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Temporal and Spatial Variations in Chesapeake Bay Water Quality: A Video Data Report

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Introduction

Over the past two years we have been developing computer programs to investigate various scientific visualization techniques as applied to estuarine data. The original impetus was to be able to visualize the results of the three-dimensional hydrodynamic model under development at the Virginia Institute of Marine Science, College of William and Mary (VIMS). We quickly recognized the superior ability of certain graphic approaches, especially pseudocolor animation, to efficiently transmit a tremendous amount of information to the viewer, allowing the scientist to gain an insight into the dynamics of the data not otherwise available. We decided to apply this technique to the U.S. Environmental Protection Agency (EPA) Bay Monitoring data set, a field collection effort so large that it sometimes overwhelms our traditional information presentations. What we present here is an alternative way of presenting and archiving large amounts of field measurements.

The Chesapeake Bay Program began its water quality monitoring in the summer of 1984. Data collection in the mainstem of the Bay was done by University of Maryland (UMD), VIMS, and Old Dominion University (ODU), supported by EPA, while state regulatory agencies have been responsible for water quality data from the Maryland and Virginia tributaries. More than 130 stations (49 in the Bay proper) were occupied over 120 times each during the water years 1985 through 1990 (Figure 1). This information has been brought together to create color contoured images of the 10 different physical and water quality parameters that were measured. Each parameter for each month is summarized in a color image that shows the map-view surface and bottom distributions plus a vertical North-South section running down the natural channel from the Susquehanna to the mouth of the Bay. Each pixel in the map-view represents a 1km X 1km area. Although a certain amount of data manipulation must occur between the original logged measurements and these images, the distributions shown should best be understood as raw "snapshots" of what was present in the Chesapeake during that month. No data analysis or interpretation is attempted in this report.

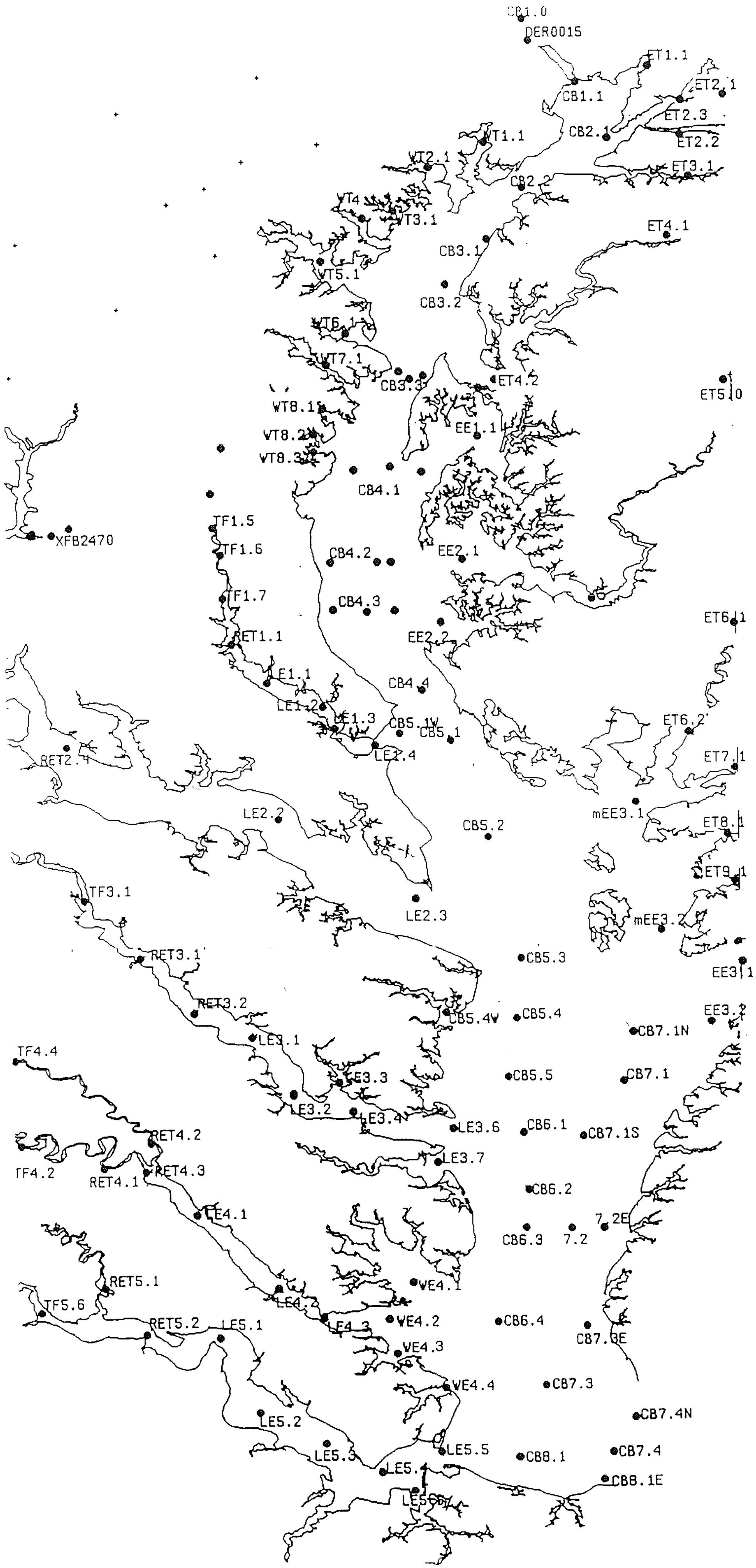


Figure 1

Map of Station Locations

Description of the Monitoring Program

As a result of findings and recommendations made by the Chesapeake Bay Program in September 1983 (US-EPA, 1983) a comprehensive Water Quality Monitoring program was initiated in June of the following year, funded by the U.S. EPA. The Maryland Department of the Environment (MDE) samples 22 stations from the mouth of the Susquehanna to south of the mouth of the Potomac. Responsibility for monitoring in Virginia is shared between the VIMS and ODU. VIMS samples 19 stations in the mid-portion of the bay, and ODU contributes 8 stations in the lower Bay. Simultaneously, the states of Virginia and Maryland, along with the District of Columbia also established tributary monitoring programs. This report includes data that the Virginia Water Control Board (VWCB) collected from the tidal portions of the James, York and Rappahanock rivers. Various agencies in Maryland contributed data for more than 50 stations from the tributaries and embayments around the upper part of the Bay. Appendix I & Figure 1 show the names and locations of the stations included in this report.

All of the 49 stations in the bay proper are usually occupied within a three or four day interval. Occasionally poor weather or equipment problems result in a longer sampling window. Tributary monitoring schedules attempted to match the open bay's schedule but this was achieved probably only half the time. Stations are generally occupied 20 times each year. Stations were sampled during monthly cruises between November and February. Then during the months of March through October, when biological activity is highest and water quality problems most evident, cruises were made twice a month. In 1988 the winter sampling schedule in Virginia was extended into the months of October and March due to budgetary constraints.

At each station, a standard protocol for sampling is followed. The physical parameters are measured using continuously profiling instruments Temperature, salinity, dissolved oxygen and pH readings are recorded at one or two meter intervals beginning at 1 meter below the surface and continuing to 1 meter above the bottom. Water samples are collected at each station for laboratory analysis of nutrients, chlorophyll and suspended solids. The list of parameters analyzed is given in Table 1 Water samples are collected at 1 meter below the surface and 1 meter above the bottom. Additional samples are collected at the deep "main stem" stations (see stations marked with ** in Appendix I). The mainstem stations are used in the North-South vertical cross-section image. If the water column shows little stratification, the additional samples are taken at 1/3 and 2/3 the total station depth. If there is appreciable stratification, the samples are collected at 1 meter above and 1 meter below the pycnocline. Portions of this data set have been published previously in traditional data report format (Curling and Neilson, 1985,1988,1989,1990; VWCB 1985,1987; Magnien et al, 1987).

TABLE 1
Chesapeake Bay Monitoring Program
Water Quality Parameters Visualized

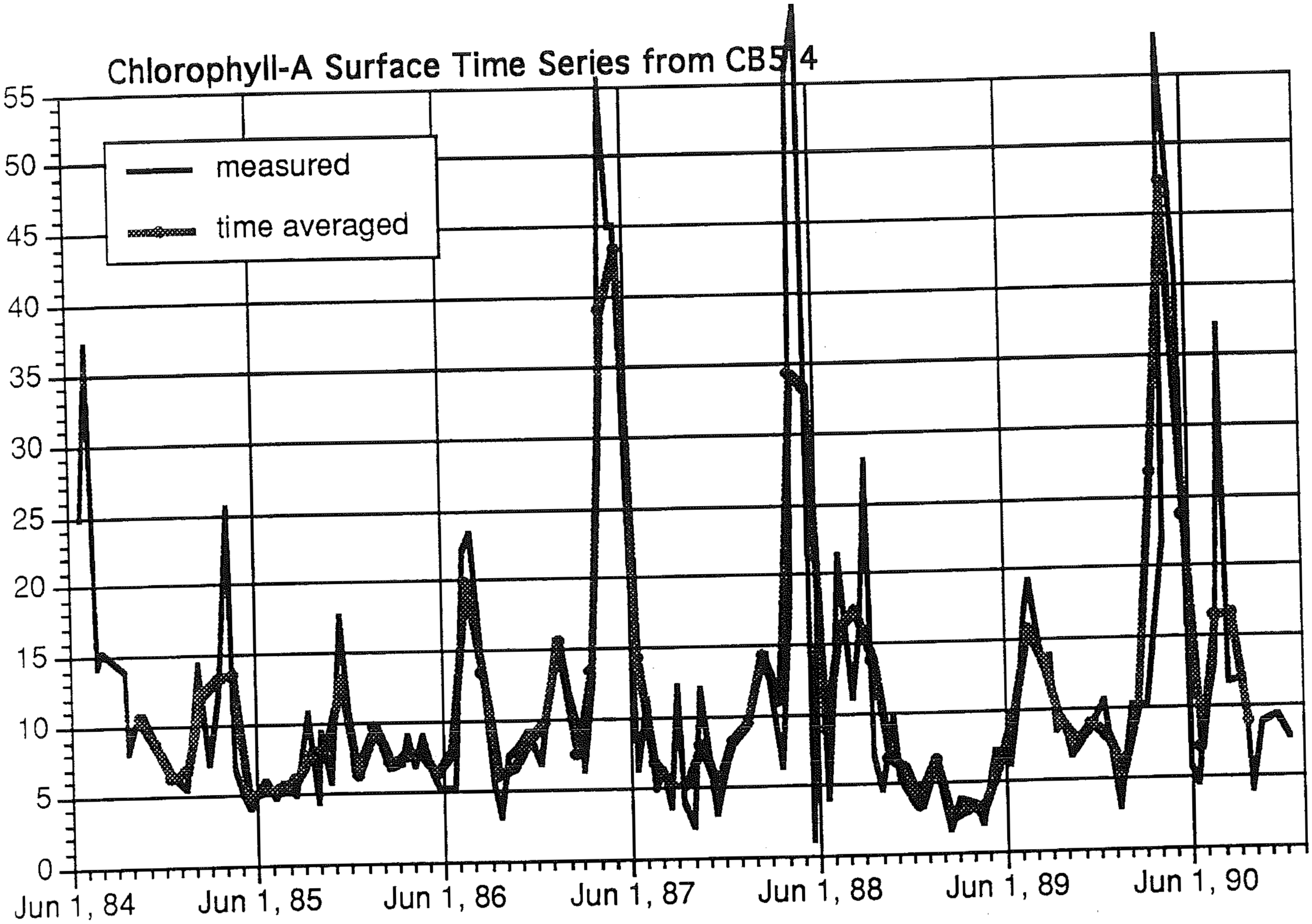
Parameter	Units	Colormap Range**
Chlorophyll-a	ug/l	0 -> 40; 50,60
Dissolved Oxygen	mg/l	0 -> 14; 15,16
pH	pH	6.5 -> 9.0; 9.2,9.4
Salinity	psu	0 -> 30; 32,34
Silica	mg/l	0 -> 3; 4,6
Temperature	Deg.C	0-> 30; 31,32
Total Nitrogen	mg/l	0.1 -> 2.2; 3,4
Total Organic Carbon	mg/l	1 -> 7; 8,9
Total Phosphorus	mg/l	0.01 -> 0.1; 0.15,0.2
Total Suspended Solids	mg/l	0 -> 50; 60,70

** values of parameter over which the range of 250 colors are spread; followed by the upper limits of two high ranges , each represented by a single color. See text for further explanation.

Pseudocolor Images

To create our images we compute a representative value for each point in our grid, and then assign a certain color to each value. We work with a 1km X 1km grid, covering a map area of 100 km from west to east and 300 km south to north. To blank out the land areas, we first re-gridded the National Oceanic and Atmospheric Administration (NOAA) bathymetric data set (originally on a 15 second grid, with some irregularities) to our 1km X 1km basis (Figure 2) and used that image to mask our water parameter information. We are working with 8-bit deep images, meaning that we can discriminate among 256 different levels. This resolution is obviously much coarser than the original measurements, but by

Figure 2
1km X 1km Gridded Bathymetry


Chlorophyll-A Surface Time Series from CB5.4
measured
time averaged
55
50
45
40
35
30
25
20
15
10
5
0
Jun 1, 84
Jun 1, 85
Jun 1, 86
Jun 1, 87
Jun 1, 88
Jun 1, 89
Jun 1, 90

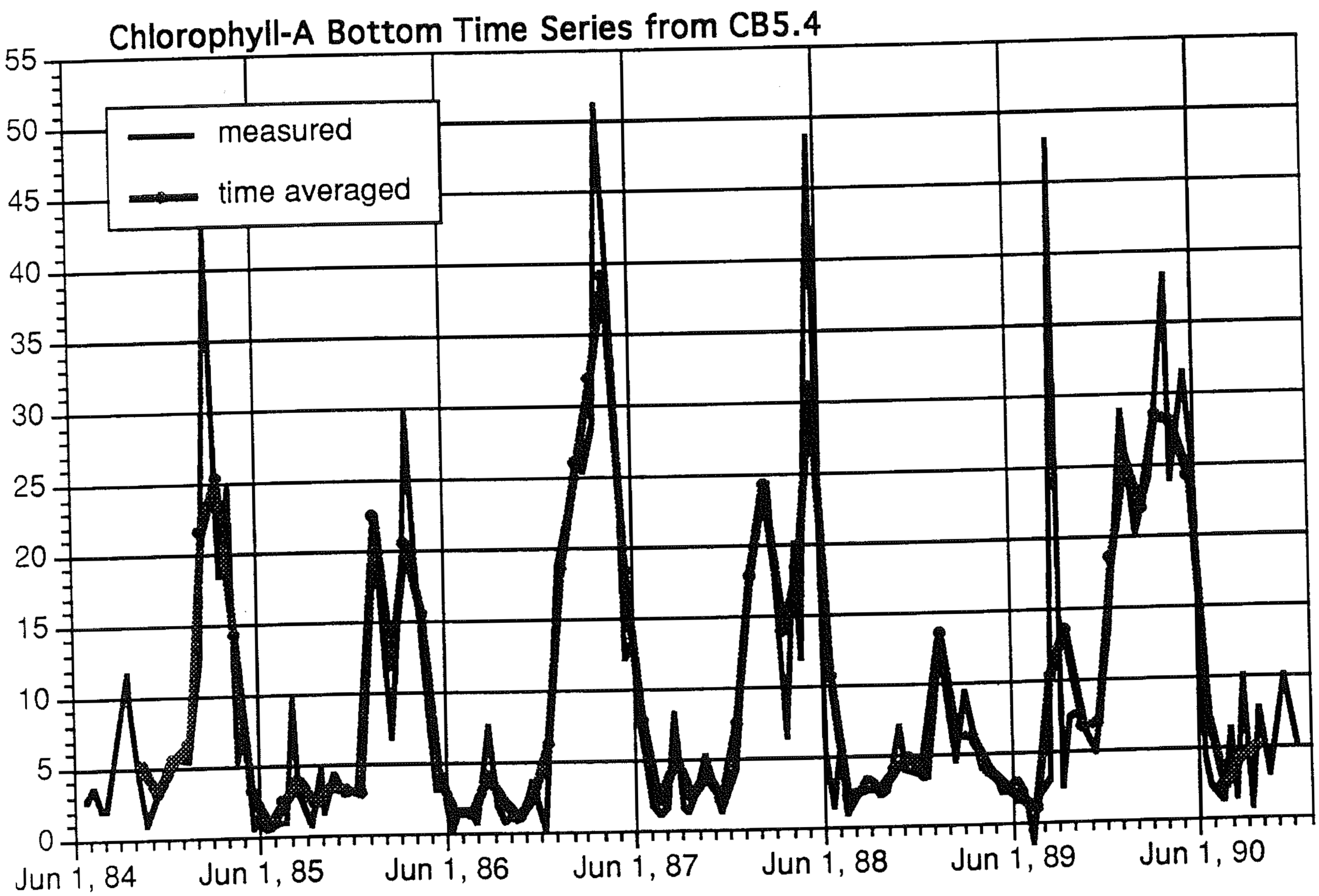

Chlorophyll-A Bottom Time Series from CB5.4
measured
time averaged
55
50
45
40
35
30
25
20
15
10
5
0
Jun 1, 84
Jun 1, 85
Jun 1, 86
Jun 1, 87
Jun 1, 88
Jun 1, 89
Jun 1, 90

Figure 4

involves the fitting of a fifth-degree polynomial in x and y for each triangular cell which has three stations data points as its vertexes (Akima,1978) . The resulting surface is then constrained to pass through all the input points. This method works particularly well with highly irregularly-spaced measurements and is recommended by the National Center for Atmospheric Research (NCAR). The algorithm used is also available with Edition 8 of the IMSL (International Mathematical and Statistical Libraries, Inc.) package as the IQHSCV routine (Akima,1984) .

Since the interpolation uses triangulation, we can constrain the averaging not to pass over land by creating additional "shadow" stations by reflecting a station onto a point on the intervening land area. Observe the shadow station locations (marked by X) in Figure 1.

We used a "jackknife" technique (Clark, 1980) to measure how well this bivariate interpolation could estimate a value for a grid cell, given the surrounding information.
Each station location's value was estimated without its measurement available, and then this estimate was compared to the original measurement. This test was performed using only the open bay stations. Selected results of these jackknife tests are presented in Appendix III. For the surface level interpolation, the correlation coefficient between estimate and actual measurement was greater than 0.9 for Salinity and greater than 0.8 for Dissolved Oxygen. The bottom estimates do not fare as well since both deep channel and shallow margins are thrown together. Other parameters that have much more spatial variability, such as Total Phosphorus, have correlation coefficients more like 0.5. These results are comparable to those obtained by a volume interpolator developed by CSC (Reynolds & Bahner, 1989) for which they used a more traditional inverse-distance^2 interpolation scheme.

When dealing with the major tributaries: Patuxent, Potomac, Rappahanock, York and the James rivers, we switched to a linear interpolation running along the channel, as the monitoring stations do, and took that value from bank to bank.

Use of Video Atlas

These images of the Chesapeake Bay can be viewed on a personal computer screen that has 8-bit color capability. The sequencing of monthly images at a reasonable pace on the screen provides an animation effect that is extremely effective in conveying a sense of how these parameters varied. With software currently available for the Macintosh computer, sets of images can be viewed side by side or manipulated in interesting ways. For example, images may be averaged together on a pixel by pixel basis to create an image of an "average month"; or one image could be subtracted from another the display the spatial pattern of differences. There is also the ability to "interrogate" the image in a point & click manner to extract numerical values of the parameter levels, rather than having to interpret the colors. The difficulty in working with the images in this form is their enormous size -- each image takes up over 110K of disk storage, meaning that a single parameter needs almost 8 megabytes in uncompressed form.

In addition to using the images on a computer, the images are also available sequenced on a VHS video tape that can be viewed with an ordinary VCR and television. The visual quality and color discrimination of the VHS reproduction is much poorer than in the digital format, but as a distribution medium it is inexpensive and readily accessible.

Acknowledgements

We would like to thank Kevin Curling and Gary Anderson of VIMS for their assistance in obtaining the original data.

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List of Monitoring Station locations

Virginia Bay Stations

NAME	LONG	LAT	EW UTM*	NS UTM*	Location	Agency
8.1E	-76.0250	36.9450	408.730	89.059	S mouth of bay	ODU
CB8.1	-76.1680	36.9875	396.054	93.920	lower bay	ODU
LE5.5	-76.3033	36.9967	384.027	95.097	mouth of James	ODU
WE4.4	-76.2933	37.1100	385.088	107.654	mouth of Back	VIMS
WE4.3	-76.3733	37.1767	378.086	115.154	mouth of Poquoson	VIMS
WE4.2	-76.3867	37.2417	377.002	122.383	mouth of York	VIMS
WE4.1	-76.3467	37.3117	380.661	130.097	Mobjack	VIMS
7.4N	-75.9730	37.0580	413.489	101.546	mouth of bay	ODU
CB7.4	-76.0105	36.9933	410.078	94.403	mouth of bay	ODU **
7.3E	-76.0542	37.2287	406.479	120.560	lower bay	ODU
CB7.3	-76.1255	37.1167	400.006	108.208	lower bay	ODU **
7.2E	-76.0250	37.4113	409.290	140.790	mid bay	VIMS
CB7.2	-76.0800	37.4113	404.422	140.844	mid bay	VIMS
7.1S	-76.0583	37.5812	406.555	159.672	mid bay	VIMS
CB7.1	-75.9900	37.6833	412.705	170.934	mid bay	VIMS
7.1N	-75.9750	37.7750	414.134	181.094	mid bay	VIMS
CB6.4	-76.2083	37.2363	392.819	121.567	mid bay	ODU **
CB6.3	-76.1600	37.4113	397.342	140.928	mid bay	VIMS **
CB6.2	-76.1567	37.4867	397.737	149.290	mid bay	VIMS **
CB6.1	-76.1625	37.5883	397.363	160.568	mid bay	VIMS **
LE3.7	-76.3070	37.5305	384.516	154.323	mouth of Piankatank	VIMS
LE3.6	-76.2850	37.5967	386.560	161.641	mouth of Rappahanock	VIMS
EE3.2	-75.8437	37.7935	425.716	183.034	Pocomoke sound	VIMS
EE3.1	-75.7917	37.9083	430.402	195.731	Pocomoke sound	VIMS
CB5.5	-76.1900	37.6917	395.081	172.071	mid bay	VIMS **
5.4W	-76.2950	37.8133	386.010	185.685	mouth of Gr.Wicomico	VIMS
CB5.4	-76.1750	37.8000	396.554	184.070	mid bay	VIMS **

Virginia Bay Stations

* Universal Transverse Mercator Projection position (Zone 18) in Kilometers
** Mainstem stations used in North-South Vertical cross-section image

List of Monitoring Station locations (cont.)

Maryland Bay Stations

NAME	LONG	LAT	EW UTM*	NS UTM*	Location	Agency
CB5.2	-76.2270	38.1350	392.466	221.299	upper bay	MDE **
CB5.1	-76.2930	38.3160	386.962	241.461	upper bay	MDE **
CB4.4	-76.3400	38.4120	383.007	252.172	upper bay	MDE **
CB4.3C	-76.4340	38.5550	375.047	268.164	upper bay	MDE **
CB4.3E	-76.3870	38.5550	379.143	268.101	upper bay	MDE
CB4.3W	-76.4920	38.5550	369.993	268.245	upper bay	MDE
CB4.2C	-76.4180	38.6450	376.596	278.130	upper bay	MDE **
CB4.2E	-76.3980	38.6450	378.336	278.103	upper bay	MDE
CB4.2W	-76.5000	38.6430	369.456	278.021	upper bay	MDE
CB4.1C	-76.3980	38.8240	378.640	297.967	upper bay	MDE **
CB4.1E	-76.3710	38.8140	380.967	296.821	upper bay	MDE
CB4.1W	-76.4610	38.8130	373.151	296.832	upper bay	MDE
CB3.3C	-76.3590	38.9940	382.307	316.781	upper bay	MDE **
CB3.3E	-76.3440	39.0000	383.615	317.428	upper bay	MDE
CB3.3W	-76.3870	39.0020	379.895	317.706	upper bay	MDE
CB3.2	-76.3050	39.1620	387.251	335.357	upper bay	MDE **
CB3.1	-76.2340	39.2480	393.515	344.815	upper bay	MDE **
CB2.2	-76.1720	39.3460	399.007	355.620	upper bay	MDE **
CB2.1	-76.0230	39.4390	411.963	365.785	upper bay	MDE **
CB1.1	-76.0780	39.5430	407.368	377.382	mouth of Susquehanna	MDE **

Maryland Bay Stations

* Universal Transverse Mercator Projection position (Zone 18) in Kilometers
** Mainstem stations used in North-South Vertical cross-section image

List of Monitoring Station locations (cont.)

Virginia Tributary Stations

NAME	LONG	LAT	EW UTM*	NS UTM*	Location	Agency
TF4.2	-77.0143	37.5650	322.097	159.255	York	VWCB
TF4.4	-77.0280	37.7220	321.263	176.702	York	VWCB
RET4.1	-76.8714	37.5260	334.633	154.667	York	VWCB
RET4.2	-76.7914	37.5710	341.798	159.522	York	VWCB
RET4.3	-76.7960	37.5170	341.277	153.538	York	VWCB
LE4.1	-76.7183	37.4340	347.976	144.201	York	VWCB
LE4.2	-76.5720	37.2930	360.660	128.331	York	VWCB
LE4.3	-76.4977	37.2430	367.159	122.677	York	VWCB
LE3.1	-76.6200	37.7680	357.313	181.105	Rappahanock	VWCB
LE3.2	-76.5526	37.6573	363.046	168.722	Rappahanock	VWCB
LE3.3	-76.4737	37.6840	370.053	171.572	Rappahanock	VWCB
LE3.4	-76.4497	37.6293	372.076	165.470	Rappahanock	VWCB
RET3.2	-76.7217	37.8120	348.445	186.147	Rappahanock	VWCB
RET3.1	-76.8120	37.9133	340.714	197.538	Rappahanock	VWCB
TF3.3	-76.9149	38.0187	331.908	209.415	Rappahanock	VWCB
TF3.2	-77.1000	38.1707	316.039	226.633	Rappahanock	VWCB
LE5.1	-76.6743	37.2070	351.423	118.945	James	VWCB
LE5.2	-76.6057	37.0650	357.244	103.086	James	VWCB
LE5.3	-76.4937	37.0070	367.101	96.489	James	VWCB
LE5.4	-76.4000	36.9580	375.359	90.926	James	VWCB
LE5.6	-76.3440	36.9190	380.283	86.527	James	VWCB
TF5.6	-76.9766	37.2520	324.698	124.455	James	VWCB
RET5.1A	-76.8723	37.2975	334.049	129.315	James	VWCB
RET5.2	-76.7983	37.2140	340.433	119.924	James	VWCB

Virginia Tributary Stations

* Universal Transverse Mercator Projection position (Zone 18) in Kilometers

List of Monitoring Station locations (cont.)

Maryland Tributary Stations

NAME	LONG	LAT	EW UTM*	NS UTM*	Location	Agency
TF1.1	-76.6910	38.8550	353.267	301.837	Patuxent	UMD-CBL
TF1.2	-76.7500	38.8130	348.057	297.272	Patuxent	UMD-CBL
TF1.3	-76.7110	38.8090	351.435	296.764	Patuxent	UMD-CBL
TF1.4	-76.7070	38.7710	351.704	292.541	Patuxent	UMD-CBL
TF1.5	-76.6990	38.7090	352.271	285.647	Patuxent	UMD-CBL
TF1.6	-76.6840	38.6560	353.468	279.742	Patuxent	UMD-CBL
TF1.7	-76.6800	38.5800	353.661	271.302	Patuxent	UMD-CBL
RET1.1	-76.6640	38.4900	354.874	261.289	Patuxent	UMD-CBL
LE1.1	-76.6020	38.4240	360.155	253.869	Patuxent	UMD-CBL
LE1.2	-76.5080	38.3770	368.275	248.515	Patuxent	UMD-CBL
LE1.3	-76.4880	38.3400	369.956	244.381	Patuxent	UMD-CBL
LE1.4	-76.4180	38.3110	376.025	241.067	Patuxent	UMD-CBL
CB5.1W	-76.3750	38.3240	379.806	242.452	mouth of Patuxent	UMD-CBL
RET2.4	-76.9880	38.3610	326.306	247.534	Potomac	UMD
RET2.3	-77.1290	38.3870	314.052	250.694	Potomac	UMD
ANA0082	-76.9410	38.9380	331.768	311.480	western tributary	MDE
CB1.0	-76.1740	39.6590	399.287	390.360	Susquehanna	MDE
DER0015	-76.1650	39.6230	400.007	386.354	western tributary	MDE
EE1.1	-76.2500	38.8830	391.578	304.328	Eastern Bay	MDE
EE2.1	-76.2750	38.6500	389.049	278.502	Choptank	MDE
EE2.2	-76.3080	38.5330	385.992	265.559	Little Choptank	MDE
mEE3.1	-75.9730	38.1990	414.801	228.136	Tangier Sound	MDE
mEE3.2	-75.9300	37.9650	418.307	202.134	Tangier Sound	MDE
EE3.3	-75.7660	37.9410	432.691	199.340	eastern shore	MDE

Maryland Tributary Stations

* Universal Transverse Mercator Projection position (Zone 18) in Kilometers

List of Monitoring Station locations (cont.)

Maryland Tributary Stations (cont.)

NAME	LONG	LAT	EW UTM*	NS UTM*	Location	Agency
ET1.1	-75.9570	39.5740	417.803	380.705	NE river	MDE
ET2.1	-75.8170	39.5250	429.778	375.149	Elk	MDE
ET2.2	-75.8750	39.4650	424.728	368.537	Bohemia	MDE
ET2.3	-75.8980	39.5080	422.797	373.328	Elk	MDE
ET3.1	-75.8830	39.3650	423.931	357.445	Sassafras	MDE
ET4.1	-75.9220	39.2580	420.450	345.604	Chester	MDE
ET4.2	-76.2150	38.9900	394.772	316.161	Chester	MDE
ET5.0	-75.7870	38.9970	431.847	316.530	head of Choptank	MDE
ET5.1	-76.0470	38.5820	408.804	270.705	Choptank	MDE
ET5.2	-76.0550	38.5660	408.087	268.938	Choptank	MDE
ET6.1	-75.7150	38.5330	437.680	264.990	Nanticoke	MDE
ET6.2	-75.8830	38.3320	422.823	242.815	Nanticoke	MDE
ET7.1	-75.7890	38.2660	430.977	235.417	Wicomico	MDE
ET8.1	-75.8160	38.1410	428.492	221.568	Manokin	MDE
ET9.1	-75.8050	38.0570	429.376	212.239	Annemessy	MDE
GUN0125	-76.5290	39.4260	368.392	364.958	western tributary	MDE
GUN0258	-76.6360	39.5500	359.432	378.882	western tributary	MDE
JON0184	-76.6620	39.3930	356.876	361.498	western tributary	MDE
LE2.2	-76.5820	38.1660	361.411	225.210	Potomac	MDE
PAT0176	-76.7060	39.2180	352.721	342.147	western tributary	MDE
PXT0809	-76.8750	39.1170	337.898	331.226	western tributary	MDE
WT1.1	-76.2380	39.4320	393.450	365.240	NW shore	MDE
WT2.1	-76.3400	39.3830	384.590	359.928	NW shore	MDE
WT3.1	-76.3980	39.2990	379.450	350.681	NW shore	MDE
WT4.1	-76.4490	39.2830	375.024	348.974	NW shore	MDE
WT5.1	-76.5230	39.2070	368.499	340.645	NW shore	MDE
WT6.1	-76.4730	39.0740	372.577	325.813	NW shore	MDE
WT7.1	-76.5080	39.0160	369.443	319.426	NW shore	MDE
WT8.1	-76.5160	38.9320	368.595	310.115	NW shore	MDE
WT8.2	-76.5310	38.8830	367.203	304.699	NW shore	MDE
WT8.3	-76.5310	38.8500	367.142	301.037	NW shore	MDE
XFB2470	-77.0470	38.7050	322.000	285.822	western tributary	MDE

* Universal Transverse Mercator Projection position (Zone 18) in Kilometers

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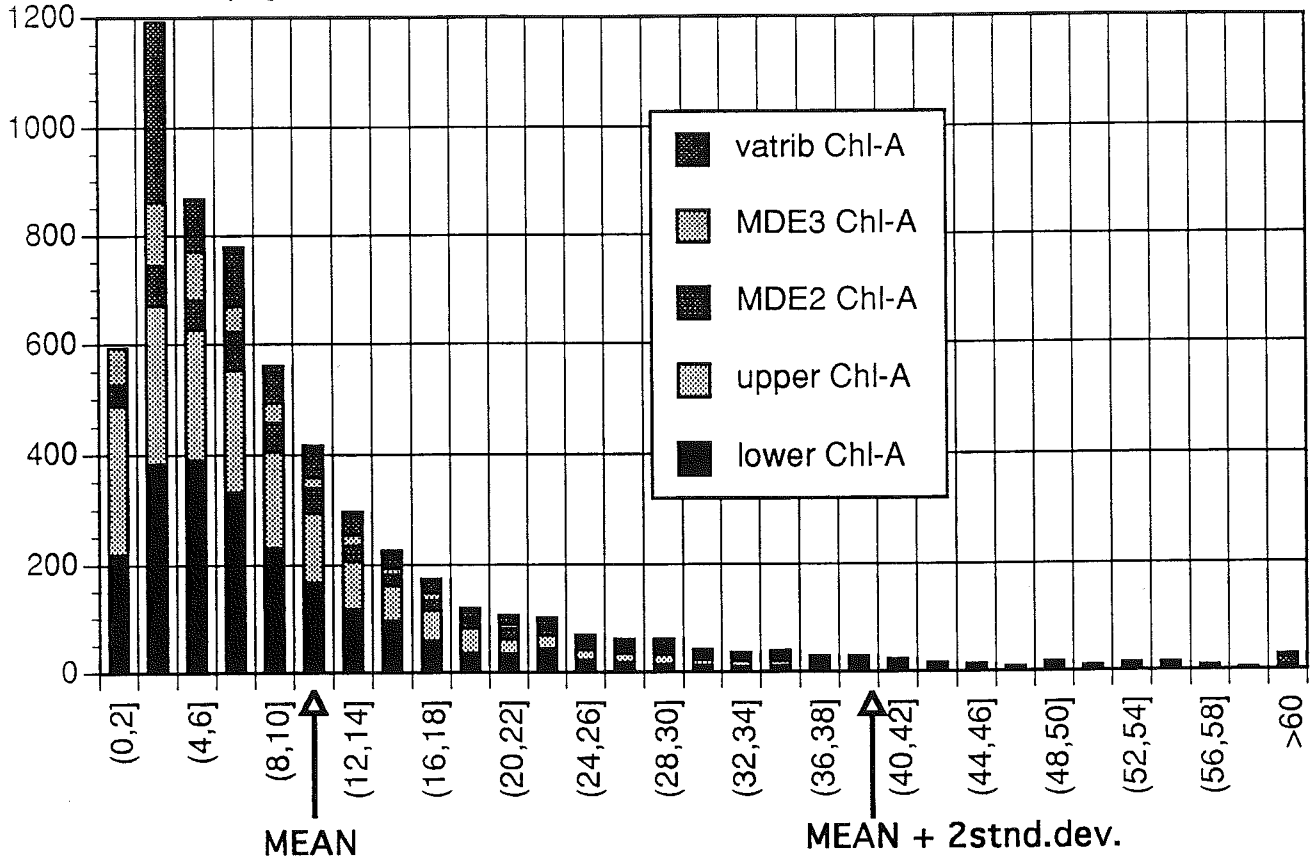
Summary Statistics for U.S.EPA Bay Water Quality Monitoring Data Set					
SALINITY	# of points	MEAN	STND-DEV.	MEAN+2sd	
Virginia Bay	40709	21.2214	4.2662	29.7538	
Maryland Bay	35571	14.0445	5.4412	24.9269	
Maryland tributaries	26975	9.0249	6.2884	21.6017	
Patuxent and Potomac	7554	8.8375	5.9197	20.6769	
Virginia tributaries	16121	9.7584	9.0411	27.8406	
	126930	**14.425**		**25.885**	**SALIN**
TEMPERATURE	# of points	MEAN	STND-DEV.	MEAN+2sd	
Virginia Bay	40851	17.0206	7.800015	32.62063	
Maryland Bay	35571	16.6314	7.936348	32.504096	
Maryland tributaries	26972	16.4174	8.328706	33.074812	
Patuxent and Potomac	7557	16.8837	8.236708	33.357116	
Virginia tributaries	16904	18.2962	7.76555	33.8273	
	127855	**16.946**		**32.887**	**TEMP**
TOTAL PHOSPHORUS	# of points	MEAN	STND-DEV.	MEAN+2sd	
Virginia Bay	8462	0.03433	0.02213	0.07859	
Maryland Bay	10577	0.0417	0.027821	0.097342	
Maryland tributaries	7176	0.09552	0.067763	0.231046	
Patuxent and Potomac	7073	0.12821	0.105751	0.339712	
Virginia tributaries	7463	0.0964	0.084195	0.26479	
	40751	**0.0747**		**0.1897**	**TP**
DO2	# of points	MEAN	STND-DEV.	MEAN+2sd	
Virginia Bay	37947	7.7829	2.569537	12.921974	
Maryland Bay	35236	6.7157	3.761455	14.23861	
Maryland tributaries	26866	8.3159	3.056405	14.42871	
Patuxent and Potomac	7527	7.9988	3.093154	14.185108	
Virginia tributaries	16691	7.748	2.473966	12.695932	
	124267	**7.604**		**13.667**	**DO2**
Chlorophyll-a	# of points	MEAN	STND-DEV.	MEAN+2sd	
Virginia Bay	8449	9.3094	9.440991	28.191382	
Maryland Bay	10422	9.6655	12.388507	34.442514	
Maryland tributaries	7169	16.5728	25.624148	67.821096	
Patuxent and Potomac	6710	12.089	15.768546	43.626092	
Virginia tributaries	3272	11.7587	13.619053	38.996806	
	36022	**11.598**		**41.744**	**Chlor-A**

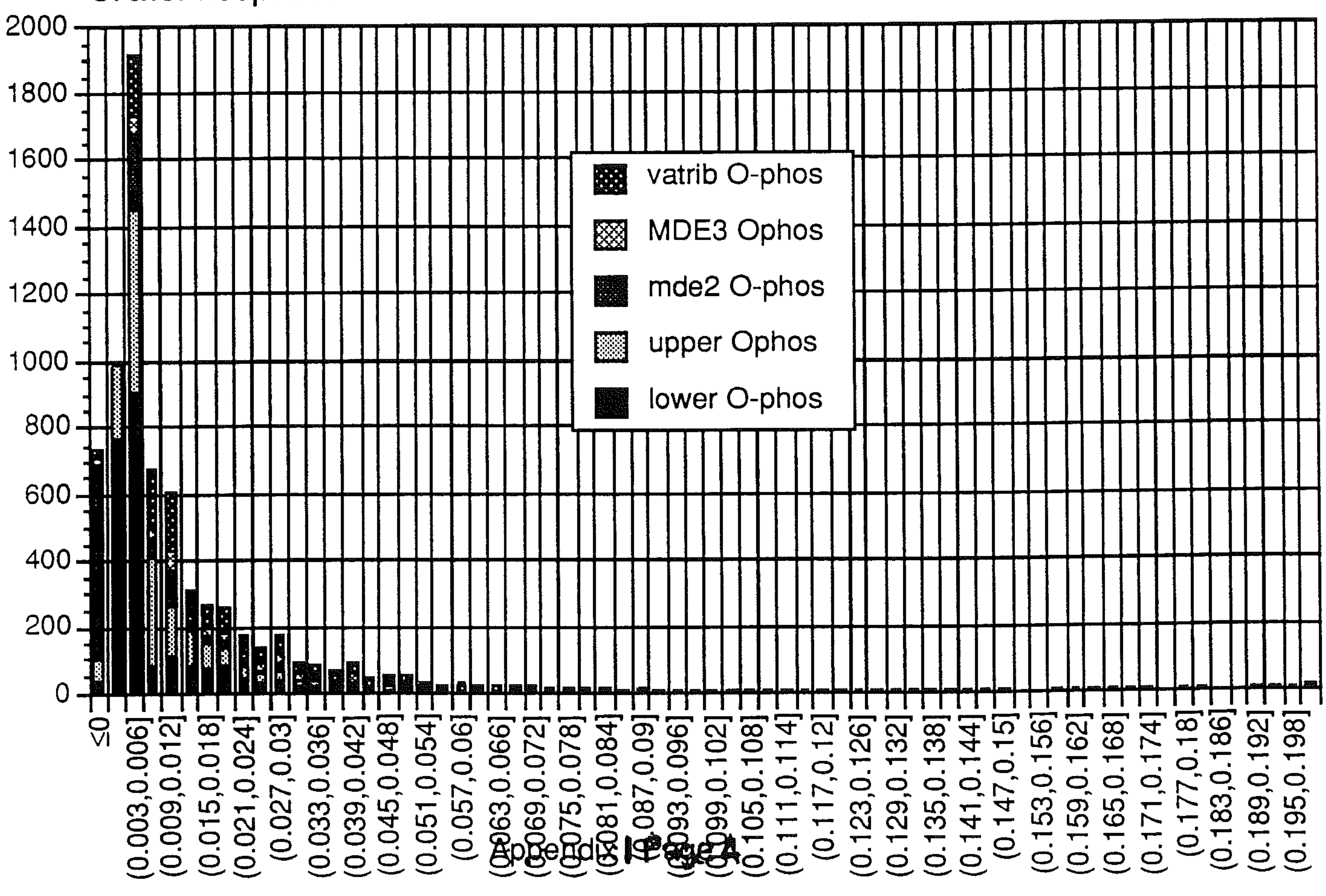
Summary Statistics for U.S.EPA Bay Water Quality Monitoring Data Set (cont.)					
Ortho-Phos	# of points	MEAN	STND-DEV.	MEAN+2sd	
Virginia Bay	8578	0.00731	0.00882	0.02495	
Maryland Bay	9906	0.01156	0.013965	0.03949	
Maryland tributaries	7127	0.01329	0.018077	0.049444	
Patuxent and Potomac	6988	0.03346	0.0484	0.13026	
Virginia tributaries	7309	0.03026	0.048081	0.126422	
	39908	**0.0182**		**0.0700**	**OPHOS**
Total Nitrogen	# of points	MEAN	STND-DEV.	MEAN+2sd	
Virginia Bay	8474	0.5044	0.16441	0.83322	
Maryland Bay	10650	0.89914	0.403536	1.706212	
Maryland tributaries	7131	1.26124	1.093159	3.447558	
Patuxent and Potomac	6604	1.35256	1.039149	3.430858	
Virginia tributaries	7207	0.88036	0.393302	1.666964	
	40066	**0.9515**		**2.1087**	**TN**
Ammonia	# of points	MEAN	STND-DEV.	MEAN+2sd	
Virginia Bay	8557	0.0377	0.047781	0.133262	
Maryland Bay	10723	0.09331	0.095671	0.284652	
Maryland tributaries	7135	0.13486	0.462587	1.060034	
Patuxent and Potomac	7049	0.11193	0.136314	0.384558	
Virginia tributaries	6899	0.10498	0.132441	0.369862	
	40363	**0.0941**		**0.4216**	**NH3**
Nitrate	# of points	MEAN	STND-DEV.	MEAN+2sd	
Virginia Bay	8545	0.03179	0.056135	0.14406	
Maryland Bay	10719	0.28321	0.354548	0.992306	
Maryland tributaries	7267	0.38411	0.60196	1.58803	
Patuxent and Potomac	7073	0.52912	0.809624	2.148368	
Virginia tributaries	7417	0.21169	0.213416	0.638522	
	41021	**0.2782**		**1.0565**	**NO3**
Silica	# of points	MEAN	STND-DEV.	MEAN+2sd	
Virginia Bay	8565	0.31232	0.310323	0.932966	
Maryland Bay	10722	0.79253	0.558824	1.910178	
Maryland tributaries	7144	1.31712	1.332923	3.982966	
Patuxent and Potomac	7071	1.80471	1.536296	4.877302	
Virginia tributaries	7381	5.09448	3.814998	12.724476	
	40883	**1.7353**		**4.5332**	**SILICA**

Summary Statistics for U.S.EPA Bay Water Quality Monitoring Data Set (cont.)					
Total Org. Carbon	# of points	MEAN	STND-DEV.	MEAN+2sd	
Virginia Bay	8452	3.6294	1.358748	6.346896	
Maryland Bay	10525	3.7518	1.314391	6.380582	
Maryland tributaries	6748	3.7096	1.836515	7.38263	
Patuxent and Potomac	6797	4.3206	2.905612	10.131824	
Virginia tributaries	6806	5.3107	2.25977	9.83024	
	39328	**4.086**		**7.791**	TOC
Total Susp.Solids	# of points	MEAN	STND-DEV.	MEAN+2sd	
Virginia Bay	8541	14.6751	19.554975	53.78505	
Maryland Bay	10590	10.6077	13.439294	37.486288	
Maryland tributaries	7341	21.5784	23.872881	69.324162	
Patuxent and Potomac	7172	23.4523	30.990291	85.432882	
Virginia tributaries	3844	34.8094	53.541926	141.893252	
	37488	**18.622**		**67.313**	TSS
pH	# of points	MEAN	STND-DEV.	MEAN+2sd	
Virginia Bay	14962	8.1089	0.32718	8.76326	
Maryland Bay	34986	7.7034	0.385975	8.47535	
Maryland tributaries	26443	7.6645	0.471558	8.607616	
Patuxent and Potomac	7557	7.6739	0.460918	8.595736	
Virginia tributaries	6836	7.4354	0.617755	8.67091	
	90784	**7.736**		**8.586**	pH

Chlorophyll -A Measurement Distribution

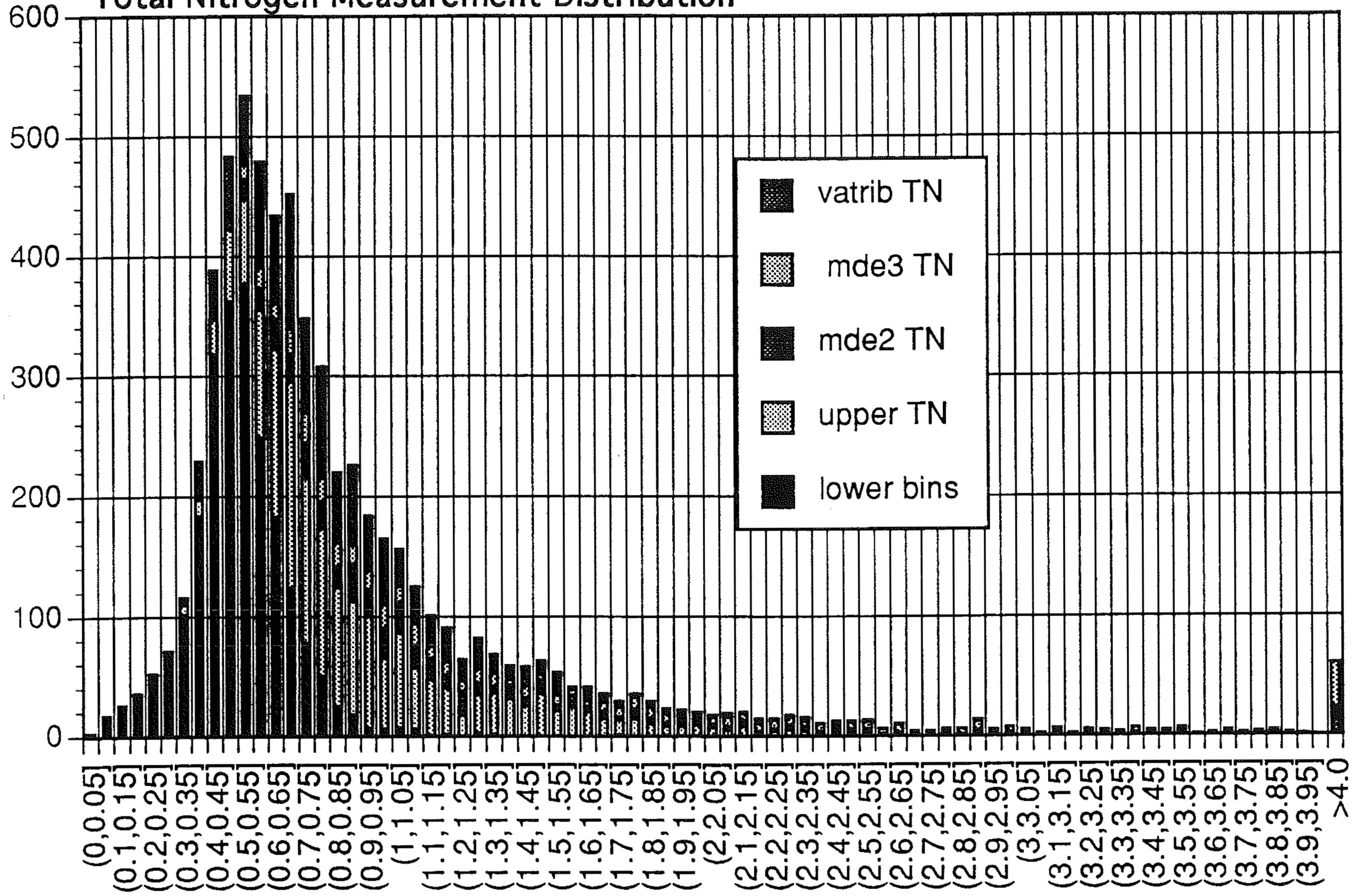


OrthoPhosphate Measurement Distribution

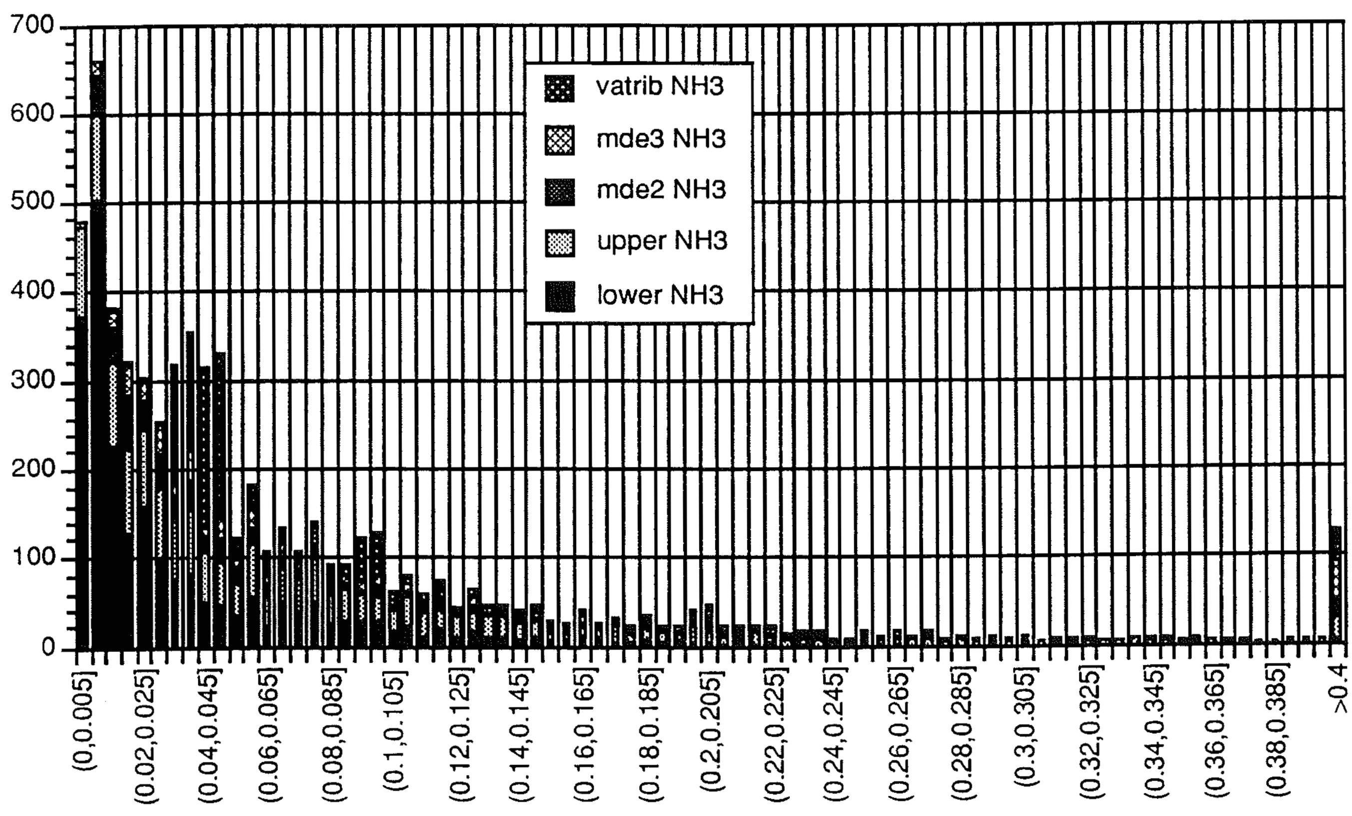


Appendix II Summary Statistics for Water Quality Monitoring Data Set (cont.)

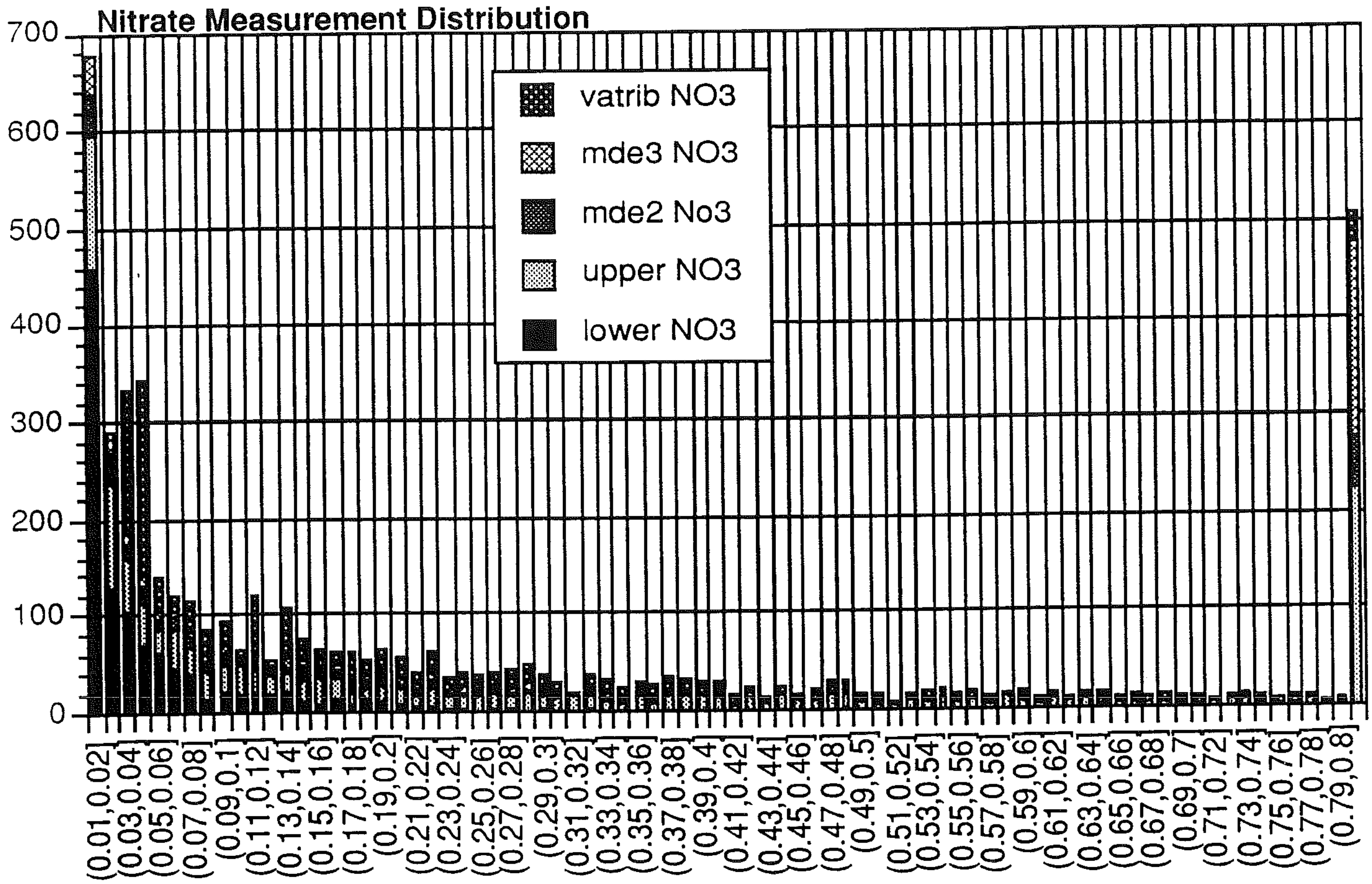
Total Nitrogen Measurement Distribution

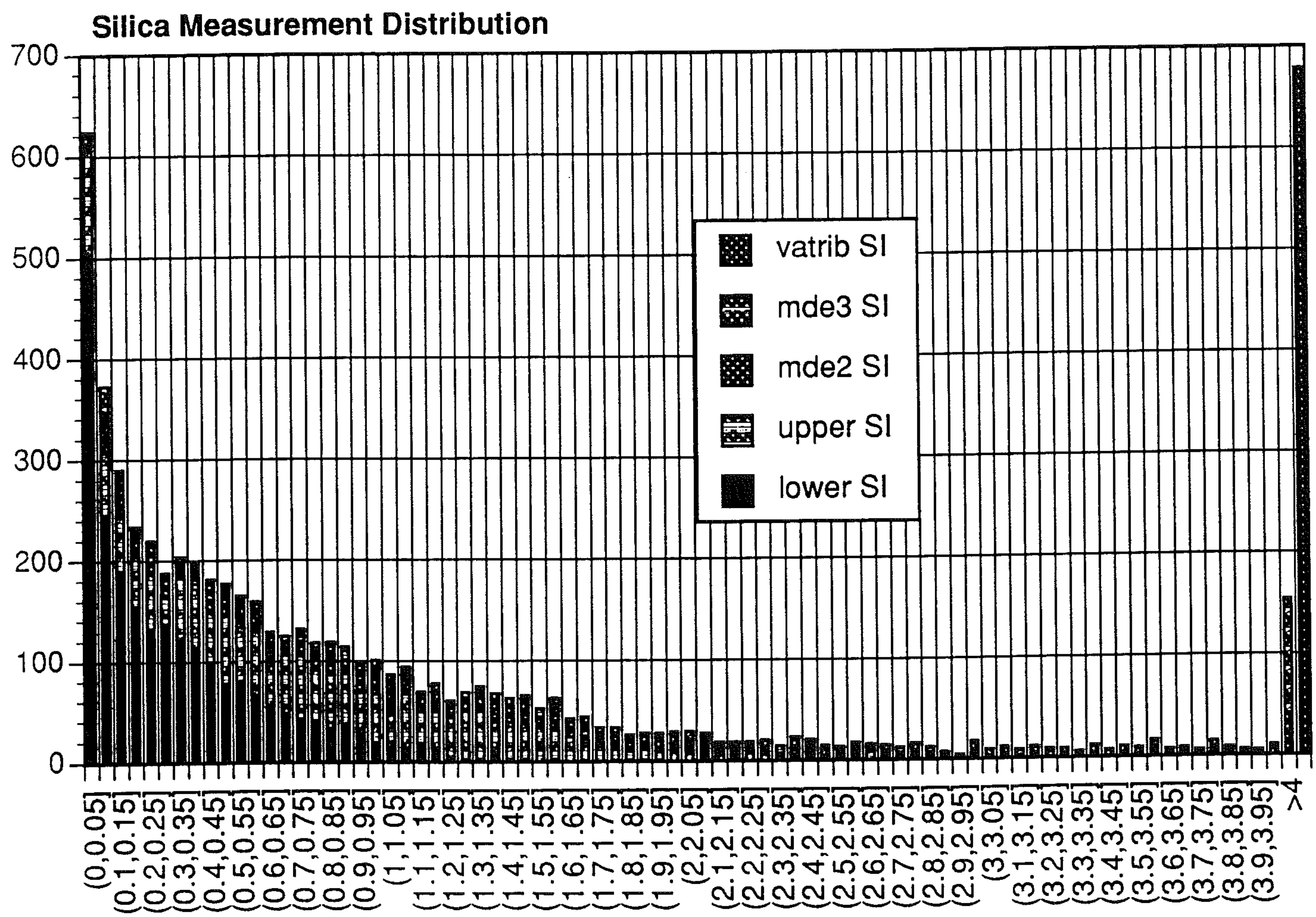


Total Ammonia Measurement Distribution



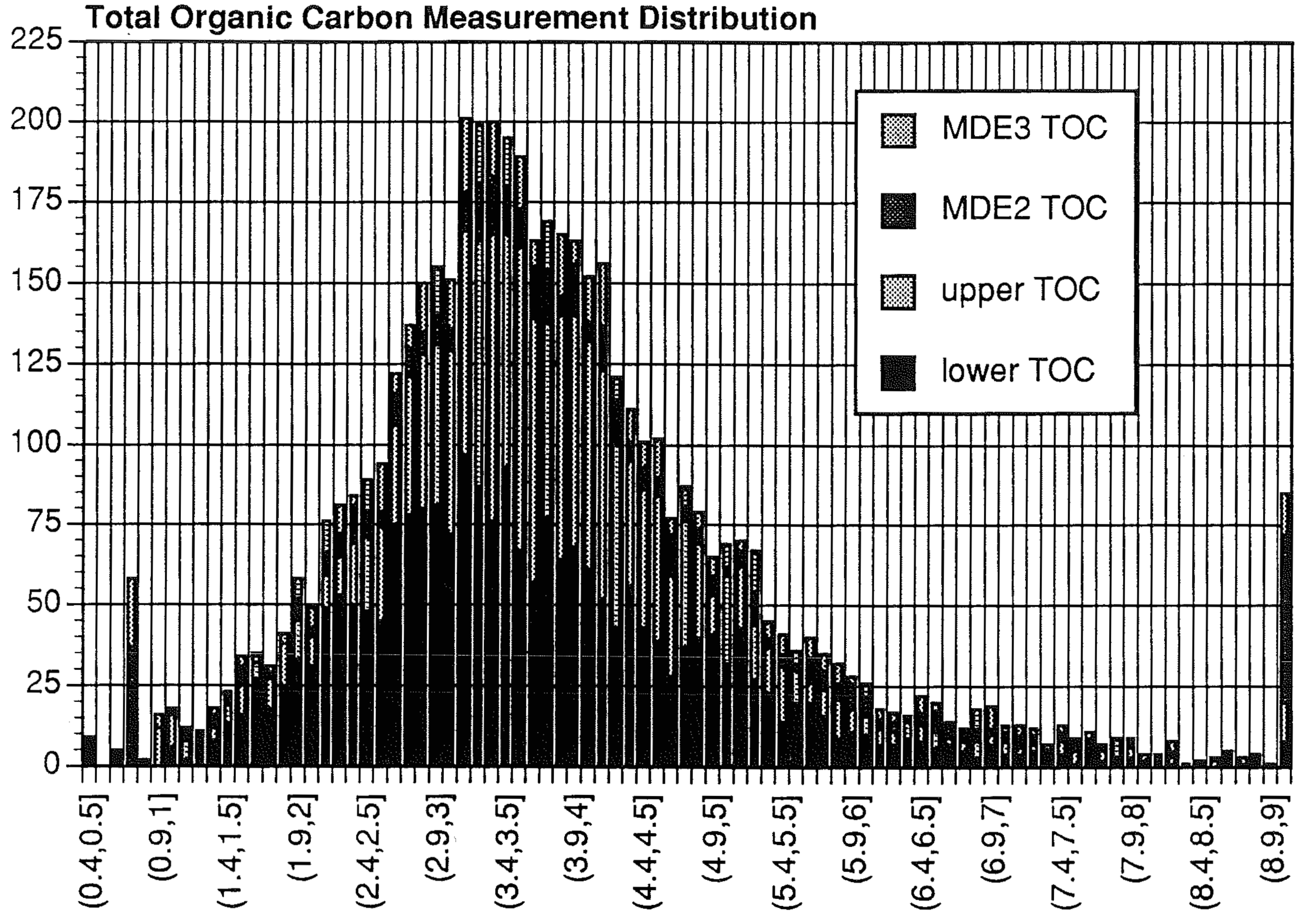
Appendix II Summary Statistics for Water Quality Monitoring Data Set (cont.)



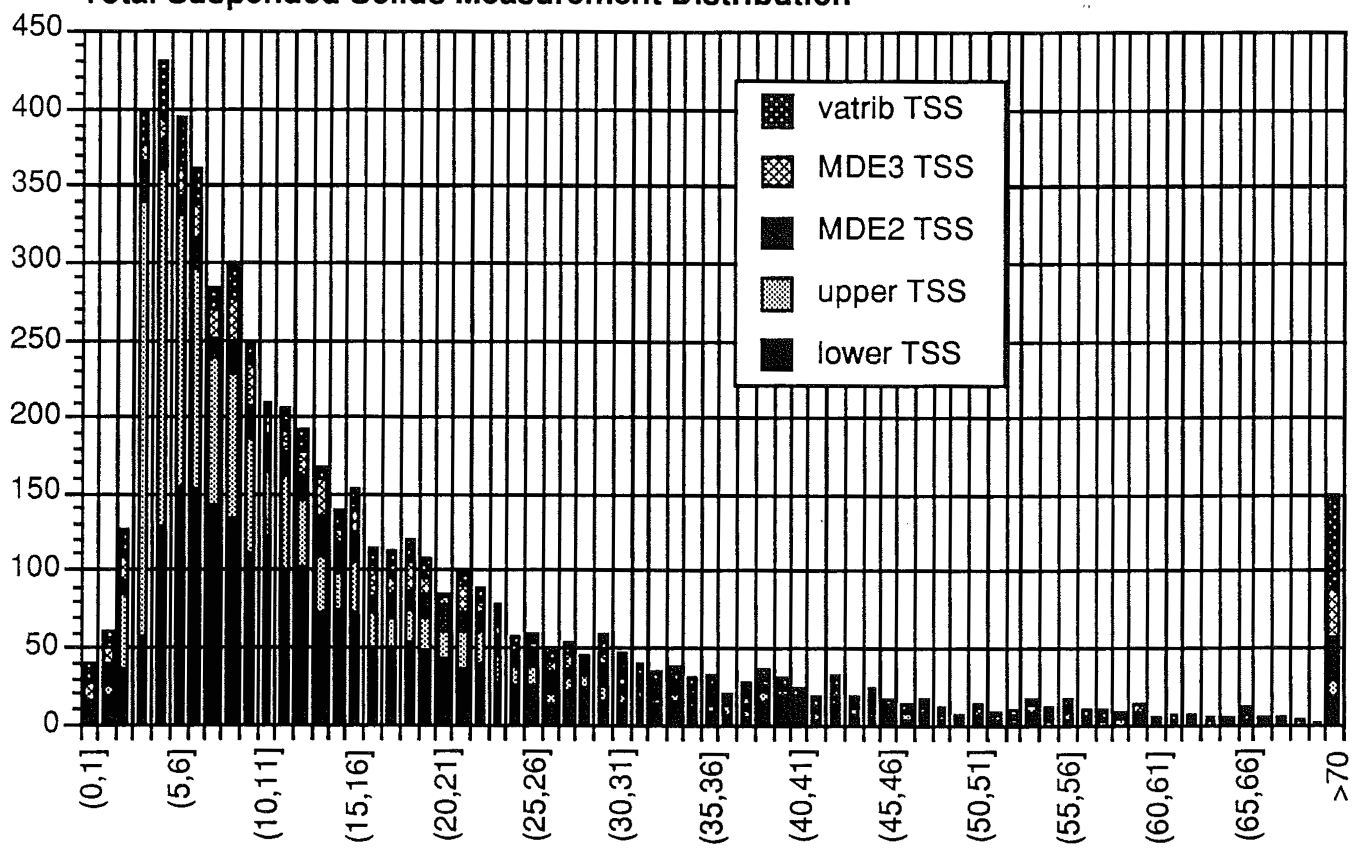


Appendix II Summary Statistics for Water Quality Monitoring Data Set (cont.)

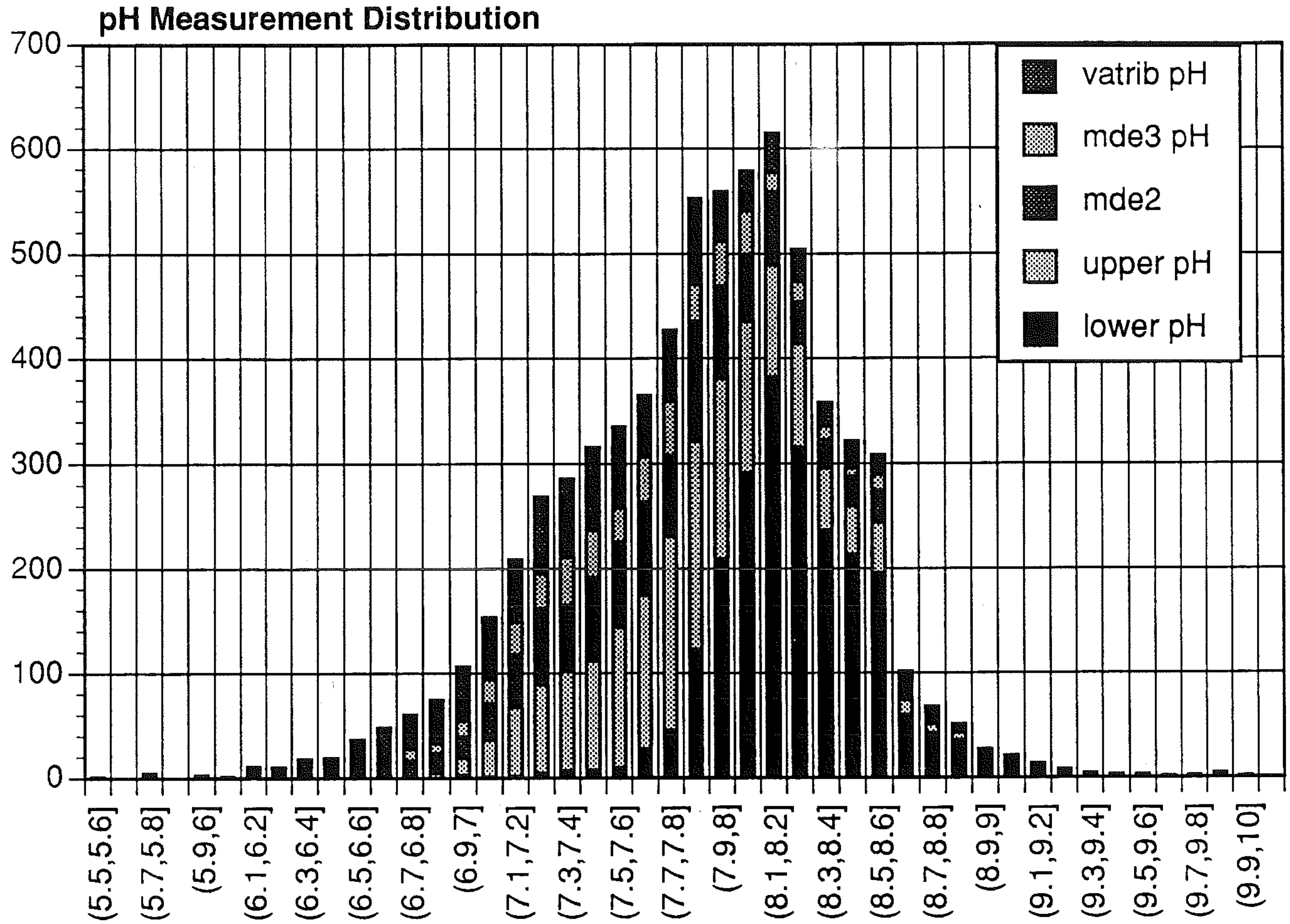
Total Organic Carbon Measurement Distribution



Total Suspended Solids Measurement Distribution

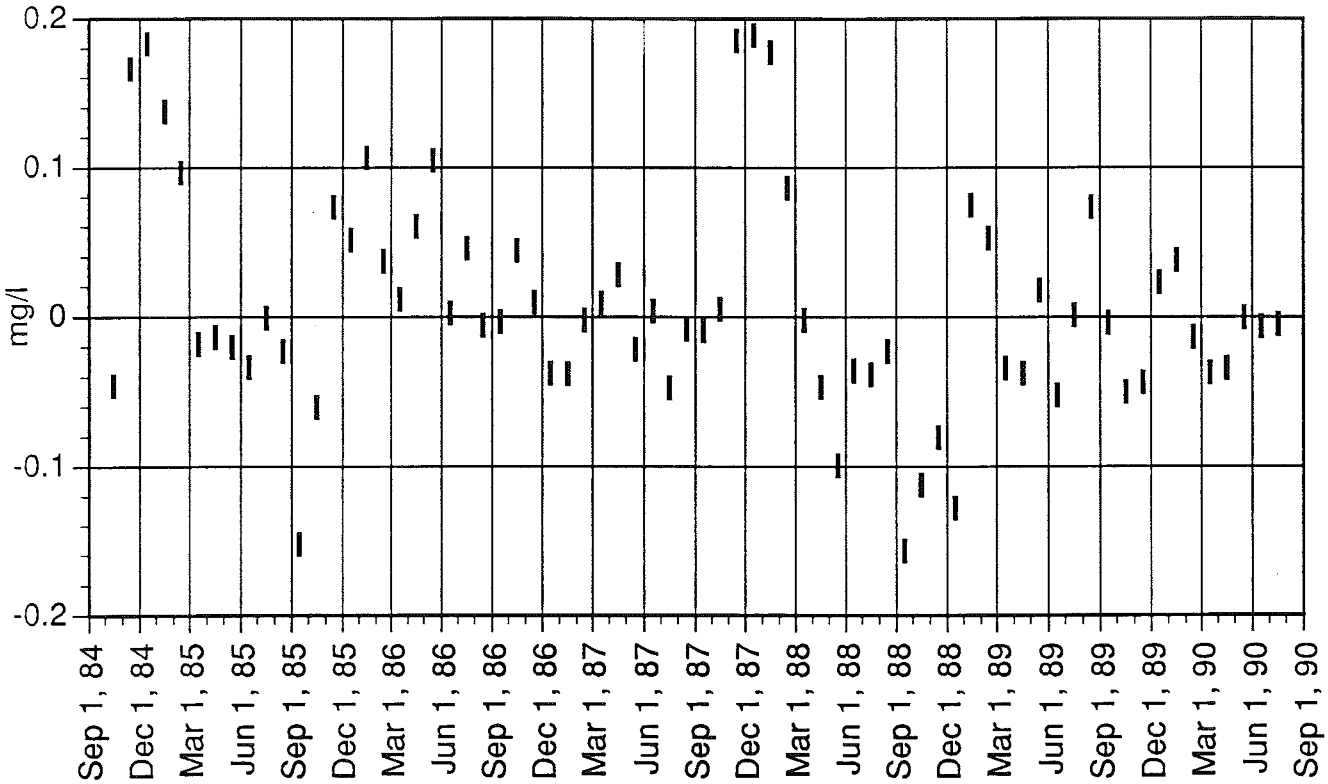


Appendix II Summary Statistics for Water Quality Monitoring Data Set (cont.)

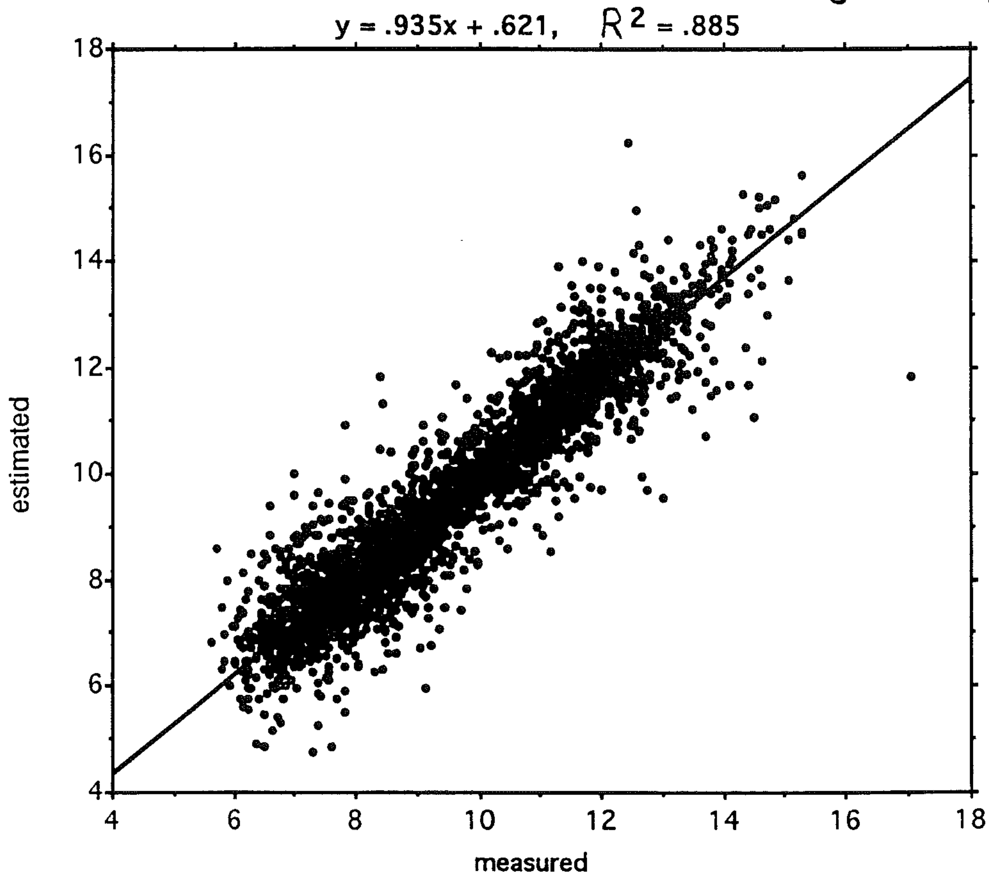


Appendix III Jackknife Results

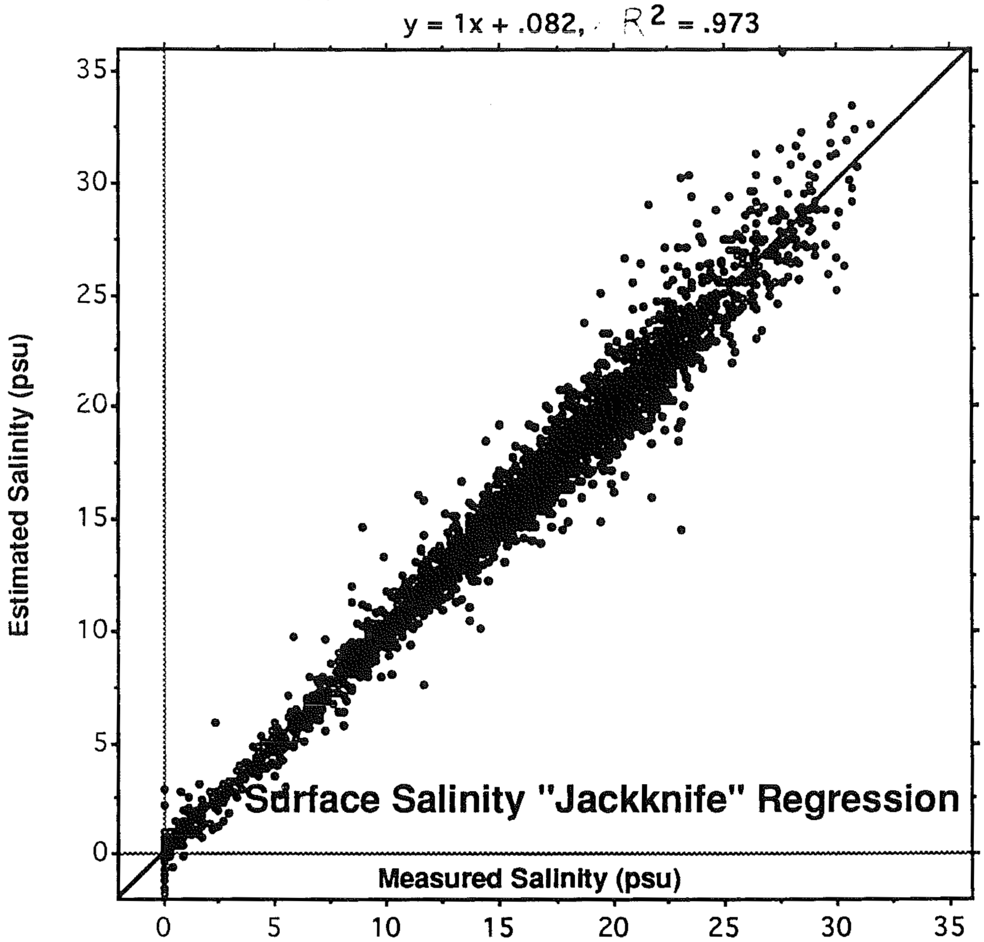
Average Error (DO2 measure - DO2 estimated) for @ month

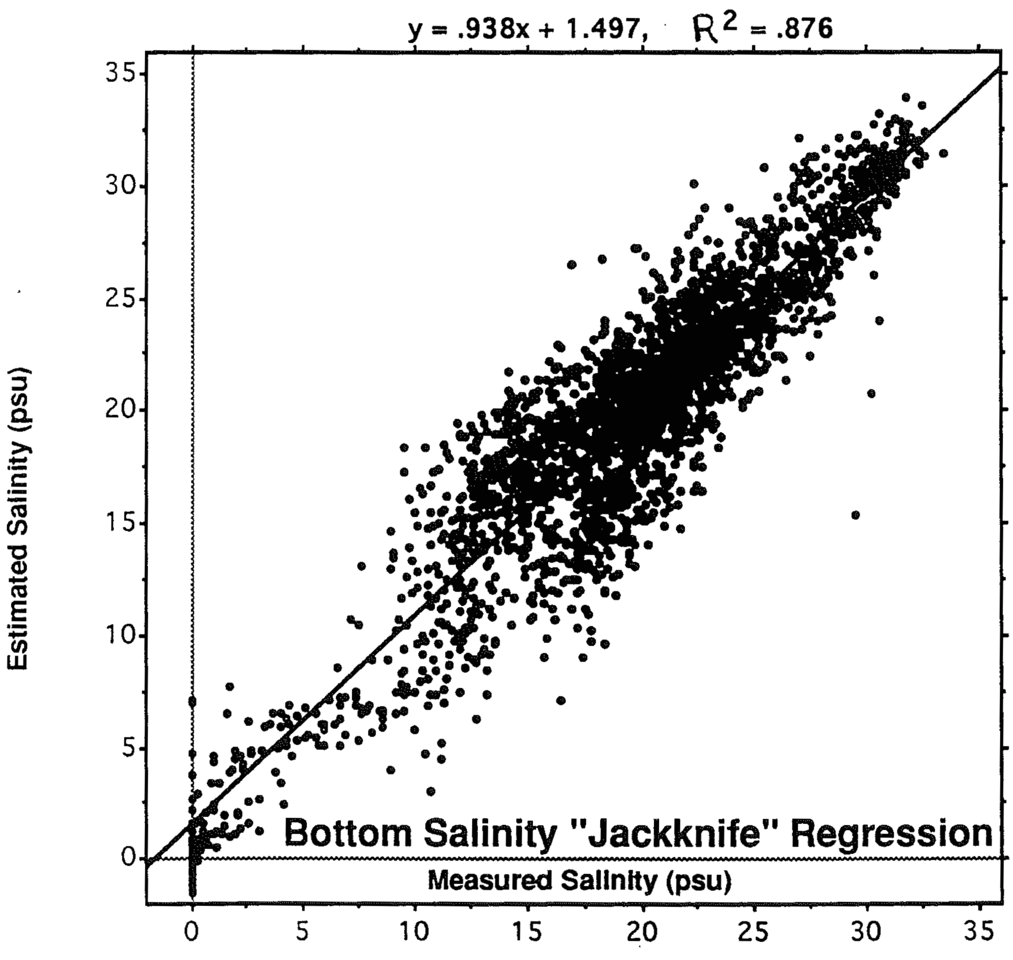


Regression of Surface DO2 measured vs DO2 estimated (jackknife)

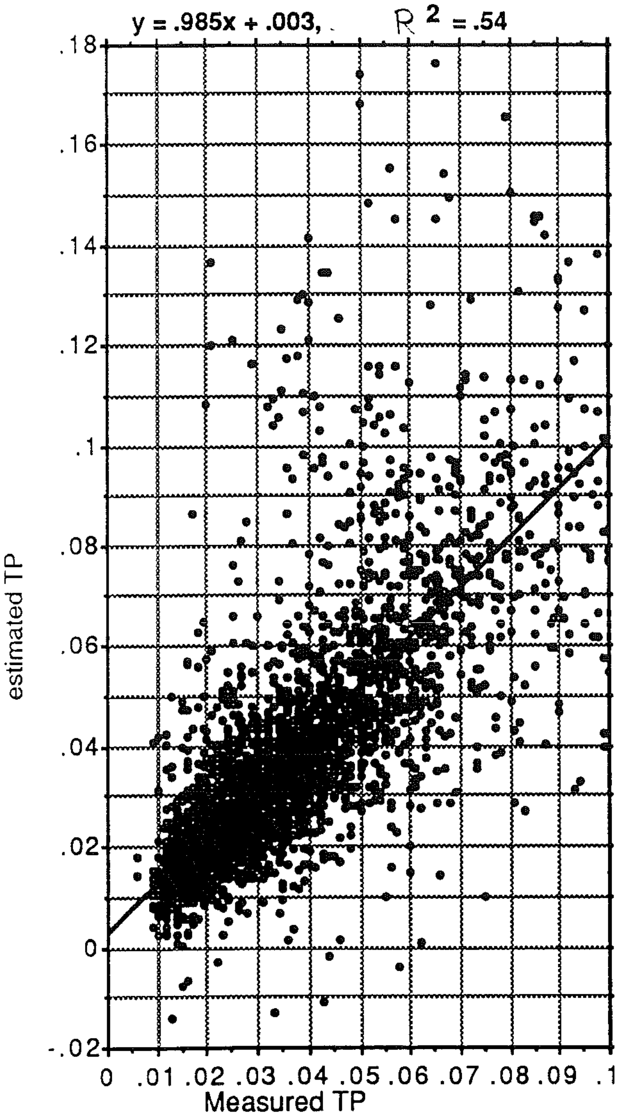


Appendix III Jackknife Results (cont.)

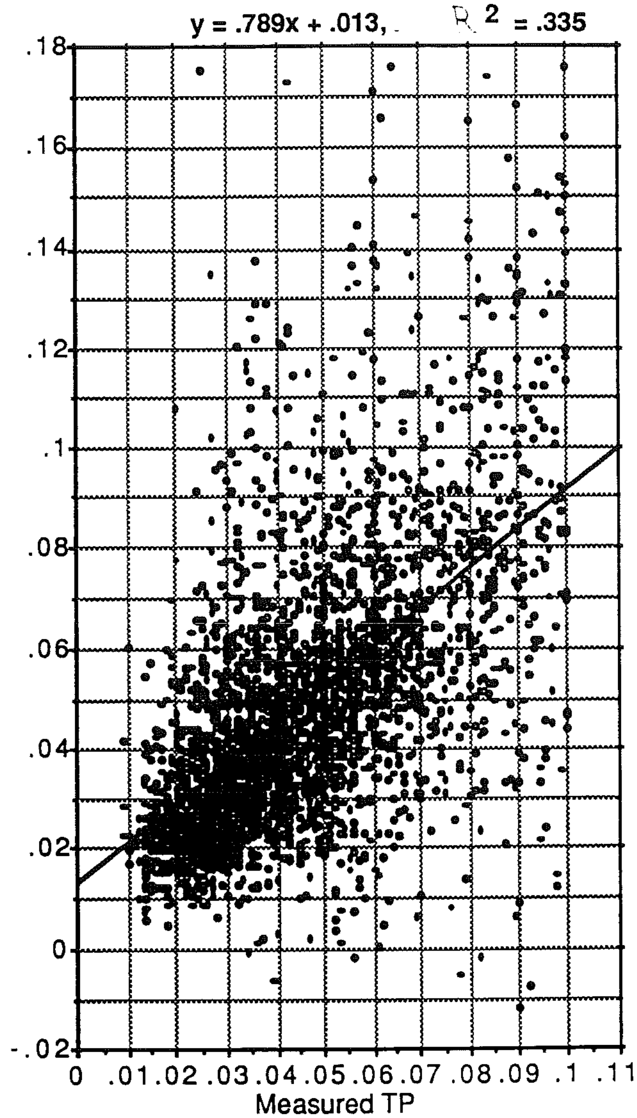




Appendix III Jackknife Results (cont.)



Surface Total Phosphorus "Jackknife" Regression



Bottom Total Phosphorus "Jackknife" Regression