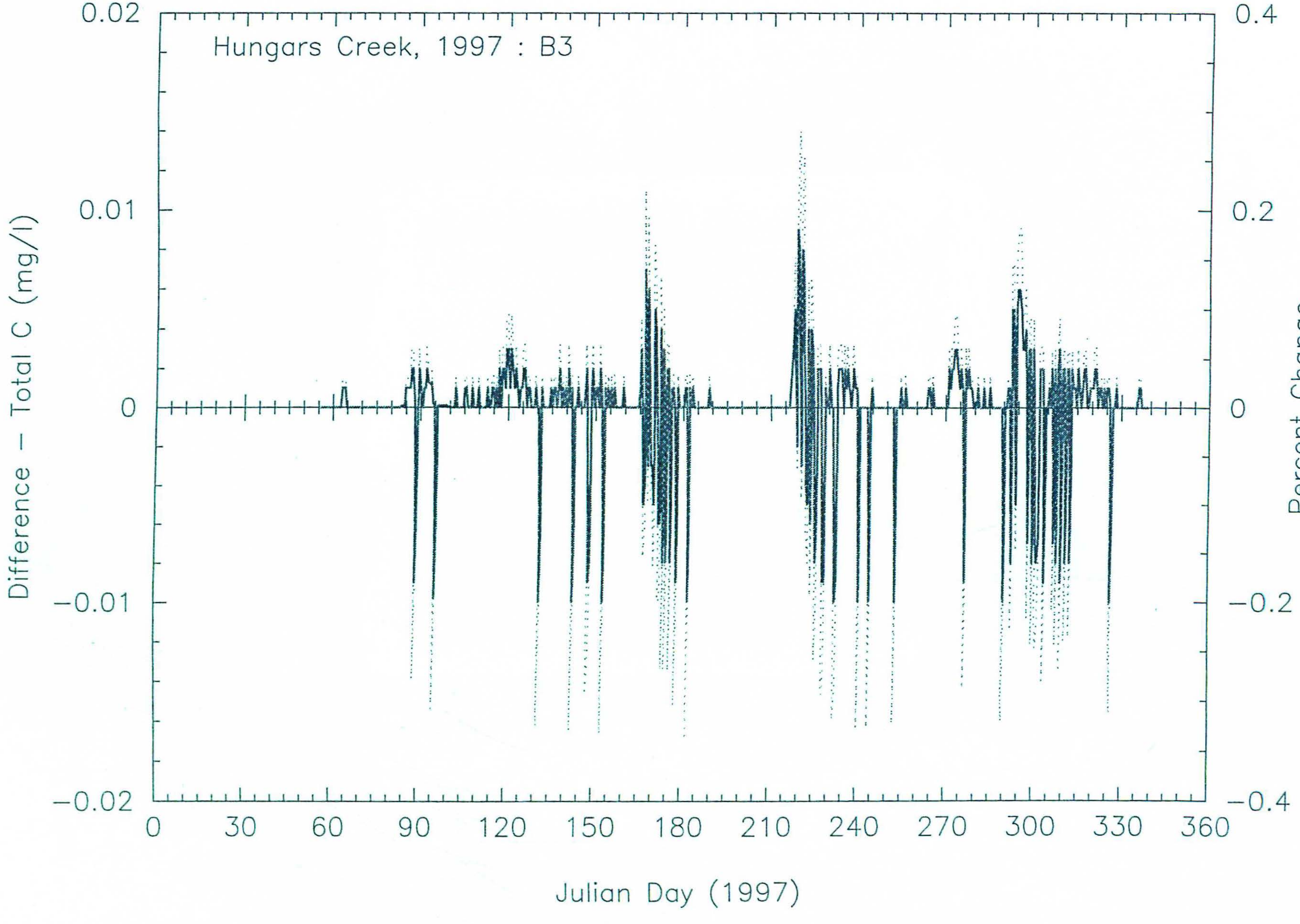
Hungars Creek, 1997 : B3
1.6
1.2
0.8
0.4
0
−0.4
12
9
6
3
0
−3
0
30
60
90
120
150
180
210
240
270
300
330
360
Difference − Chlorophyll (μg/l)
Percent Change
Julian Day (1997)



Hungars Creek, 1997 : M2
Difference – Total C (mg/l)
Percent Change
Julian Day (1997)
0.02
0.01
0
−0.01
−0.02
0.4
0.2
0
−0.2
−0.4
0
30
60
90
120
150
180
210
240
270
300
330
360



Hungars Creek, 1997 : M7
0.02
0.01
0
−0.01
−0.02
Difference − Total C (mg/l)
0.4
0.2
0
−0.2
−0.4
Percent Change
0
30
60
90
120
150
180
210
240
270
300
330
360
Julian Day (1997)



Hungars Creek, 1997 : B3
0.02
0.01
0
−0.01
−0.02
0.4
0.2
0
−0.2
−0.4
Difference – Total C (mg/l)
Percent Change
0
30
60
90
120
150
180
210
240
270
300
330
360
Julian Day (1997)