Baltimore Harbor and Back River
Eutrophication Model

By

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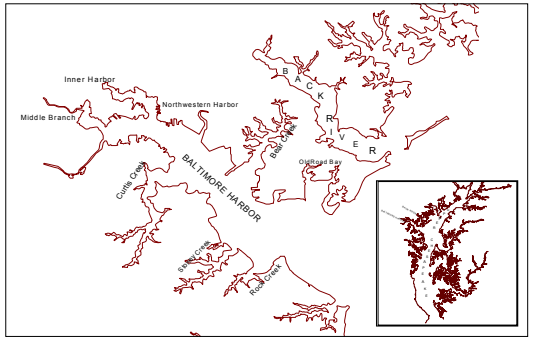

Review of Eutrophication Model Calibration in Baltimore Harbor/Back River

CONTENTS:

- DO, Chla, TN and TP Calibration Results (Time Series)
- Longitudinal Profiles
- Light extinction coefficients
- Sediment Fluxes
- Primary Productivity
- Nutrient Limitation
- Statistics

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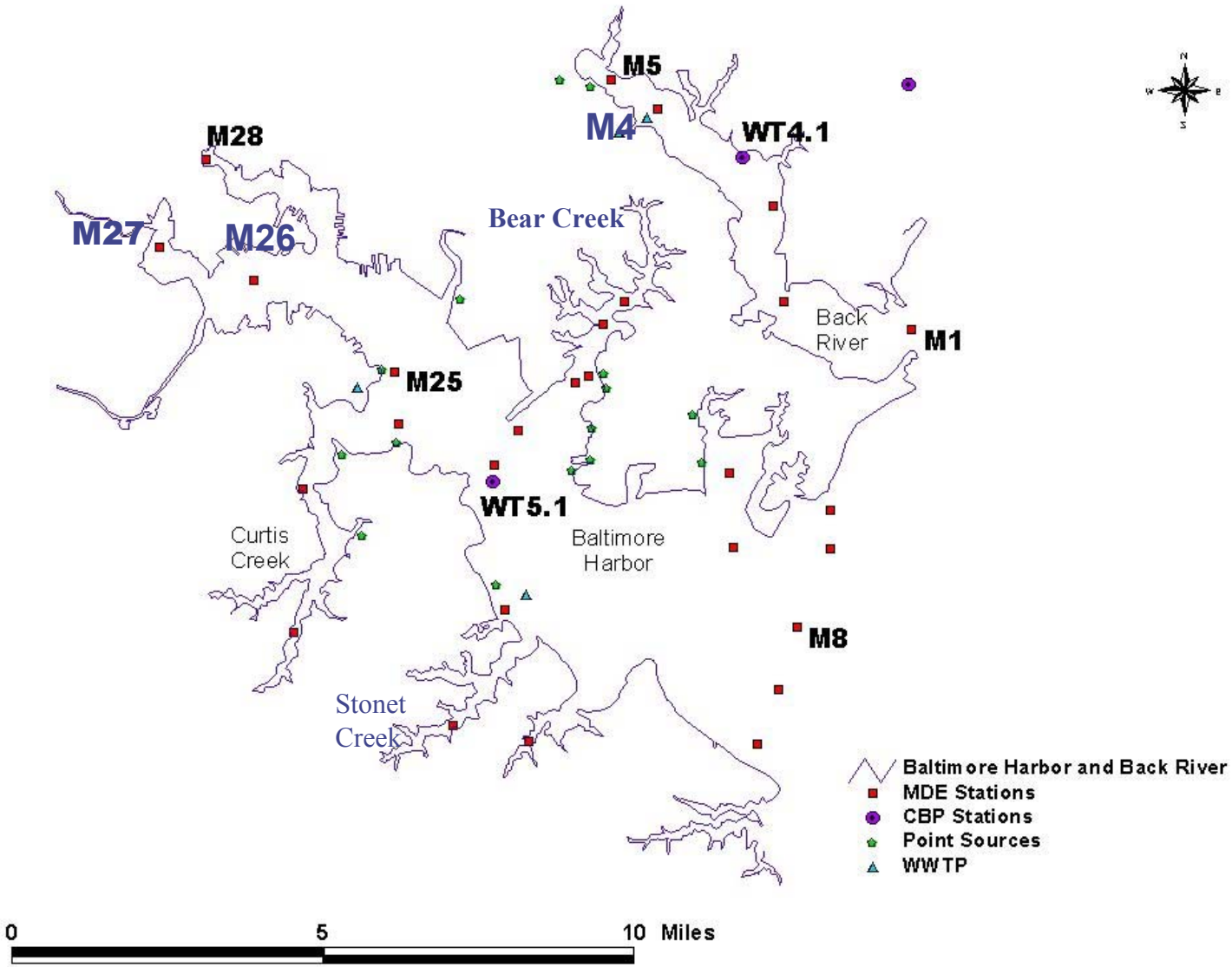
Review Update

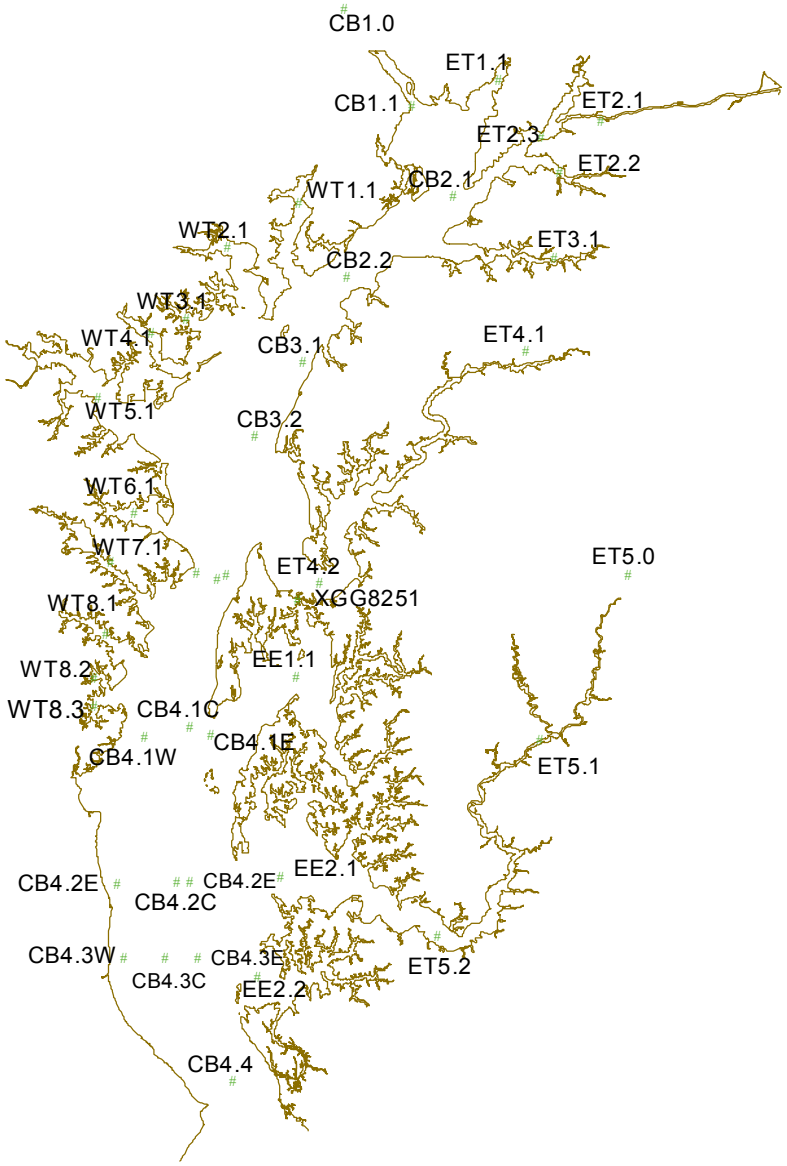
Reviewed by State agencies, Baltimore County and Baltimore City

Reviewed by Chesapeake Bay Program Modeling Subcommittee

Location of Water Quality Stations



Location of Long Term Water Quality Stations

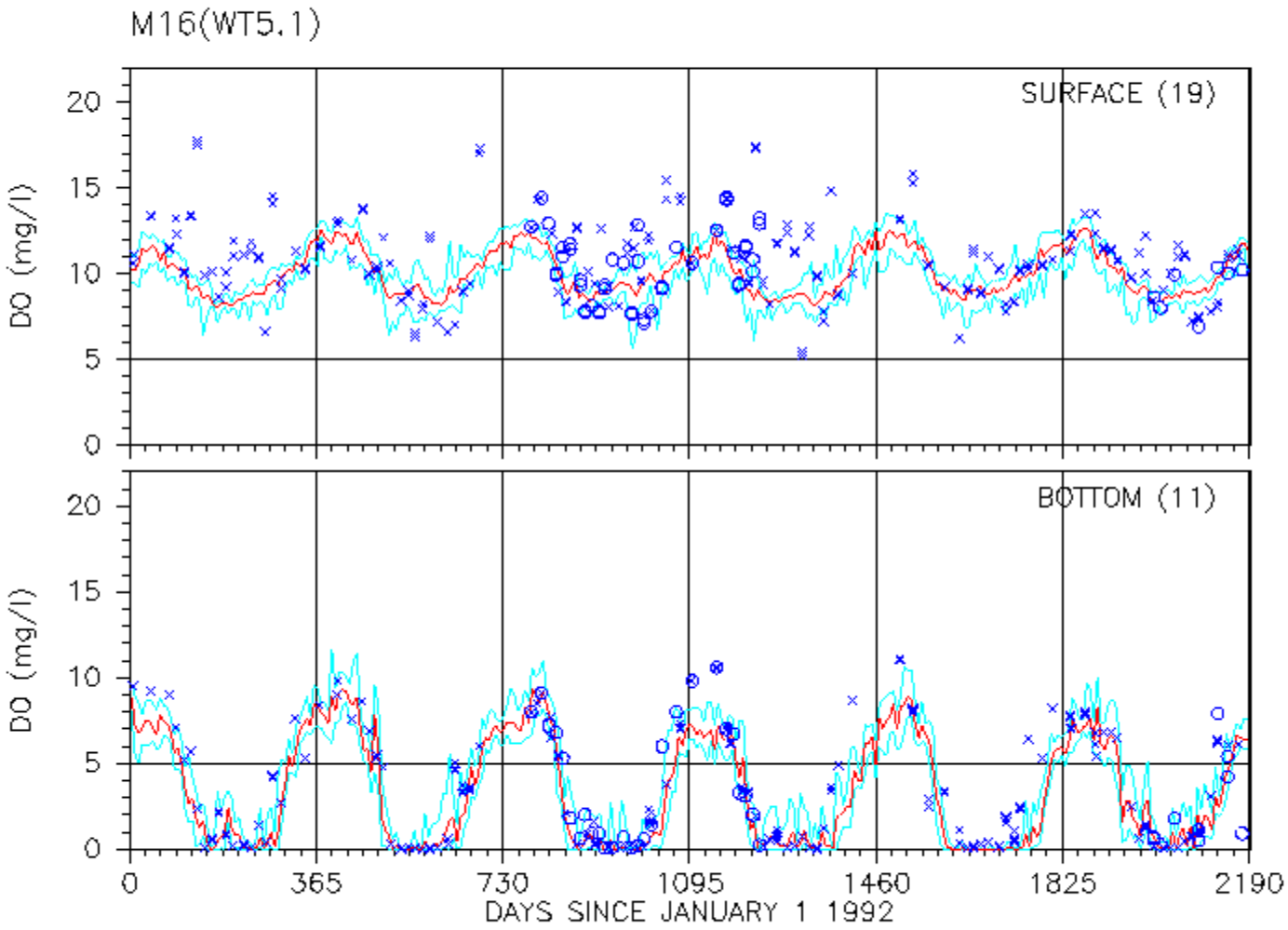


Model Output Vs. Observed Data

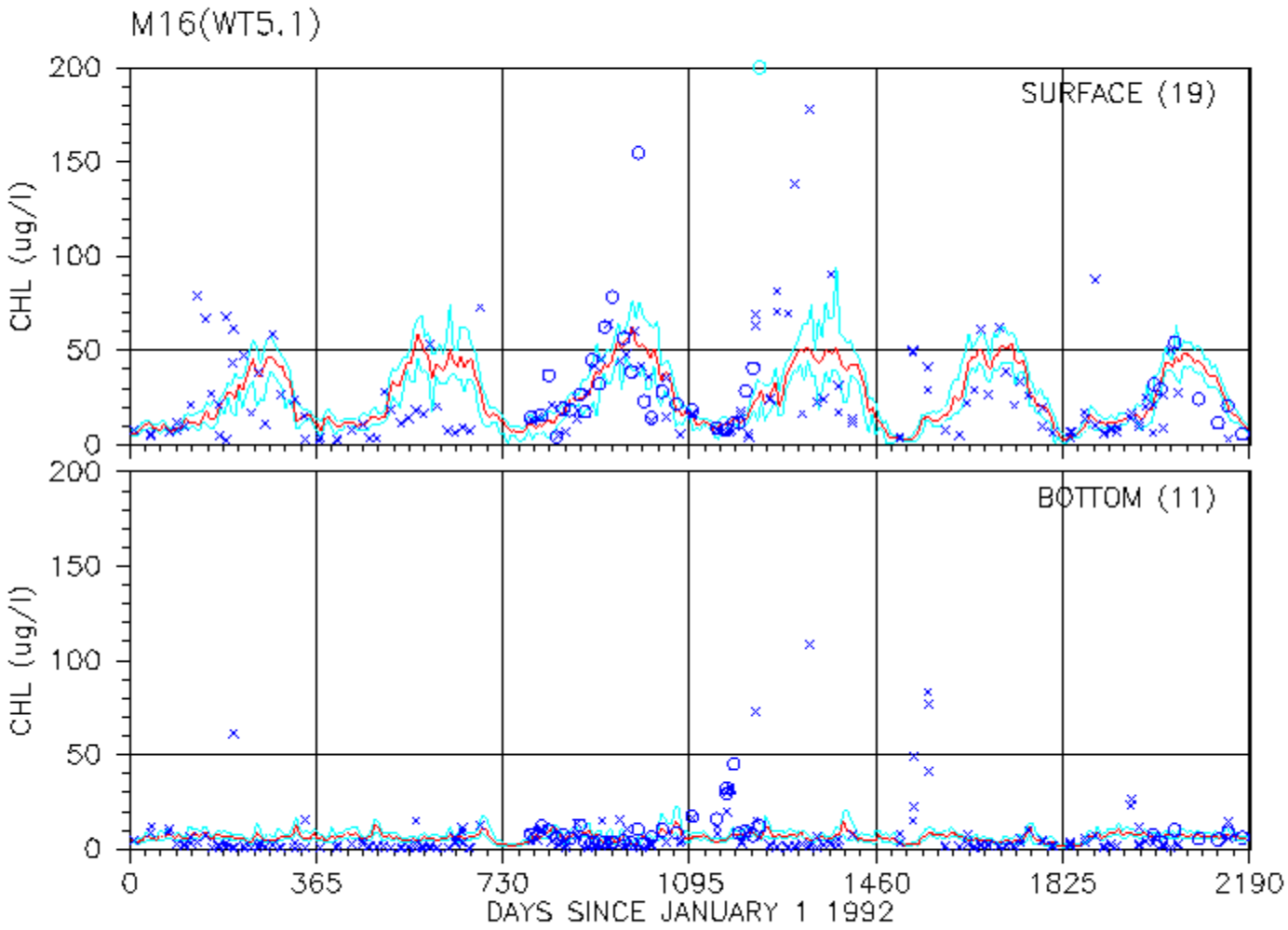
Time Series

- Main Bay
- Baltimore Harbor
- Back River

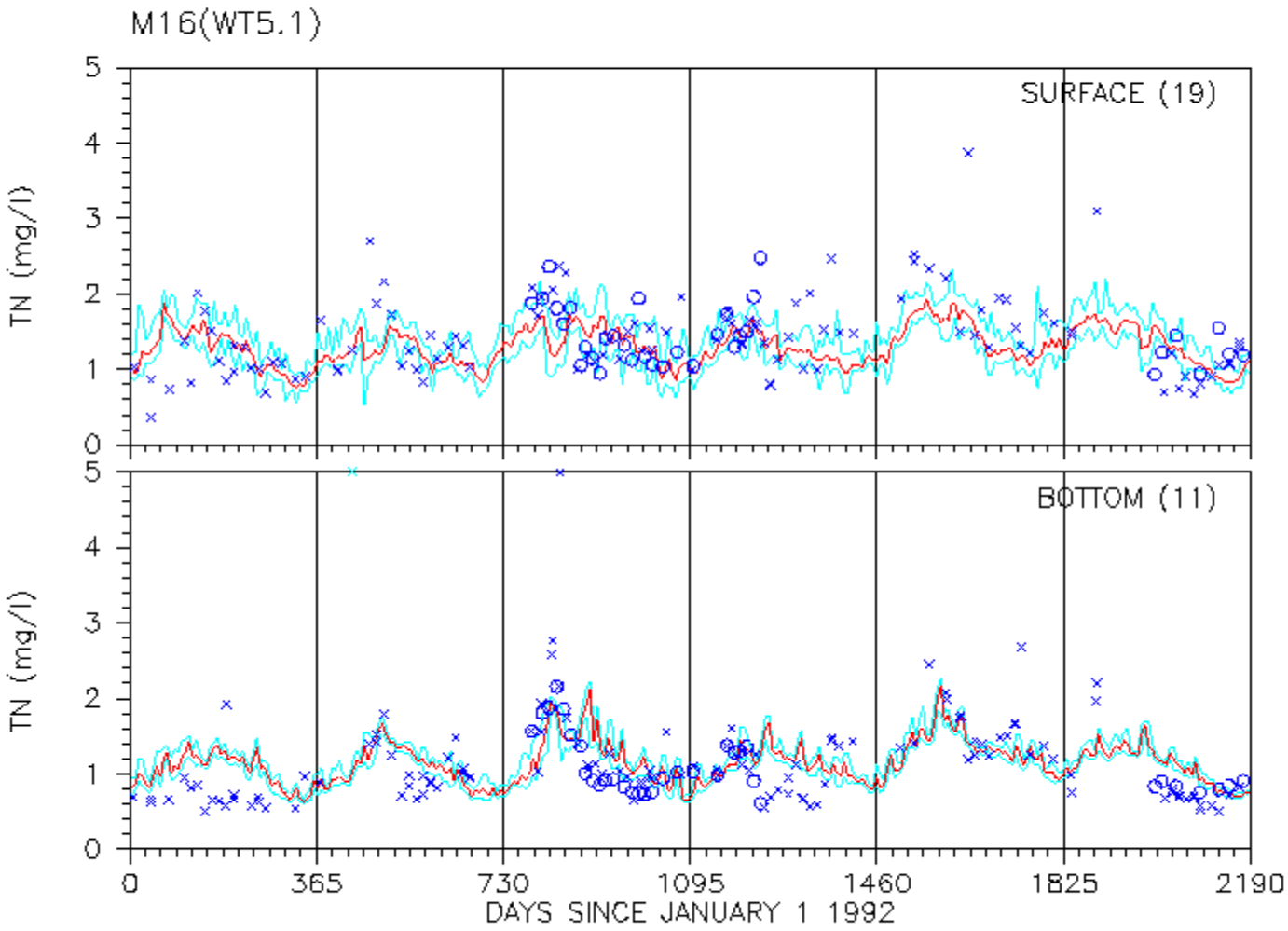
Harbor Channel
(long term station)



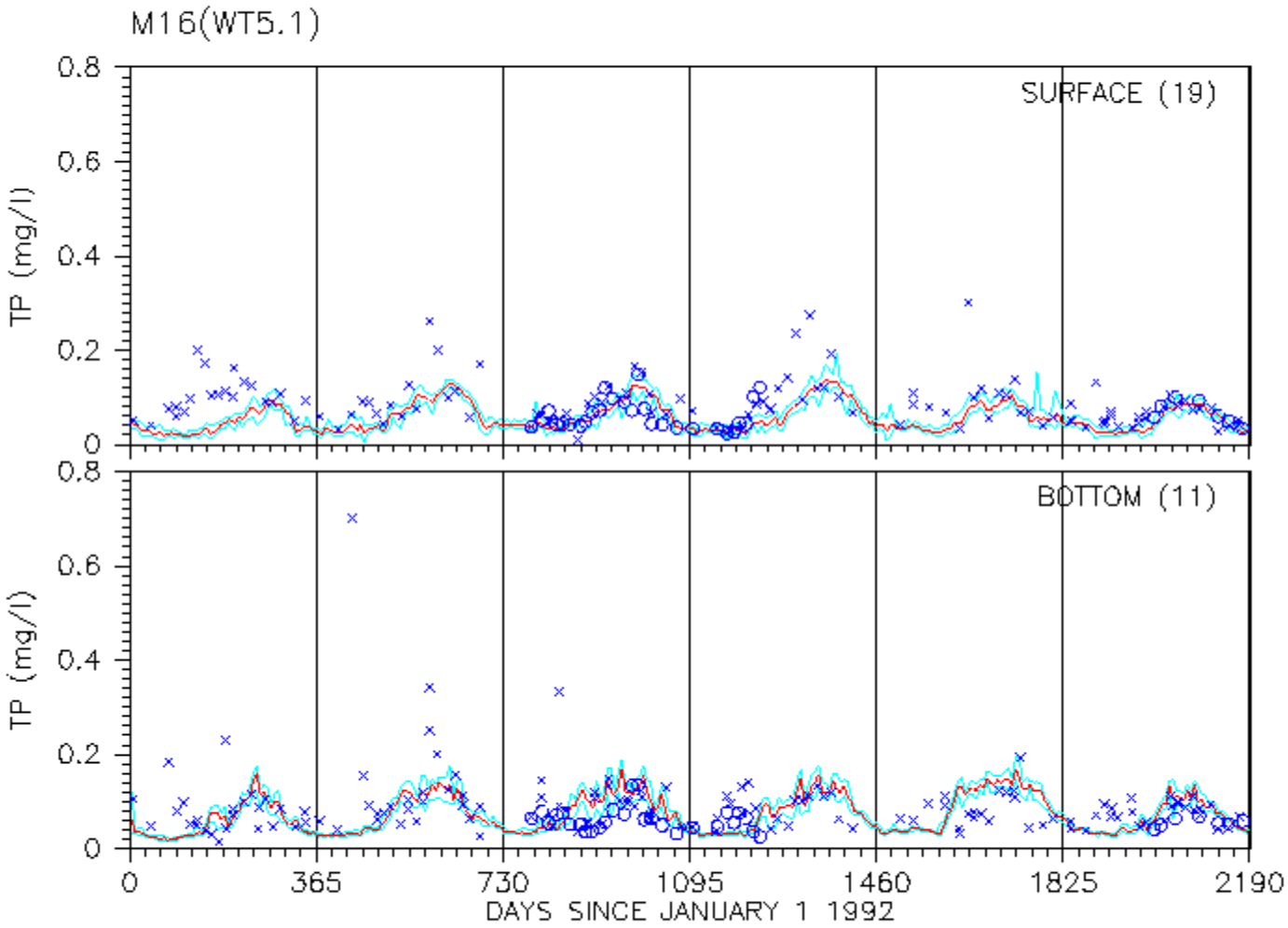
Harbor Channel
(long term station)



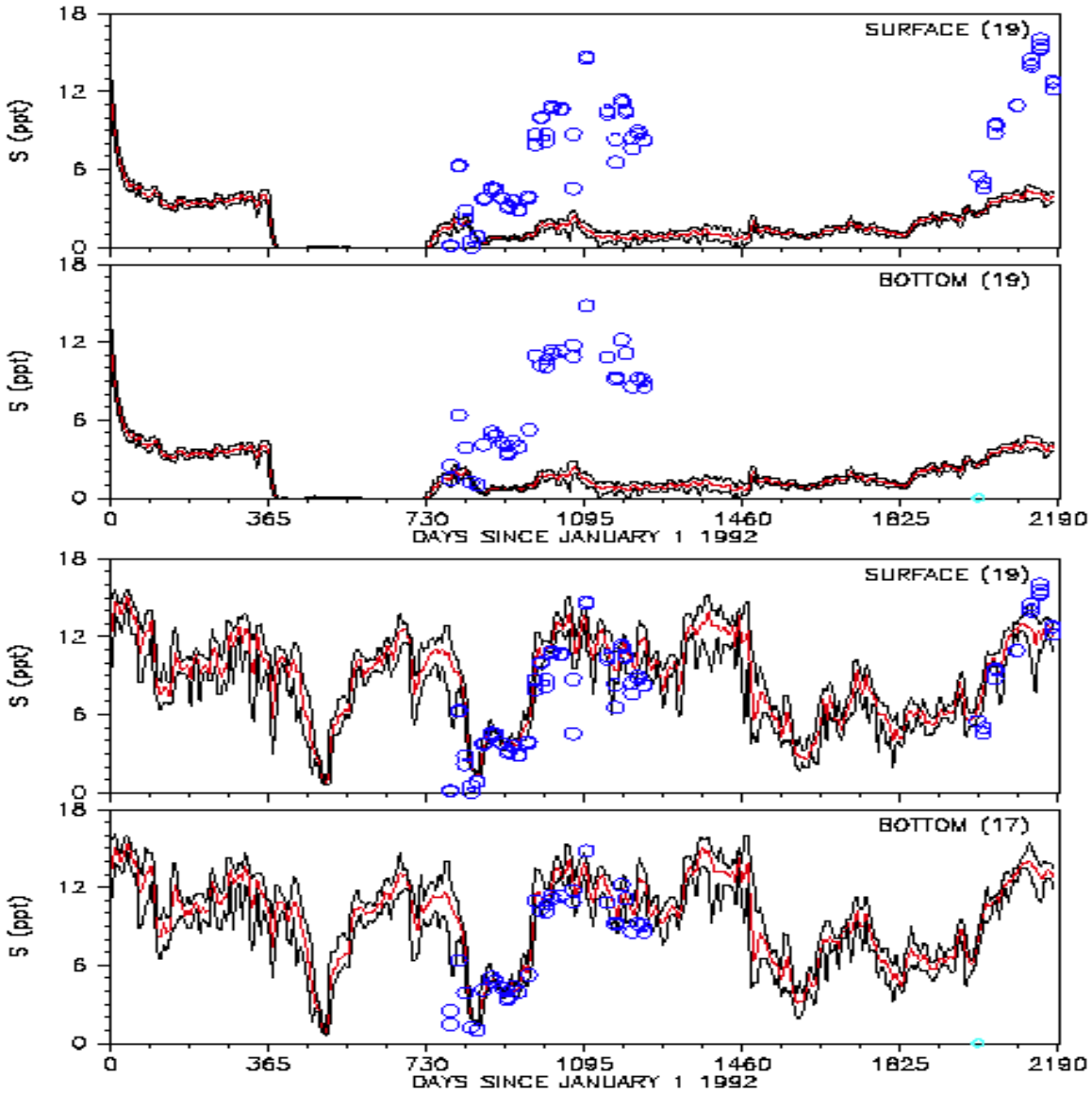
Harbor Channel
(long term station)



Harbor Channel
(long term station)



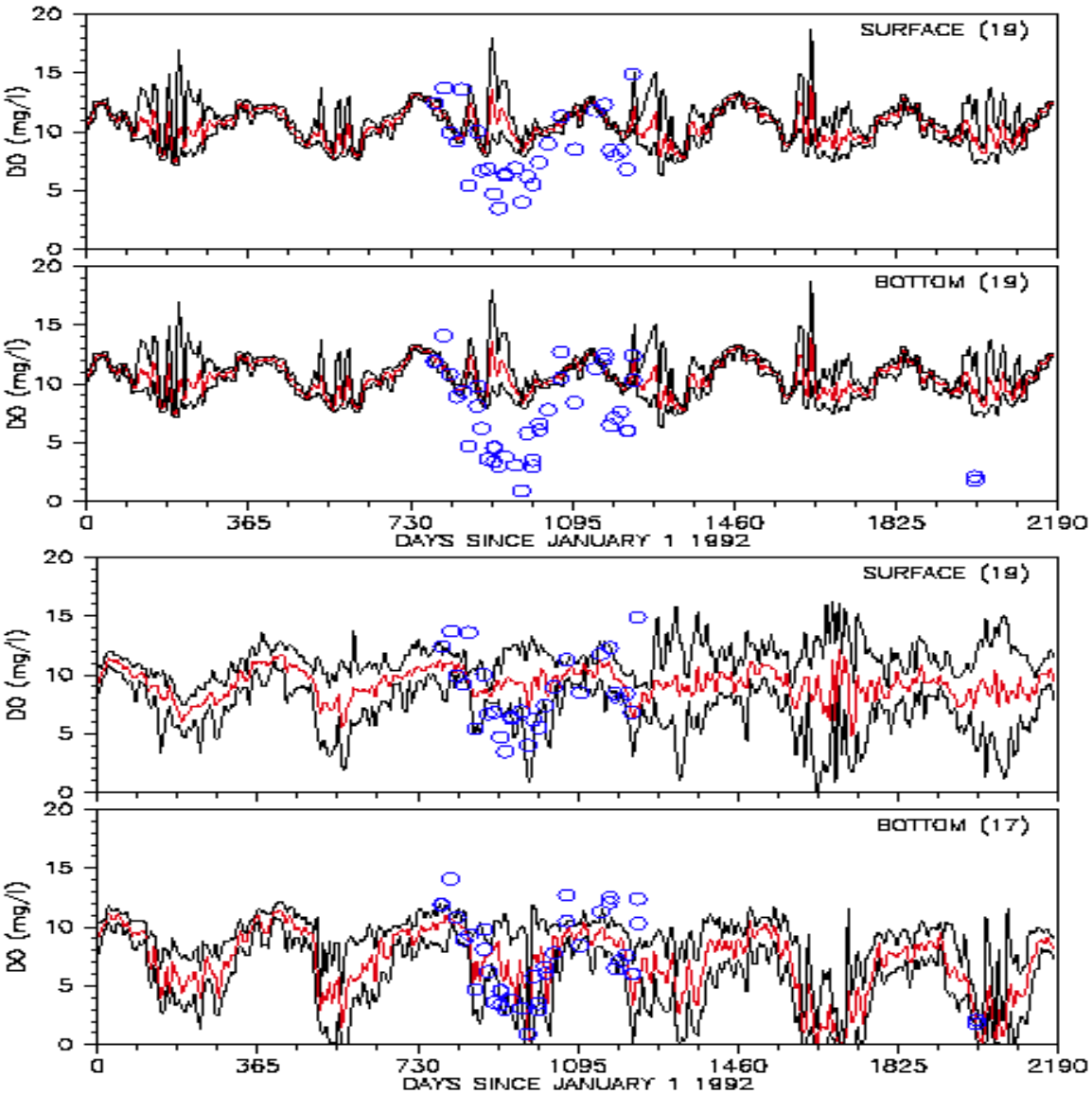
Inner Harbor



Before
(Shallow channel)

After
(Deep channel)

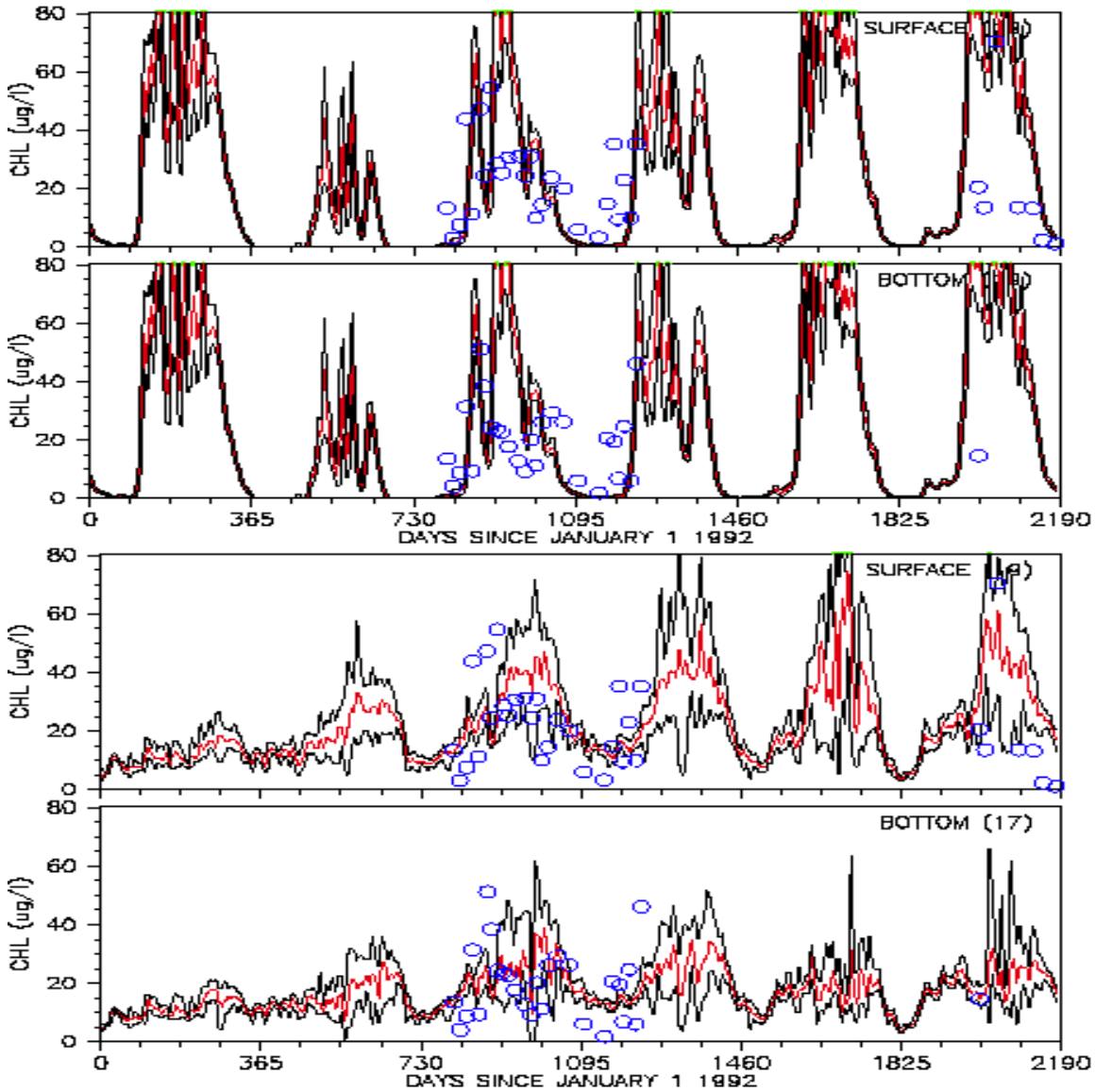
Inner Harbor



Before
(Shallow channel)

After
(Deep channel)

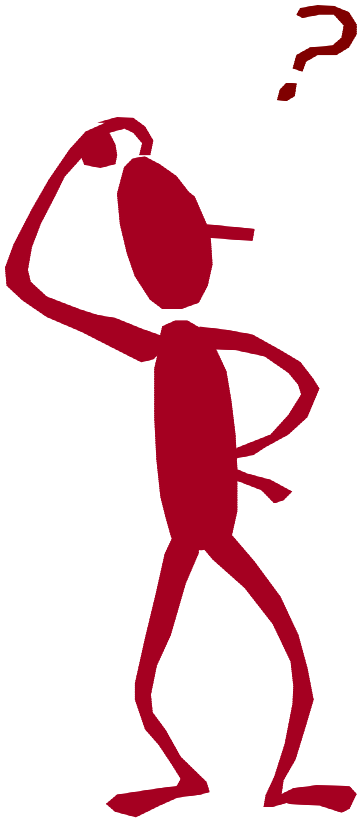
Inner Harbor



Before
(Shallow channel)

After
(Deep channel)

in the Back River …



Why is chlorophyll abnormally high?

Proposition

(1) The abnormally high chlorophyll concentration is the result of enhanced sediment phosphorus release.

(2) The sediment phosphorus release is triggered by high pH.

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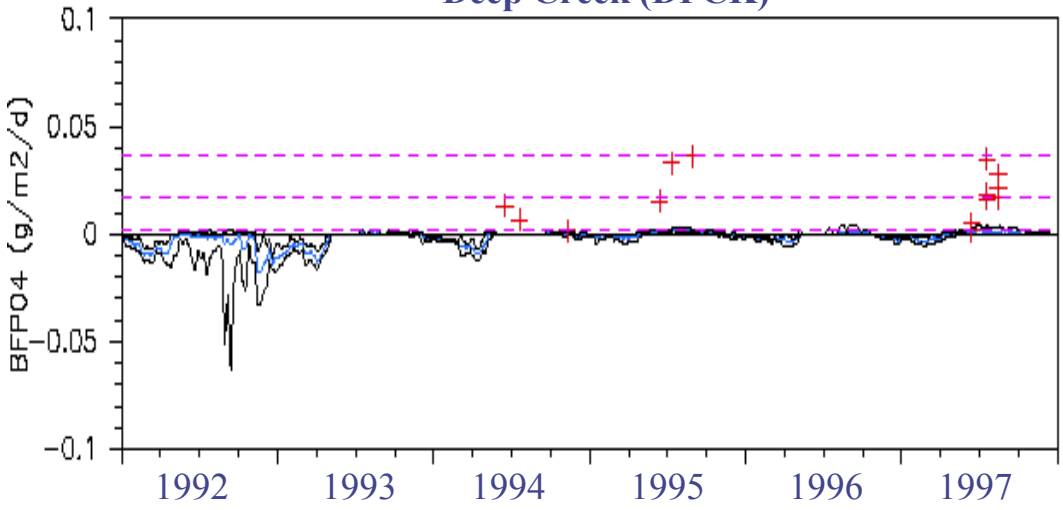
Deep Creek (DPCK)



Muddy Gut (MDGT)

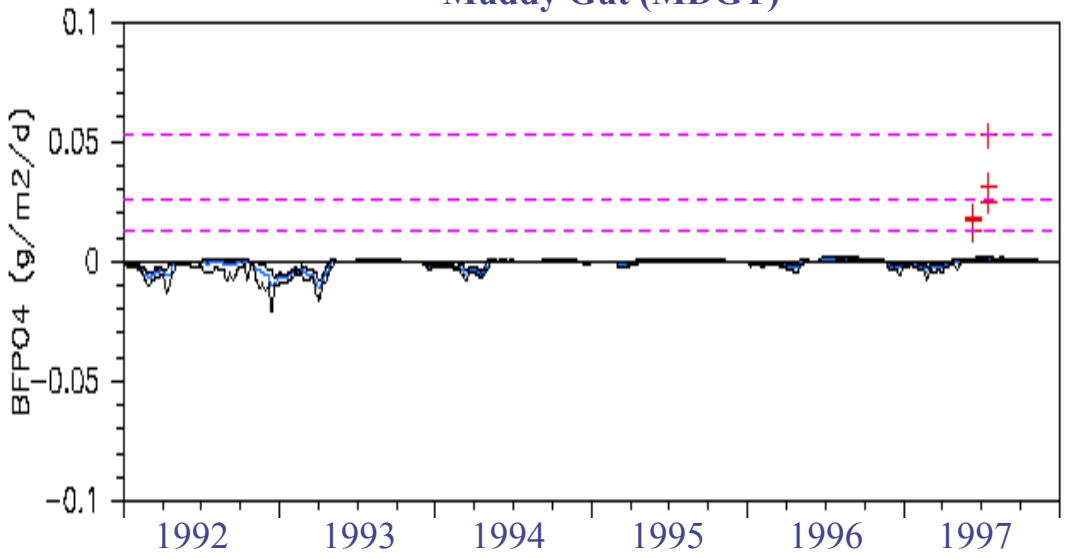


Table 2. Statistics of benthic flux data from Back River and Baltimore Harbor (Boynton et al., 1998).

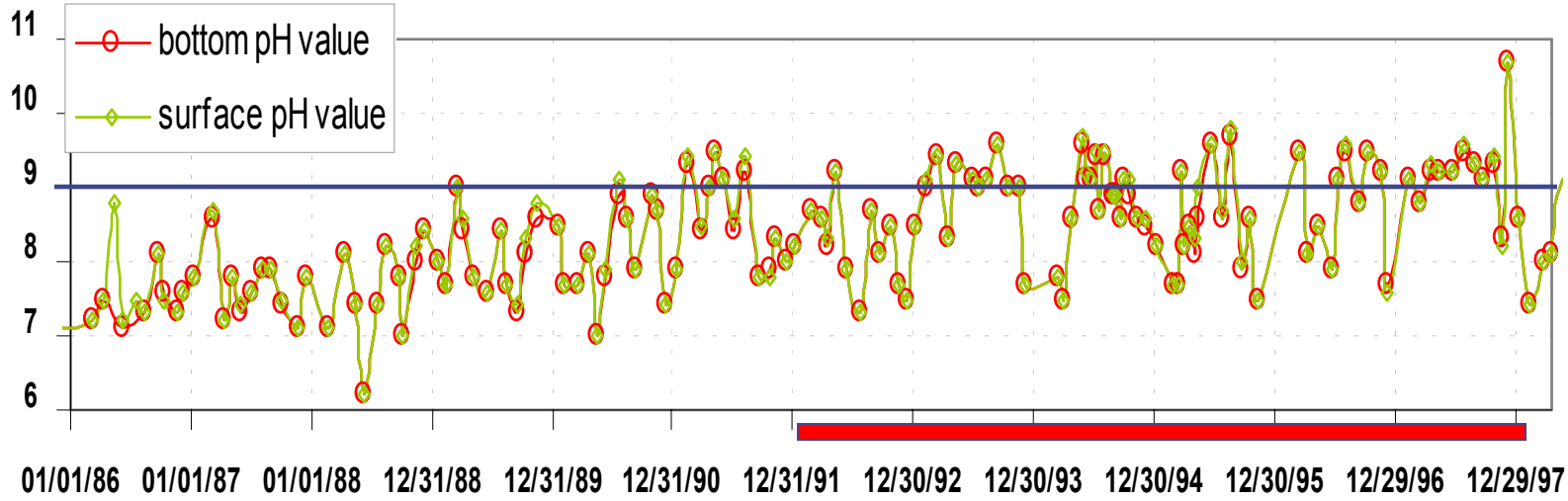
	$BFNH_4$ ($g/m^2/day$)				$BFNO_3$ ($g/m^2/day$)			
STATION	MIN	MAX	MEAN	NUMBER	MIN	MAX	MEAN	NUMBER
WCPT*	0.02	0.25	0.13	15	-0.10	0.03	-0.01	13
MDGT*	0.04	0.26	0.14	8	-0.02	0.01	0.00	8
DPCK*	0.04	0.32	0.17	15	-0.16	0.03	-0.06	15
RVBH	0.01	0.10	0.05	6	-0.03	0.05	-0.01	6
HMC	0.05	0.24	0.14	9	-0.06	-0.01	-0.02	8
CTBY	0.00	0.19	0.08	6	-0.05	0.01	-0.02	6
FFOF	0.06	0.23	0.14	8	-0.08	-0.01	-0.05	9
FYBR	0.01	0.13	0.08	6	-0.03	0.00	-0.01	6
INHB	0.14	0.73	0.46	6	-0.05	0.00	-0.02	6

	$BFPO_4$ ($g/m^2/day$)				BFSI ($g/m^2/day$)			
STATION	MIN	MAX	MEAN	NUMBER	MIN	MAX	MEAN	NUMBER
WCPT*	0.00	0.13	0.05	15	0.08	0.53	0.27	14
MDGT*	0.01	0.05	0.03	6	0.14	0.27	0.18	8
DPCK*	0.00	0.04	0.02	15	0.03	0.53	0.26	14
RVBH	0.00	0.01	0.01	6	0.13	0.33	0.23	6
HMCK	0.00	0.05	0.01	7	0.08	0.24	0.17	9
CTBY	0.00	0.08	0.02	6	0.10	0.36	0.21	6
FFOF	0.00	0.06	0.02	9	0.14	0.34	0.23	9
FYBR	0.00	0.02	0.01	6	0.12	0.25	0.22	6
INHB	0.00	0.10	0.06	6	0.10	0.30	0.23	6

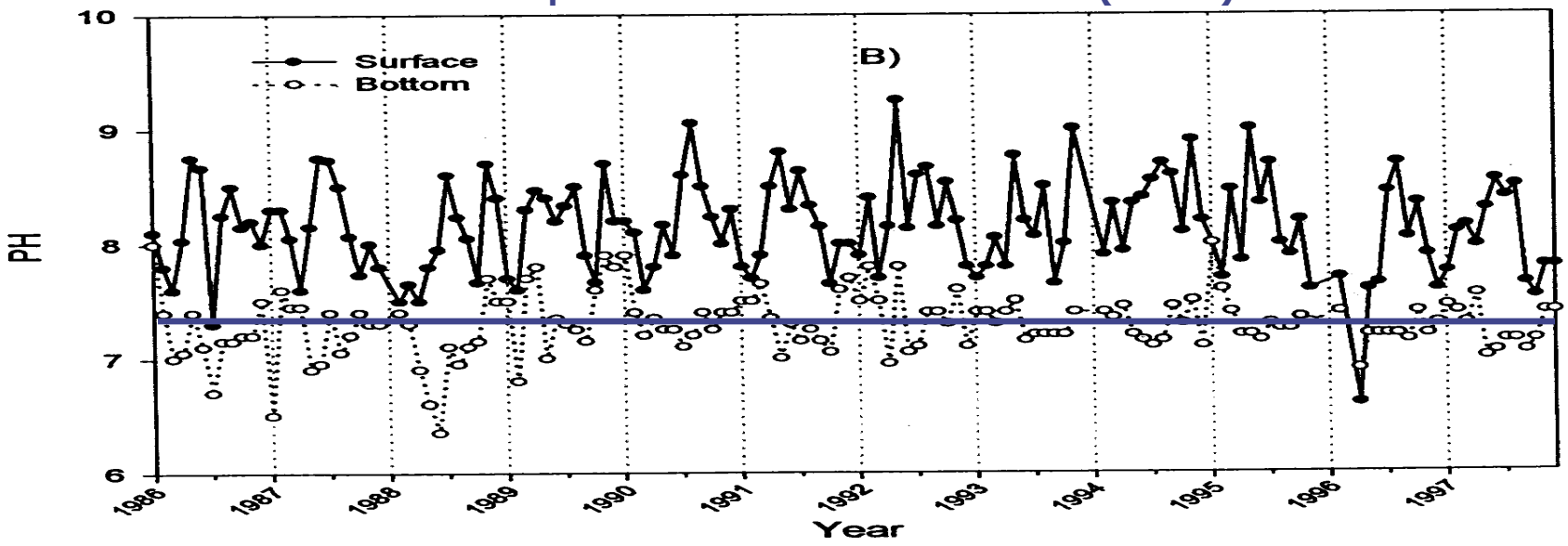
	SOD ($g/m^2/day$)			
STATION	MIN	MAX	MEAN	NUMBER
WCPT*	-3.31	-0.82	-2.16	15
MDGT*	-3.07	-1.17	-1.94	9
DPCK*	-2.78	-1.12	-1.98	15
RVBH	-4.12	-0.85	-2.18	6
HMCK	-2.04	-1.71	-1.84	9
CTBY	-3.12	-0.71	-1.34	6
FFOF	-2.18	-1.63	-1.88	9
FYB	-1.63	-0.67	-1.09	6
INHB	-1.82	-0.38	-0.85	6

* WCPT, MDGT, DPCK are in Back River, the other stations are in Baltimore Harbor.

pH value in Back River (WT4.1)



pH value in Baltimore Harbor(WT5.1)



United States Environmental Protection Agency
CBP/TRS 15

November 1987

The Effect of pH on the Release of Phosphorus from Potomac River Sediment

Chesapeake Bay Program

Estuarine, Coastal and Shelf Science (1991) 33, 409–418

The Effect of pH on the Release of Phosphorus from Potomac Estuary Sediments: Implications for Blue-green Algal Blooms

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Received 2 May 1990 and in revised form 8 April 1991

Keywords: phosphorus; sediment; pH; algal blooms; estuary; blue-green algae

The recurrence of a blue-green algal bloom (*Microcystis aeruginosa*) in the freshwater tidal portion of the Potomac estuary in 1983 was related to the enhanced release of phosphorus from benthic sediments. The release of phosphorus was measured from Potomac estuary sediment cores incubated with water at pH levels encompassing the range outside (pH 7–8) and inside (pH 9·5–10·5) the 1983 bloom area. Phosphate release under aerobic conditions increased as a function of overlying water pH: between pH 8 and 9 the sediment–water phosphate flux was low; beginning with an overlying water pH of 9·5, the phosphate flux markedly increased. The increased release of phosphate at high pH is probably a result of solubilization of iron and aluminium phosphate complexes. Phosphorus release rates from the sediments at high pH (pH 9·5–10·5) are similar to the phosphorus source needed to account for the excess phosphorus measured in the bloom area and required to support the phytoplankton production.

Introduction

Nutrient inputs to many aquatic systems from anthropogenic activities have greatly exceeded the inputs from natural sources for many decades. We are now entering an era in which nutrient and other pollutant inputs to many estuaries, rivers and lakes are decreasing as a result of water quality legislation. The effectiveness of these pollution control efforts is now being evaluated, testing our understanding of these systems. Of particular concern is the long-term release of nutrients or other pollutants from the sediments in response to changing water column conditions (Oviatt *et al.*, 1984; Bostrom, 1984).

The benthos is an important source of recycled nutrients (both nitrogen and phosphorus) for phytoplankton production in many estuaries and other near-shore marine systems (Nixon, 1981; Boynton & Kemp, 1984). The magnitude of benthic nutrient fluxes in the tidal freshwater portion of estuaries (Callendar & Hammond, 1982) or in streams and rivers (Meyer, 1979; Newbold, 1987) has been less studied. The importance of benthic recycling as a source of nutrients for phytoplankton production in those systems has been largely unquantified.

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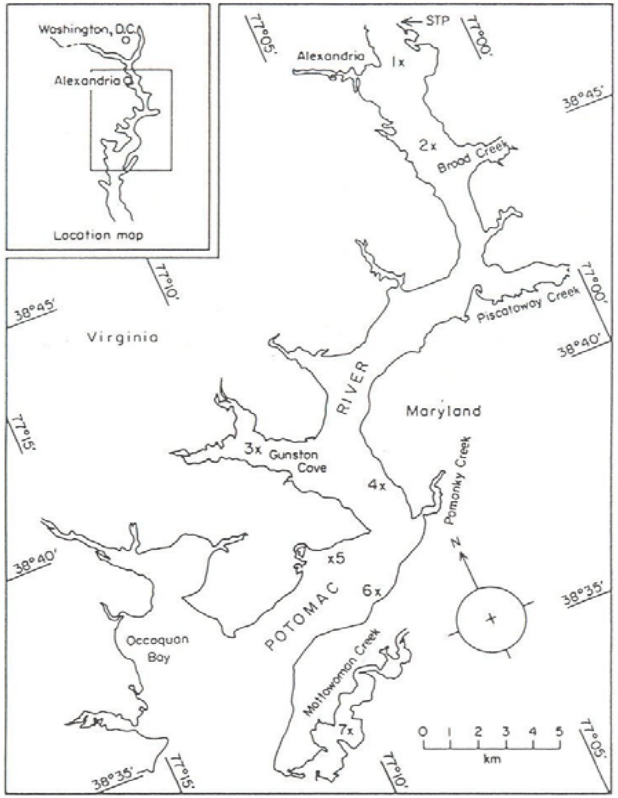


Figure 1. Sediment core collection sites in the tidal freshwater Potomac estuary. The phytoplankton bloom was located between river km 30 (near Piscataway Creek) and km 60 (approximately 5 km below Mattawoman Creek), with the peak located near km 42 (Gunston Cove). The location of Blue Plains, the major sewage treatment plant for the metropolitan Washington, D.C. area is indicated (STP). Site 8 (not shown) is at approximately river km 74.

locations, the release of phosphate was measured on four cores with the overlying water at pH 8. The pH of the water over two cores from each location was increased to 10; after 5 days the release of phosphate was again measured for all four cores. The overlying water s changed every 24 to 48 h with water previously adjusted to the desired pH.

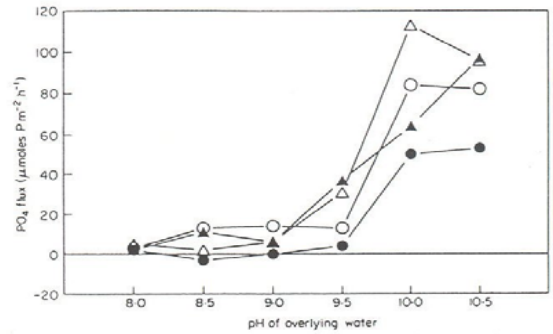


Figure 2. Sediment–water phosphate fluxes from Potomac estuary sediments as a function of overlying water pH. ○——○, Site 1; ●——●, site 2; △——△, site 3; ▲——▲, site 4.

TABLE 1. Sediment–water phosphate fluxes (average ±SD) from Potomac estuary sediment (sites 5–8) with overlying water maintained at pH 8 or pH 10. See Figure 1 for site locations

Site	Treatment pH	N	PO_4 flux average (±SD) (μmol P m^{-2} h^{-1})
5	8·0	6	2 (1·0)
	10·0	2	34 (1·4)
6	8·0	6	5 (3·9)
	10·0	2	30 (0·7)
7	8·0	6	10 (6·6)
	10·0	2	39 (12·7)
8	8·0	6	22 (12·2)
	10·0	2	46 (6·3)

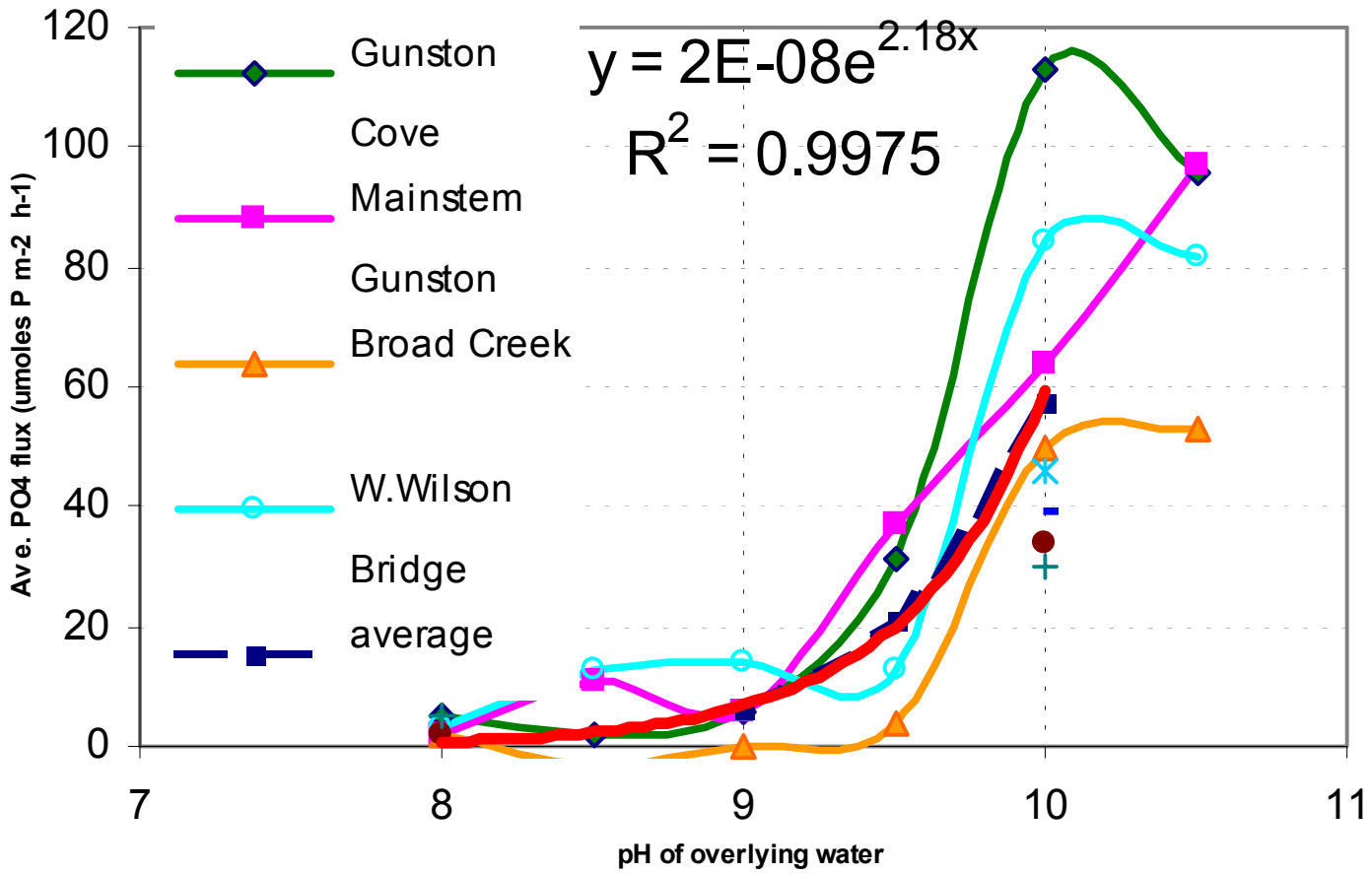
N = number of separate flux measurements.

summer to fall denitrification is removing an amount of N equivalent to approximately 35% of the N loading (77 715 lb N day^{-1} during fall from 1980 to 1983; Thomann *et al.*, 1985) from point and non-point sources to this area of the river.

Discussion

For over two centuries the tidal freshwater portion of the Potomac River estuary experienced increasing eutrophication, marked by low dissolved oxygen concentrations and massive blue-green algal blooms, due primarily to discharges of domestic wastewater from the metropolitan Washington, D.C., area (Jaworski, 1990). Major upgrades in the

- **Literature research:** *Seitzinger, Sybil P. (1986)*



The Effect of pH on the Release of Phosphorus from Potomac River Sediment, Div. Env. Res., Academy of Natural Sciences of Philadelphia.

Phosphorus Release pH–dependent function

$$BF(t) = BF_{BFM} * \{ EXP [K_{PH} * (PH(t)-PHR)]\}$$

0.75 8.0

Where

BF: enhanced phosphorus release (g P m^{-2} day^{-1});
BF_{BFM}: calculated phosphorus release without pH impact(g P m^{-2} day^{-1});
K_{PH}: the effect of pH on phosphorus exchange rate;
PH: pH value of the overlying water.
PHR: reference pH value of the overlying water column

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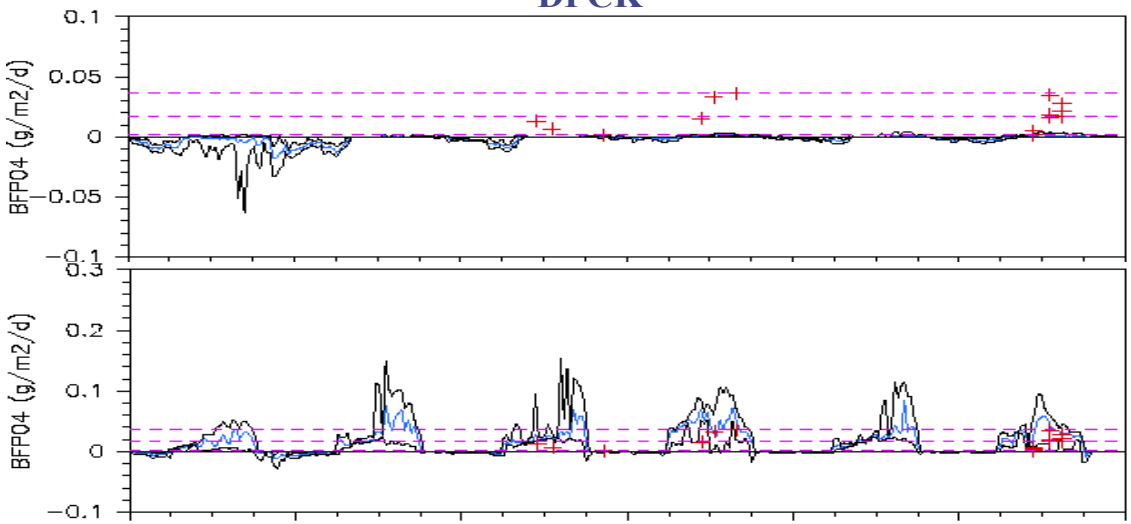
Model results after implementing pH function …

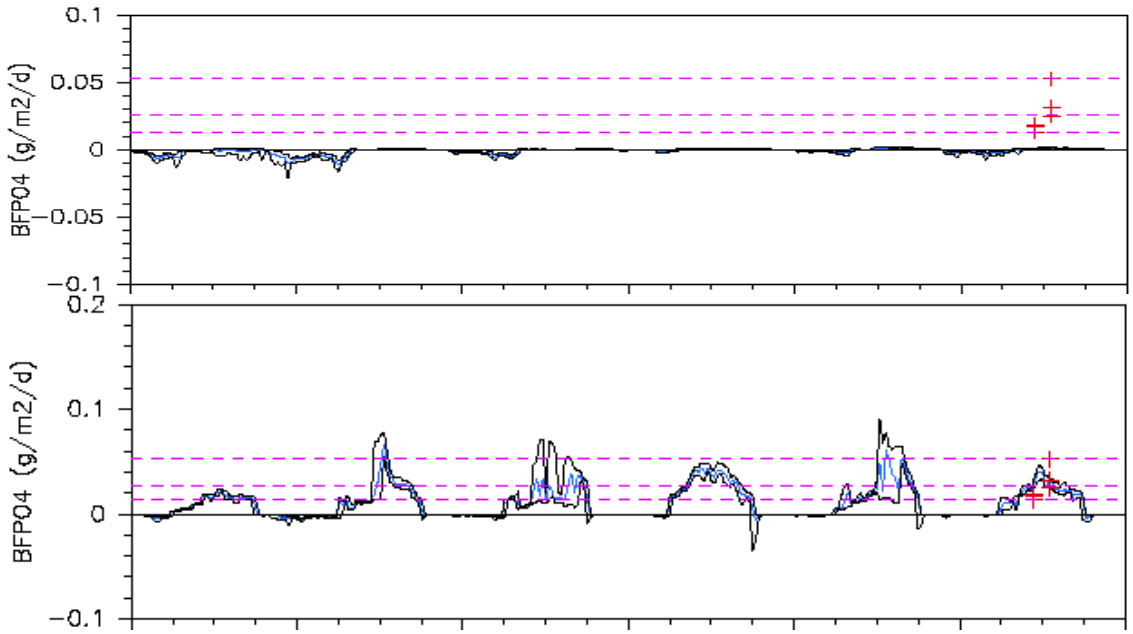
DPCK



Before (apply pH function)

After (apply pH function)

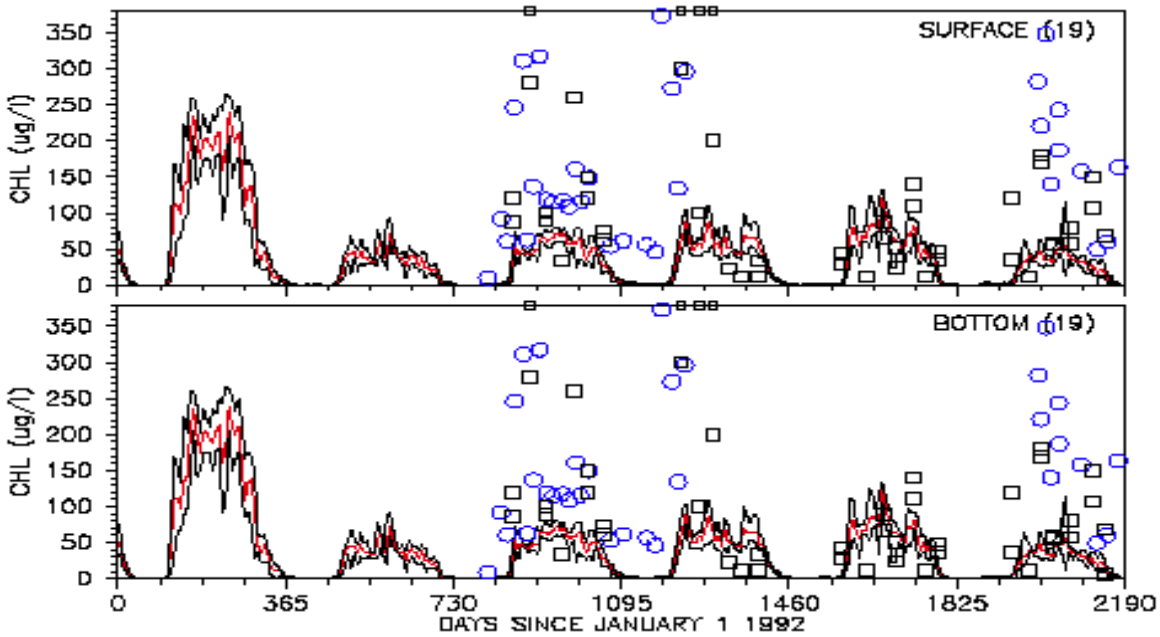
MDGT



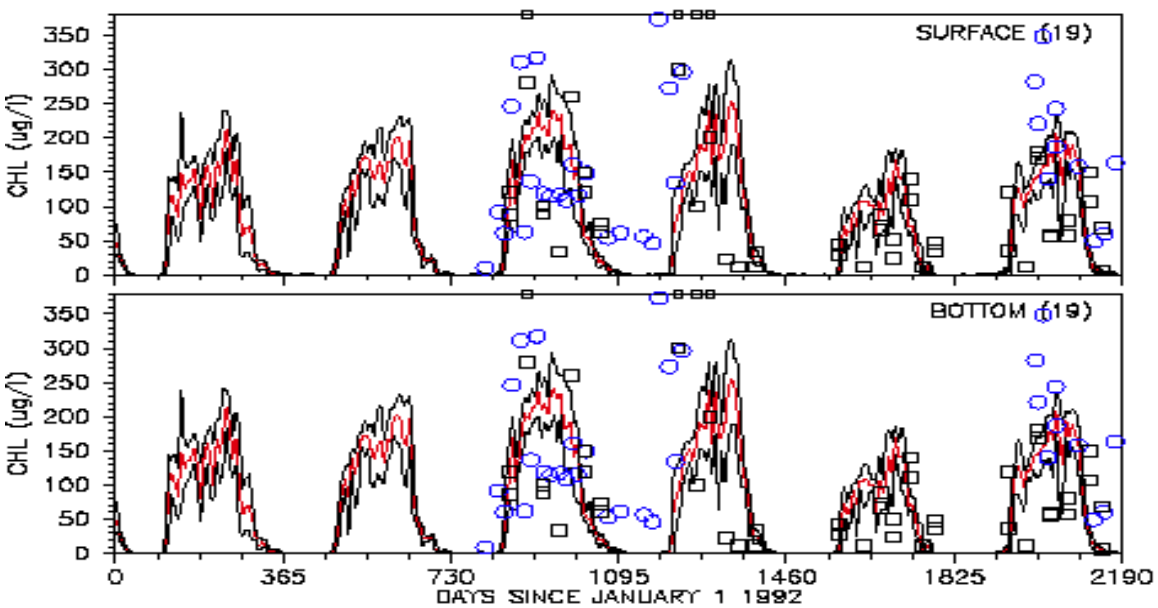
Before (apply pH function)

After (apply pH function)

M05



Before
(apply pH function)



After
(apply pH function)

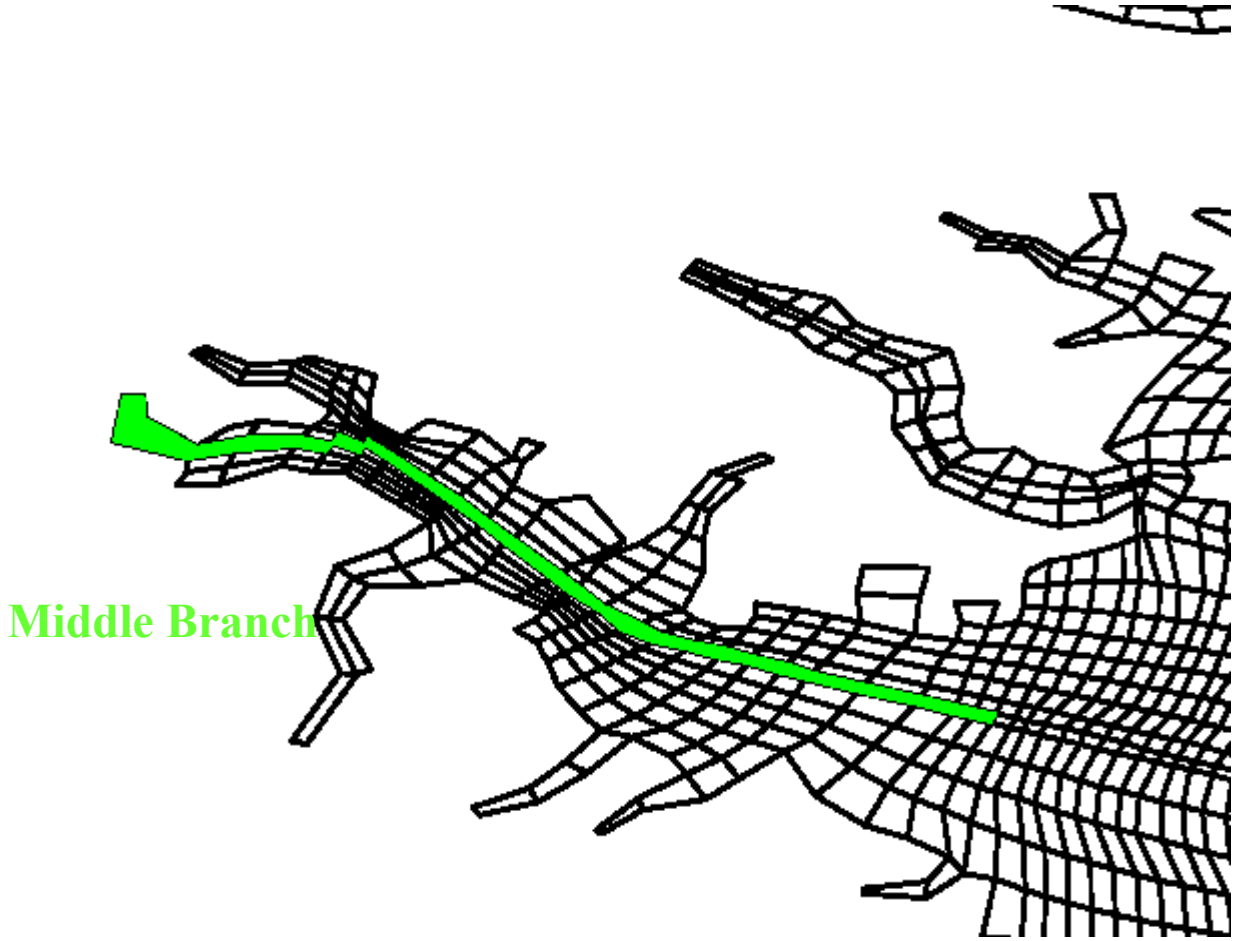
Model Output Vs. Observed Data

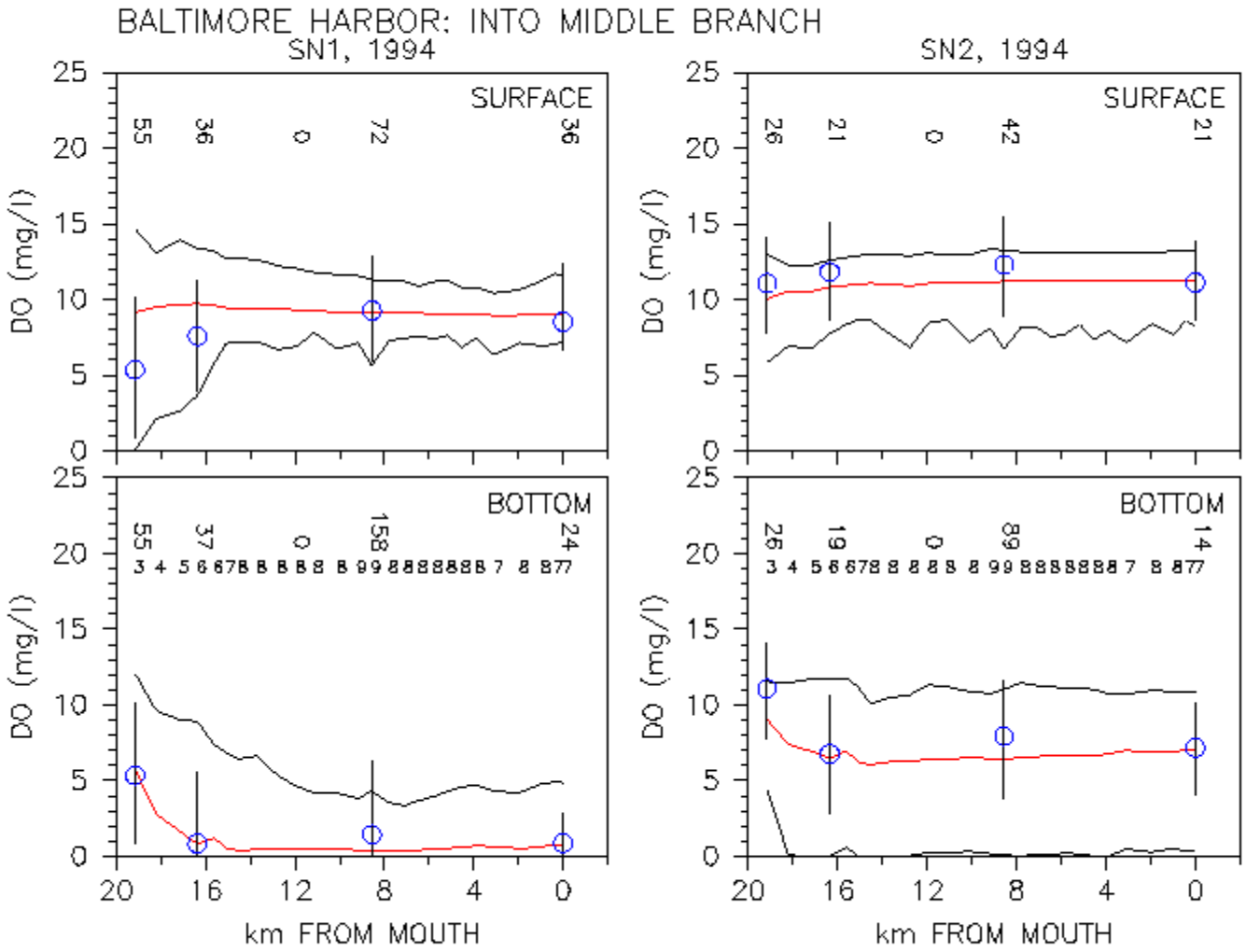
LONGITUDINAL PROFILES

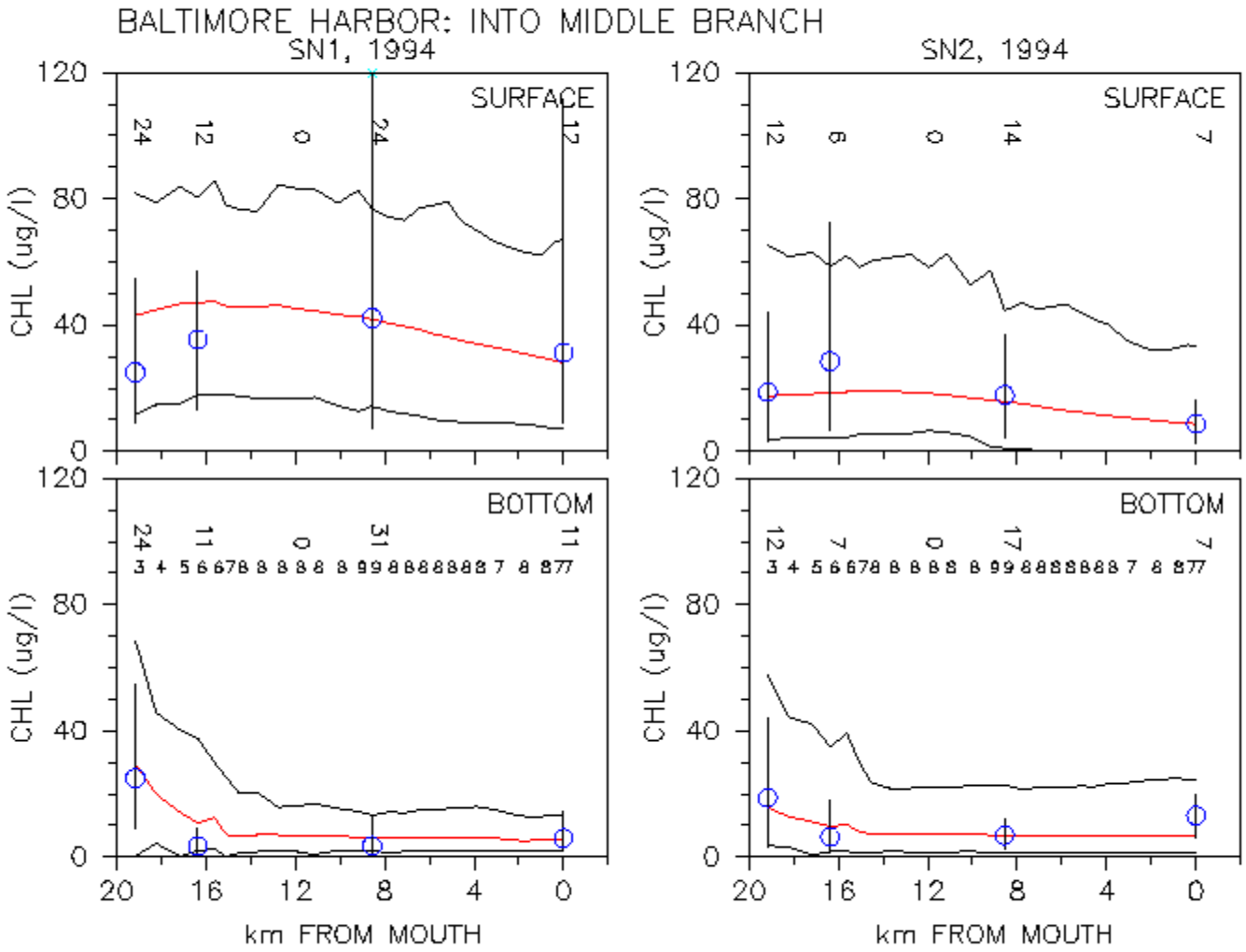
(1) Main Chesapeake Bay Channel
(2) Baltimore Harbor Main Channel - to Middle Branch
(3) Baltimore Harbor Main Channel - to Inner Harbor
(4) Baltimore Harbor mouth transection
(5) Bear Creek transection
(6) Curtis Creek transection
(7) Back River transection

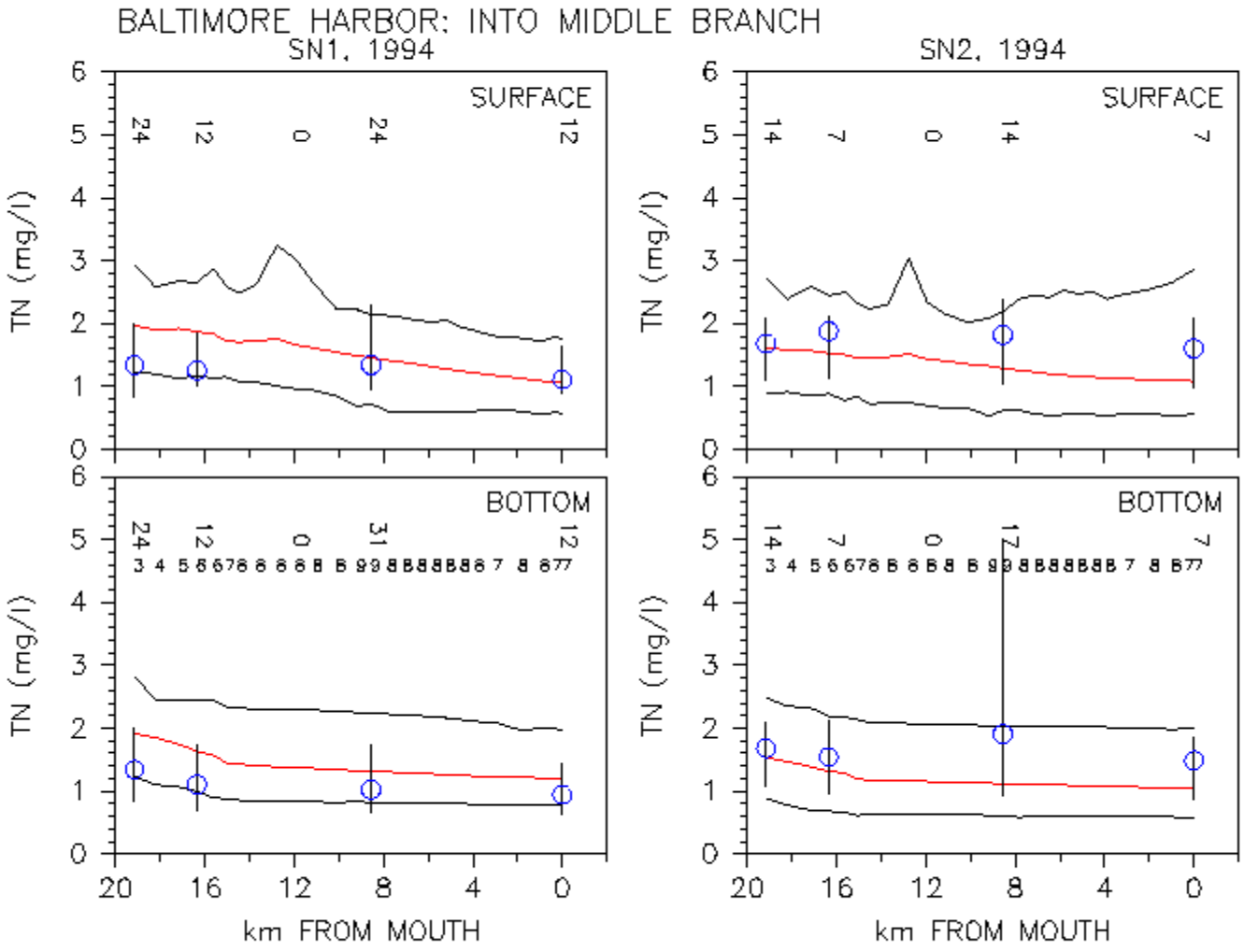
MDE

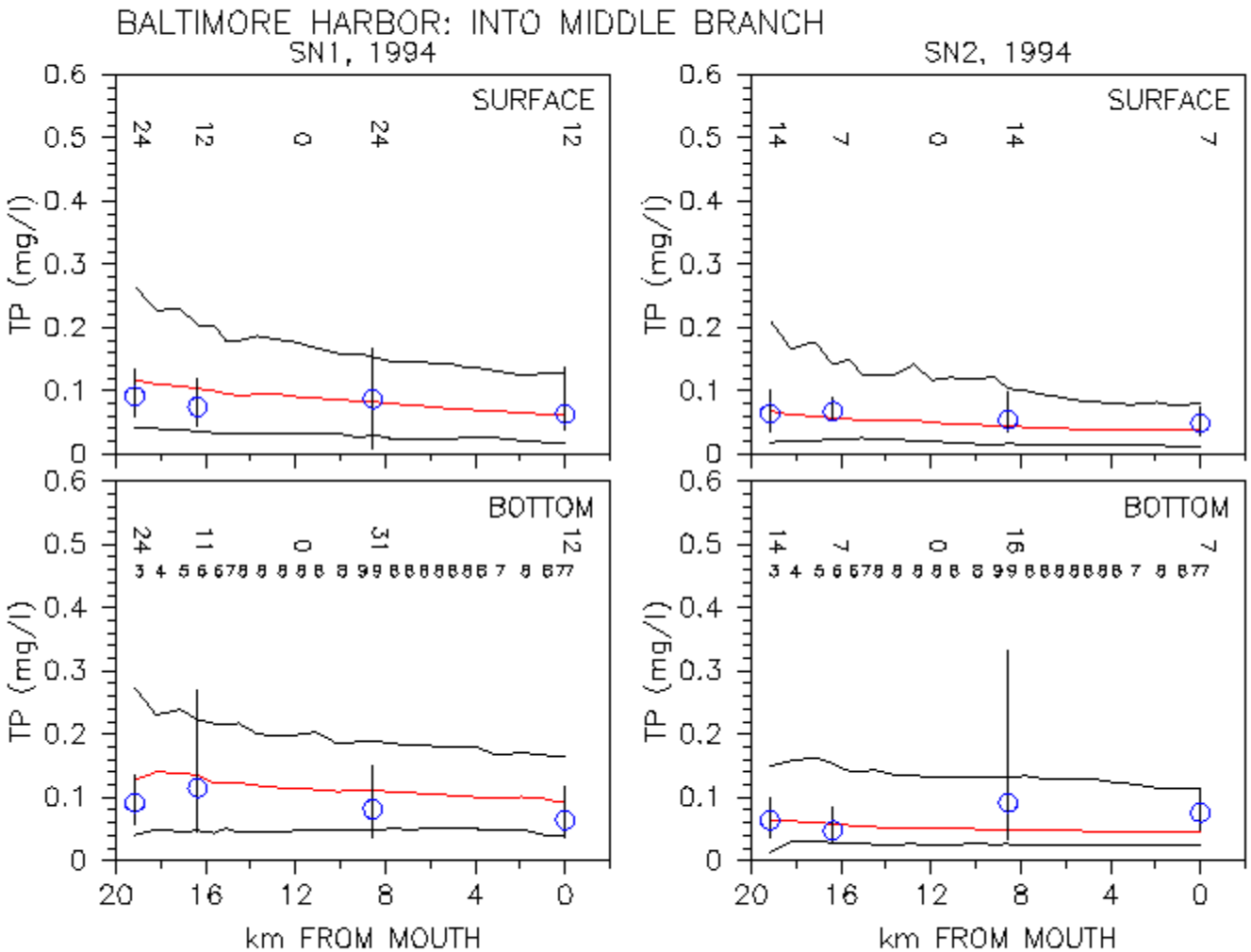
Baltimore Harbor Main Channel
--- to Middle Branch



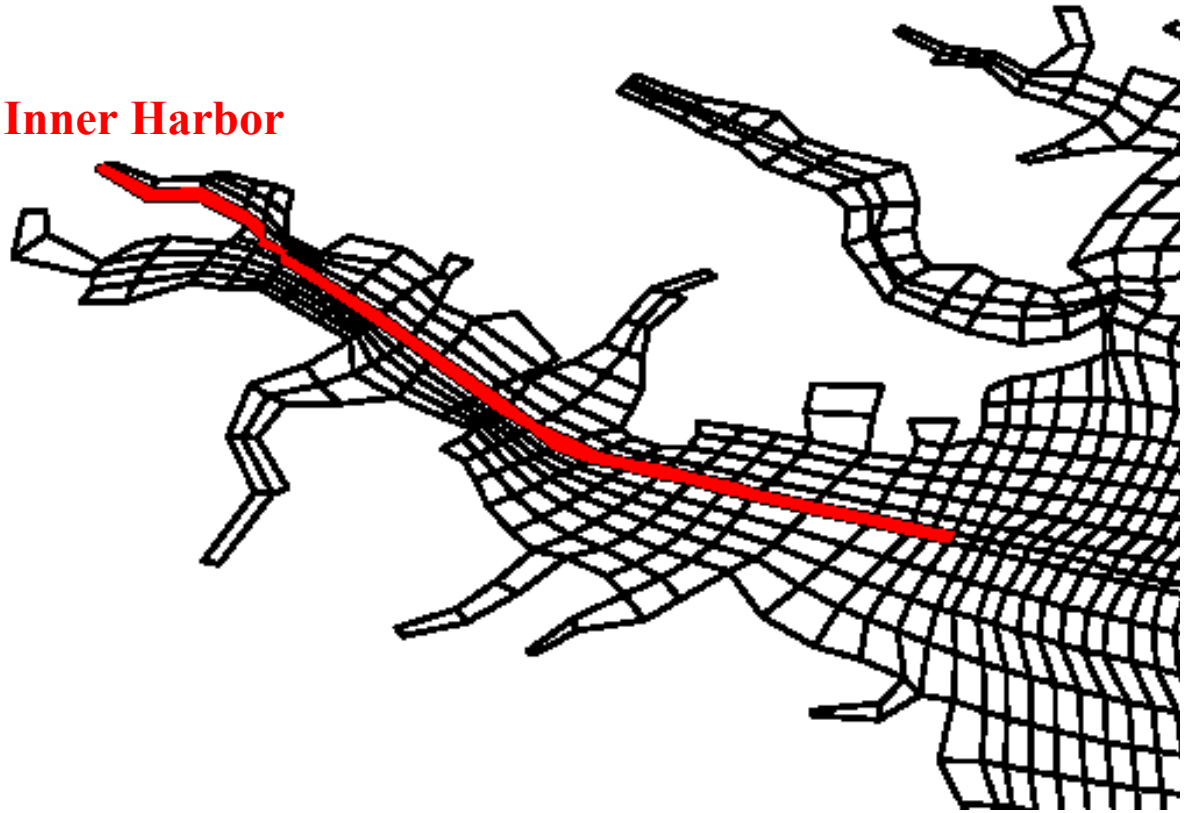

BALTIMORE HARBOR: INTO MIDDLE BRANCH
SN1, 1994
SN2, 1994
SURFACE
BOTTOM
DO (mg/l)
km FROM MOUTH
0
5
10
15
20
25
20
16
12
8
4
0
55
36
0
72
36
26
21
0
42
21
37
158
24
19
89
14

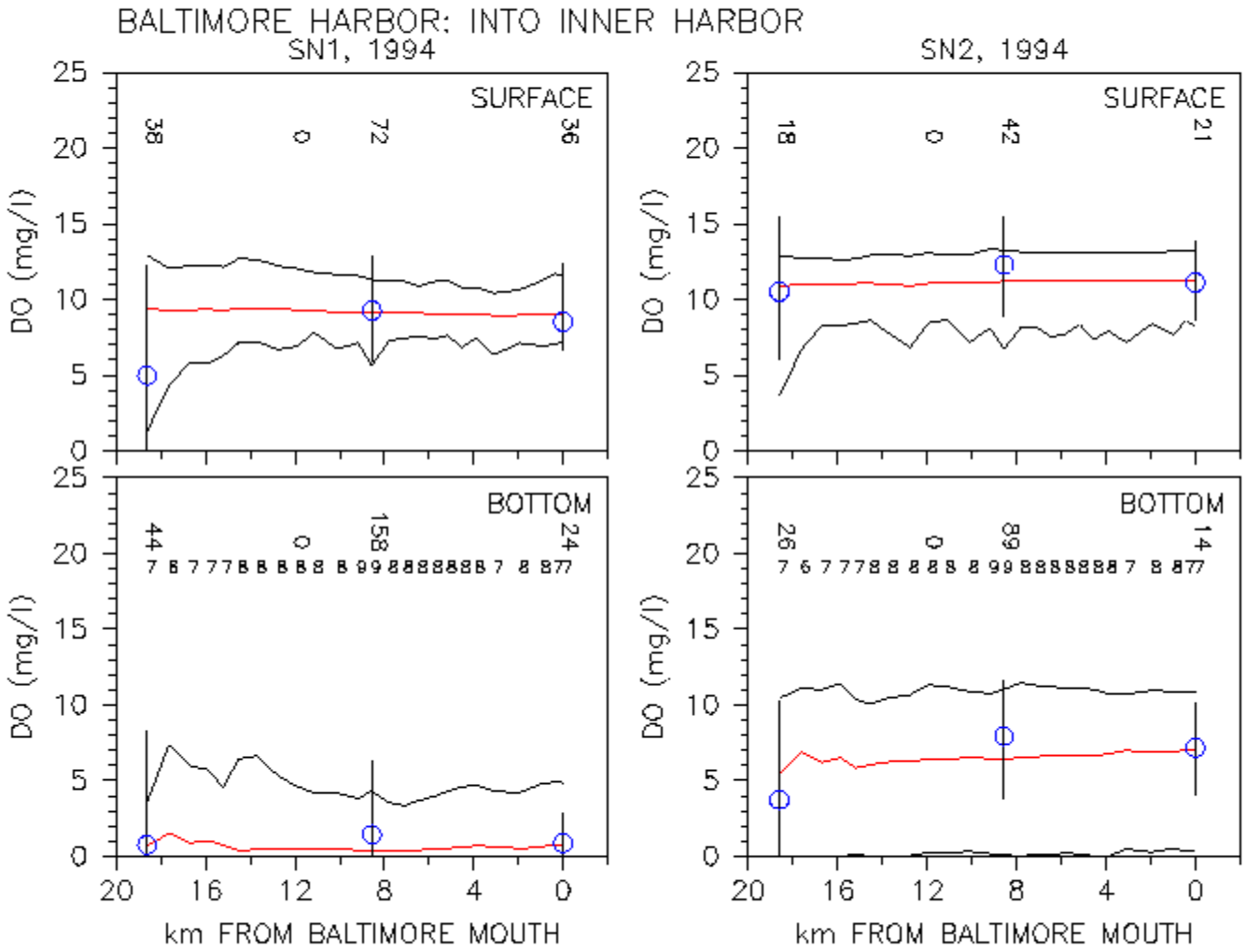

BALTIMORE HARBOR: INTO MIDDLE BRANCH
SN1, 1994
SN2, 1994
SURFACE
BOTTOM
CHL (ug/l)
km FROM MOUTH
0
40
80
120
20
16
12
8
4
0

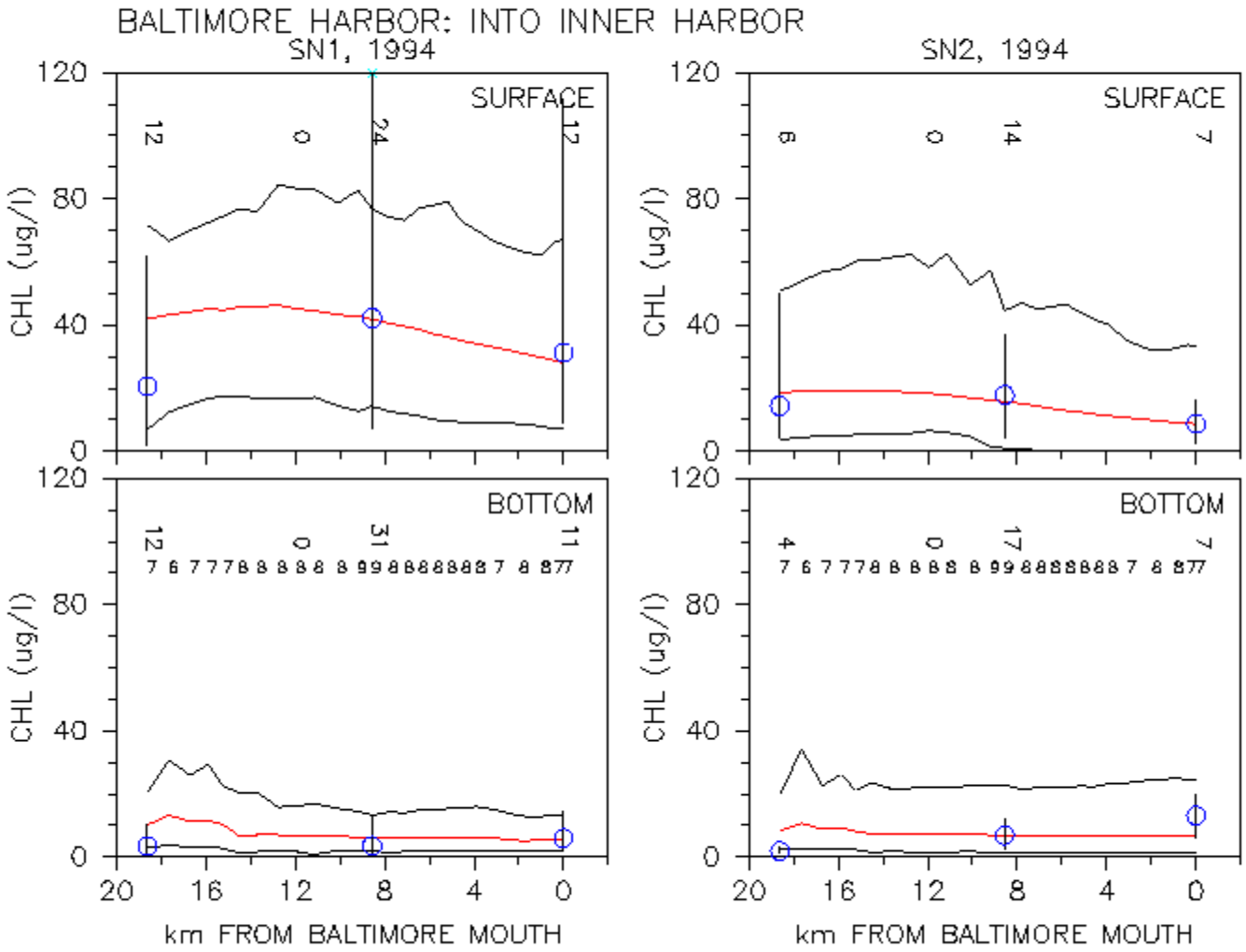

BALTIMORE HARBOR: INTO MIDDLE BRANCH
SN1, 1994
SN2, 1994
SURFACE
BOTTOM
TN (mg/l)
km FROM MOUTH
0
1
2
3
4
5
6
20
16
12
8
4
0

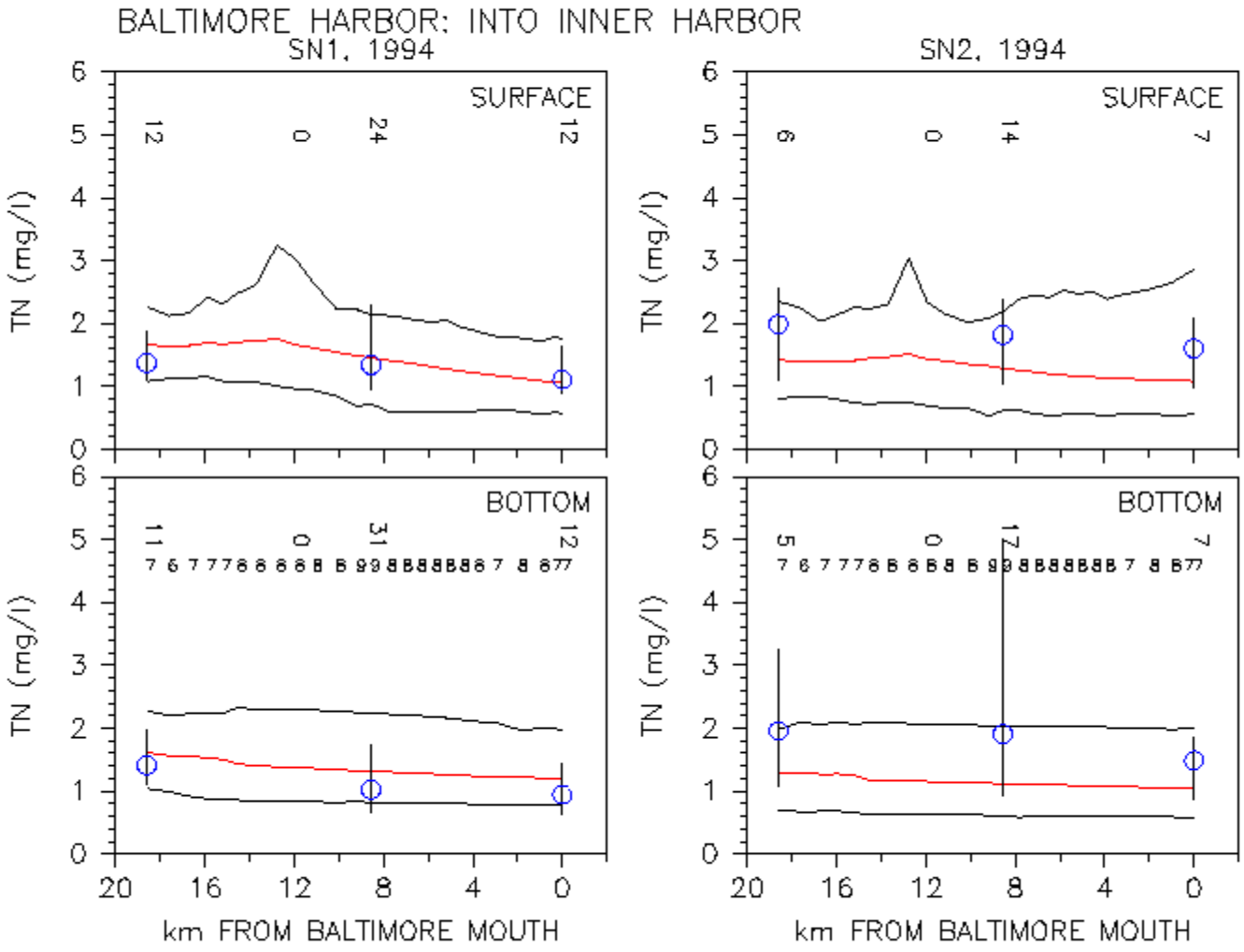

BALTIMORE HARBOR: INTO MIDDLE BRANCH
SN1, 1994
SN2, 1994
SURFACE
BOTTOM
TP (mg/l)
km FROM MOUTH
0.6
0.5
0.4
0.3
0.2
0.1
0
20
16
12
8
4
0

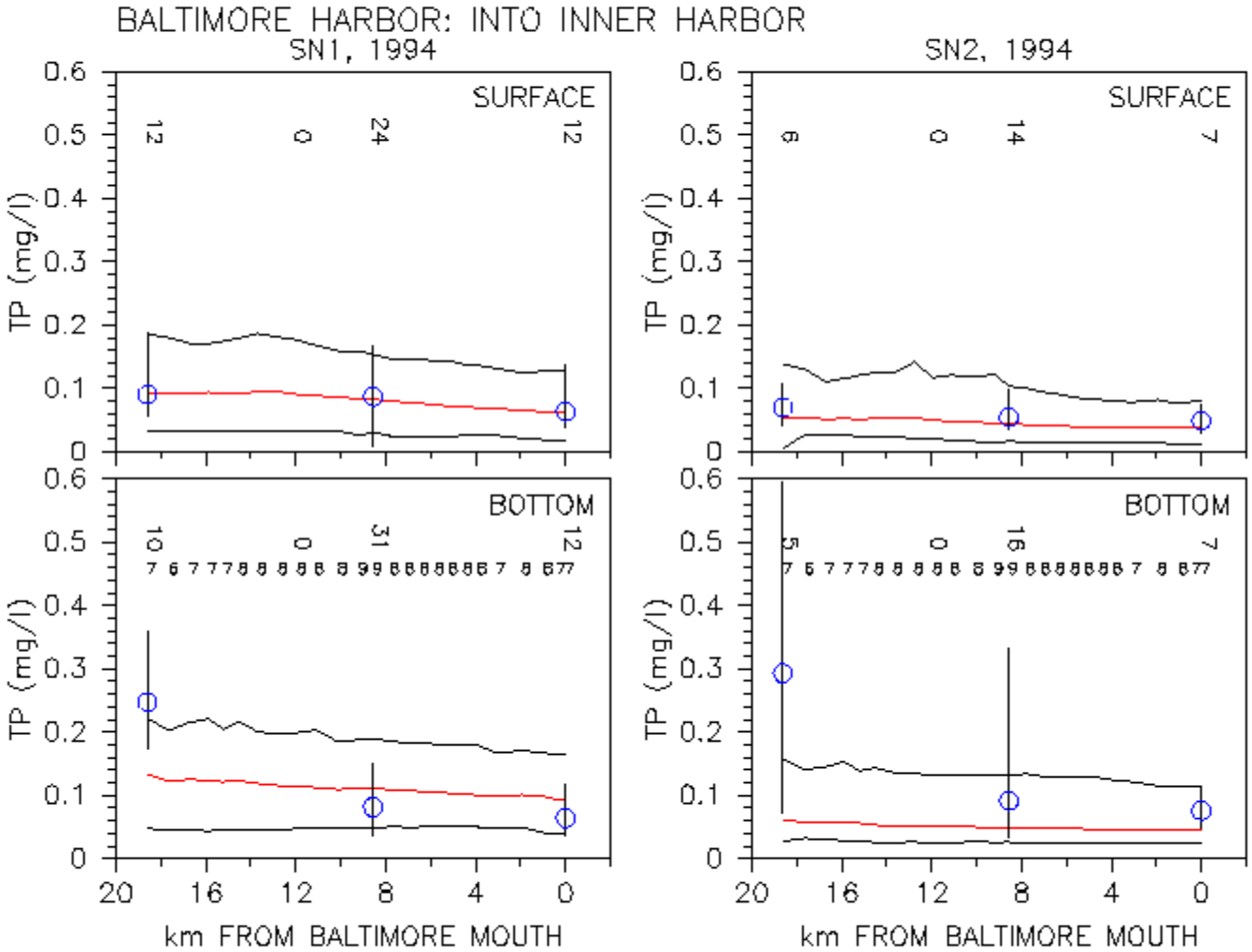
Baltimore Harbor Main Channel
--- to Inner Harbor



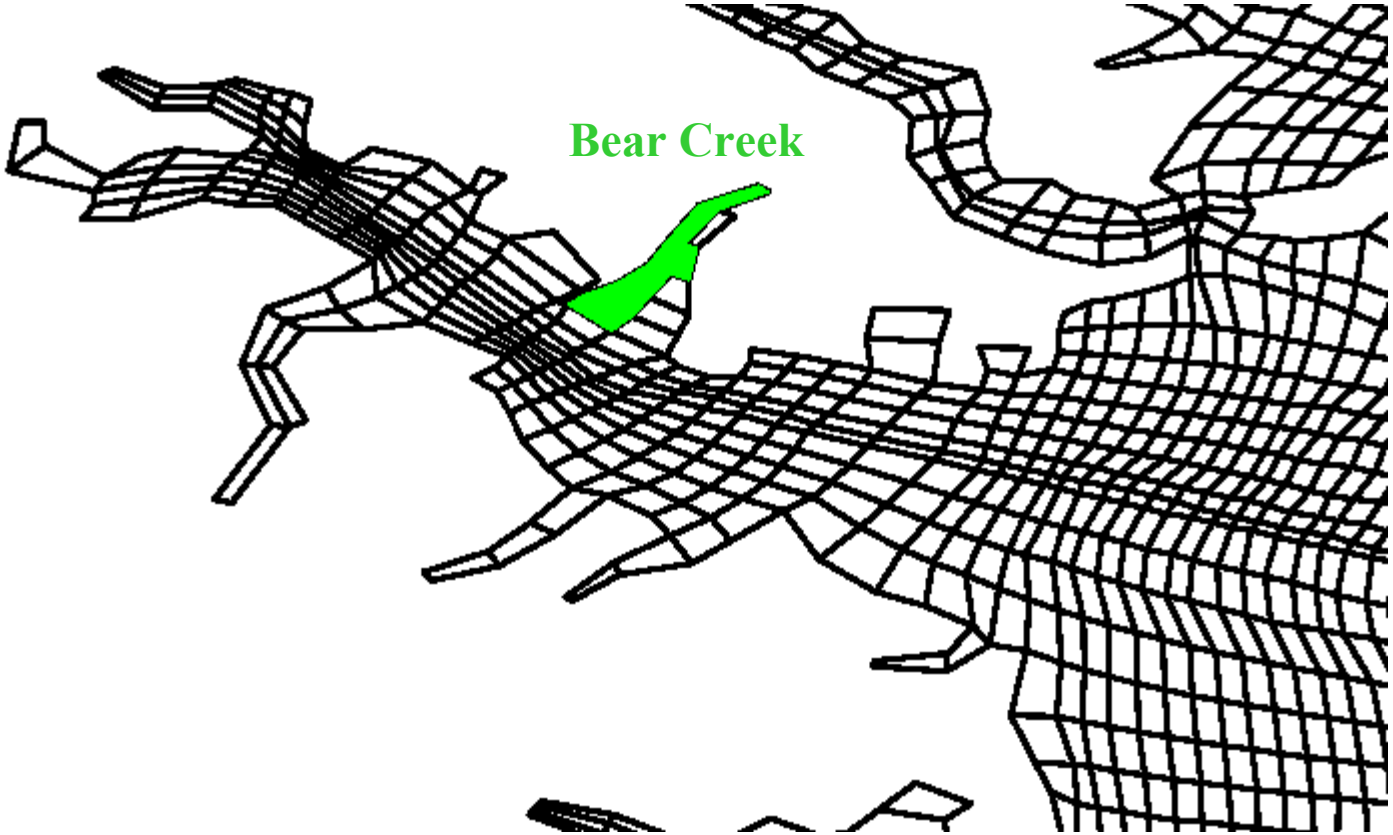

BALTIMORE HARBOR: INTO INNER HARBOR
SN1, 1994
SN2, 1994
SURFACE
BOTTOM
DO (mg/l)
km FROM BALTIMORE MOUTH
38
0
72
36
18
42
21
44
158
24
26
89
14

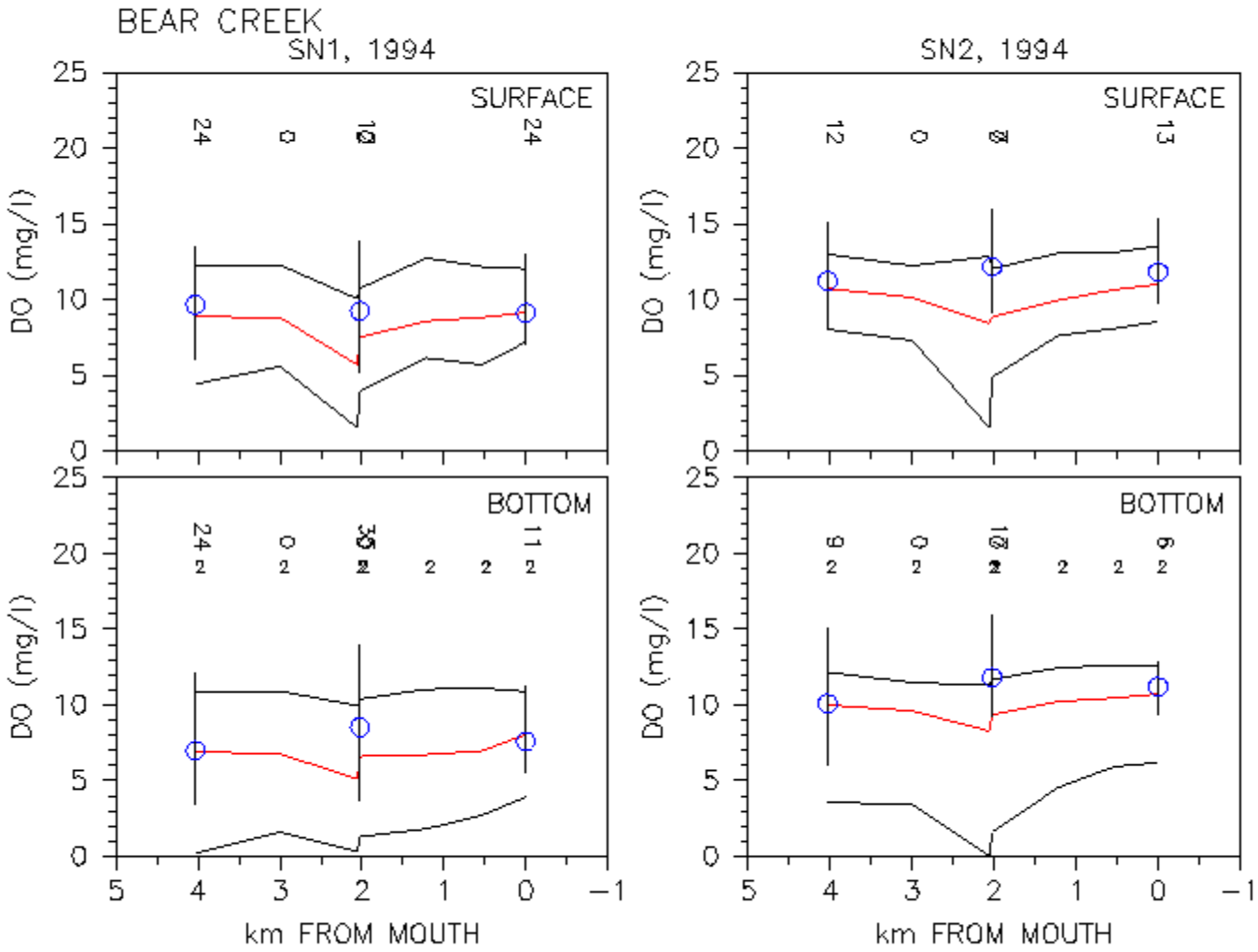

BALTIMORE HARBOR: INTO INNER HARBOR
SN1, 1994
SN2, 1994
SURFACE
BOTTOM
CHL (ug/l)
km FROM BALTIMORE MOUTH
120
80
40
0
20
16
12
8
4
0

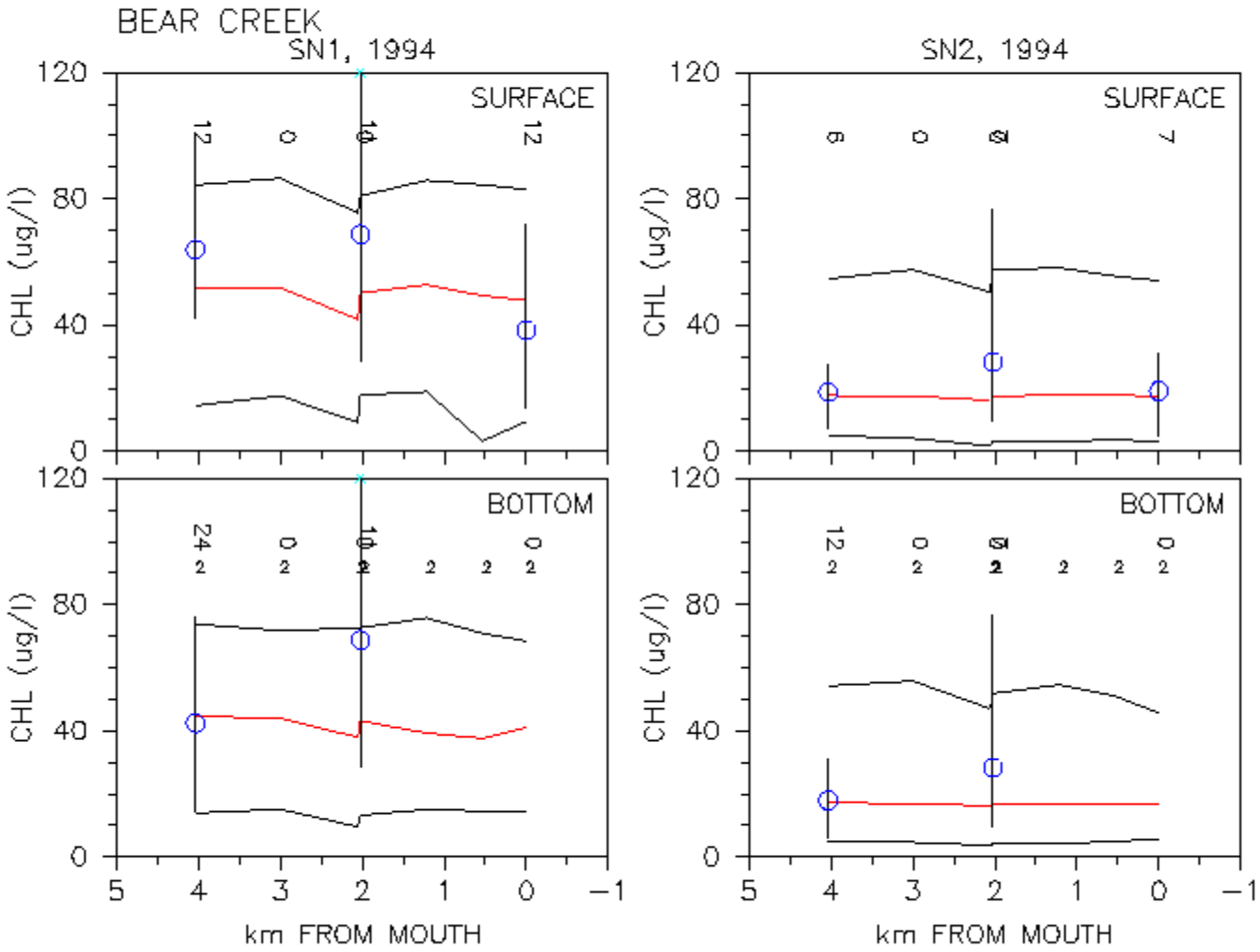

BALTIMORE HARBOR: INTO INNER HARBOR
SN1, 1994
SN2, 1994
SURFACE
BOTTOM
TN (mg/l)
km FROM BALTIMORE MOUTH
0
1
2
3
4
5
6
20
16
12
8
4
0

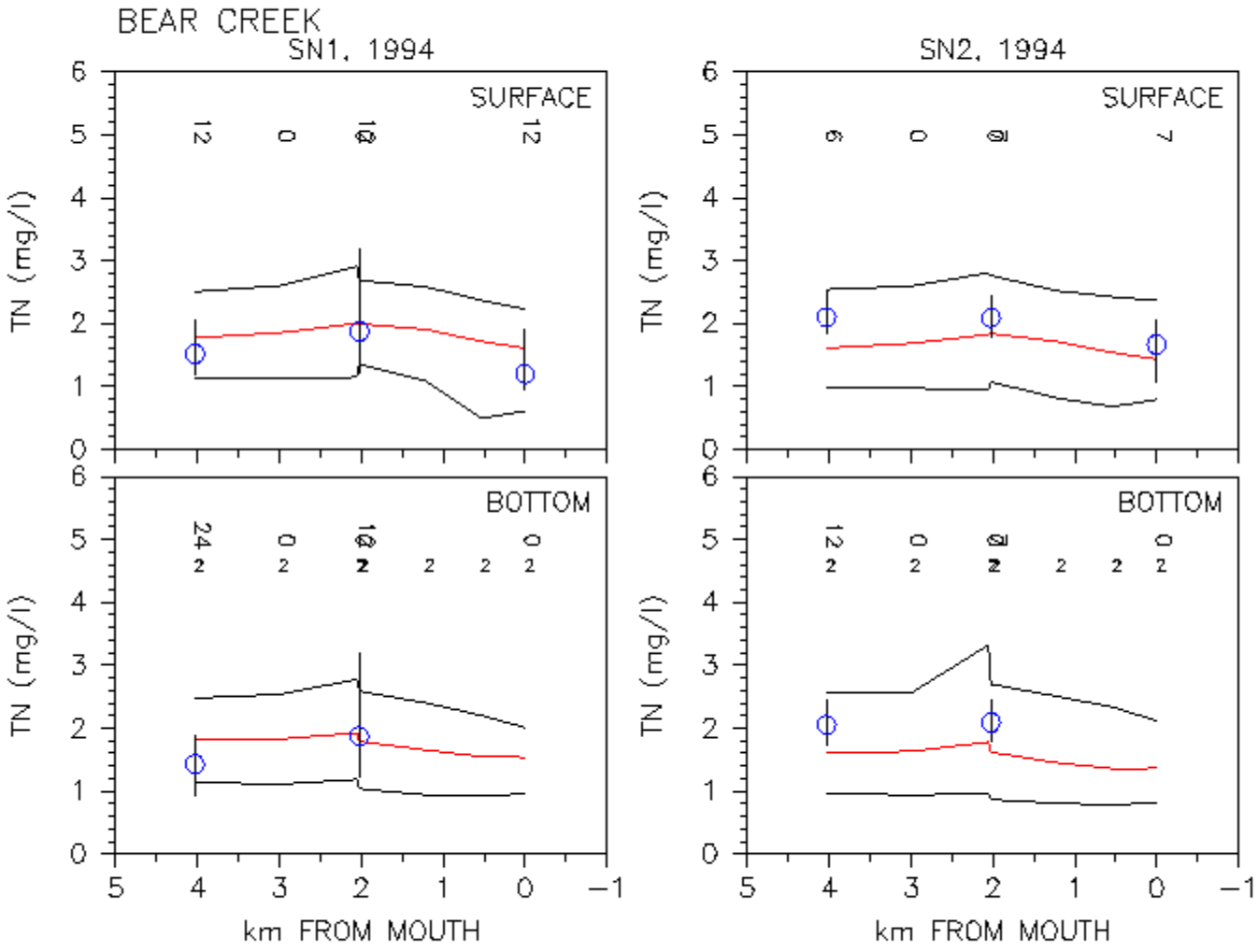

BALTIMORE HARBOR: INTO INNER HARBOR
SN1, 1994
SN2, 1994
SURFACE
BOTTOM
TP (mg/l)
0.6
0.5
0.4
0.3
0.2
0.1
0
20
16
12
8
4
km FROM BALTIMORE MOUTH

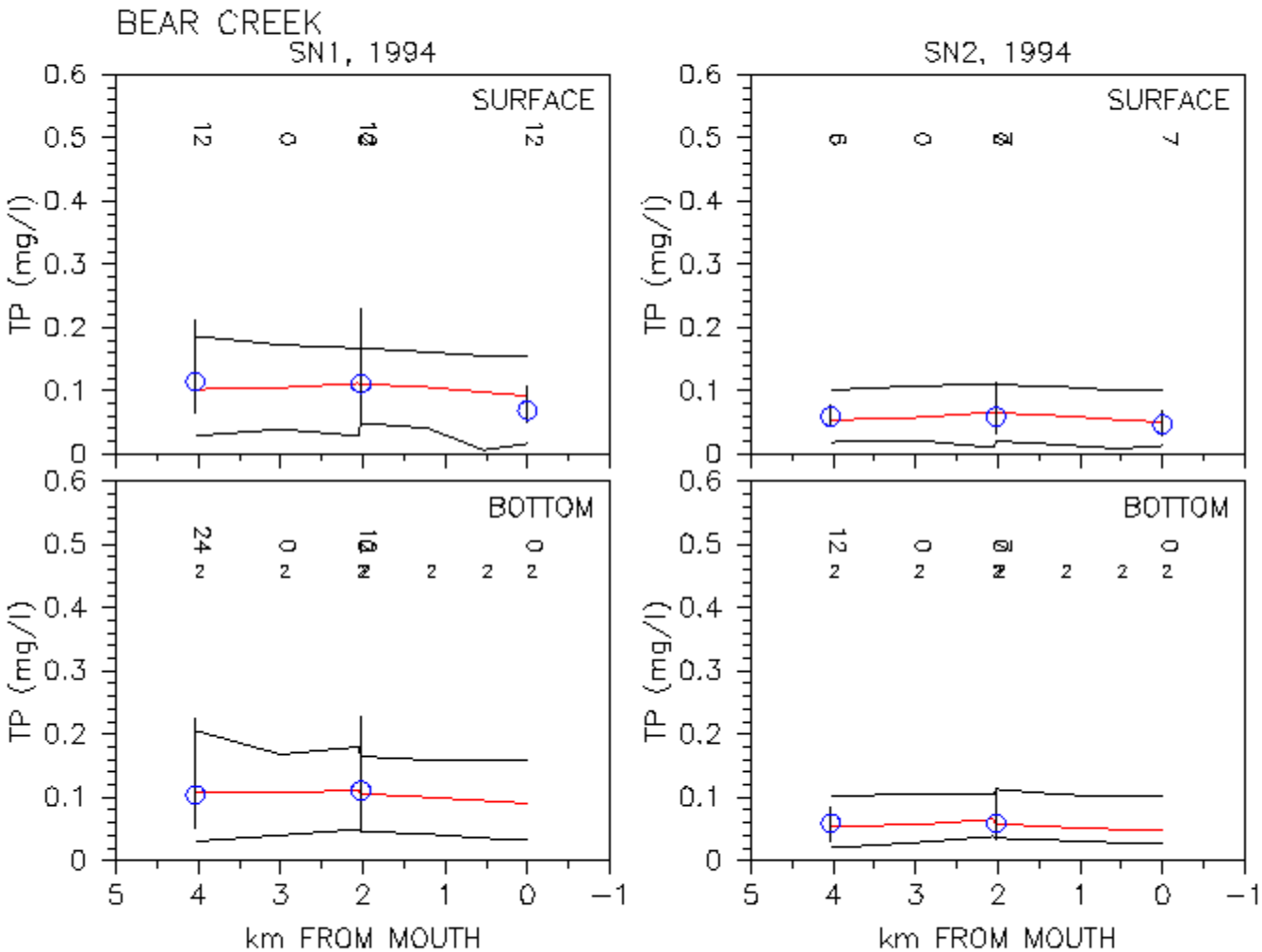
Bear Creek transection



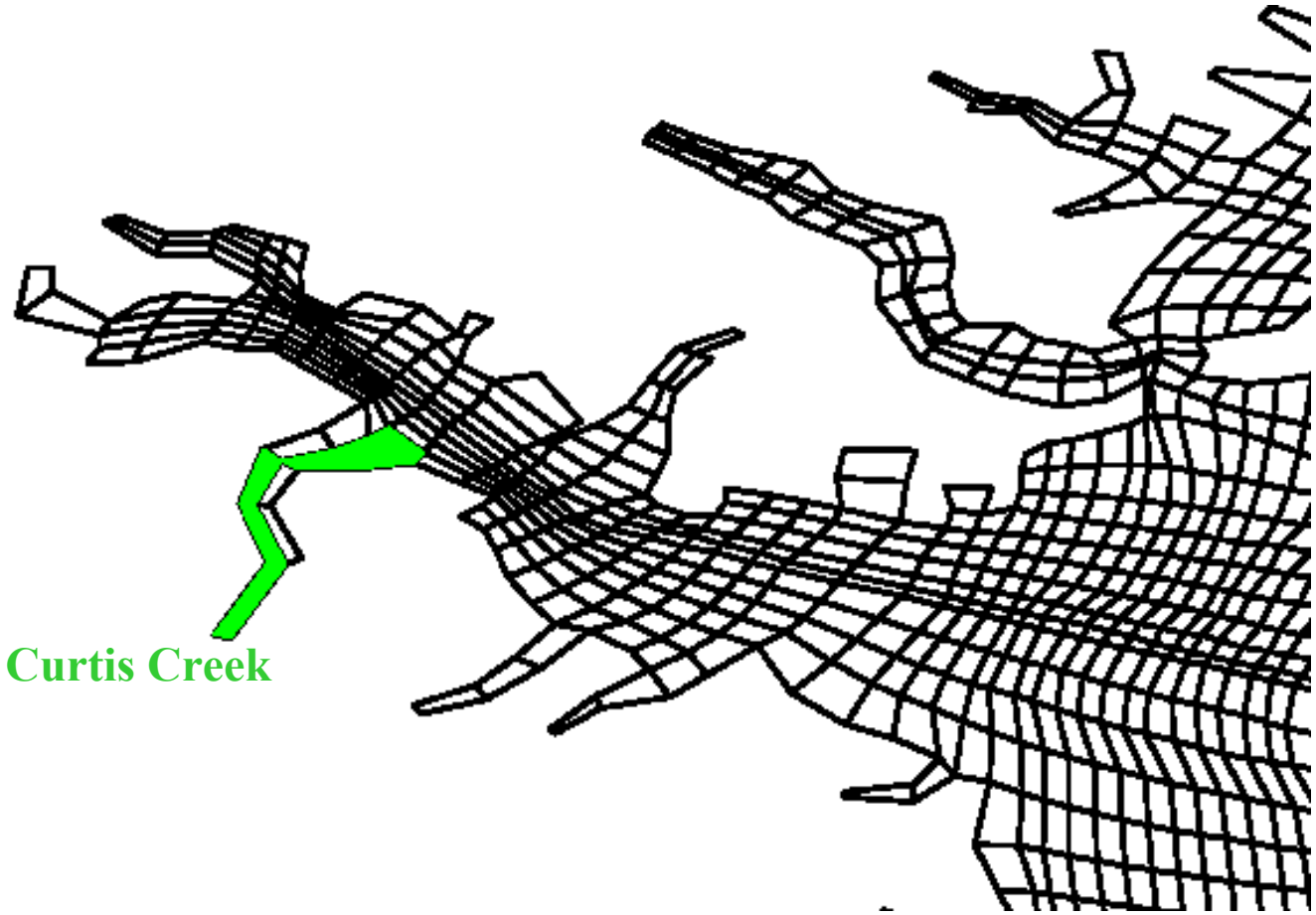

BEAR CREEK
SN1, 1994
SN2, 1994
SURFACE
BOTTOM
DO (mg/l)
km FROM MOUTH

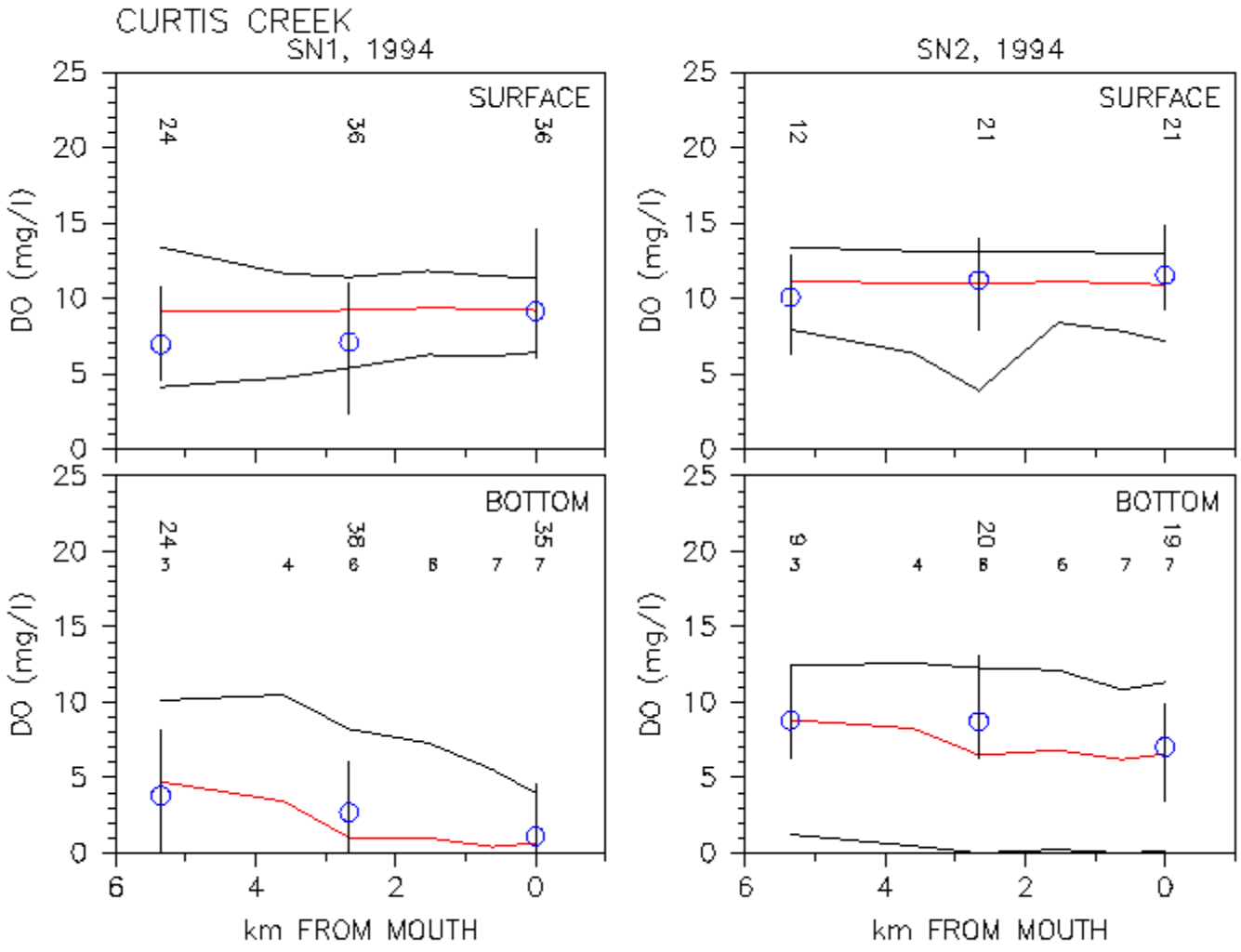

BEAR CREEK
SN1, 1994
SN2, 1994
SURFACE
BOTTOM
CHL (ug/l)
km FROM MOUTH
120
80
40
0
5
4
3
2
1
0
−1

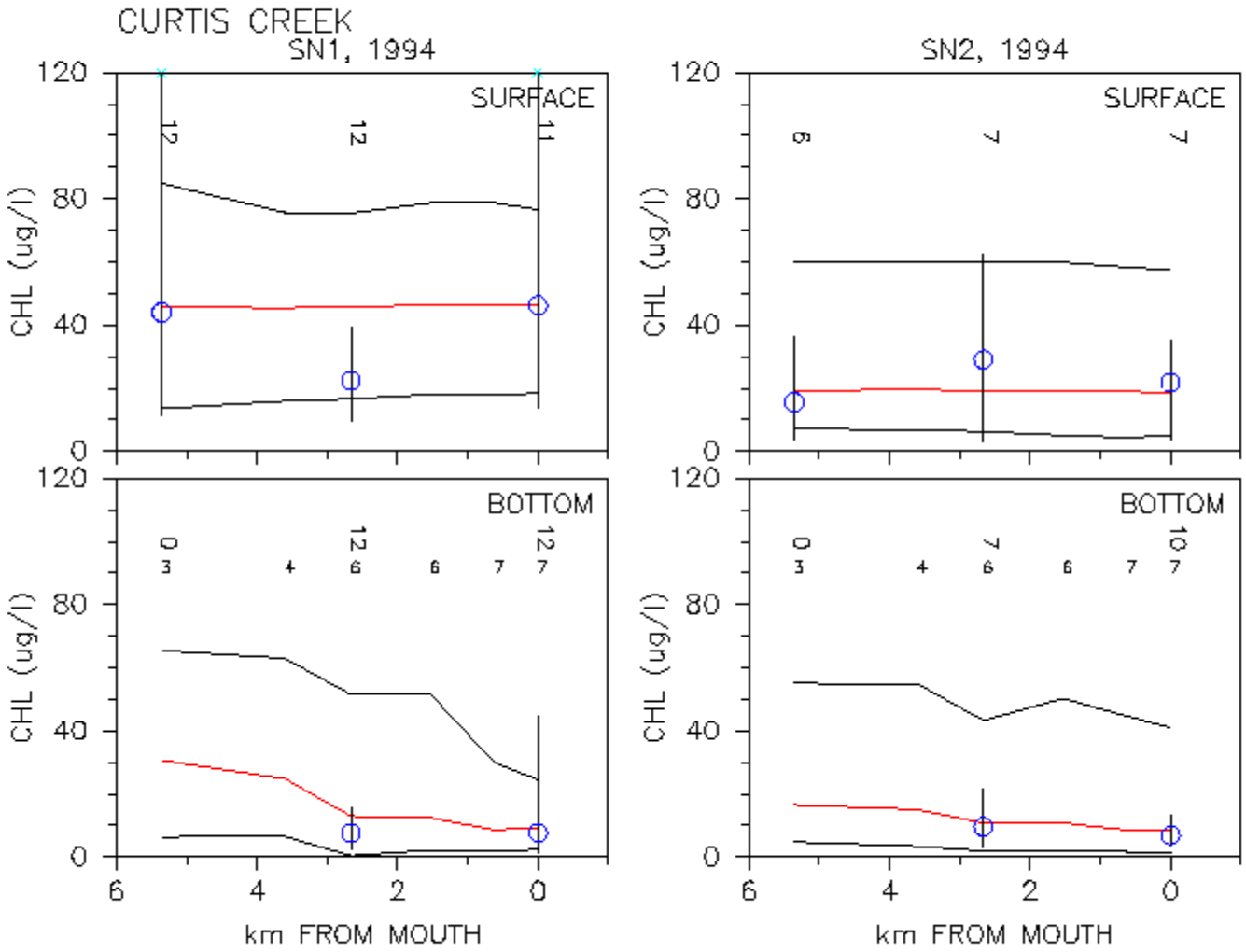

BEAR CREEK
SN1, 1994
SN2, 1994
SURFACE
BOTTOM
TN (mg/l)
km FROM MOUTH

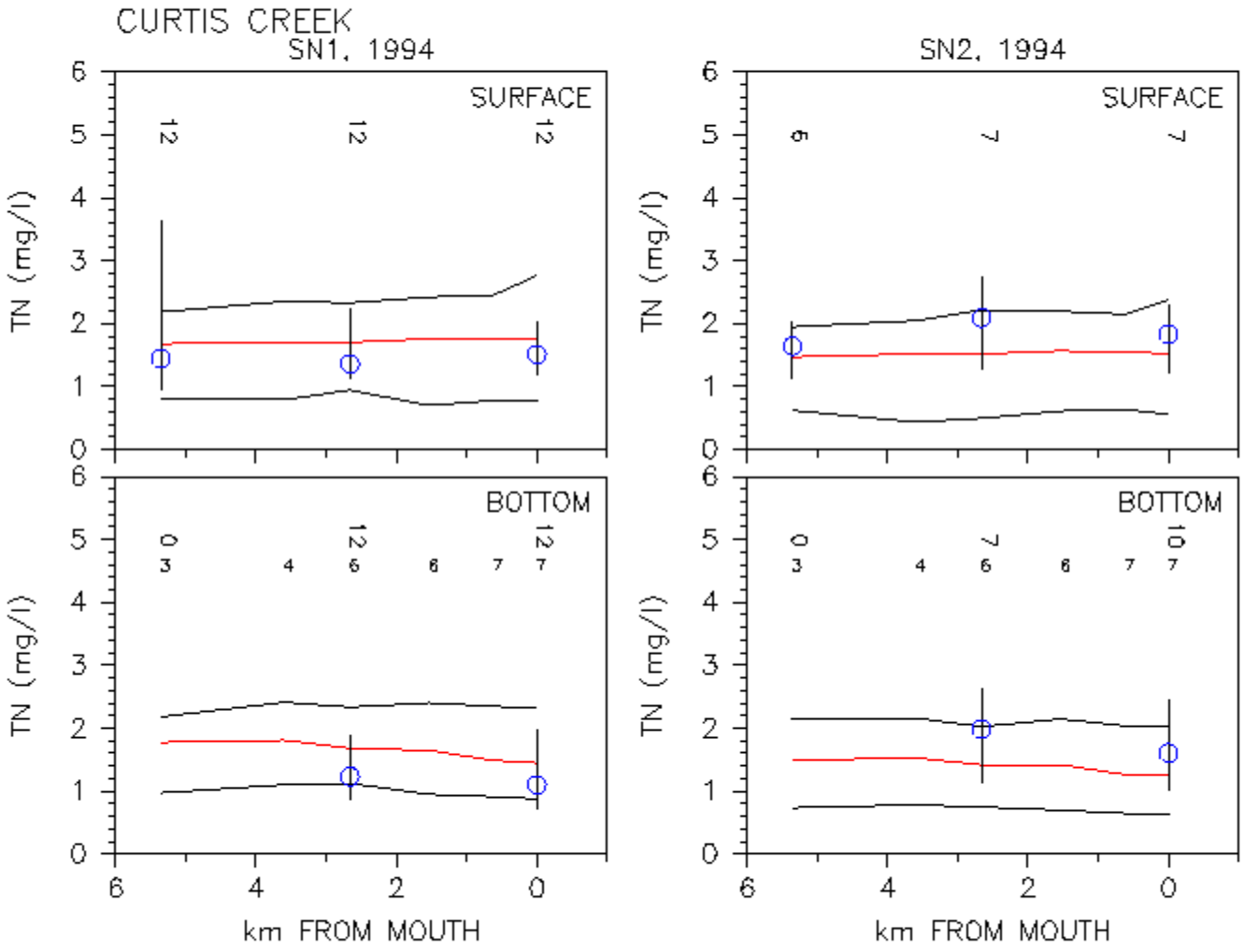

BEAR CREEK
SN1, 1994
SN2, 1994
SURFACE
BOTTOM
TP (mg/l)
km FROM MOUTH
0.6
0.5
0.4
0.3
0.2
0.1
0
5
4
3
2
1
0
−1

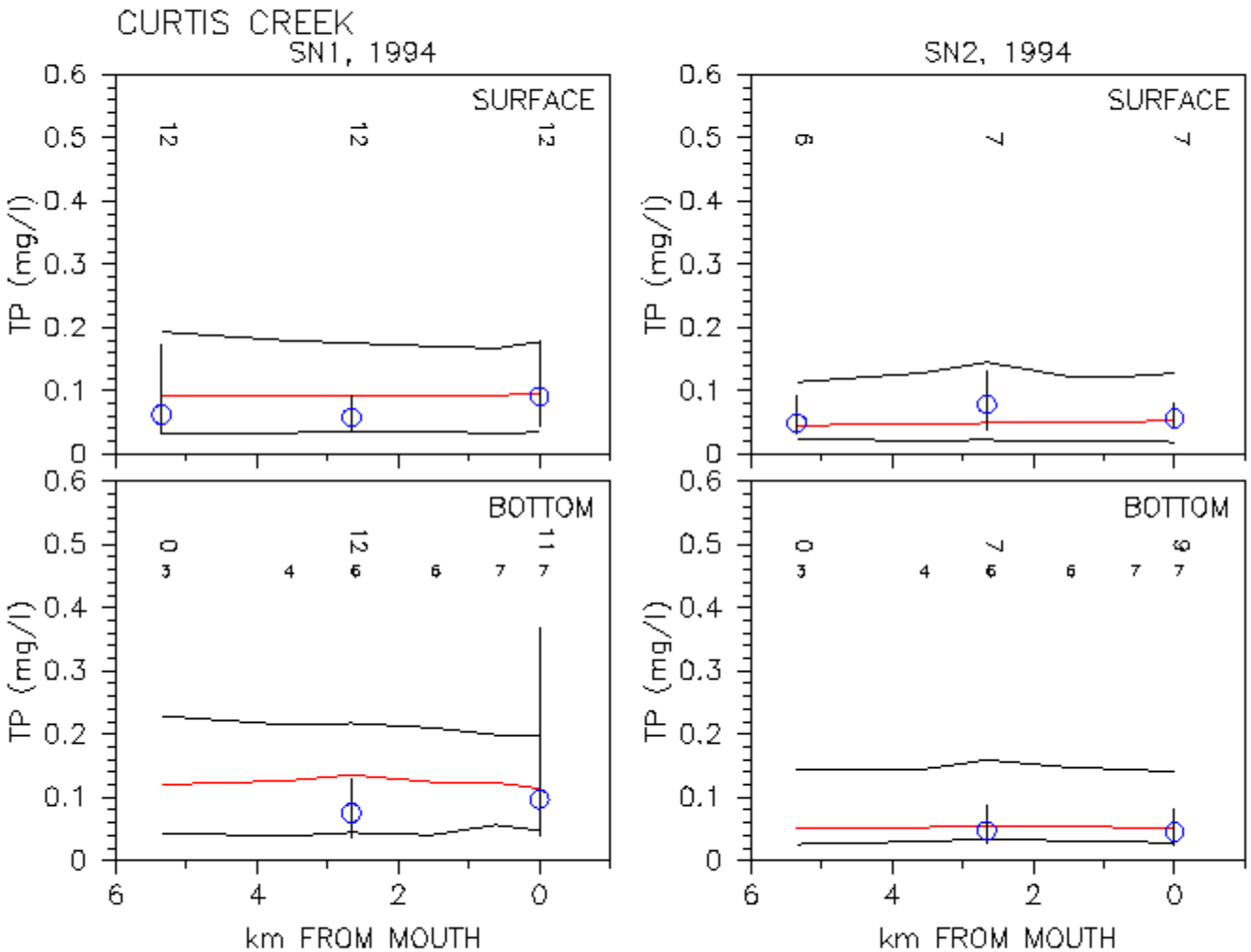
Curtis Creek transection



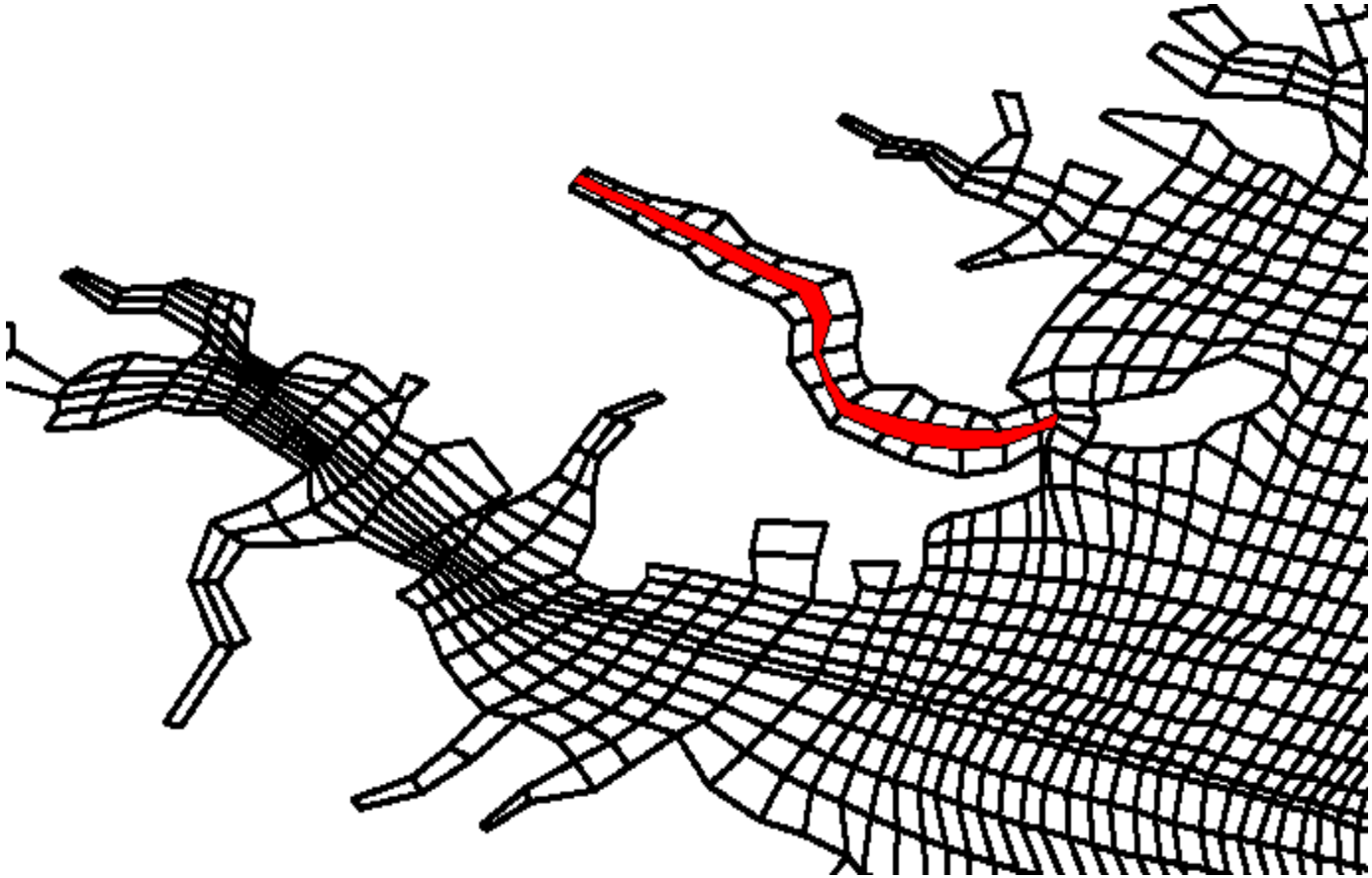

CURTIS CREEK
SN1, 1994
SN2, 1994
SURFACE
BOTTOM
DO (mg/l)
km FROM MOUTH
0
5
10
15
20
25
6
4
2
0
24
36
36
12
21
21
24
3
4
36
6
6
7
35
7
9
3
4
20
6
6
7
19
7

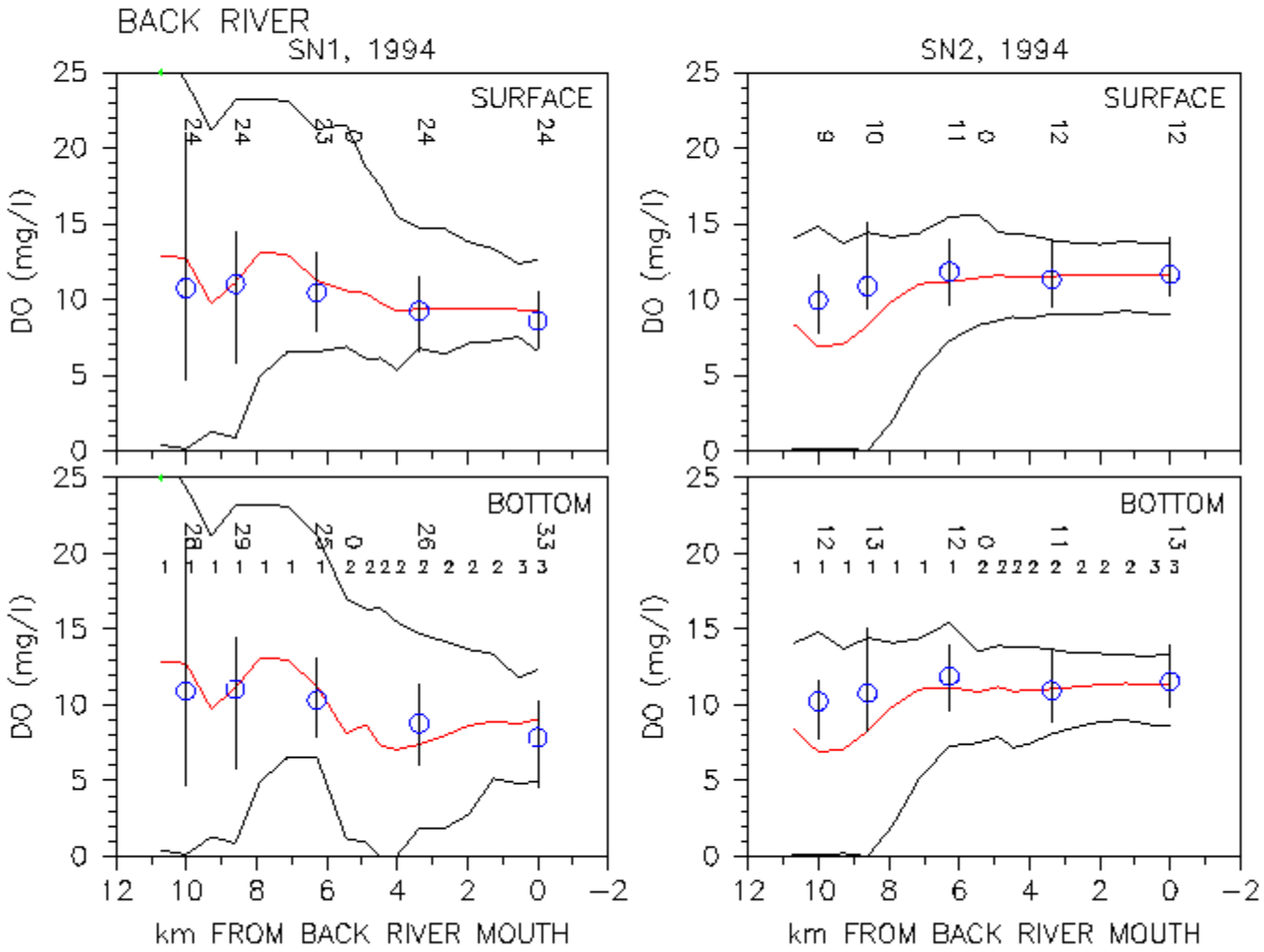

CURTIS CREEK
SN1, 1994
SN2, 1994
SURFACE
BOTTOM
CHL (ug/l)
km FROM MOUTH
120
80
40
0
6
4
2
0

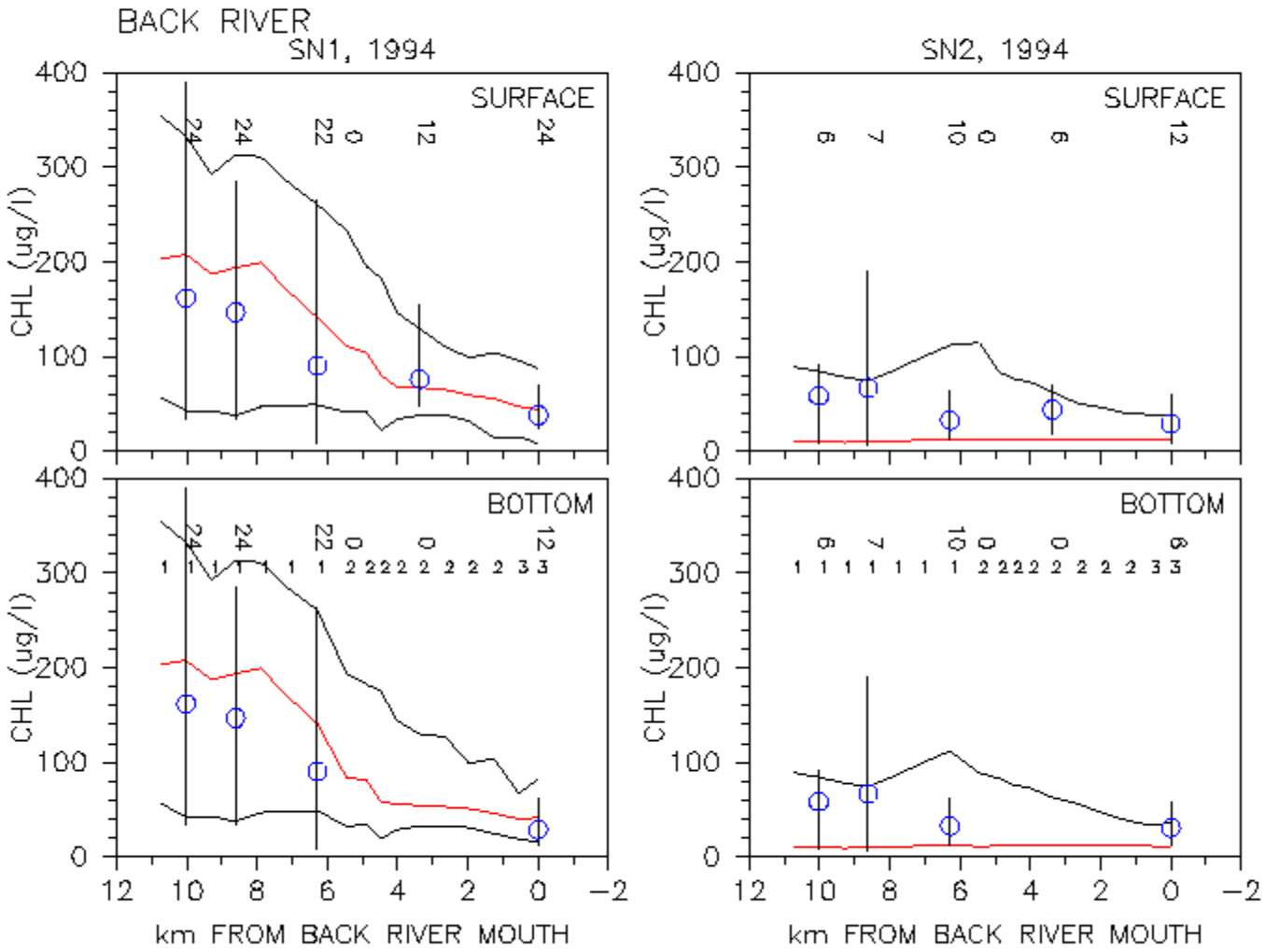

CURTIS CREEK
SN1, 1994
SN2, 1994
SURFACE
BOTTOM
TN (mg/l)
km FROM MOUTH

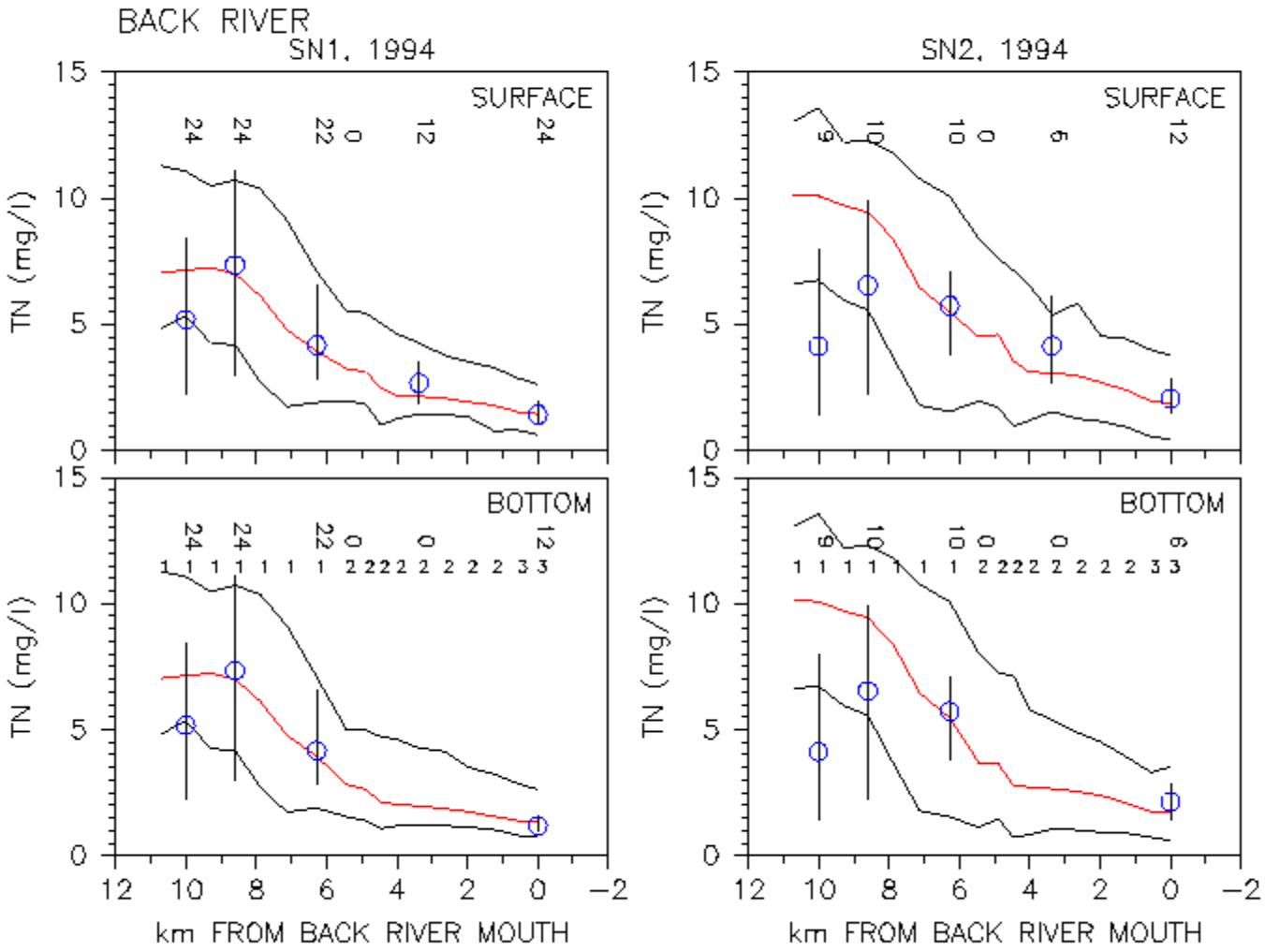

CURTIS CREEK
SN1, 1994
SN2, 1994
SURFACE
BOTTOM
TP (mg/l)
km FROM MOUTH
0.6
0.5
0.4
0.3
0.2
0.1
0
6
4
2
0

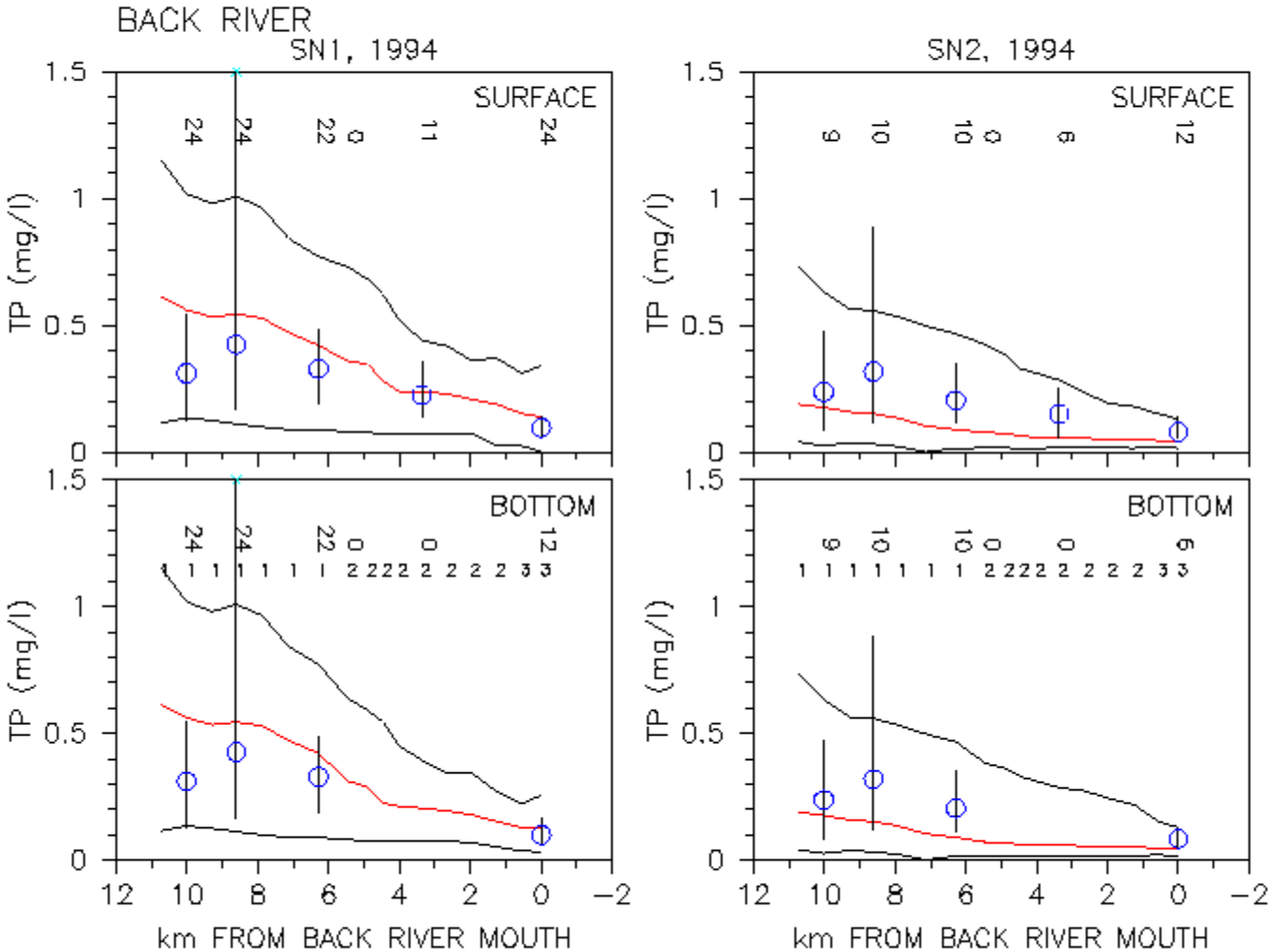
Back River transection




BACK RIVER
SN1, 1994
SN2, 1994
SURFACE
BOTTOM
DO (mg/l)
km FROM BACK RIVER MOUTH


BACK RIVER
SN1, 1994
SN2, 1994
SURFACE
BOTTOM
CHL (ug/l)
km FROM BACK RIVER MOUTH


BACK RIVER
SN1, 1994
SN2, 1994
SURFACE
BOTTOM
TN (mg/l)
km FROM BACK RIVER MOUTH


BACK RIVER
SN1, 1994
SN2, 1994
SURFACE
BOTTOM
TP (mg/l)
km FROM BACK RIVER MOUTH

Model Output Vs. Observed Data

SEDIMENT FLUXES

AN ENVIRONMENTAL EVALUATION OF BACK RIVER WITH SELECTED DATA FROM PATAPSCO RIVER

(June - September 1997)

PREPARED AT THE REQUEST OF:

Whitman Requardt and Associates, LLP
2315 St. Paul Street
Baltimore, MD 21218

FOR:

The Baltimore City Department of Public Works
Project 613
Master Waste Water Facilities Plan
The Wolman Building, North Holliday Street
Baltimore, MD 21202

PREPARED BY:

W.R. Boynton (Principal Investigator), N.H. Burger, R.M. Stankelis, F.M. Rohland, J.D. Hagy III, J.M. Frank, L.L. Matteson and M.M. Weir

University of Maryland Center for Environmental Science
Chesapeake Biological Laboratory (CBL)
Solomons, MD 20688-0038

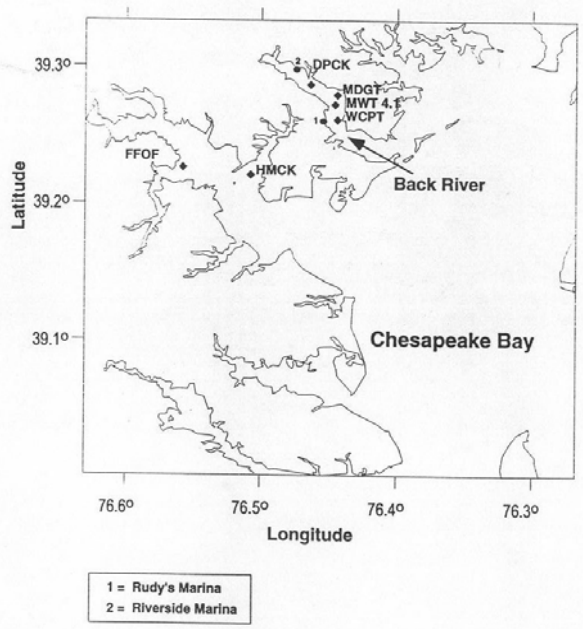
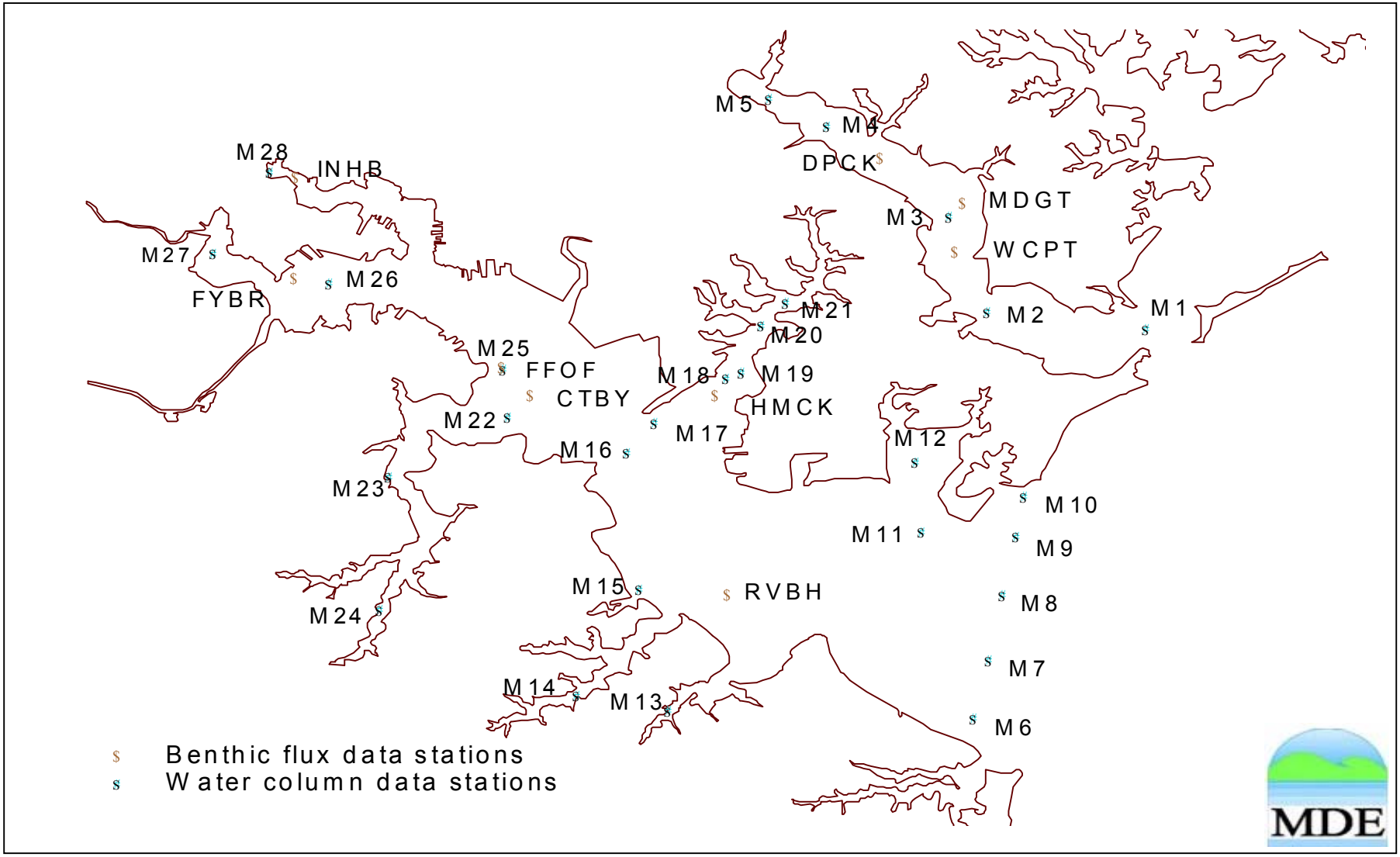


Figure 3-1. Map of Back River and Patapsco River showing high frequency monitoring stations and sediment-water flux stations sampled during 1997.

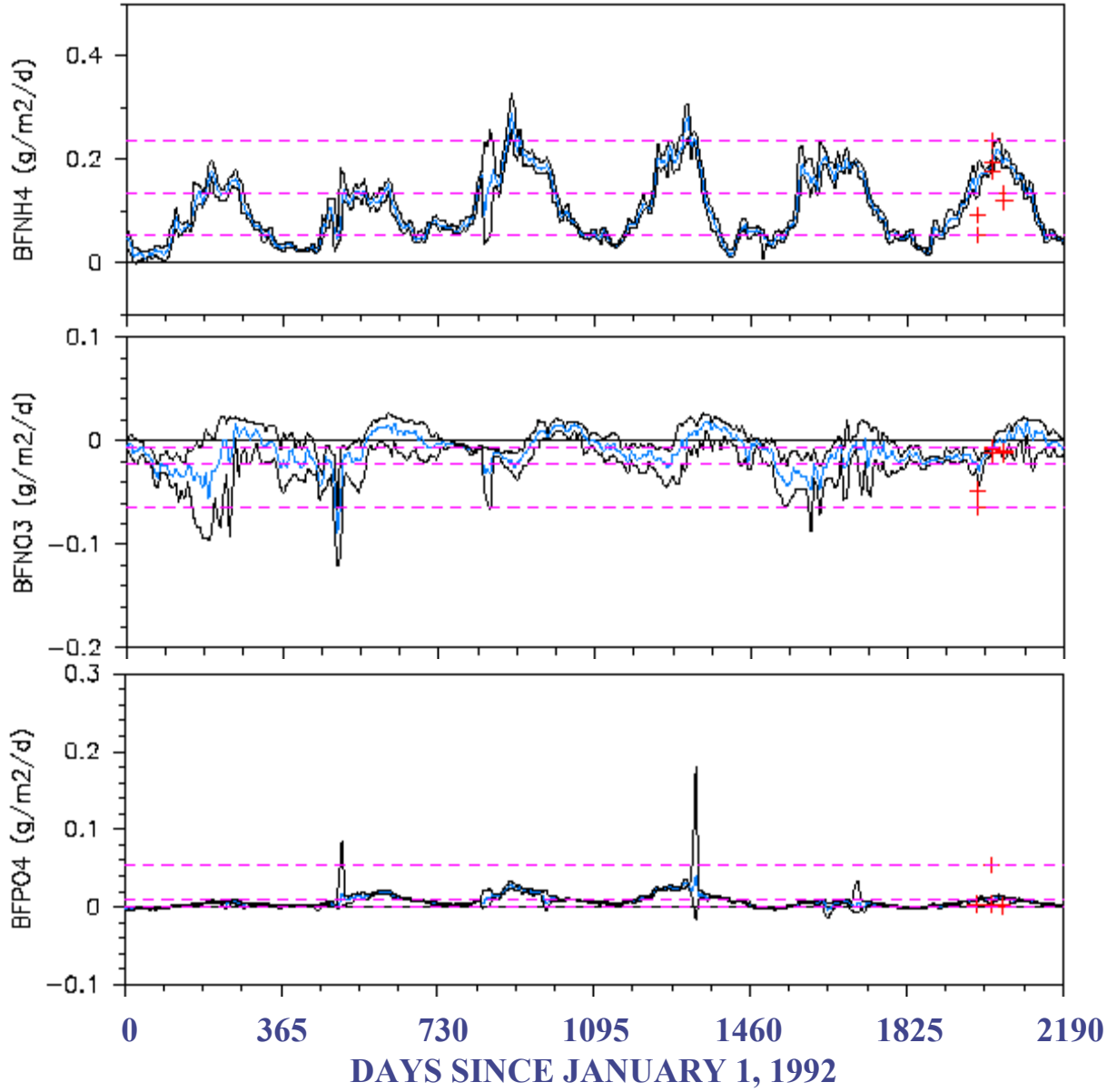
Location of Water Quality Stations



Baltimore Harbor

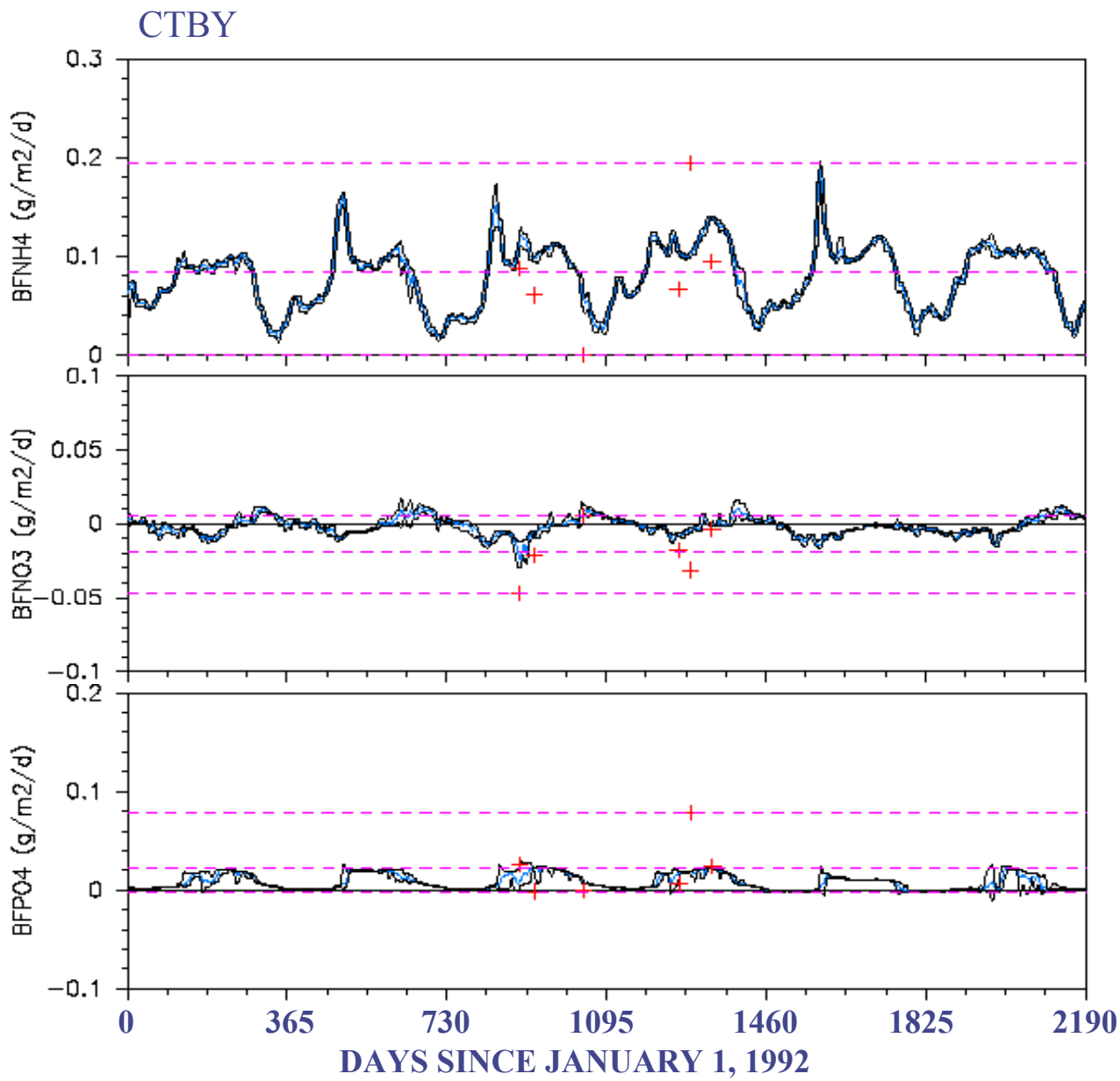
(Bear Creek)

HMCK



Baltimore Harbor

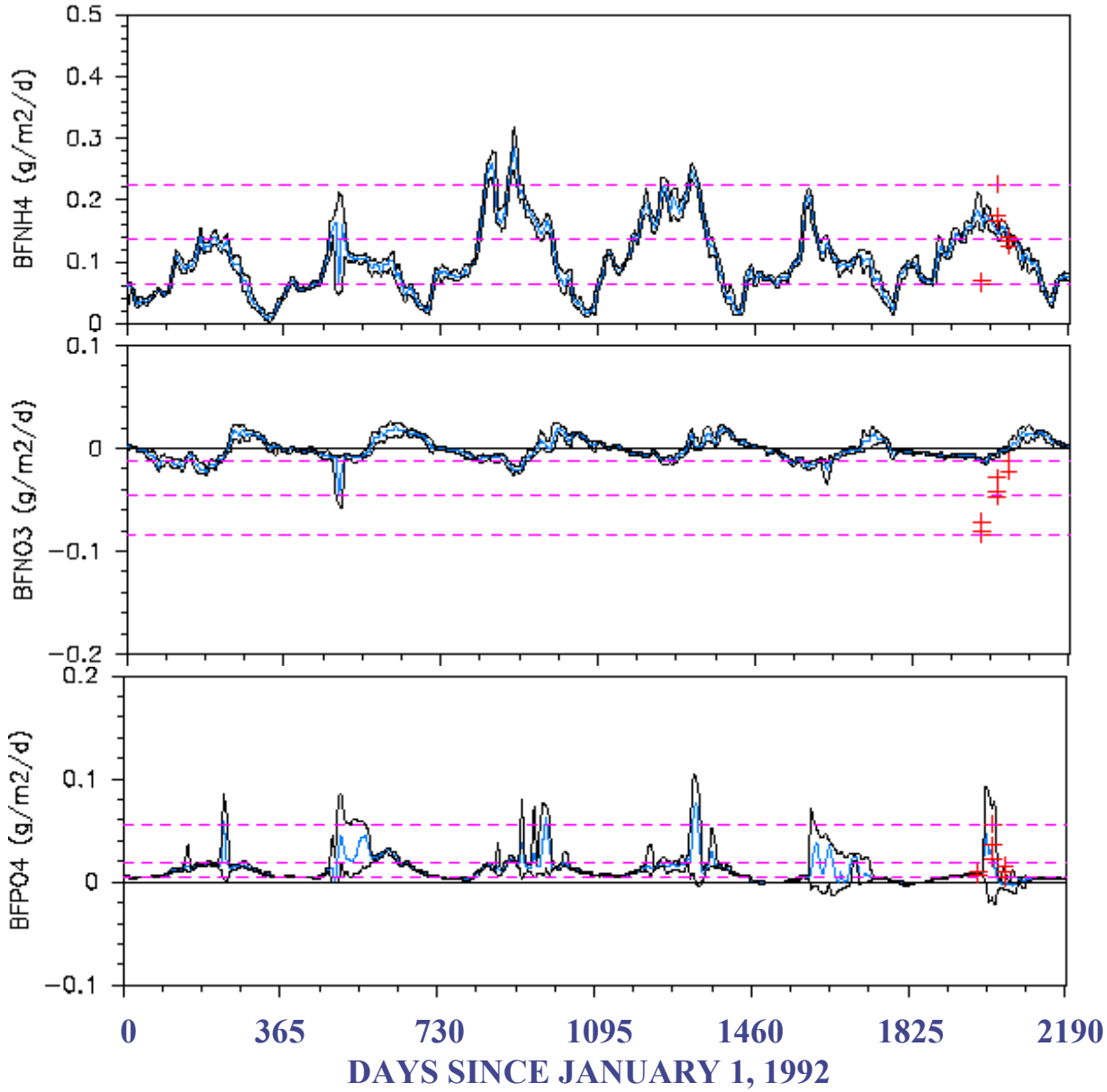
(Curtis Bay)



Baltimore Harbor

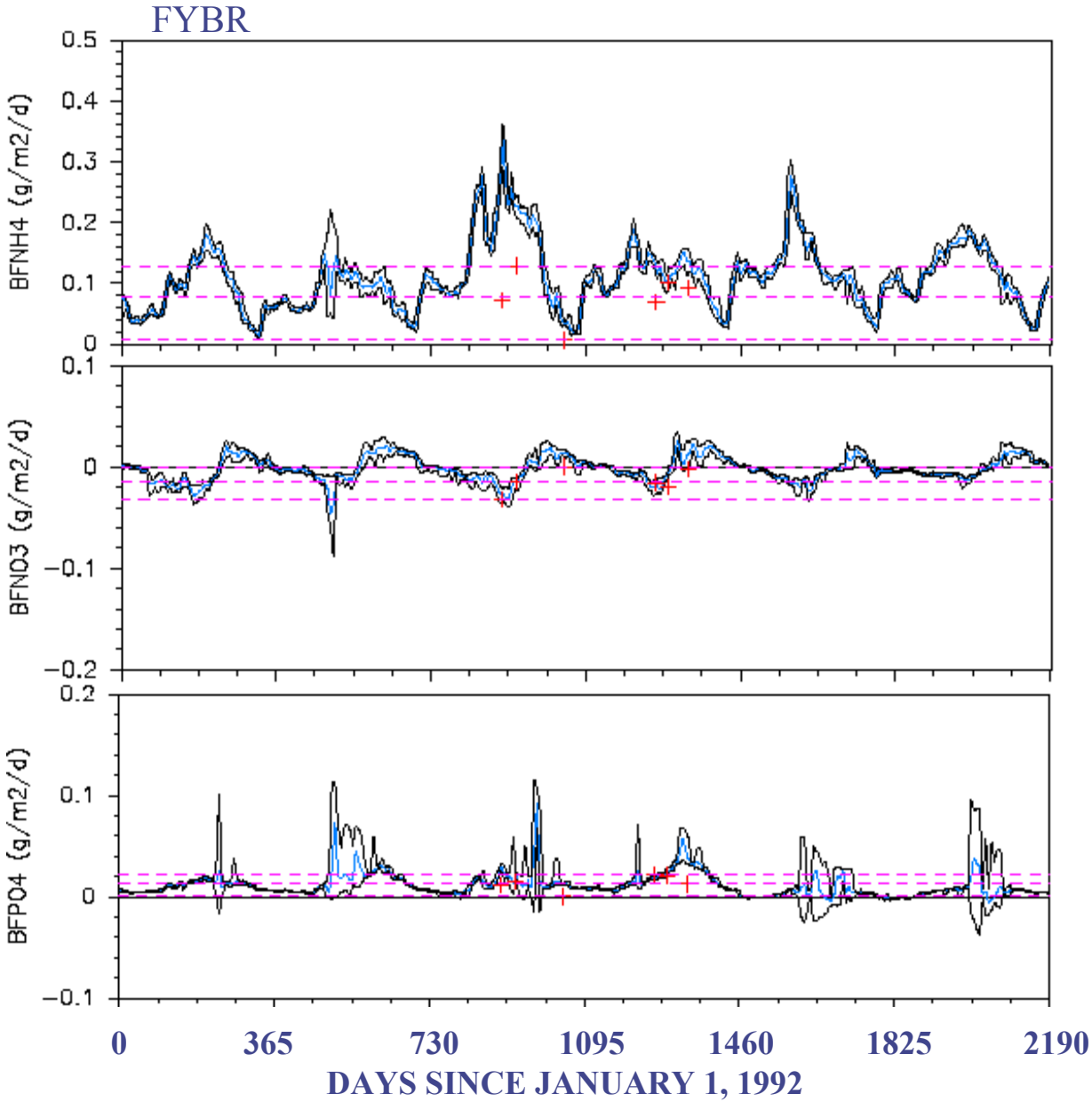
(Curtis Bay)

FFOF

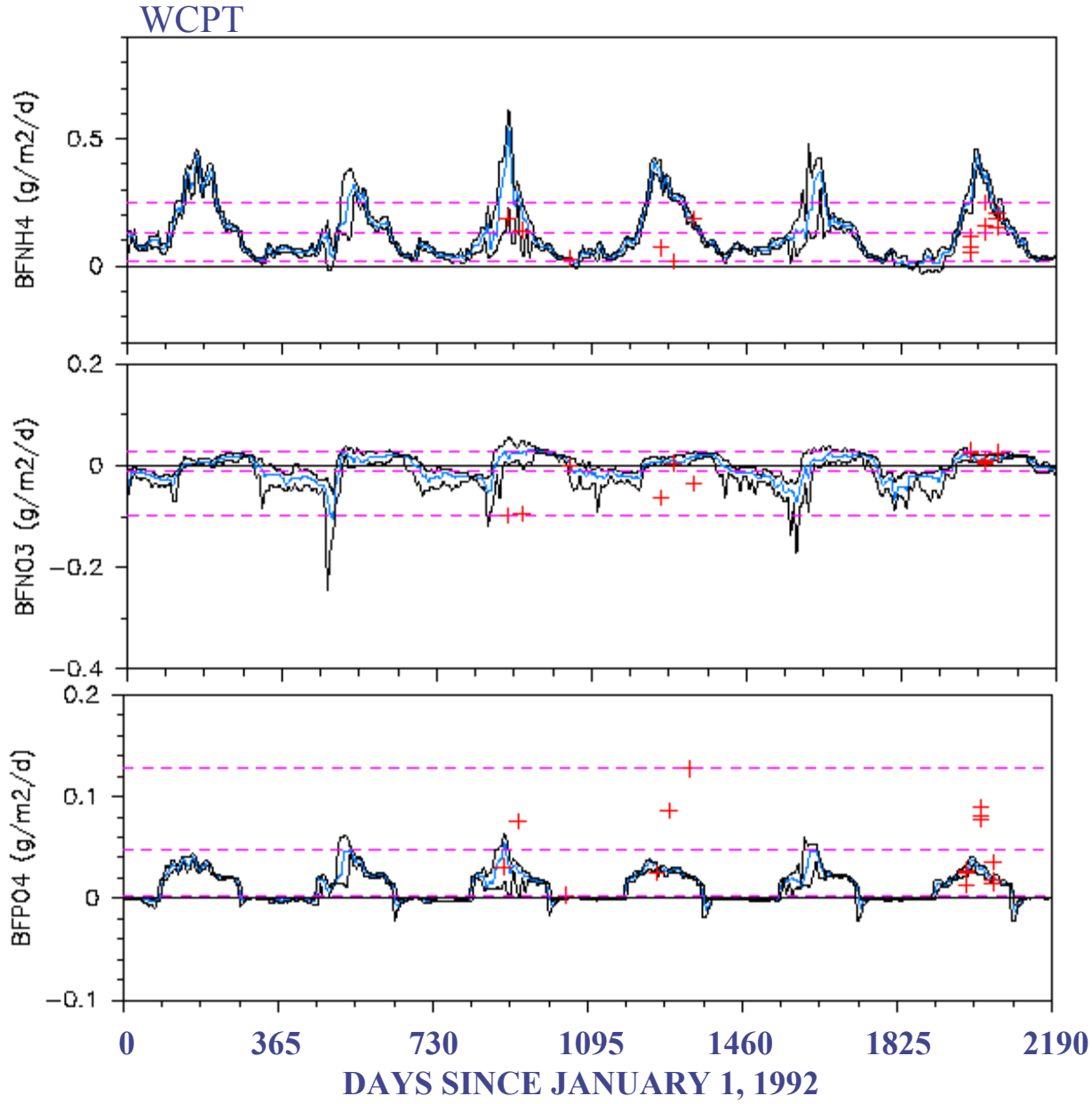


Baltimore Harbor

(Middle Branch)

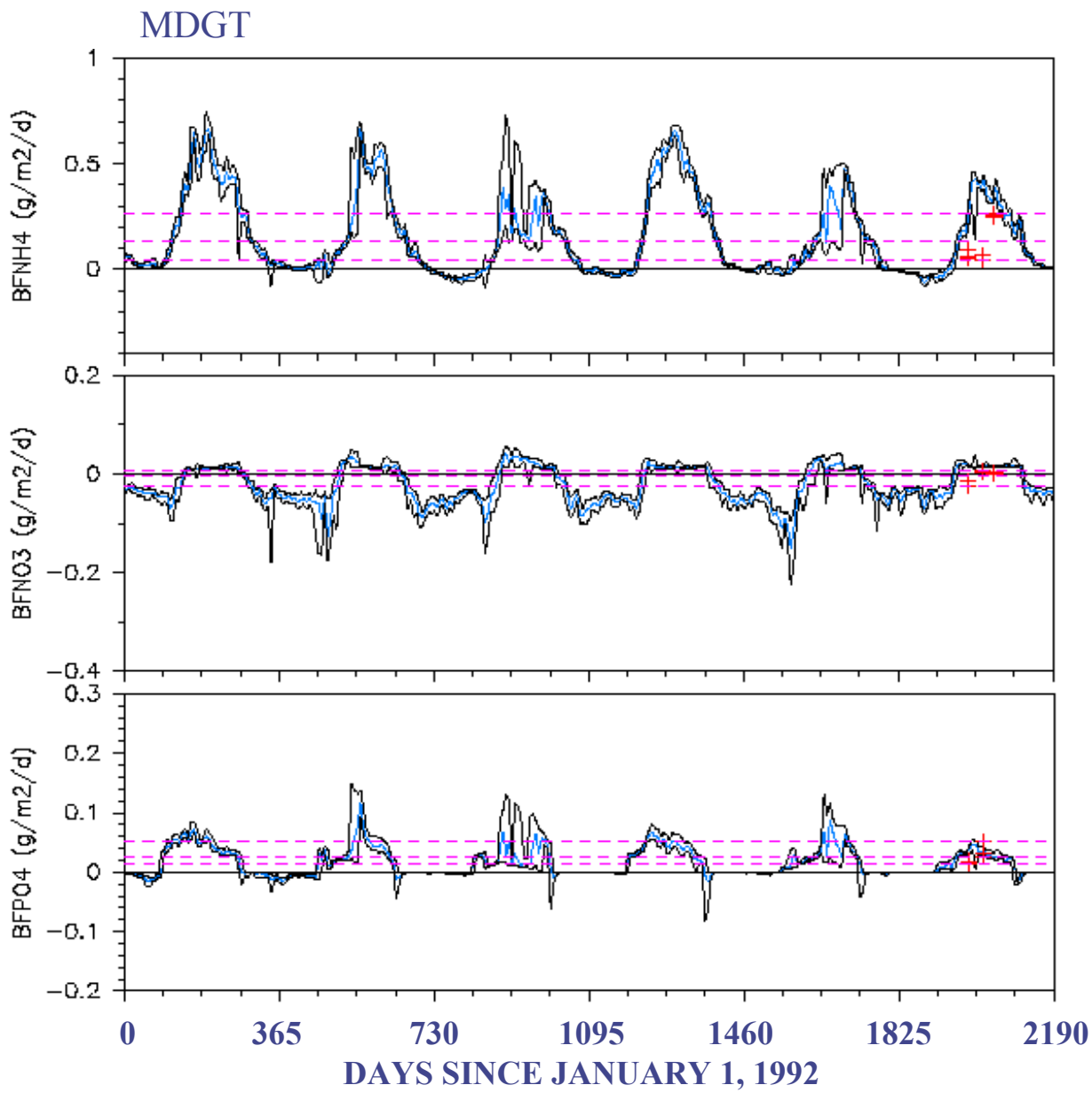


Back River
(Middle)



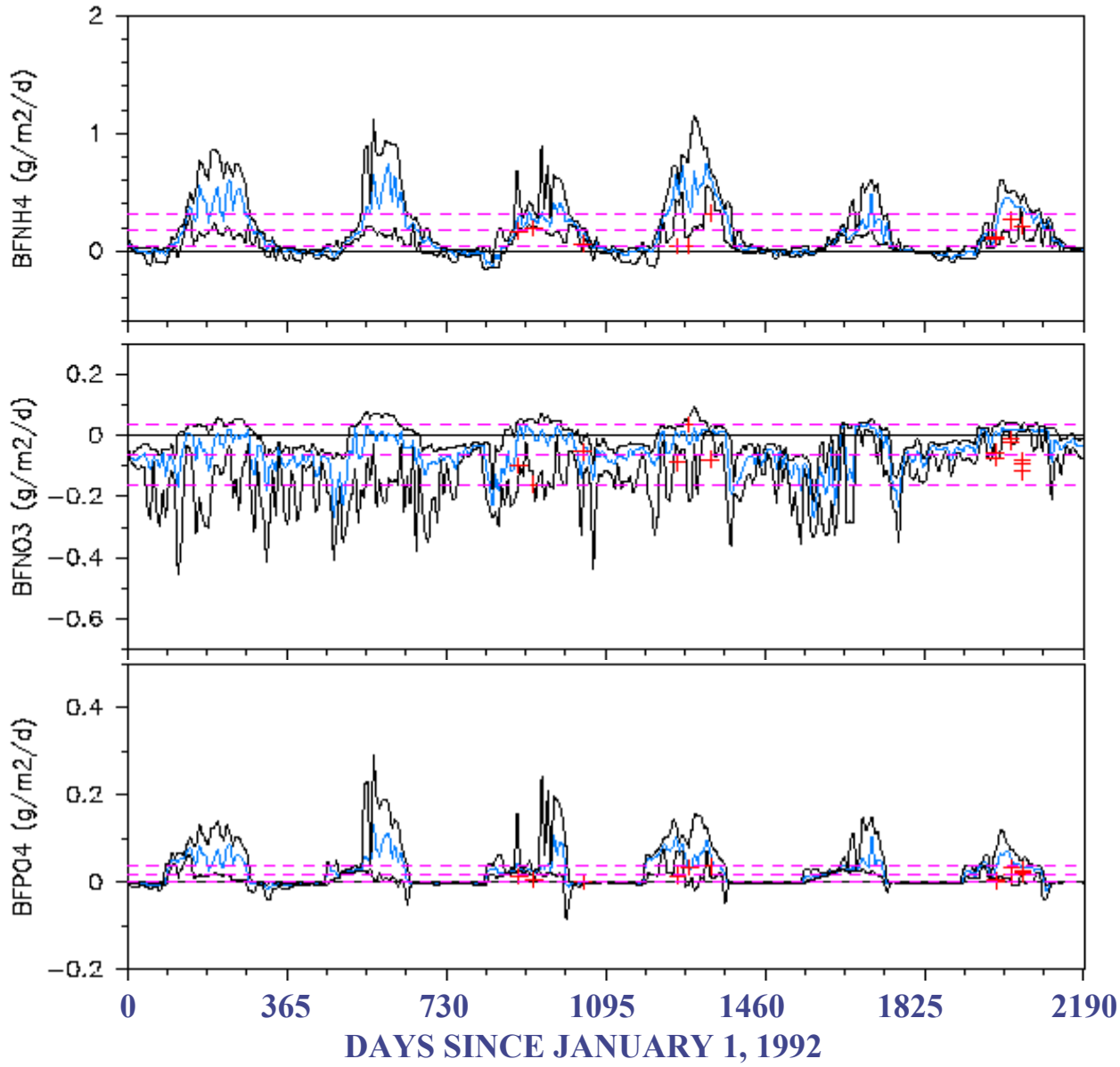
Back River

(Close to Long-term station)



Back River
(Upstream)

DPCK

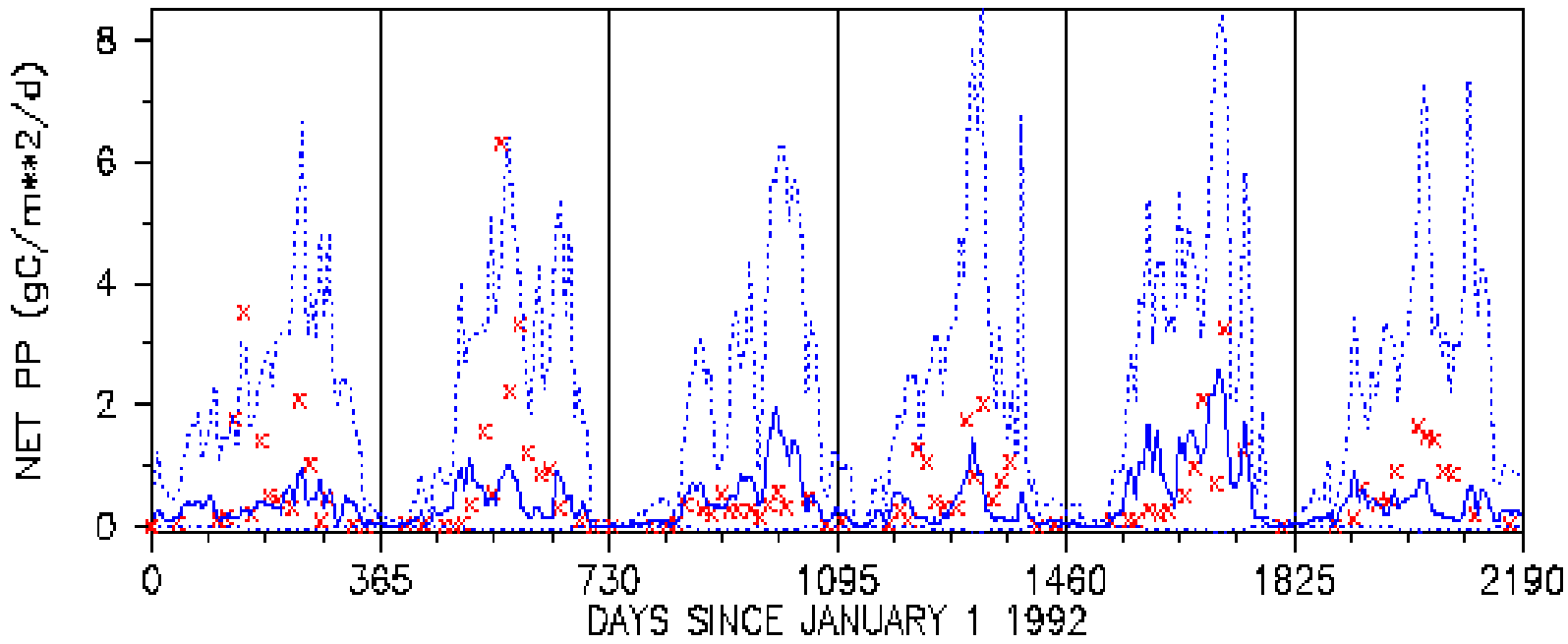


Model Output Vs. Observed Data

PRIMARY PRODUCTIVITY

Main Bay

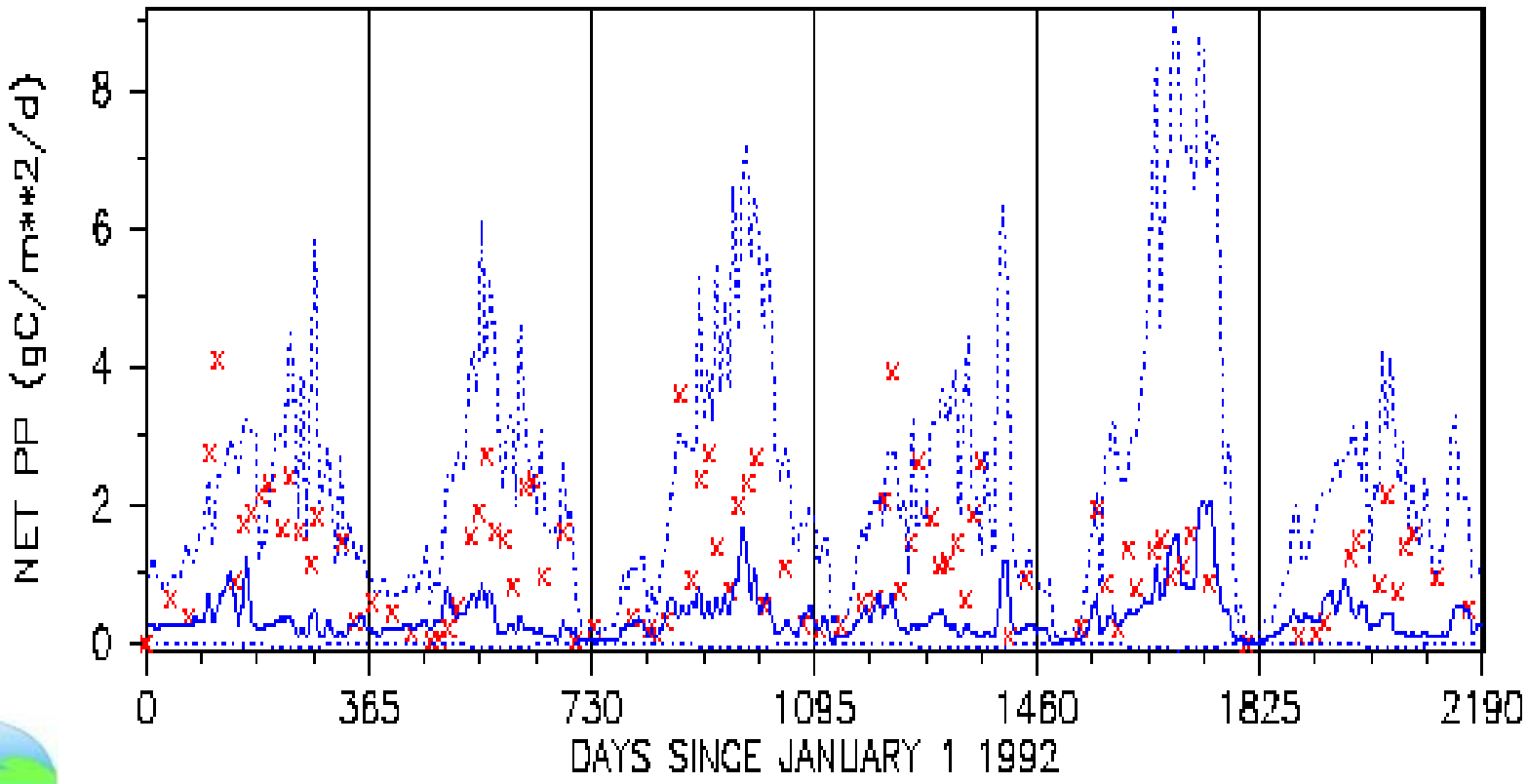
CB2.2



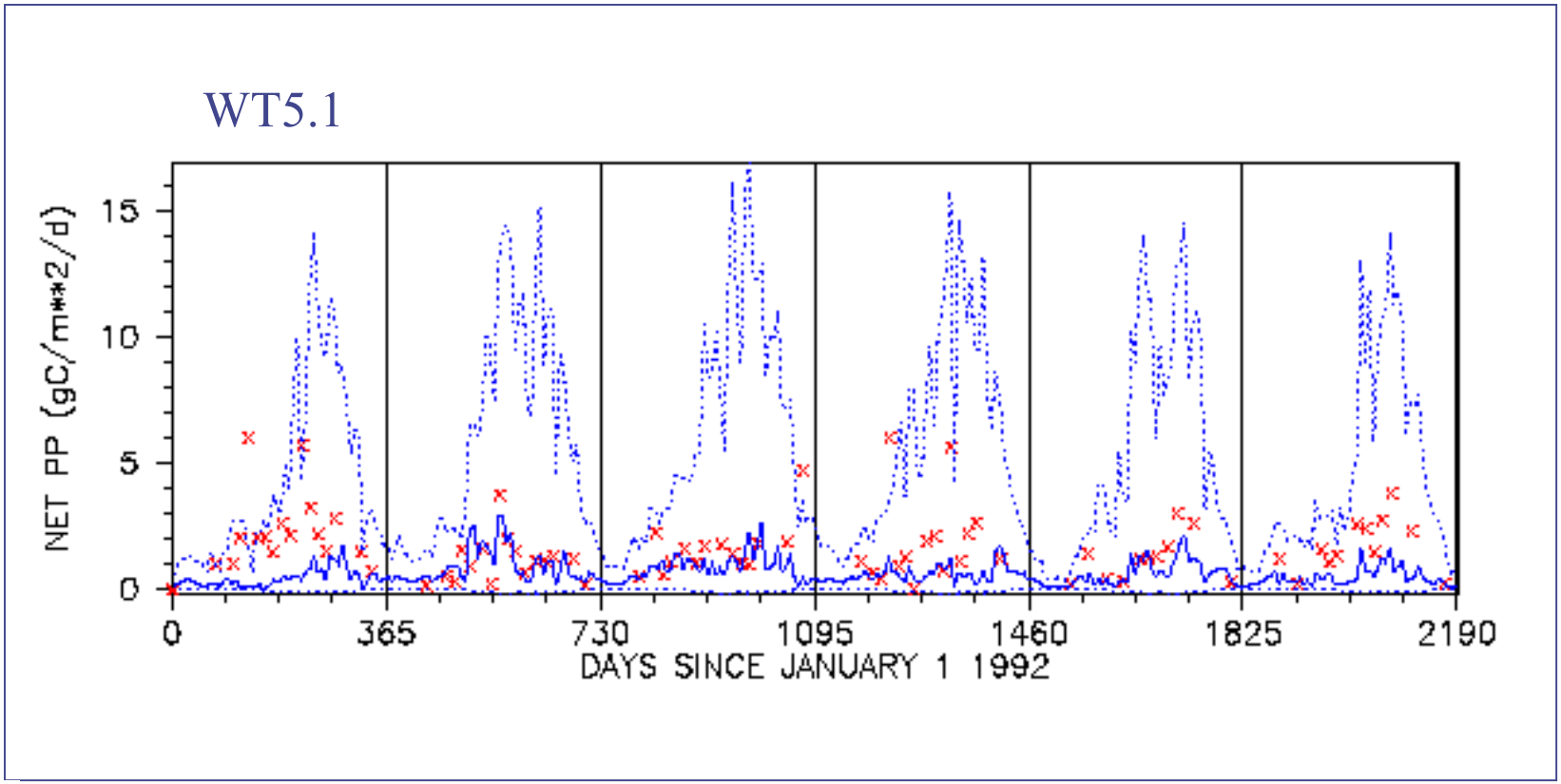
MDE

Main Bay

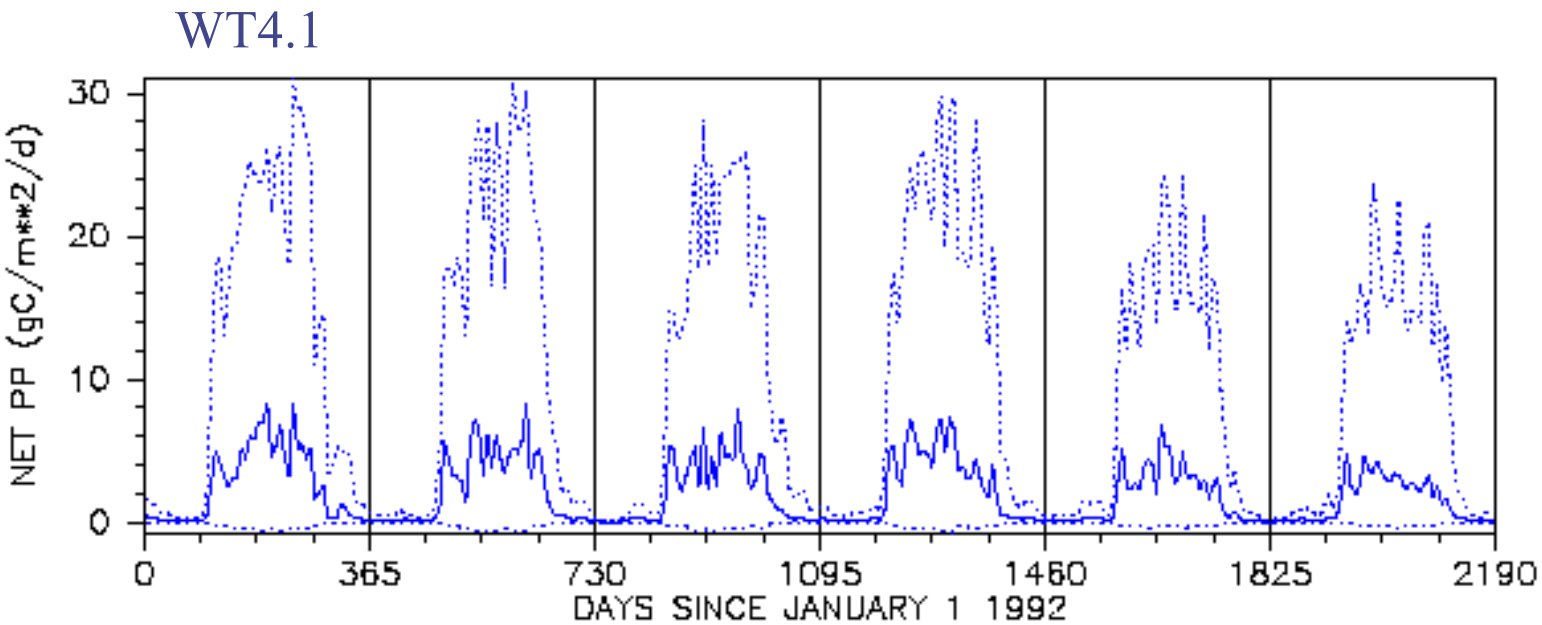
CB3.3C



Baltimore Harbor

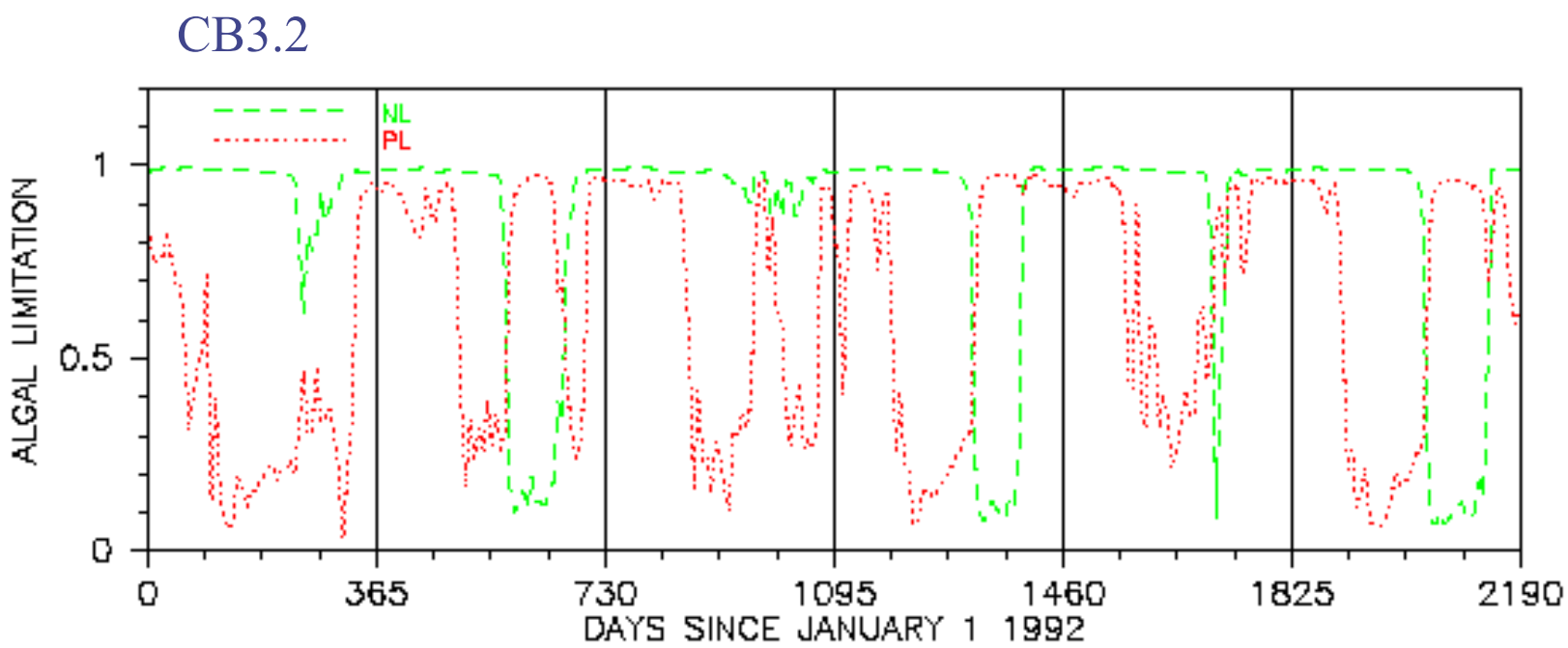


Back River
(no data available)

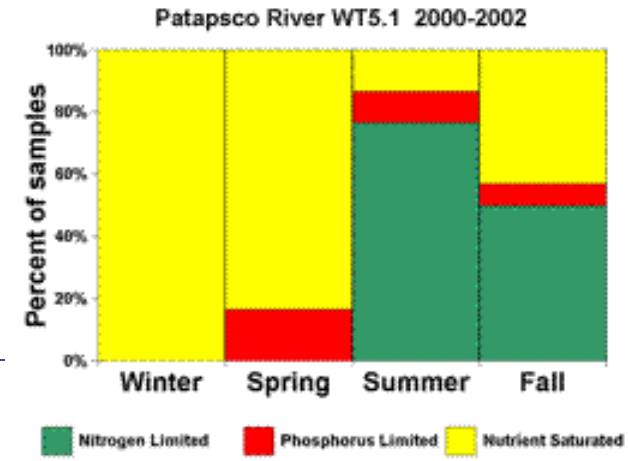


NUTRIENT LIMITATIONS

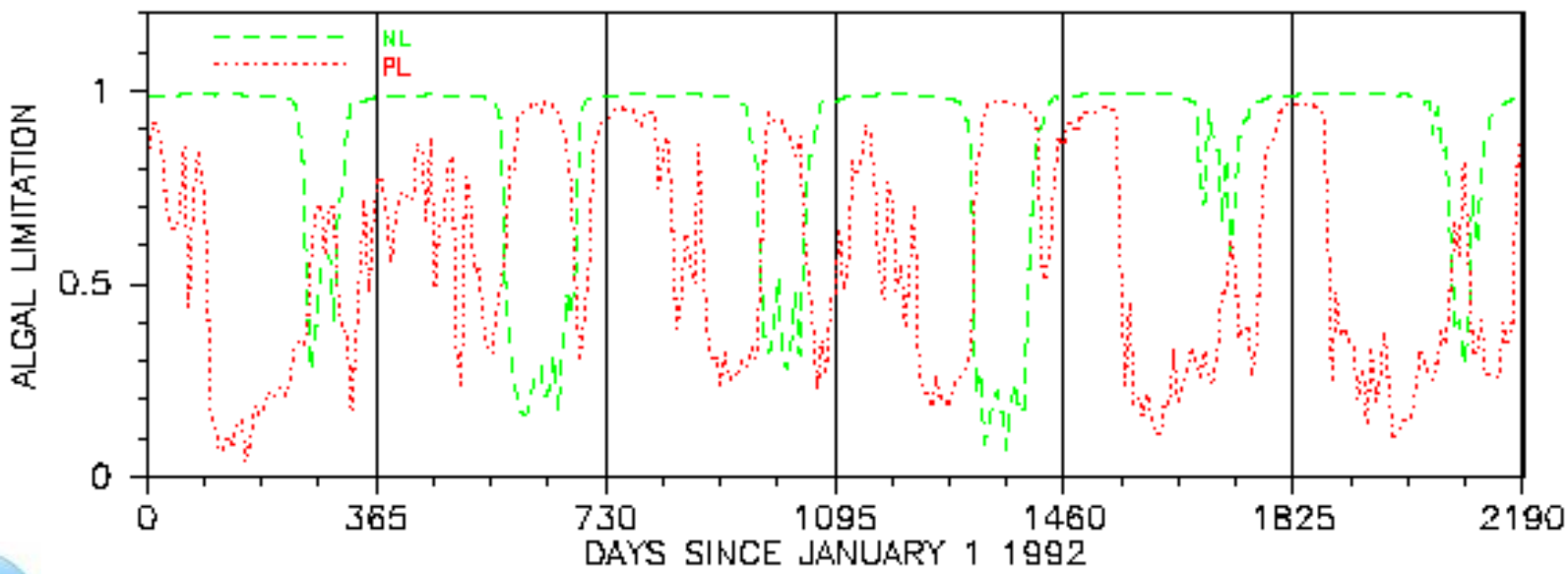
Main Bay


CB3.2
NL
PL
ALGAL LIMITATION
1
0.5
0
0
365
730
1095
1460
1825
2190
DAYS SINCE JANUARY 1 1992

Baltimore Harbor

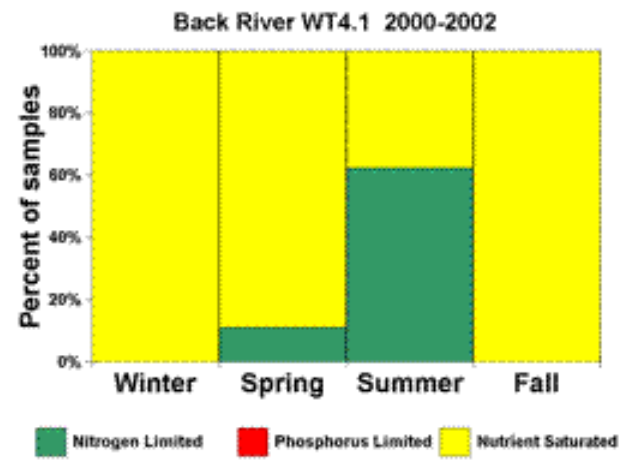


WT5.1

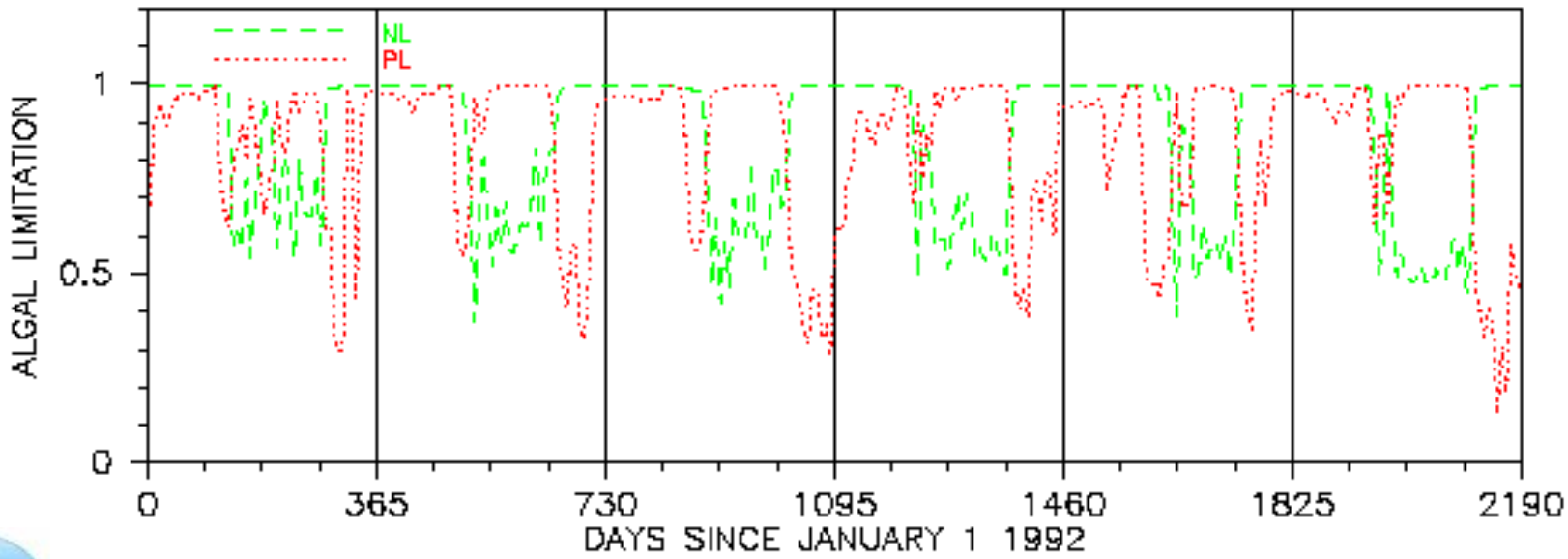


MDE

Back River



WT4.1

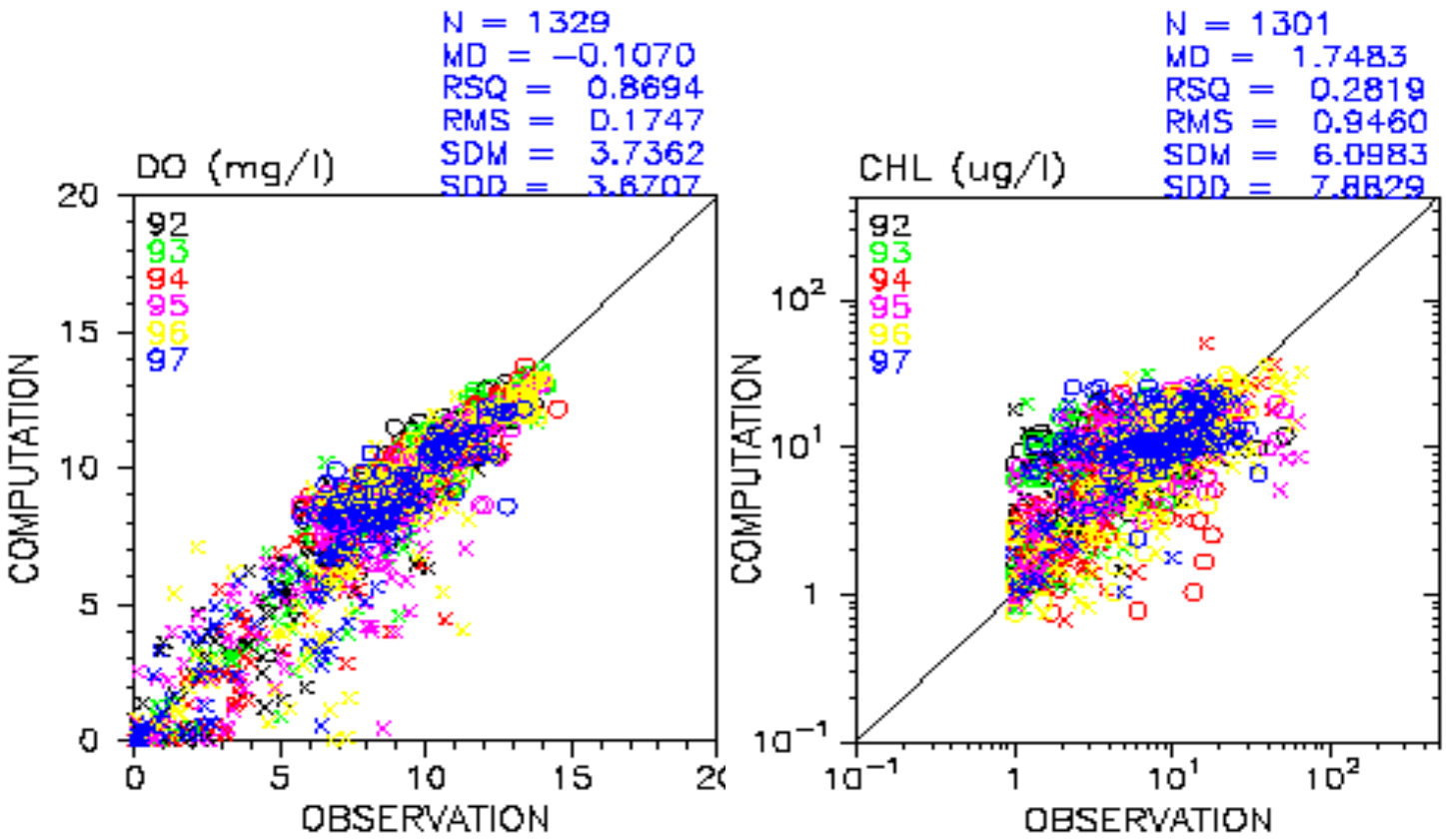


MDE

STATISTICS

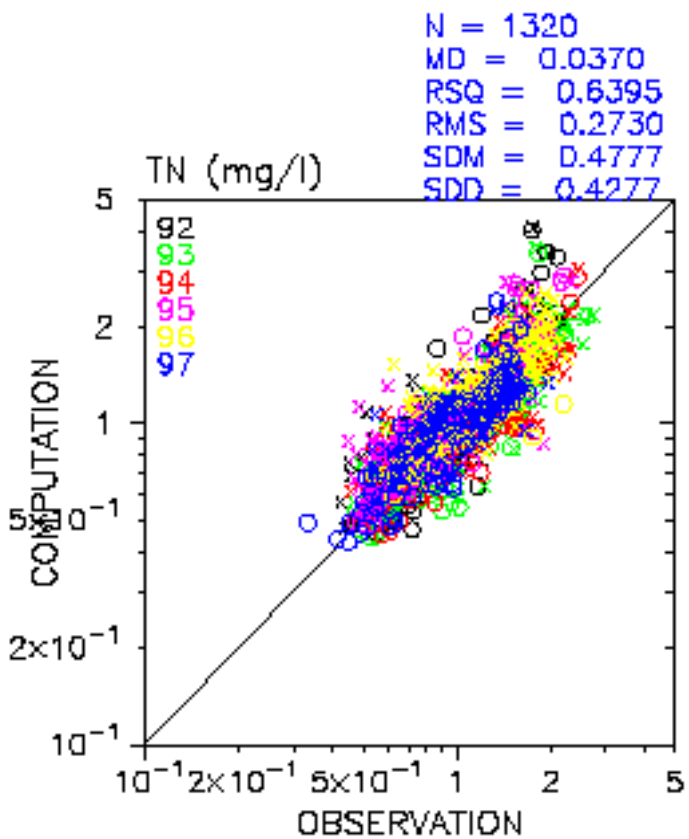
Model vs. Observed Data

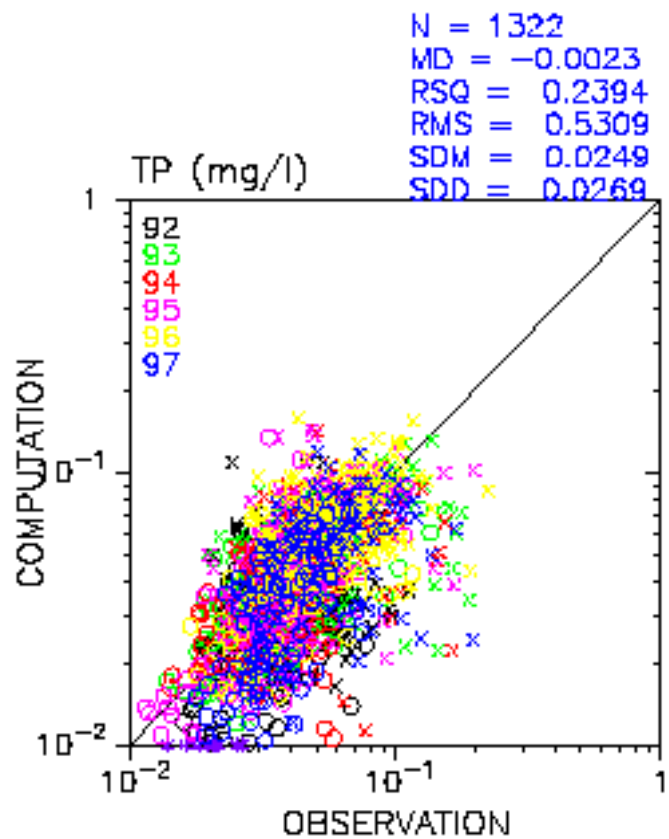
Main Bay


N = 1329
MD = −0.1070
RSQ = 0.8694
RMS = 0.1747
SDM = 3.7362
SDD = 3.6707
DO (mg/l)
92
93
94
95
96
97
COMPUTATION
OBSERVATION
N = 1301
MD = 1.7483
RSQ = 0.2819
RMS = 0.9460
SDM = 6.0983
SDD = 7.8829
CHL (ug/l)
92
93
94
95
96
97
COMPUTATION
OBSERVATION

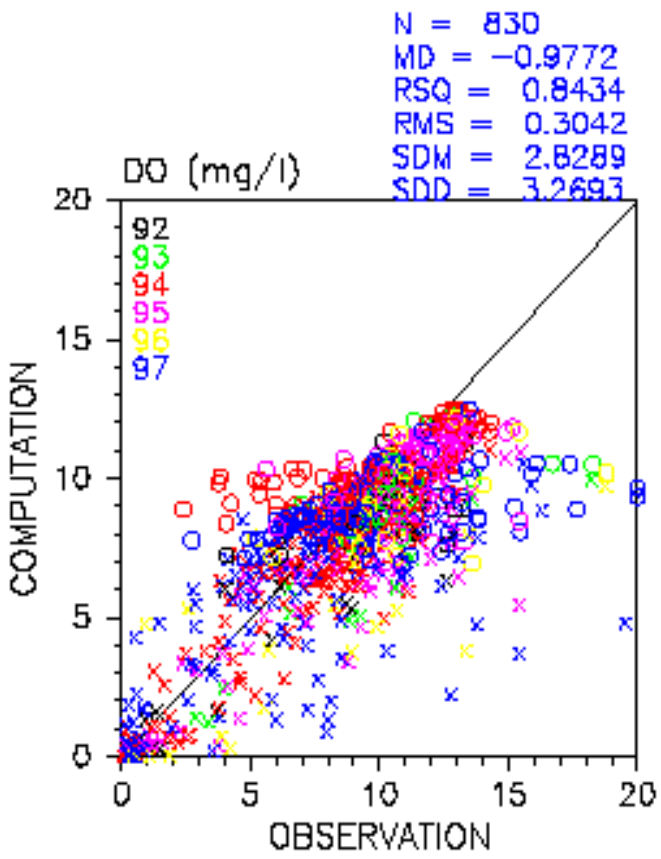
MDE

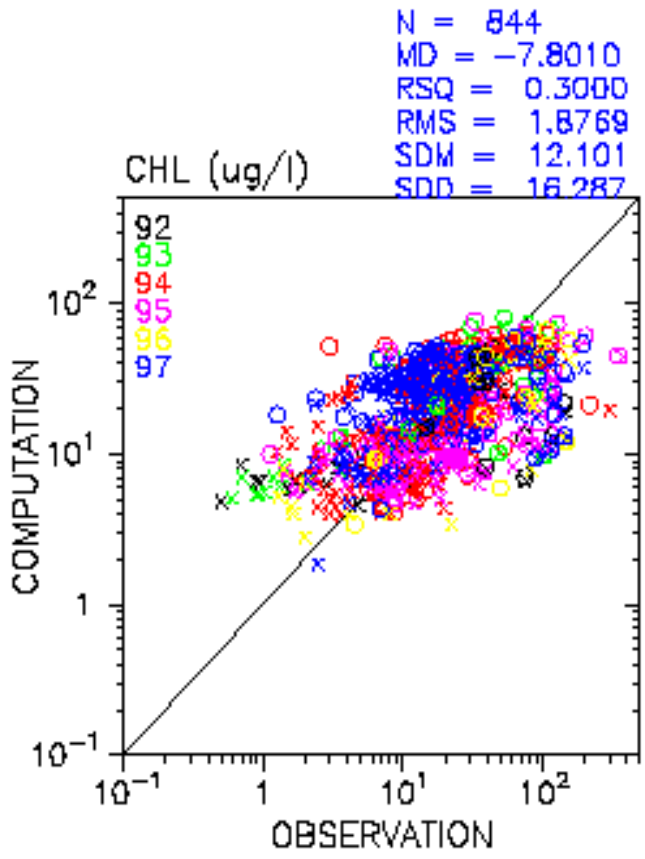
Main Bay


N = 1320
MD = 0.0370
RSQ = 0.6395
RMS = 0.2730
SDM = 0.4777
SDD = 0.4277
TN (mg/l)
92
93
94
95
96
97
COMPUTATION
OBSERVATION

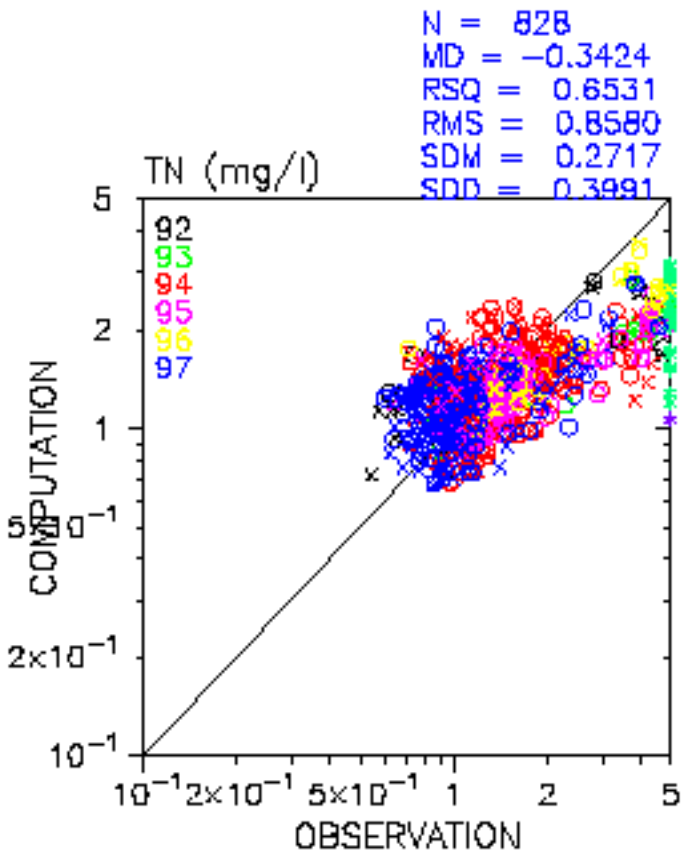

N = 1322
MD = −0.0023
RSQ = 0.2394
RMS = 0.5309
SDM = 0.0249
SDD = 0.0269
TP (mg/l)
92
93
94
95
96
97
COMPUTATION
OBSERVATION

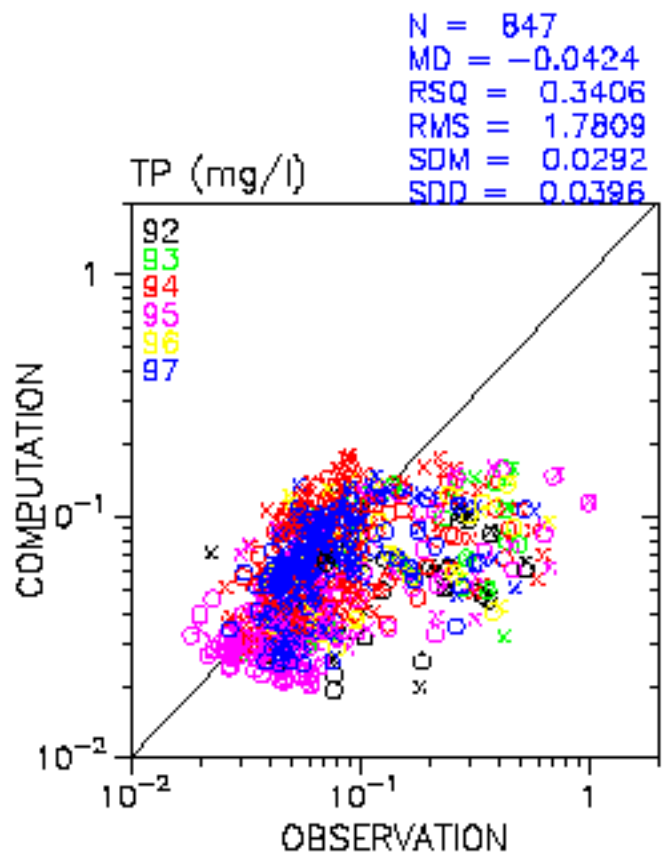
Baltimore Harbor



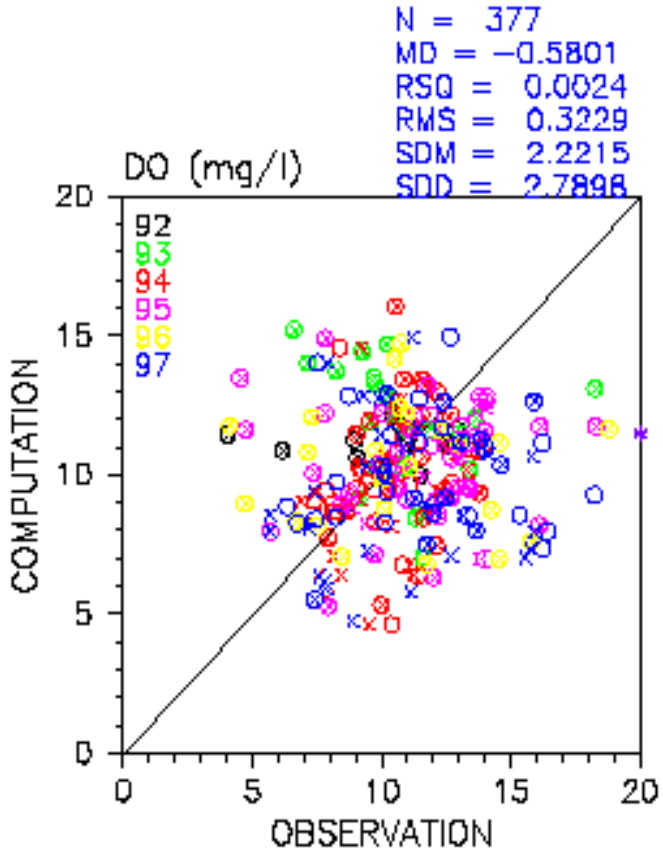


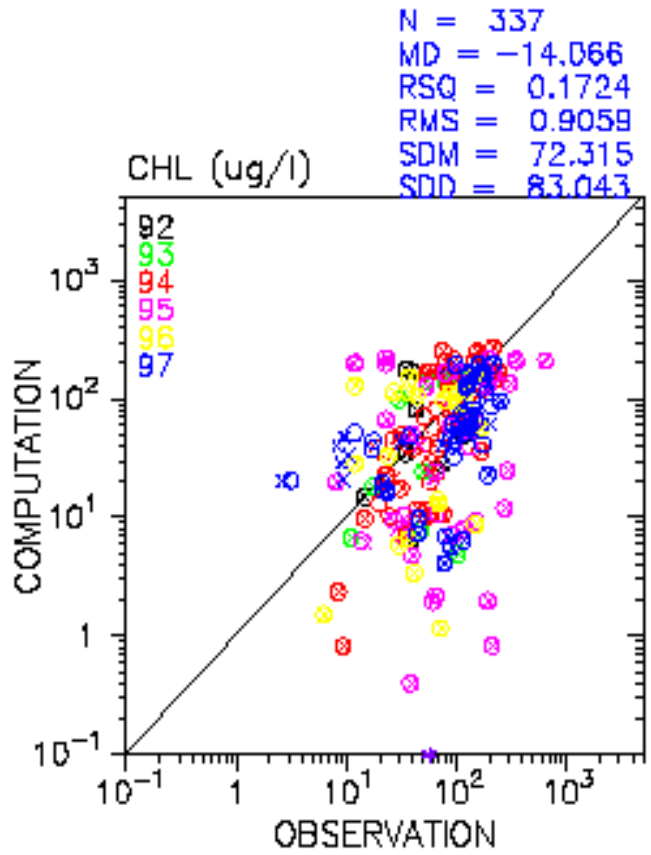
Baltimore Harbor



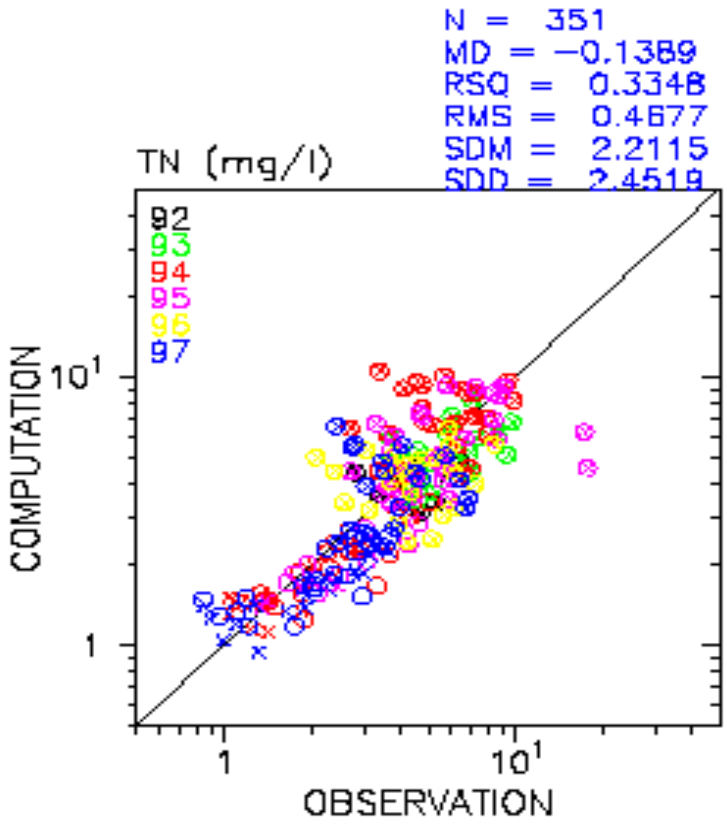


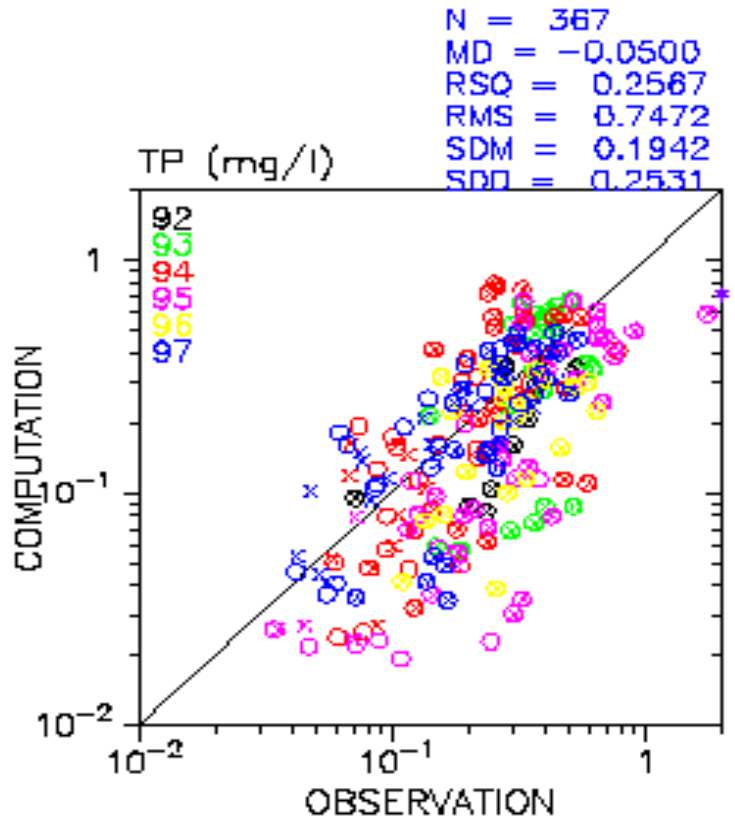
Back River


N = 377
MD = −0.5801
RSQ = 0.0024
RMS = 0.3229
SDM = 2.2215
SDD = 2.7898
DO (mg/l)
92
93
94
95
96
97
COMPUTATION
OBSERVATION
0
5
10
15
20


N = 337
MD = −14.066
RSQ = 0.1724
RMS = 0.9059
SDM = 72.315
SDD = 83.043
CHL (ug/l)
92
93
94
95
96
97
COMPUTATION
OBSERVATION
10^{-1}
1
10^{1}
10^{2}
10^{3}

Back River


N = 351
MD = −0.1389
RSQ = 0.3348
RMS = 0.4677
SDM = 2.2115
SDO = 2.4519
TN (mg/l)
92
93
94
95
96
97
COMPUTATION
OBSERVATION
1
10¹


N = 367
MD = −0.0500
RSQ = 0.2567
RMS = 0.7472
SDM = 0.1942
SDO = 0.2531
TP (mg/l)
92
93
94
95
96
97
COMPUTATION
OBSERVATION
1
10⁻¹
10⁻²

Summary

- 1. Baltimore Harbor and Back River are impaired by low DO and high Chlorophyll, based on DO and Chlorophyll water quality criteria.
- 2. The model simulation follows the trend and matches nutrient data very well in most places.
- 3. The calibration for DO performs reasonably well everywhere. Chlorophyll calibrations are good in most places, except in Rock Creek and Stony Creek.
- 4. Important parameters inferred from the model simulation, such as light extinction, sediment-water column exchange, and primary production, were also investigated with satisfactory comparison results.