CHESAPEAKE BAY WATER QUALITY MONITORING PROGRAM

LONG-TERM BENTHIC MONITORING AND ASSESSMENT COMPONENT LEVEL I COMPREHENSIVE REPORT

JULY 1984CDECEMBER 2002 (VOLUME 1)

Prepared for

Maryland Department of Natural Resources
Resource Assessment Service
Tidewater Ecosystem Assessments
Annapolis, Maryland

Prepared by

Roberto J. Llansó
Lisa C. Scott
Frederick S. Kelley

Versar, Inc.
9200 Rumsey Road
Columbia, Maryland 21045

July 2003

FOREWORD

This document, Chesapeake Bay Water Quality Monitoring Program: Long-Term Benthic Monitoring and Assessment Component, Level I Comprehensive Report (July 1984C December 2002), was prepared by Versar, Inc., at the request of Dr. Robert Magnien of the Maryland Department of Natural Resources under Cooperative Agreement CA-07-4-30767-3734 between Versar, Inc., and the University of Maryland Center for Environmental and Estuarine Studies. The report assesses the status of Chesapeake Bay benthic communities in 2002 and evaluates their responses to changes in water quality.

ACKNOWLEDGMENTS

We are grateful to the State of Maryland's Environmental Trust Fund which partially funded this work. The benthic studies discussed in this report were conducted from the University of Maryland's research vessels and we appreciate the efforts of their captains and crew. We thank Nancy Mountford and Tim Morris of Cove Corporation who identified benthos in many of the samples and provided current taxonomic and autecological information. We also thank those at Versar whose efforts helped produce this report: the field crews who collected samples, including Martin Berlett, Katherine Dillow, and Lauren Nowell; the laboratory technicians for processing samples, including David Wong, Josh Vanderwagon, Jeff Tomlinson, and Todd Beser; Michael Winnel for verifying identifications; Jody Dew for managing and analyzing data; Allison Brindley for GIS support; Sherian George and Gail Lucas for document production support; and Dr. Don Strebel for web-page development.

We appreciate the efforts of Dr. Daniel M. Dauer and Anthony (Bud) Rodi of Old Dominion University who coordinate the activities of the Virginia Benthic Monitoring Program.

EXECUTIVE SUMMARY

Benthic macroinvertebrates have been an important component of the State of Maryland's Chesapeake Bay water quality monitoring program since the program's inception in 1984. Benthos integrate temporally variable environmental conditions and the effects of multiple types of environmental stress. They are sensitive indicators of environmental status. Information on the condition of the benthic community provides a direct measure of the effectiveness of management actions. This report is the nineteenth in a series of annual reports that summarize data up to the current sampling year. Benthic community condition and trends in the Chesapeake Bay are assessed for 2002 and compared to results from previous years.

Sampling Design and Methods

Maryland's long-term benthic monitoring program currently contains two elements: a fixed site monitoring effort directed at identifying temporal trends and a probability-based sampling effort intended to assess the areal extent of degraded benthic community condition. Benthic community condition is assessed using the benthic index of biotic integrity (B-IBI), which evaluates the ecological condition of a sample by comparing values of key benthic community attributes to reference values expected under non-degraded conditions in similar habitat types. These reference values are the benthic community restoration goals for the Chesapeake Bay. Application of the B-IBI is limited to samples collected in summer, defined as July 15 through September 30.

Twenty-seven fixed sites are sampled twice a year, in May and in late August or September. Three replicate sediment samples for benthos are collected at each fixed site with gear used since 1984. These sites are part of a more extensive suite of sites that were sampled previously at various times and locations. The probability-based sampling design is stratified simple random. It was established in 1994. Twenty-five random sites are allocated annually to each of six strata in the Maryland portion of the Chesapeake Bay. A similar stratification scheme has been used by the Commonwealth of Virginia since 1996, permitting annual estimates for the entire Chesapeake Bay. The largest portion of the Chesapeake Bay, the mainstem, is divided into three strata, and five strata consist of the major tributaries (Patuxent, Potomac, Rappahannock, York, and James rivers). Two additional strata include the remaining smaller tributaries of the Maryland upper western shore and Maryland eastern shore. The strata sampled represent the entire tidal region of the Chesapeake Bay from freshwater to polyhaline zones. Probability sites are sampled once a year in late August or September. One sample is collected at each probability site using a Young grab with a surface area of 440 cm^2.

All samples are sieved on a 0.5-mm screen and preserved in the field. At each site, temperature, conductivity, salinity, dissolved oxygen concentration, and pH of the water column are measured at various depths, and silt-clay percent, total organic carbon, total inorganic carbon, and total nitrogen are measured from sediment samples processed in the laboratory.

Trends in Fixed Site Benthic Condition

Statistically significant 18-year B-IBI trends were detected at 9 of the 27 sites currently monitored. Benthic community condition declined at three sites and improved at six sites. Trends detected through 2001 were still present in 2002 with the exception of a degrading trend in the Patuxent River near Broomes Island (Sta. 71), and improving trends in the Potomac River (Sta. 36, Rosier Bluff) and Chester River (Sta. 68), which were no longer significant. Sites with improving trends still present in 2002 were located in the main stem of the Bay (3 sites), the Elk River (Sta. 29), and the Potomac River at St. Clements Island (Sta. 51). Sites with declining trends still present in 2002 were located in the Patuxent River at Holland Cliff (Sta. 77) and in the Nanticoke River (Sta. 62). Two new trends were detected, improving in the Choptank River (Sta. 64) and degrading in the Potomac River at Morgantown (Sta. 44). Benthic organisms respond to long-term patterns in water quality parameters, such as dissolved oxygen concentrations, chlorophyll a, total nitrogen, and sediment loadings, in addition to natural fluctuations in salinity. Improving trends are likely to reflect undergoing basin-wide changes resulting from management actions. Degrading trends reflect the cumulative impacts of pollution loadings in regions with significant problems that are not yet responding to pollution abatement.

The new improving trend in the Choptank River was associated with an increase in diversity and the abundance of pollution-sensitive organisms. The degrading trend at Station 44 in the Potomac River was marginally significant. This station is on the slope of the deep channel of the Potomac River and is affected by tilts of the pycnocline bringing episodic fluctuations in dissolved oxygen and salinity, which in turn affect the benthos. Improving trends continuing in 2002 were attributed to an increase in faunal abundance (mainstem sites), positive changes in the abundance of pollution-indicative organisms (Elk River) possibly related to improving trends for nutrients, chlorophyll, and sediment concentrations in this region, and increases in diversity and a general improvement of the condition of the benthic community in the lower shallow Potomac River (Sta. 51) suggesting improvements in water quality in this region of the river.

Degrading trends continuing through 2002 were attributed to replacement of large organisms by small, abundant opportunist organisms indicative of pollution in the upper Patuxent River (Sta. 77), and to a decrease in diversity, abundance, and biomass possibly linked to high sediment loads in the Nanticoke River. Low biomass relative to reference conditions is a problem common to the Nanticoke River and the other tributaries of the lower eastern shore of Maryland. The Patuxent River site showed signs of recovery (the magnitude of the B-IBI decline diminished) with increases in the abundance and biomass of bivalves in the last three years. Positive changes in the benthic community at the lower Patuxent River site near Broomes Island were also detected in 2002. However, it is not clear whether these changes in benthic condition are related to improvements in water quality or to changes in river flow resulting from drier than normal years since 1999.

Baywide Benthic Community Condition

The area of Chesapeake Bay estimated to fail the restoration goals in 2002 increased slightly over the previous years, but the change was within the uncertainty margin of the estimate. This is surprising since 2002 was a drought year. Drought years are generally thought to be better for the Bay because of the reduced flows and associated nutrient loads, which act together to alleviate the low dissolved oxygen problem. We suggest that sediments in some Chesapeake Bay tributaries are nutrient saturated, and that excess particulate organic matter on the bottom results in higher productivity of small pollution-indicative organisms and shifts in species composition that are long-lasting. Essentially, substantial improvements in benthic community condition in Chesapeake Bay were not observed over the 1996-2002 time series. About 50% of the Chesapeake Bay and 65% of the Maryland tidal waters failed the Chesapeake Bay benthic community restoration goals in 2002. Although a large portion of the area failing the restoration goals in Chesapeake Bay had mild degradation that should respond quickly to moderate improvements in water quality, no obvious trends in the percentage of area with marginally or moderately degraded benthos were observed.

Baywide, the Potomac River and the Maryland mainstem were in worst condition in 2002, with over 70% of the bottom area failing the restoration goals. As in previous years, the upper Bay mainstem, the Virginia mainstem, and the eastern tributaries of Maryland continued to have best condition overall. Generally, there was good agreement between the status and trends for water quality parameters and the benthic community condition. Over the period 1996-2002, high percentages of severely degraded sites failing the restoration goals due to insufficient abundance or biomass occurred in the mainstem of the Chesapeake Bay, the Patuxent River, and the Potomac River. Sites with high incidence of failure due to excess abundance were most frequently located in the upper region of the Bay and the Maryland eastern tributaries. Severely degraded and depauperate benthic communities are symptomatic of prolonged oxygen stress while excess abundance and biomass are symptomatic of eutrophic conditions in the absence of low dissolved oxygen stress. Low dissolved oxygen events are common and severe in the Potomac River and the Maryland mainstem, and the Patuxent River experiences annual events of variable intensity. Maryland eastern tributaries have high agricultural land use, high nutrient input, and high chlorophyll values but low frequencies of low dissolved oxygen events.

As in previous years, restoration goal failure due to severely degraded and depauperate benthic fauna was more common than failure due to excess abundance or biomass of benthic organisms.

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1.0 INTRODUCTION

1.1 BACKGROUND

Monitoring is a necessary part of environmental management because it provides the means for assessing the effectiveness of previous management actions and the information necessary to focus future actions (NRC 1990). Towards these ends, the State of Maryland has maintained an ecological monitoring program for Chesapeake Bay since 1984. The goals of the program are to:

- quantify the types and extent of water quality problems (i.e., characterize the "state-of-the-bay");

- determine the response of key water quality measures to pollution abatement and resource management actions;

- identify processes and mechanisms controlling the bay's water quality;

- define linkages between water quality and living resources;
and

- contribute information to the Water Quality Characterization Report (305(b) report) and the List of Impaired Waters (303(d) list).

The program includes elements to measure water quality, sediment quality, phytoplankton, zooplankton, and benthic macroinvertebrates (i.e., those invertebrates retained on a 0.5-mm mesh sieve). The monitoring program includes assessments of biota because the condition of biological indicators integrates temporally variable environmental conditions and the effects of multiple types of environmental stress. In addition, most environmental regulations and contaminant control measures are designed to protect biological resources; therefore, information about the condition of biological resources provides a direct measure of the effectiveness of management actions.

The Maryland program uses benthic macroinvertebrates as biological indicators because they are reliable and sensitive indicators of habitat quality in aquatic environments. Most benthic organisms have limited mobility and cannot avoid changes in environmental conditions (Gray 1979). Benthos live in bottom sediments, where exposure to contaminants and oxygen stress are most frequent. Benthic assemblages include diverse taxa representing a variety of sizes, modes of reproduction, feeding guilds, life history characteristics, and physiological tolerances to environmental conditions; therefore, they respond to and integrate natural and anthropogenic changes in environmental conditions in a variety of ways (Pearson and Rosenberg 1978; Warwick 1986; Dauer 1993; Wilson and Jeffrey 1994).

Benthic organisms are also important secondary producers, providing key linkages between primary producers and higher trophic levels (Virnstein 1977; Holland et al. 1980, 1989; Baird and Ulanowicz 1989; Diaz and Schaffner 1990). Benthic invertebrates are among the most important components of estuarine ecosystems and may represent the largest standing stock of organic carbon in estuaries (Frithsen 1989). Many benthic organisms, such as oysters and clams, are economically important. Others, such as poly-chaete worms and small crustaceans, contribute significantly to the diets of economically important bottom feeding juvenile and adult fishes, such as spot and croaker (Homer and Boynton 1978; Homer et al. 1980).

The Chesapeake Bay Program's decision to adopt Benthic Community Restoration Goals (Ranasinghe et al. 1994a updated by Weisberg et al. 1997) enhanced use of benthic macroinvertebrates as a monitoring tool. Based largely on data collected as part of Maryland's monitoring effort, these goals describe the characteristics of benthic assemblages expected at sites exposed to little environmental stress. The Restoration Goals provide a quantitative benchmark against which to measure the health of sampled assemblages and ultimately the Chesapeake Bay. Submerged aquatic vegetation (Dennison et al. 1993) and benthic macroinvertebrates are the only biological communities for which such quantitative goals have been established in Chesapeake Bay. Restoration goals for phytoplankton and zooplankton are under development.

A variety of anthropogenic stresses affect benthic macroinvertebrate communities in Chesapeake Bay. These include toxic contamination, organic enrichment, and low dissolved oxygen. While toxic contamination is generally restricted to urban and industrial areas typically associated with ports, low dissolved oxygen (hypoxia) is the more widespread problem encompassing an area of about 600 million m^2, mainly along the deep mainstem of the bay and at the mouth of the major Chesapeake Bay tributaries (Flemer et al. 1983).

A variety of factors contribute to the development and spatial variation of hypoxia in the Chesapeake Bay. Freshwater inflow, salinity, temperature, wind stress, and tidal circulation are primary factors in the development of hypoxia (Holland et al. 1987; Tuttle et al. 1987; Boicourt 1992). The development of vertical salinity gradients during the spring freshwater run off leads to water column density stratification. The establishment of a pycnocline, in association with periods of calm and warm weather, restricts water exchange between the surface and the bottom layers of the estuary, where oxygen consumption is large. The formation or the disruption of the pycnocline is probably the most important process determining the intensity and extent of hypoxia (Seliger et al. 1985; Boicourt 1992), albeit not the only one. Biological processes contribute significantly to deep water oxygen depletion in Chesapeake Bay (Officer et al. 1984). Benthic metabolic rates increase during spring and early summer, leading to an increase of the rate of oxygen consumption in bottom waters. This depends in part on the amount of organic carbon available for the benthos, which is derived to a large extent from seasonal phyto-plankton blooms (Officer et al. 1984). Anthropogenic nutrient inputs to the Chesapeake Bay further stimulate phytoplankton growth, which results in increased deposition of organic matter to the sediments and a concomitant increase in chemical and biological oxygen demand (Malone 1987). Winter to spring accumulation of phytoplankton biomass has been linked to depletion of bottom water oxygen in Chesapeake Bay (Malone et al. 1988; Boynton and Kemp 2000).

The effects of hypoxia on benthic organisms vary as a function of the severity, spatial extent, and duration of the low dissolved oxygen event. Oxygen concentrations down to about 2 mg l^{-1} do not appear to significantly affect benthic organisms, although incipient community effects have been measured at 3 mg l^{-1} (Diaz and Rosenberg 1995; Ritter and Montagna 1999). Hypoxia brings about structural and organizational changes in the community, and may lead to hypoxia resistant communities. With an increase in the frequency of hypoxic events, benthic populations become dominated by fewer and short-lived species, and their overall productivity is decreased (Diaz and Rosenberg 1995). Major reductions in species number and abundance in the Chesapeake Bay have been attributed to hypoxia (Llansó 1992). These reductions become larger both spatially and temporally as the severity and duration of hypoxic events increase. As hypoxia becomes persistent, mass mortality of benthic organisms often occurs with almost complete elimination of the macrofauna.

Hypoxia has also major impacts on the survival and behavior of a variety of benthic organisms and their predators (Diaz and Rosenberg 1995). Many infaunal species respond to low oxygen by migrating toward the sediment surface, thus potentially increasing their availability to demersal predators. On the other hand, reduction or elimination of the benthos following severe hypoxic or anoxic (no oxygen) events may result in a reduction of food for demersal fish species and crabs. Therefore, the structural changes and species replacements that occur in communities affected by hypoxia may alter the food supply of important ecological and economical fish species in Chesapeake Bay. Given that dissolved oxygen and nutrient inputs are critical factors in the health of the resources of the Chesapeake Bay region, monitoring that evaluates benthic community condition and tracks changes over time helps Chesapeake Bay managers assess the effectiveness of nutrient reduction efforts and the status of the biological resources of one of the largest and most productive estuaries in the nation.

1.2 OBJECTIVES OF THIS REPORT

This report is the nineteenth in a series of Level I Comprehensive reports produced annually by the Long-Term Benthic Monitoring and Assessment Component (LTB) of the Maryland Chesapeake Bay Water Quality Monitoring Program. Level I reports summarize data from the latest sampling year and provide a limited examination of how conditions in the latest year differ from conditions in previous years of the study, as well as how data from this year contribute to describing trends in the bay's condition.

The report reflects the maturity of the current program=s focus and design. Approaches introduced when the new program design was implemented in 1995 continue to be extended, developed, and better defined. The level of detail in which changes are examined at the fixed stations sampled for trend analysis continues to increase. For example, we report on how species contribute to changes in condition and discuss results in relation to changes in water quality. The Benthic Index of Biotic Integrity (B-IBI) is applied to each sampling site, from tidal freshwater to polyhaline habitats, and thus provides an uniform measure of ecological condition across the estuarine gradient. In describing baywide benthic community condition, estimates of degraded condition are presented for at least seven years for all subregions of the Bay, and community measures that contribute to Restoration Goal failure are used to diagnose the causes of failure.

The continued presentation of estimates of Bay area meeting the Chesapeake Bay Program=s Benthic Community Restoration Goals, rather than Maryland estimates only, reflects improved coordination and unification of objectives among the Maryland and Virginia benthic monitoring programs. The sampling design and methods in both states are compatible and complementary.

In addition to the improvements in technical content, we have enhanced electronic production and transmittal of data. This report is produced in Adobe Acrobat format to facilitate distribution across the internet. Data and program information are available to the research community and the general public through the Chesapeake Bay Benthic Monitoring Program Home Page on the World-Wide-Web at http://www.baybenthos.versar.com. Expansion of the site continues, with new program information, data, and documents being added every year. The 2002 data, as well as the data from previous years, can be downloaded from this site. The Benthic Monitoring Program Home Page represents the culmination of collaborative efforts between Versar, Maryland DNR, and the Chesapeake Information Management System (CIMS). The activities that Versar undertakes as a partner of CIMS were recorded in a Memorandum of Agreement signed October 28, 1999.

1.3 ORGANIZATION OF REPORT

This report has two volumes. Volume 1 is organized into four major sections and three appendices. Section 1 is this introduction. Section 2 presents the field, laboratory, and data analysis methods used to collect, process, and evaluate LTB samples. Section 3 presents the results of analyses conducted for 2002 and previous years, and consists of two assessments: an assessment of trends in benthic community condition at sites sampled annually by LTB in the Maryland Chesapeake Bay, and an assessment of the area of the Bay that meets the Chesapeake Bay Benthic Community Restoration Goals. Section 4 discusses the results and evaluates status and trends relative to recent changes in water quality. Section 5 is the literature cited in the report. Appendix A amplifies information presented in Table 3-2 by providing p-values and rates of change for the 1985-2002 fixed site trend analysis. Finally, Appendices B and C present the B-IBI values for the 2002 fixed and random samples, respectively. Volume 2 consists of the raw data appendices.

2.0 METHODS

2.1 SAMPLING DESIGN

The LTB sampling program contains two primary elements: a fixed site monitoring effort directed at identifying trends in benthic condition and a probability-based sampling effort intended to estimate the area of the Maryland Chesapeake Bay with benthic communities meeting the Chesapeake Bay Program's benthic community restoration goals (Ranasinghe et al. 1994a, updated by Weisberg et al. 1997; Alden et al. 2002). The sampling design for each of these elements is described below.

2.1.1 Fixed Site Sampling

The fixed site element of the program involves sampling at 27 sites, 23 of which have been sampled since the program's inception in 1984, 2 since 1989, and 2 since 1995 (Figure 2-1). Sites are defined by geography (within 1 km from a fixed location), and by specific depth and substrate criteria (Table 2-1).

The 2002 fixed site sampling continues trend measurements, which began with the program's initiation in 1984. In the first five years of the program, from July 1984 to June 1989, 70 fixed stations were sampled 8 to 10 times per year. On each visit, three benthic samples were collected at each site and processed. Locations of the 70 fixed sites are shown in Figure 2-2.

In the second five years of the program, from July 1989 to June 1994, fixed site sampling was continued at 29 sites and a stratified random sampling element was added. Samples were collected at random from approximately 25 km^2 small areas surrounding these sites (Figure 2-3) to assess the representativeness of the fixed locations. Sites 06, 47, 62, and 77, which are part of the current design, were not sampled during this five-year period. Stratum boundaries were delineated on the basis of environmental factors that are important in controlling benthic community distributions: salinity regime, sediment type, and bottom depth (Holland et al. 1989). In addition, four new areas were established in regions of the Bay targeted for management actions to abate pollution: the Patuxent River, Choptank River, and two areas in Baltimore Harbor. Each area was sampled four to six times each year.

From July 1994 to the present, three replicate samples were collected in spring and summer at most of the current suite of 27 sites (Stations 203 and 204 were added in1995,Table 2-1, Fig. 2-1). This sampling regime was selected as being most cost effective after analysis of the first 10 years of data jointly with the Virginia Benthic Monitoring Program (Alden et al. 1997).

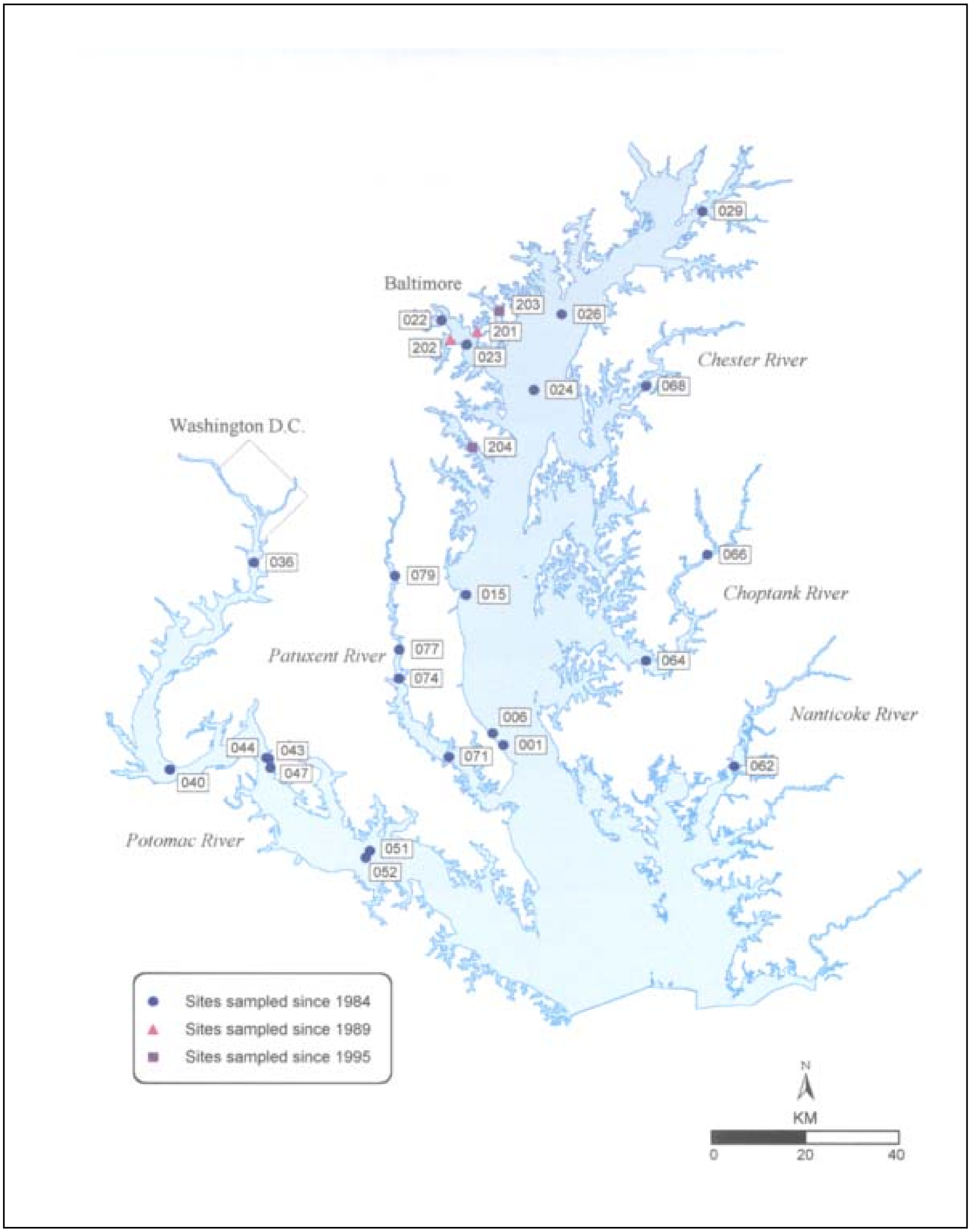

Figure 2-1. Fixed sites sampled in 2002

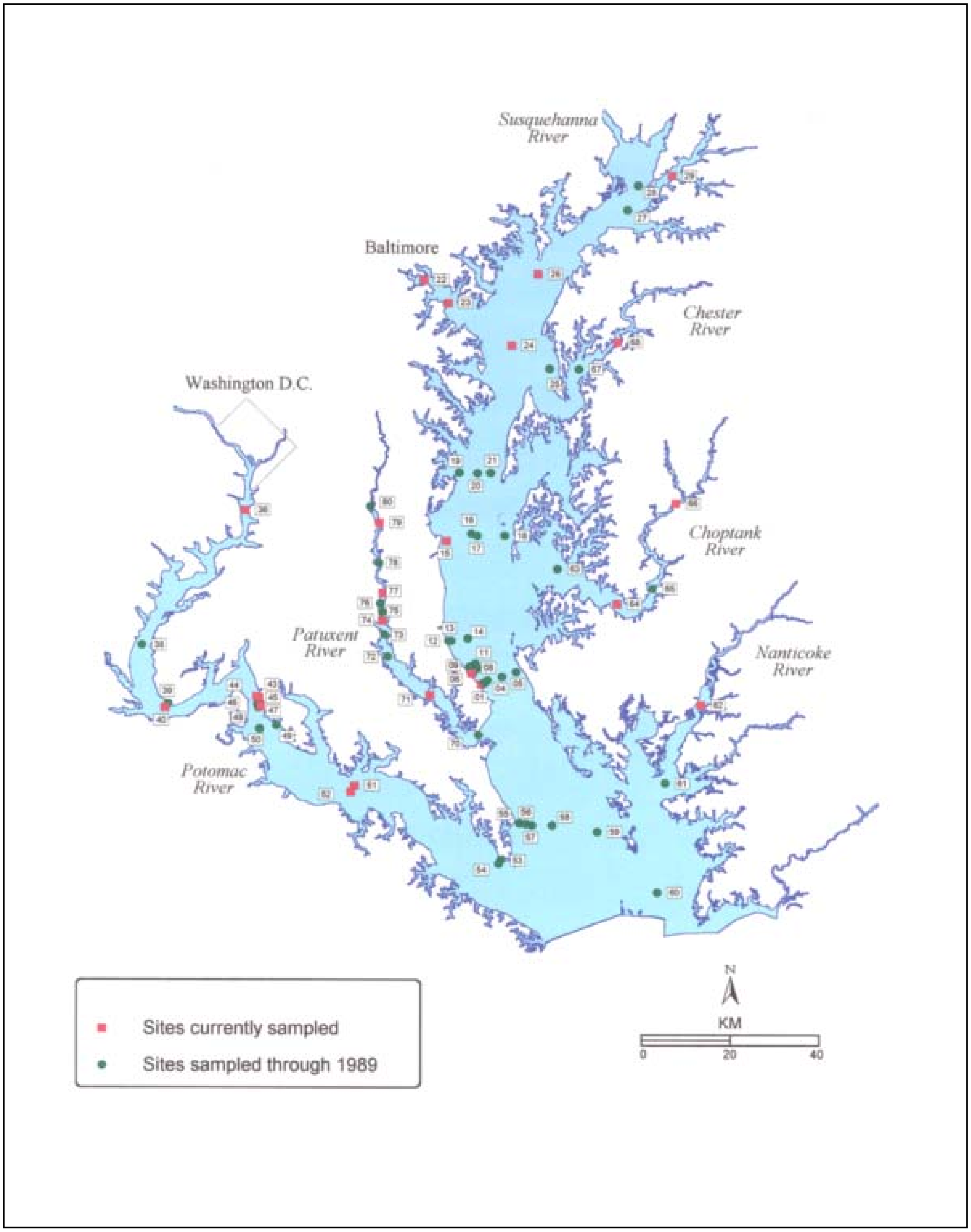

Figure 2-2. Fixed sites sampled from 1984 to 1989; some of these sites are part of the current design

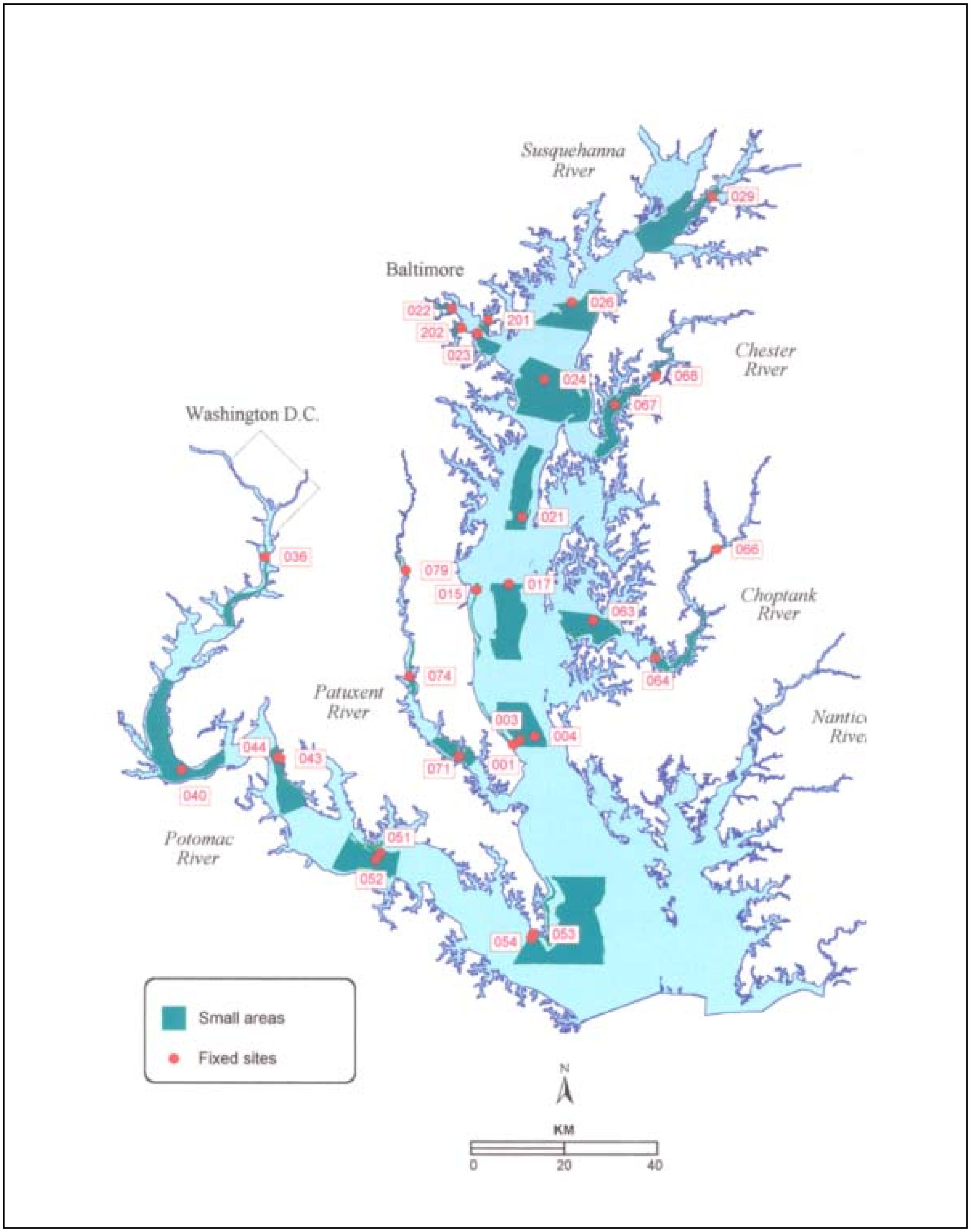

Figure 2-3. Small areas and fixed sites sampled from 1989 to 1994

Table 2-1. Location, habitat type, (Table 5, Weisberg et al. 1997), sampling gear, and habitat criteria for fixed sites

Stratum	Sub-Estuary	Habitat	Station	Latitude (NAD 83)	Longitude (NAD 83)	Sampling Gear	Habitat Criteria		
							Depth (m)	Siltclay (%)	Distance (km)
Potomac River	Potomac River	Tidal Freshwater	036	38.769781	77.037531	WildCo Box Corer	< =5	> =40	1.0
		Oligohaline	040	38.357458	77.230534	WildCo Box Corer	6.5-10	> =80	1.0
		Low Mesohaline	043	38.384125	76.989028	Modified Box Corer	< =5	< =30	1.0
		Low Mesohaline	047	38.365125	76.984695	Modified Box Corer	< =5	< =30	0.5
		Low Mesohaline	044	38.385625	76.995695	WildCo Box Corer	11-17	> =75	1.0
		High Mesohaline Sand	051	38.205462	76.738020	Modified Box Corer	< =5	< =20	1.0
		High Mesohaline Mud	052	38.192297	76.747687	WildCo Box Corer	9-13	> =60	1.0
Patuxent River	Patuxent River	Tidal Freshwater	079	38.750448	76.689020	WildCo Box Corer	< =6	> =50	1.0
		Low Mesohaline	077	38.604452	76.675017	WildCo Box Corer	< =5	> =50	1.0
		Low Mesohaline	074	38.547288	76.674851	WildCo Box Corer	< =5	> =50	0.5
		High Mesohaline Mud	071	38.395124	76.548844	WildCo Box Corer	12-18	> =70	1.0

Table 2-1. (Continued)

Stratum	Sub-Estuary	Habitat	Station	Latitude (NAD 83)	Longitude (NAD 83)	Sampling Gear	Habitat Criteria		
							Depth (m)	Siltclay (%)	Distance (km)
Upper Western Tributaries	Patapsco River	Low Mesohaline	023	39.208275	76.523352	WildCo Box Corer	4-7	> = 50	1.0
	Middle Branch	Low Mesohaline	022	39.254940	76.587354	WildCo Box Corer	2-6	> = 40	1.0
	Bear Creek	Low Mesohaline	201	39.234275	76.497184	WildCo Box Corer	2-4.5	> = 70	1.0
	Curtis Bay	Low Mesohaline	202	39.217940	76.563853	WildCo Box Corer	5-8	> = 60	1.0
	Back River	Oligohaline	203	39.275107	76.446015	Young-Grab	1.5-2.5	> = 80	1.0
	Severn River	High Mesohaline Mud	204	39.006778	76.504683	Young-Grab	5-7.5	> = 50	1.0
Eastern Tributaries	Chester River	Low Mesohaline	068	39.132941	76.078679	WildCo Box Corer	4-8	> = 70	1.0
	Choptank River	Oligohaline	066	38.801447	75.921825	WildCo Box Corer	< = 5	> = 60	1.0
		High Mesohaline Mud	064	38.590464	76069340	WildCo Box Corer	7-11	> = 70	1.0
	Nanticoke River	Low Mesohaline	062	38.383952	75.849988	Petite Ponar Grab	5-8	> = 75	1.0

Table 2-1. (Continued)

Stratum	Sub-Estuary	Habitat	Station	Latitude (NAD 83)	Longitude (NAD 83)	Sampling Gear	Habitat Criteria		
							Depth (m)	**Siltclay (%)**	**Distance (km)**
Upper Bay	Elk River	Oligohaline	029	39.479615	75.944499	WildCo Box Corer	3-7	> =40	1.0
	Mainstem	Low Mesohaline	026	39.271441	76.290011	WildCo Box Corer	2-5	> =70	1.0
		High Mesohaline Mud	024	39.122110	76.355346	WildCo Box Corer	5-8	> =80	1.0
Mid Bay	Mainstem	High Mesohaline Sand	015	38.715118	76.513677	Modified Box Corer	< =5	< =10	1.0
		High Mesohaline Sand	001	38.419956	76.416672	Modified Box Corer	< =5	< =20	1.0
		High Mesohaline Sand	006	38.442456	76.443006	Modified Box Corer	< =5	< =20	0.5

2.1.2 Probability-based Sampling

The second sampling element, which was instituted in 1994, was probability-based summer sampling designed to estimate the area of the Maryland Chesapeake Bay and its tributaries that meet the Chesapeake Bay benthic community restoration goals (Ranasinghe et al. 1994a, updated by Weisberg et al. 1997; Alden et al. 2002). Different probability sample allocation strategies were used in 1994 than in later years. In 1994, the design was intended to estimate impaired area for the Maryland Bay and one sub-region, while in later years the design targeted five additional sub-regions as well.

The 1994 sample allocation scheme was designed to produce estimates for the Maryland Bay and the Potomac River. The Maryland Bay was divided into three strata with samples allocated unequally among them (Table 2-2); sampling intensity in the Potomac was increased to permit estimation of degraded area with adequate confidence, while mainstem and other tributary and embayment samples were allocated in proportion to their area.

Table 2-2. Allocation of probability-based baywide samples, 1994

Stratum	Area		Number of Samples
	km^2	%	
Maryland Mainstem (including Tangier and Pocomoke Sounds)	3611	55.5	27
Potomac River	1850	28.4	28
Other tributaries and embayments	1050	16.1	11

In subsequent years, the stratification scheme was designed to produce an annual estimate for the Maryland Bay and six subdivisions. Samples were allocated equally among strata (Figure 2-4, Table 2-3). According to this allocation, a fresh new set of sampling sites were selected each year. Figure 2-5 shows the locations of the probability-based Maryland sampling sites for 2002. Regions of the Maryland mainstem deeper than 12 m were not included in sampling strata because these areas are subjected to summer anoxia and have consistently been found to be azoic.

A similar stratification scheme has been used by the Commonwealth of Virginia since 1996, permitting annual estimates for the extent of area meeting the benthic community restoration goals for the entire Chesapeake Bay (Table 2-3, Figure 2-6). These samples were collected and processed, and the data analyzed by the Virginia Chesapeake Bay Benthic Monitoring Program.

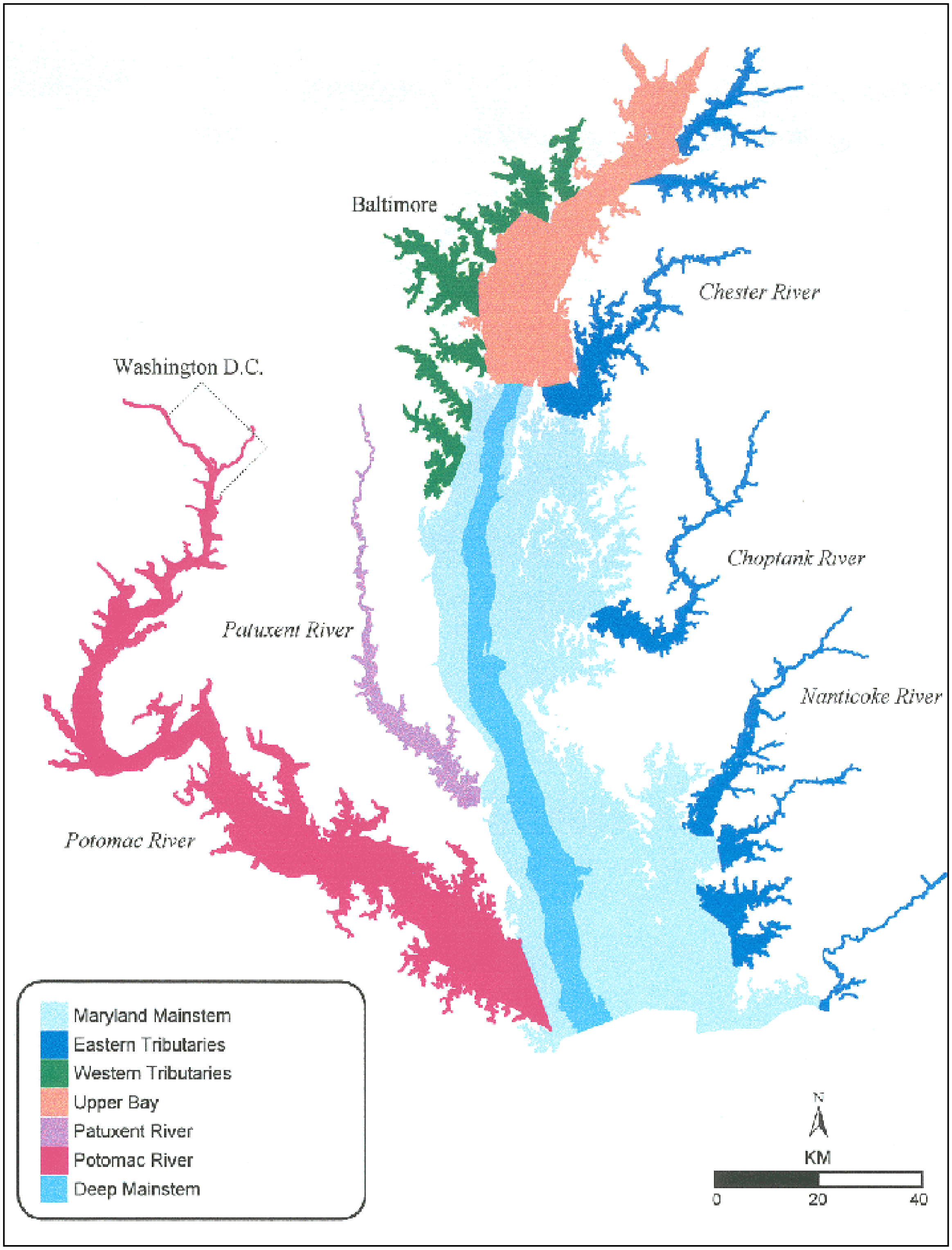

Figure 2-4. Maryland baywide sampling strata in and after 1995

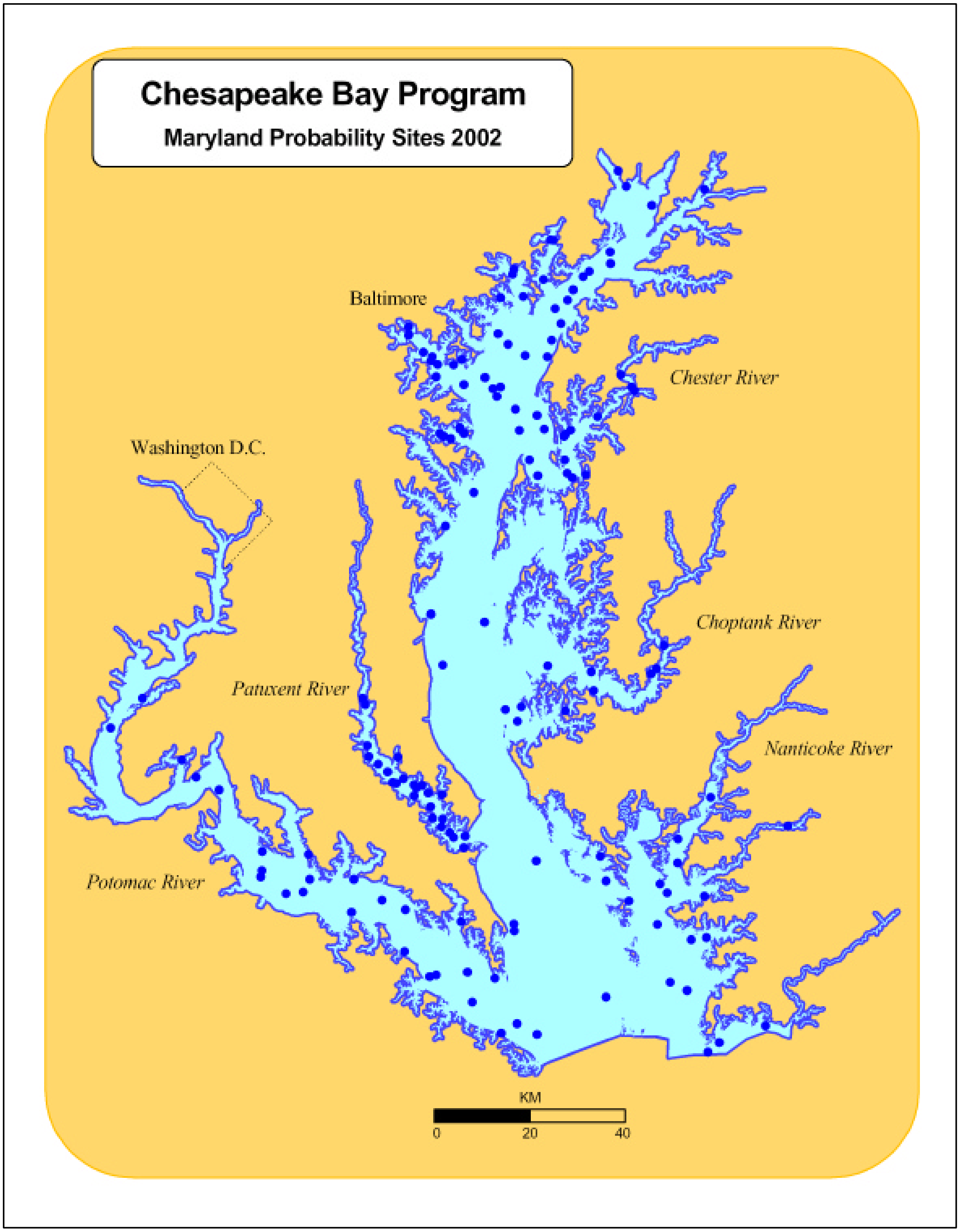

Figure 2-5. Maryland probability-based sampling sites for 2002

Table 2-3. Allocation of probability-based baywide samples, in and after 1995. Maryland areas exclude 676 km^2 of mainstem habitat deeper than 12 m. Virginia strata were sampled by the Virginia Chesapeake Bay Benthic Monitoring Program commencing in 1996.					
		Area			
State	Stratum	km2	State %	Bay %	Number of Samples
Maryland	Deep Mainstem	676	10.8	5.8	0
	Mid Bay Mainstem	2,552	40.9	22.0	25
	Eastern Tributaries	534	8.6	4.6	25
	Western Tributaries	292	4.7	2.5	25
	Upper Bay Mainstem	785	12.6	6.8	25
	Patuxent River	128	2.0	1.1	25
	Potomac River	1,276	20.4	11.0	25
	TOTAL	6,243	100.0	53.8	150
Virginia	Mainstem	4,120	76.8	35.5	25
	Rappahannock River	372	6.9	3.2	25
	York River	187	3.5	1.6	25
	James River	684	12.8	5.9	25
	TOTAL	5,363	100.0	46.2	100

2.2 SAMPLE COLLECTION

2.2.1 Station Location

From July 1984 to June 1996, stations were located using Loran-C. After June 1996 stations were located using a differential Global Positioning System. The NAD83 coordinate system is currently used.

2.2.2 Water Column Measurements

Water column vertical profiles of temperature, conductivity, salinity, dissolved oxygen concentration (DO), oxidation reduction potential (ORP), and pH were measured at each site. For fixed sites, profiles consisted of water quality measurements at 1 m intervals from surface to bottom at sites 7 m deep or less, and at 3 m intervals, with addi-ional measurements at 1.5 m intervals in the vicinity of the pycnocline, at sites deeper than 7 m. Surface and bottom measurements were made at all other sampling sites. Table 2-4 lists the measurement methods used.

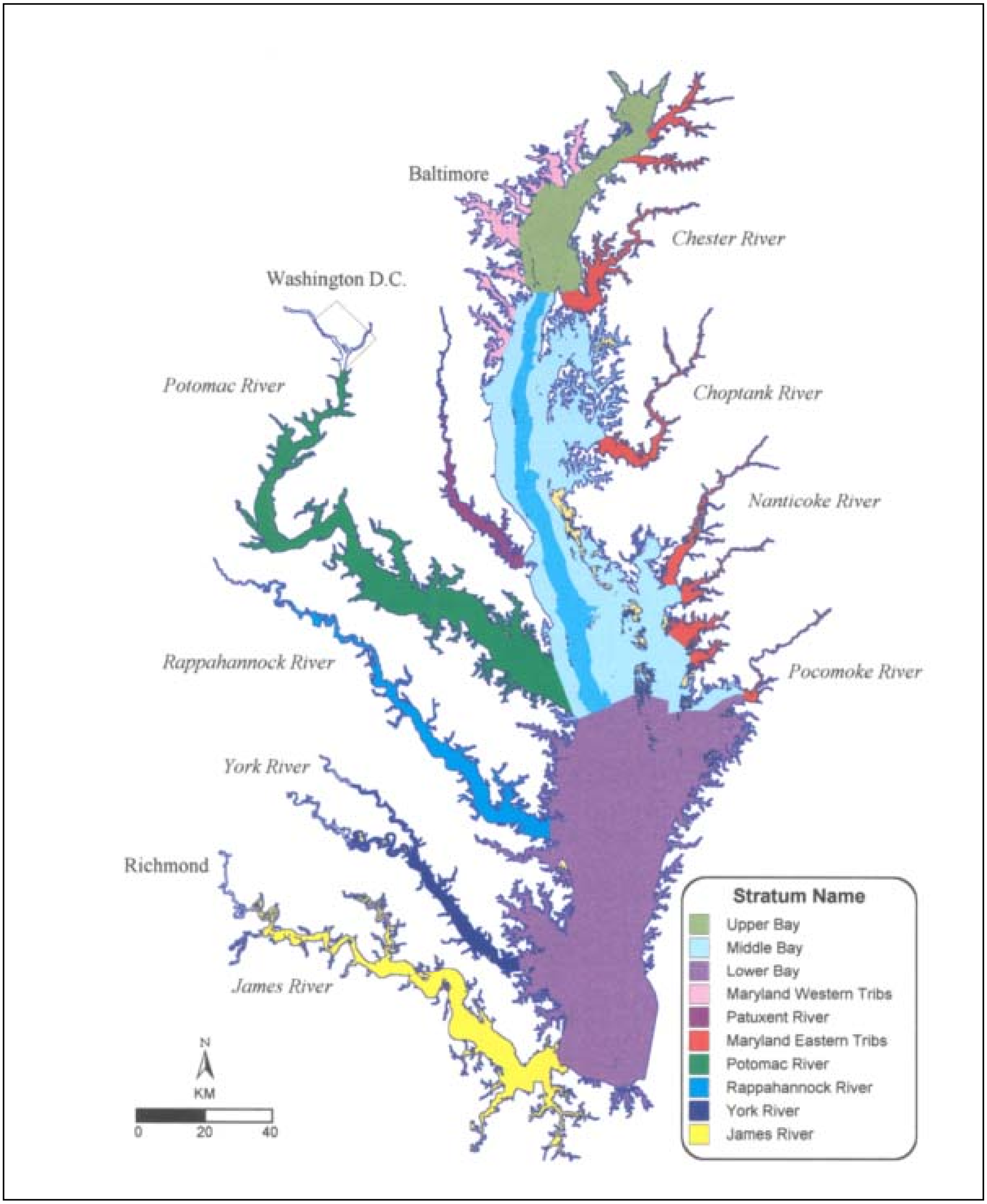

Figure 2-6. Chesapeake Bay stratification scheme

Table 2-4. Methods used to measure water quality parameters.

Parameter	Period	Method
Temperature	July 1984 to November 1984	Thermistor attached to Beckman Model RS5-3 salinometer
	December 1984 to December 1995	Thermistor attached to Hydrolab Surveyor II
	January 1996 to present	Thermistor attached to Hydrolab DataSonde 3 or YSI-6600 Sonde
Salinity and Conductivity	July to November 1984	Beckman Model RS5-3 salinometer toroidal conductivity cell with thermistor temperature compensation
	December 1984 to December 1995	Hydrolab Surveyor II nickel six-pin electrode-salt water cell block combination with automatic temperature compensation
	January 1996 to present	Hydrolab DataSonde 3 or YSI-6600 Sonde nickel six-pin electrode-salt water cell block combination with automatic temperature compensation
Dissolved Oxygen	July to November 1984	YSI Model 57 or Model 58 Oxygen Meter with automatic temperature and manual salinity compensation
	December 1984 to December 1995	Hydrolab Surveyor II membrane design probe with automatic temperature and salinity compensation
	January 1996 to present	Hydrolab DataSonde 3 or YSI-6600 Sonde membrane design probe with automatic temperature and salinity compensation
pH	July to November 1984	Orion analog pH meter with Ross glass combination electrode manually compensated for temperature
	December 1984 to December 1995	Hydrolab Surveyor II glass pH electrode and Lazaran reference electrode automatically compensated for temperature
	January 1996 to present	Hydrolab DataSonde 3 or YSI-6600 Sonde glass pH electrode and standard reference (STDREF) electrode automatically compensated for temperature
Oxidation Reduction Potential	December 1984 to December 1995	Hydrolab Surveyor II platinum banded glass ORP electrode

2.2.3 Benthic Samples

Samples were collected using four kinds of gear depending on the program element and habitat type. For the fixed site element (Table 2-1), a hand-operated box corer ("modified box corer"), which samples a 250 cm^2 area to a depth of 25 cm, was used in the nearshore shallow sandy habitats of the mainstem bay and tributaries. A Wildco box corer, which samples an area of 225 cm^2 to a depth of 23 cm, was used in shallow muddy or deep-water (> 5 m) habitats in the mainstem bay and tributaries. A Petite Ponar Grab, which samples 250 cm^2 to a depth of 7 cm, was used at the fixed site in the Nanticoke River to be consistent with previous sampling in the 1980s. At the two fixed sites first sampled in 1995 and at all probability-based sampling sites, a Young Grab, which samples an area of 440 cm^2 to a depth of 10 cm, was used.

Sample volume and penetration depth were measured for all samples; Wildco and hand-operated box cores penetrating less than 15 cm, and Young and Petite Ponar grabs penetrating less than 7 cm into the sediment were rejected and the site was re-sampled.

In the field, samples were sieved through a 0.5-mm screen using an elutriative process. Organisms and detritus retained on the screen were transferred into labeled jars and preserved in a 10% formaldehyde solution stained with rose bengal (a vital stain that aids in separating organisms from sediments and detritus).

Two surface-sediment sub-samples of approximately 120 ml each were collected for grain-size, carbon, and nitrogen analysis from an additional grab sample at each site. Surface sediment samples were frozen until they were processed in the laboratory.

2.3 LABORATORY PROCESSING

Organisms were sorted from detritus under dissecting microscopes, identified to the lowest practical taxonomic level (most often species), and counted. Oligochaetes and chironomids were mounted on slides and examined under a compound microscope for genus and species identification.

Ash-free dry weight biomass was determined by three comparable techniques during the sampling period. For samples collected from July 1984 to June 1985, biomass was directly measured using an analytical balance for major organism groups (e.g., polychaetes, molluscs, and crustaceans). Ash-free dry weight biomass was determined by drying the organisms to a constant weight at 60 EC and ashing in a muffle furnace at 500 EC for four hours. For samples collected between July 1985 and August 1993, a regression relationship between ash-free dry weight biomass and size of morphometric characters was defined for 22 species (Ranasinghe et al. 1993). The biomass of the 22 selected species was estimated from these regression relationships. These taxa (Table 2-5) were selected because they accounted for more than 85% of the abundance (Holland et al. 1988). After August 1993, ash-free dry weight biomass was measured directly for each species by drying the organisms to a constant weight at 60 EC and ashing in a muffle furnace at 500 EC for four hours.

Table 2-5. Taxa for which biomass was estimated in samples collected between 1985 and 1993.

Polychaeta	**Mollusca**
Eteone heteropoda *Glycinde solitaria* *Heteromastus filiformis* *Marenzelleria viridis* *Neanthes succinea* *Paraprionospio pinnata* *Streblospio benedicti*	*Acteocina canaliculata* *Corbicula fluminea* *Gemma gemma* *Haminoe solitaria* *Macoma balthica* *Macoma mitchelli* *Mulinia lateralis* *Mya arenaria* *Rangia cuneata* *Tagelus plebeius*
Crustacea	
Cyathura polita *Gammarus* spp. *Leptocheirus plumulosus*	
Miscellaneous	
Carinoma tremaphoros *Micrura leidyi*	

Silt-clay composition and carbon and nitrogen content were determined for one of the two sediment sub-samples collected at each sampling site. The other sample was archived for quality assurance purposes (Scott et al. 1988). Sand and silt-clay particles were separated by wet-sieving through a 63-Fm, stainless steel sieve and weighed using the procedures described in the Versar, Inc., Laboratory Standard Operating Procedures (Versar 1999). Carbon and nitrogen content of dried sediments was determined using an elemental analyzer; sediment carbon content was measured with a Perkin-Elmer Model 240B analyzer from 1984 to 1988, and an Exeter Analytical Inc., Model CE440 analyzer in and after 1995. The results from both instruments are comparable. Samples are combusted at high temperature (975° C) and the carbon dioxide and nitrogen produced are measured by thermal conductivity detection. Prior to combustion, each sample is homogenized and oven-dried.

2.4 DATA ANALYSIS

Analyses for the fixed site and probability-based elements of LTB were both performed in the context of the Chesapeake Bay Program's benthic community restoration goals and the Benthic Index of Biotic Integrity (B-IBI) by which goal attainment is measured. The B-IBI, the Chesapeake Bay benthic community restoration goals, and statistical analysis methods for the two LTB elements are described below.

2.4.1 The B-IBI and the Chesapeake Bay Benthic Community Restoration Goals

The B-IBI is a multiple-attribute index developed to identify the degree to which a benthic assemblage meets the Chesapeake Bay Program's benthic community restoration goals (Ranasinghe et al. 1994a, updated by Weisberg et al. 1997; Alden et al. 2002). The B-IBI provides a means for comparing relative condition of benthic invertebrate assemblages across habitat types. It also provides a validated mechanism for integrating several benthic community attributes indicative of habitat "health" into a single number that measures overall benthic community condition.

The B-IBI is scaled from 1 to 5, and sites with values of 3 or more are considered to meet the restoration goals. The index is calculated by scoring each of several attributes as either 5, 3, or 1 depending on whether the value of the attribute at a site approximates, deviates slightly from, or deviates strongly from values found at the best reference sites in similar habitats, and then averaging these scores across attributes. The criteria for assigning these scores are numeric and depend on habitat. Data from seasons for which the B-IBI has not been developed were not used for B-IBI based assessment.

Benthic community condition was classified into four levels based on the B-IBI. Values less than or equal to 2 were classified as severely degraded; values from 2 to 2.6 were classified as degraded; values greater than 2.6 but less than 3.0 were classified as marginal; and values of 3.0 or more were classified as meeting the goals. Values in the marginal category do not meet the restoration goals, but they differ from the goals within the range of measurement error typically recorded between replicate samples.

2.4.2 Fixed Site Trend Analysis

Trends in condition at the fixed sites were identified using the nonparametric technique of van Belle and Hughes (1984). This procedure is based on the Mann-Kendall statistic and consists of a sign test comparing each value with all values measured in subsequent periods. The ratio of the Mann-Kendall statistic to its variance provides a normal deviate that is tested for significance. Alpha was set to 0.1 for these tests because of the low power for trend detection for biological data. An estimate of the magnitude of each significant trend was obtained using Sen's (1968) procedure which is closely related to the Mann-Kendall test. Sen's procedure identifies the median slope among all slopes between each value and all values measured in subsequent periods.

2.4.3 Probability-Based Estimation

The Maryland Bay was divided into three strata (Bay Mainstem, Potomac River, other tributaries and embayments) in 1994 (Table 2-2). It was divided into six strata in and after 1995 (Figure 2-4, Table 2-3). The Virginia Bay was divided into four strata, beginning in 1996 (Figure 2-6, Table 2-3).

To estimate the amount of area in the entire Bay that failed to meet the Chesapeake Bay benthic community restoration goals (P), we defined for every site *i* in stratum *h* a variable y_{hi} that had a value of 1 if the benthic community met the goals, and 0 otherwise. For each stratum, the estimated proportion of area meeting the goals, p_h, and its variance were calculated as the mean of the y_{hi}'s and its variance, as follows:

$$p_h = \overline{y}_h = \sum_{i=1}^{n_h} \frac{y_{hi}}{n_h} \qquad (1)$$

and

$$\text{var}\left(p_h\right) = s_h^2 = \sum_{i=1}^{n_h} \frac{\left(y_{hi} - \overline{y}_h\right)^2}{n_h - 1} \qquad (2)$$

Estimates for strata were combined to achieve a statewide estimate as:

$$\hat{P}_{ps} = \overline{y}_{ps} = \sum_{h=1}^{6} W_h \overline{y}_h \qquad (3)$$

where the weighting factor $W_h = A_h/A$; A_h is the total area of the *h*th stratum, and A is the combined area of all strata. The variance of (3) was estimated as:

$$\text{var}\left(\hat{P}_{ps}\right) = \text{var}\left(\overline{y}_{ps}\right) = \sum_{h=1}^{6} W_h^2 s_h^2 / n_h \qquad (4)$$

The standard error for individual strata is estimated as the square root of (2), and for the combined strata, as the square root of (4).

3.0 RESULTS

3.1 TRENDS IN FIXED SITE BENTHIC CONDITION

Trend analysis is conducted on 27 fixed sites located throughout the Bay and its tributaries to assess whether benthic community condition is changing. The sites are sampled yearly in the spring and summer but the trend analysis is performed on the summer data only in order to apply the B-IBI (Weisberg et al. 1997; Alden et al. 2002). B-IBI calculations and trend analysis methods are described in Section 2.4.

The B-IBI is the primary measure used in trend analysis because it integrates several benthic community attributes into a measure of overall condition. It provides context for interpretation of observed trends because status has been calibrated to reference conditions. Significant trends that result in a change of status (sites that previously met the Chesapeake Bay benthic community restoration goals which now fail, or vice versa) are of greater management interest than trends which do not result in a change. As a first step in identifying causes of changes in condition, trends on individual attributes are identified and examined.

Table 3-1 presents trends in benthic community condition from 1985 to the present. Although the Maryland benthic monitoring component began sampling in 1984, data collected in the first year of our program were excluded from analysis to facilitate comparison of results with other components of the monitoring program. Several components of the Maryland program as well as the Virginia benthic monitoring program did not start sampling until 1985. Eighteen-year (1985-2002) trends are presented for 23 of the 27 trend sites, 14-year trends are presented for two sites in Baltimore Harbor (Stations 201 and 202) first sampled in 1989, and 8-year trends are presented for two western shore tributaries (Back River, Station 203; and Severn River, Station 204) first sampled in 1995. Trend site locations are shown in Figure 2-1.

Statistically significant B-IBI trends ($p<0.1$) were detected at 9 of the 27 sites (Table 3-1). Benthic community condition declined at 3 sites (significantly decreasing B-IBI trend) and improved at 6 sites. Currently, 13 stations meet the goals and 14 fail the goals. Initially, 10 stations met the goals and 17 failed the goals (Table 3-1). Five stations with a significant trend have changed status since 1985. Stations 01 (mainstem), 06 (mainstem), 29 (Elk River), and 64 (Choptank River) have improved from initial failure to currently meeting the goals (Table 3-1). Station 62 (Nanticoke River) has declined in status from initially meeting the goals to currently failing the goals (Table 3-1). Station 44 (Potomac River, Morgantown) has declined from a marginal to a severely degraded condition. The status of Stations 64 (Choptank River), 71 (lower Patuxent River, Broomes Island), and 77 (upper Patuxent River, Holland Cliff) has improved from that reported last year, and the status of Stations 51 (Potomac River, St. Clements Island) has declined.

Significant trends present with the analysis of 2001 data were still present with the addition of the 2002 data except for Stations 71 (Patuxent River, Broomes Island), 36

(Potomac River, Rosier Bluff), and 68 (Chester River). Station 71 exhibited a significantly degrading trend for the past several years (Llansó et al. 2002), but with the addition of summer 2002 data, the station no longer has a significant trend (Table 3-1). New trends are reported this year for the Potomac River Station 44 (degrading) and Choptank River Station 64 (improving).

Trends in community attributes that are components of the B-IBI are presented in Table 3-2 (mesohaline stations), Table 3-3 (oligohaline and tidal freshwater stations), and Appendix A.

3.2 BAYWIDE BOTTOM COMMUNITY CONDITION

The fixed site monitoring provides useful information about trends in the condition of benthic biological resources at 27 locations in the Maryland Bay but it does not provide an integrated assessment of the Bay's overall condition. The fixed sites were selected for trend monitoring because they are located in areas subject to management action and, therefore, are likely to undergo change. Because these sites were selected subjectively, there is no objective way of weighting them to obtain an unbiased estimate of Maryland baywide status.

An alternative approach for quantifying status of the bay, which was first adopted in the 1994 sampling program, is to use probability-based sampling to estimate the bottom area populated by benthos meeting the Chesapeake Bay benthic community restoration goals. Where the fixed site approach quantifies change at selected locations, the probability sampling approach quantifies the spatial extent of problems. While both approaches are valuable, developing and assessing the effectiveness of a Chesapeake Bay management strategy requires understanding the extent and distribution of problems throughout the Bay, instead of only assessing site-specific problems. Our probability-based sampling element is intended to provide that information, as well as a more widespread baseline data set for assessing the effects of unanticipated future contamination (e.g., oil or hazardous waste spills).

Probability-based sampling has been employed previously by LTB, but the sampled area included only 16% of the Maryland Bay (Ranasinghe et al. 1994a) which was insufficient to characterize the entire Bay. Probability-based sampling was also used in the Maryland Bay by the U.S. EPA Environmental Monitoring and Assessment Program (EMAP), but at a sampling density too low to develop precise condition estimates for the Maryland Bay. The 2002 sampling continues with efforts initiated in 1994 to develop area-based bottom condition statements for the Maryland Bay.

Estimates of tidal bottom area meeting the benthic community restoration goals are also included for the entire Chesapeake Bay. The estimates were enabled by including a probability-based sampling element in the Virginia Benthic Monitoring Program starting in 1996. The Virginia sampling is compatible and complementary to the Maryland effort and is part of a joint effort by the two programs to assess the extent of "healthy" tidal bottom baywide.

This section presents the results of the 2002 Maryland and Virginia tidal waters probability-based sampling and adds an ninth year of results to LTB's Maryland Bay time series. The analytical methods for estimating the areal extent of bay bottom meeting the restoration goals were presented in Section 2.0. The physical data associated with the benthic samples (bottom water salinity, temperature, DO, and sediment silt-clay and organic carbon content) can be found in the appendices (Volume 2). Only summer data (July 15-September 30) are used for the probability-based assessments.

Of the 150 Maryland samples collected with the probability-based design in 2002, 64 met and 86 failed the Chesapeake Bay benthic community restoration goals (Figure 3-1). Of the 250 probability samples collected in the entire Chesapeake Bay in 2002, 120 met and 130 failed the restoration goals. The Virginia sampling results are presented in Figure 3-2.

An increase in the percent degraded area in the Maryland Bay relative to the 2001 estimate was observed with the addition of the 2002 data (Figure 3-3). The change in condition, however, was within the uncertainty margin of the estimate. The magnitude of the severely degraded condition has not changed appreciably since 1994. Results from the individual sites were weighted based on the area of the stratum represented by the site in the stratified sampling design to estimate the tidal Maryland area failing the restoration goals. In 2002, 65% ($\pm$5% SE) of the Maryland Bay was estimated to fail the restoration goals. Expressed as area, 4,086$\pm$188 km^2 of the tidal Maryland Chesapeake Bay remained to be restored in 2002.

As with previous year's results, the Potomac River, and the mid-Bay mainstem were in the poorest condition among the six Maryland strata (Figure 3-4). The condition of the Patuxent River improved slightly in 2002 relative to the previous year, but the level of degradation in this basin continued to be very high since 2000 (Figure 3-5). The level of degradation in the upper western tributaries bounced back to the high levels observed in 1999 and 2000. The upper Bay mainstem and the eastern tributaries continued to be in good condition. Over the nine-year time series (1994-2002), more than half of the tidal Potomac River (714-1,173 km^2) failed the restoration goals each year (Figure 3-5) and a large portion of that area, ranging from 48-93% (510-793 km^2, Table 3-4), was severely degraded. The mid-Bay Maryland mainstem continued to have the largest amount of degraded area among the strata: 2,412 km^2 in 2002 (Table 3-4). Sixty-six percent of this area (including the deep trough) was severely degraded. The eastern shore tributaries had the smallest amount of area with severely degraded condition over the eight year period (Table 3-4).

The area of Chesapeake Bay estimated to fail the restoration goals in 2002 increased slightly over the previous three years (Figure 3-6), but the change can be considered within the uncertainty margin of the estimate. Weighting results from the 250 probability sites in Maryland and Virginia, 53% ($\pm$4%) or 6,178$\pm$267 km^2 of the tidal

Chesapeake Bay was estimated to fail the restoration goals in 2002 (Table 3-4). The percentage for previous years ranged from 45% (±4%) in 1996 to 58% (± 4%) in 1998 (Table 3-4). About 25% of the Chesapeake Bay continued to exhibit severely degraded benthic condition.

In Virginia, levels of degradation for all tributaries in 2002 were relatively low (Figure 3-4). Benthic community condition in the James and York Rivers improved in 2002 relative to the previous year. In the York River, the percentage of bottom area failing the restoration goals decreased by 50% (Figure 3-6). The improvement in the York River was similar to that observed in 2000. The Rappahannock River also exhibited improved overall condition in 2002 compared to the 1997-2000 period (Figure 3-6); however, 75% of the river bottom or134 km^2 was severely degraded in 2002 (Table 3-4). Baywide, and over the time series, the Virginia mainstem was in best condition overall.

As reported in previous years, and for the period 1996-2002, five strata (Patuxent River, Potomac River, mid-Bay mainstem, Virginia mainstem, and upper western tributaries) had a large percentage (>67%) of sites failing the goals because of insufficient abundance or biomass of organisms relative to reference conditions (Table 3-5). Except for the Virginia mainstem, these strata also had a high percentage (>50%) of failing sites classified as severely degraded (Table 3-5). The Potomac and Patuxent rivers had the largest percentage of depauperate sites, failing for insufficient abundance or biomass. The Virginia mainstem also had a large percentage of depauperate sites, but this percentage was based on a comparatively small number of sites failing the restoration goals. The York and James rivers had the lowest percentages of depauperate sites. Low abundance, low biomass, and the level of widespread failure in most metrics necessary to classify a site as severely degraded would be expected on exposure to catastrophic events such as prolonged oxygen stress.

The upper Bay mainstem, Maryland eastern tributaries, James River, and York River, had excess abundance, excess biomass, or both in more than 23% of the failing sites (Table 3-6). Excess abundance and excess biomass are phenomena usually associated with eutrophic conditions and organic enrichment of the sediment in the absence of low dissolved oxygen stress.

Table 3-1. Summer trends in benthic community condition, 1985-2002. Trends were identified using the van Belle and Hughes (1984) procedure. Current mean B-IBI and condition are based on 2000-2002 values. Initial mean B-IBI and condition are based on 1985-1987 values. NS: not significant; (a): 1989-1991 initial condition; (b): 1995-1997 initial condition. Shaded areas highlight changes in trend or condition over those reported in 2001.

Station	Trend Significance	Median Slope (B-IBI units/yr)	Current Condition (2000-2002)	Initial Condition (1985-1987 unless otherwise noted)
Potomac River				
36	NS	0.00	3.11 (Meets Goal)	3.14 (Meets Goal)
40	NS	0.00	2.67 (Marginal)	2.80 (Marginal)
43	NS	0.00	3.71 (Meets Goal)	3.76 (Meets Goal)
44	$p < 0.1$	−0.03	1.71 (Severely Degraded)	2.80 (Marginal)
47	NS	0.00	3.62 (Meets Goal)	3.89 (Meets Goal)
51	$p < 0.001$	0.05	2.93 (Marginal)	2.43 (Degraded)
52	NS	0.00	1.07 (Severely Degraded)	1.37 (Severely Degraded)
Patuxent River				
71	NS	0.00	2.37 (Degraded)	2.59 (Degraded)
74	NS	0.00	3.62 (Meets Goal)	3.78 (Meets Goal)
77	$p < 0.01$	−0.08	3.09 (Meets Goal)	3.76 (Meets Goal)
79	NS	0.00	2.61 (Degraded)	2.75 (Marginal)
Choptank River				
64	$p < 0.1$	0.03	3.07 (Meets Goal)	2.78 (Marginal)
66	NS	0.00	2.66 (Marginal)	2.60 (Degraded)
Maryland Mainstem				
26	$p < 0.01$	0.03	3.71 (Meets Goal)	3.16 (Meets Goal)
24	NS	0.00	2.85 (Marginal)	3.04 (Meets Goal)
15	NS	0.00	2.41 (Degraded)	2.22 (Degraded)
06	$p < 0.01$	0.06	3.56 (Meets Goal)	2.56 (Degraded)
01	$p < 0.01$	0.05	3.74 (Meets Goal)	2.93 (Marginal)
Maryland Western Shore Tributaries				
22	NS	0.00	1.76 (Severely Degraded)	2.08 (Degraded)
23	NS	0.00	3.00 (Meets Goal)	2.49 (Degraded)
201	NS	0.00	1.36 (Severely Degraded)	1.10 (Severely Degraded) (a)
202	NS	0.00	1.89 (Severely Degraded)	1.40 (Severely Degraded) (a)
203	NS	0.00	2.04 (Degraded)	2.08 (Degraded) (b)
204	NS	−0.10	3.11 (Meets Goal)	3.67 (Meets Goal) (b)
Maryland Eastern Shore Tributaries				
29	$p < 0.05$	0.03	3.01 (Meets Goal)	2.38 (Degraded)
62	$p < 0.01$	−0.04	2.78 (Marginal)	3.42 (Meets Goal)
68	NS	0.00	3.71 (Meets Goal)	3.51 (Meets Goal)

Table 3-2. Summer trends in benthic community attributes at mesohaline stations 1985-2002. Monotonic trends were identified using the van Belle and Hughes (1984) procedure. ⇑: Increasing trend; ⇓: Decreasing trend. *: p< 0.1; **: p< 0.05; ***: p< 0.01; shaded trend cells indicate increasing degradation; unshaded trend cells indicate improving conditions; (a): trends based on 1989-2002 data; (b): trends based on 1995-2002 data; (c): attribute trend based on 1990-2002 data; (d): attributes are used in B-IBI calculations when species specific biomass is unavailable; NA: attribute is not part of the reported B-IBI. Blanks indicate no trend (not significant). See Appendix A for further detail.

Station	B-IBI	Abundance	Biomass	Shannon Diversity	Indicative Abundance	Sensitive Abundance	Indicative Biomass (c)	Sensitive Biomass (c)	Abundance Carnivore/ Omnivores
Potomac River									
43		⇓ **			⇑ **	⇓**(d)	NA		NA
44	⇓*	⇓ **	⇓ **	⇑ ***		(d)	NA	⇓***	NA
47				⇑ *	⇑ **	⇓ ***(d)	NA	⇓ *	NA
51	⇑***		⇓***	⇑ ***	⇓***	⇑ ***	NA	NA	⇑***
52					(d)	(d)			
Patuxent River									
71		⇓ ***	⇓ ***		⇓ ***(d)	(d)		⇑ **	⇑***
74		⇑ ***	⇓ ***		⇑ **	⇓***(d)	NA		NA
77	⇓ ***		⇓ **		⇑ ***	⇓**(d)	NA	⇑ ***	NA
Choptank River									
64	⇑ *			⇑ *	(d)	⇑ **(d)	⇑ ***		
Maryland Mainstem									
01	⇑ ***				⇓ ***	⇑ ***	NA	NA	⇑ **
06	⇑ ***	⇑ ***			⇓ *	⇑ ***	NA	NA	⇑ ***
15		⇑ **			⇓ **		NA	NA	
24		⇓ ***	⇓ **	⇓ ***	⇓ *(d)	(d)			⇑ ***
26	⇑ ***	⇑*				(d)	NA		NA
Maryland Western Shore Tributaries									
22					⇑***	⇑ *(d)	NA		NA
23		⇓ ***				⇑***(d)	NA		NA
201(a)						(d)	NA		NA
202(a)			⇑**	⇑ **		(d)	NA	⇑ **	NA
204(b)			⇓ ***		(d)	(d)	⇑ *		
Maryland Eastern Shore Tributaries									
62	⇓ ***		⇓***	⇓***	⇓***	⇓**(d)	NA	⇓*	NA
68			⇑ ***			⇑***(d)	NA		NA

Table 3-3. Summary trends in benthic community attributes at oligohaline and tidal freshwater stations 1985-2002. Monotonic trends were identified using the van Belle and Hughes (1984) procedure. ⇑: Increasing trend; ⇓: Decreasing trend. *: p< 0.1; **: p< 0.05; ***: p< 0.01; shaded trend cells indicate increasing degradation; unshaded trend cells indicate improving conditions; (a): trends based on 1995-2002 data; NA: attribute not calculated. Blanks indicate no trend (not significant). See Appendix A for further detail.

Station	B-IBI	Abundance	Tolerance Score	Freshwater Indicative Abundance	Oligohaline Indicative Abundance	Oligohaline Sensitive Abundance	Tanypodinae to Chironomidae Ratio	Abundance Deep Deposit Feeders	Abundance Carnivore/ Omnivores
Potomac River									
36		⇓ *			NA	NA	NA		NA
40				NA				NA	
Patuxent River									
79		⇑ ***		⇓ *	NA	NA	NA	⇓ **	NA
Choptank River									
66		⇑ ***	⇑ **	NA			⇑ ***	NA	⇑**
Maryland Western Shore Tributaries									
203(a)		⇑ **		NA				NA	
Maryland Eastern Shore Tributaries									
29	⇑ **		⇓ ***	NA	⇓ ***			NA	

Table 3-4. Estimated tidal area (km²) failing to meet the Chesapeake Bay benthic community restoration goals in the Chesapeake Bay, Maryland, Virginia, and each of the 10 sampling strata. In this table, the area of the mainstem deep trough is included in the estimates for the Severely Degraded portion of Chesapeake Bay, Maryland tidal waters, and Maryland mid-bay mainstem.

Region	Year	Severely Degraded	Degraded	Marginal	Total Failing	% Failing
Chesapeake Bay	1996	2,998	1,154	1,098	5,250	45.2
	1997	2,884	1,757	1,199	5,841	50.3
	1998	3,709	1,810	1,224	6,743	58.1
	1999	3,121	1,648	681	5,450	47.0
	2000	2,684	1,503	1,439	5,626	48.5
	2001	3,123	1,187	1,240	5,551	47.8
	2002	3,424	1,584	1,170	6,178	53.2
Maryland Tidal Waters	1994	2,684	1,152	497	4,332	66.5
	1995	2,872	605	182	3,659	58.6
	1996	2,614	700	155	3,469	55.6
	1997	2,349	697	483	3,529	56.5
	1998	2,663	1,016	623	4,302	68.9
	1999	2,423	1,137	374	3,935	63.0
	2000	2,455	1,137	236	3,828	61.3
	2001	2,313	582	644	3,538	56.7
	2002	2,444	713	928	4,086	65.4
Virginia Tidal Waters	1996	384	454	943	1,781	33.2
	1997	535	1,060	716	2,312	43.1
	1998	1,045	794	601	2,441	45.5
	1999	698	510	306	1,515	28.3
	2000	229	366	1,203	1,798	33.5
	2001	810	606	596	2,012	37.5
	2002	980	871	242	2,092	39.0
Potomac River	1994	793	330	0	1,123	60.7
	1995	510	153	51	714	56.0
	1996	714	51	0	765	60.0
	1997	561	204	102	867	68.0
	1998	561	510	102	1,173	92.0
	1999	663	153	102	918	72.0
	2000	612	255	0	867	68.0
	2001	612	357	51	1,020	80.0
	2002	561	204	153	918	72.0

Table 3-4. (Continued)

Region	Year	Severely Degraded	Degraded	Marginal	Total Failing	% Failing
Patuxent River	1995	51	10	5	67	52.0
	1996	41	20	0	61	48.0
	1997	20	5	10	36	28.0
	1998	31	26	5	61	48.0
	1999	20	10	10	41	32.0
	2000	51	26	10	87	68.0
	2001	56	15	20	92	72.0
	2002	36	26	20	82	64.0
Maryland Upper Western Tributaries	1995	58	47	23	129	44.0
	1996	117	47	0	164	56.0
	1997	105	23	12	140	48.0
	1998	94	23	12	129	44.0
	1999	117	47	12	175	60.0
	2000	140	70	0	211	72.0
	2001	70	12	47	129	44.0
	2002	94	47	47	187	64.0
Maryland Eastern Tributaries	1995	107	128	0	235	44.0
	1996	21	150	21	192	36.0
	1997	43	64	21	128	24.0
	1998	21	64	64	150	28.0
	1999	43	150	86	278	52.0
	2000	64	150	21	235	44.0
	2001	128	64	86	278	52.0
	2002	64	107	64	235	44.0
Maryland Upper Bay Mainstem	1995	345	63	0	408	52.0
	1996	126	126	31	283	36.0
	1997	126	94	31	251	32.0
	1998	157	188	31	377	48.0
	1999	188	63	63	314	40.0
	2000	94	126	0	220	28.0
	2001	157	31	31	220	28.0
	2002	94	126	31	251	32.0

Table 3-4. (Continued)						
Region	**Year**	**Severely Degraded**	**Degraded**	**Marginal**	**Total Failing**	**% Failing**
Maryland Mid Bay Mainstem	1995	1,799	204	102	2,106	65.2
	1996	1,595	306	102	2,004	62.1
	1997	1,493	306	306	2,106	65.2
	1998	1,799	204	408	2,412	74.7
	1999	1,391	715	102	2,208	68.4
	2000	1,493	510	204	2,208	68.4
	2001	1,289	102	408	1,799	55.7
	2002	1,595	204	613	2,412	74.7
Virginia Mainstem	1996	165	330	824	1,318	32.0
	1997	165	824	659	1,648	40.0
	1998	824	330	494	1,648	40.0
	1999	494	165	165	824	20.0
	2000	0	165	1,154	1,318	32.0
	2001	494	330	494	1,318	32.0
	2002	659	659	165	1,483	36.0
Rappahannock River	1996	119	60	0	179	48.0
	1997	134	74	15	223	60.0
	1998	60	119	45	223	60.0
	1999	74	104	45	223	60.0
	2000	164	89	15	268	72.0
	2001	30	60	45	134	36.0
	2002	134	45	0	179	48.0
York River	1996	45	37	37	120	64.0
	1997	45	52	15	112	60.0
	1998	52	45	7	105	56.0
	1999	75	22	15	112	60.0
	2000	37	30	7	75	40.0
	2001	67	52	30	150	80.0
	2002	22	30	22	75	40.0
James River	1996	55	27	82	164	24.0
	1997	191	109	27	328	48.0
	1998	109	301	55	465	68.0
	1999	55	219	82	355	52.0
	2000	27	82	27	137	20.0
	2001	219	164	27	410	60.0
	2002	164	137	55	355	52.0

Table 3-5. Sites severely degraded (B-IBI$\leq$2) and failing the restoration goals (scored at 1.0) for insufficient abundance, insufficient biomass, or both as a percentage of site failing the goals (B-IBI<3), 1996 to 2002. Strata are listed in decreasing percent order of sites with insufficient abundance/biomass.

Stratum	**Sites Severely Degraded**		**Sites Failing the Goals Due to Insufficient Abundance, Biomass, or Both**	
	Number of Sites	**As Percentage of Sites Failing the Goals**	**Number of Sites**	**As Percentage of Sites Failing the Goals**
Patuxent River	50	55.6	71	78.9
Potomac River	84	65.6	99	77.3
Mid Bay Mainstem	58	56.9	71	69.6
Virginia Mainstem	17	29.3	40	69.0
Western Tributaries	63	64.9	66	68.0
Rappahannock River	48	50.0	56	58.3
Upper Bay Mainstem	30	49.2	31	50.8
Eastern Tributaries	18	25.7	32	45.7
York River	46	41.8	42	38.2
James River	30	37.0	27	33.3

Table 3-6. Sites failing the restoration goals (scored at 1.0) for excess abundance, excess biomass, or both as a percentage of sites failing the goals (B-IBI<3), 1996 to 2002. Strata are listed in decreasing percentage order.

Stratum	**Number of Sites**	**As Percentage of Sites Failing the Goals**
Upper Bay Mainstem	18	29.5
Eastern Tributaries	18	25.7
James River	20	24.7
York River	26	23.6
Rappahannock River	18	18.8
Western Tributaries	18	18.6
Mid Bay Mainstem	17	16.7
Potomac River	19	14.8
Patuxent River	13	14.4
Virginia Mainstem	4	6.9

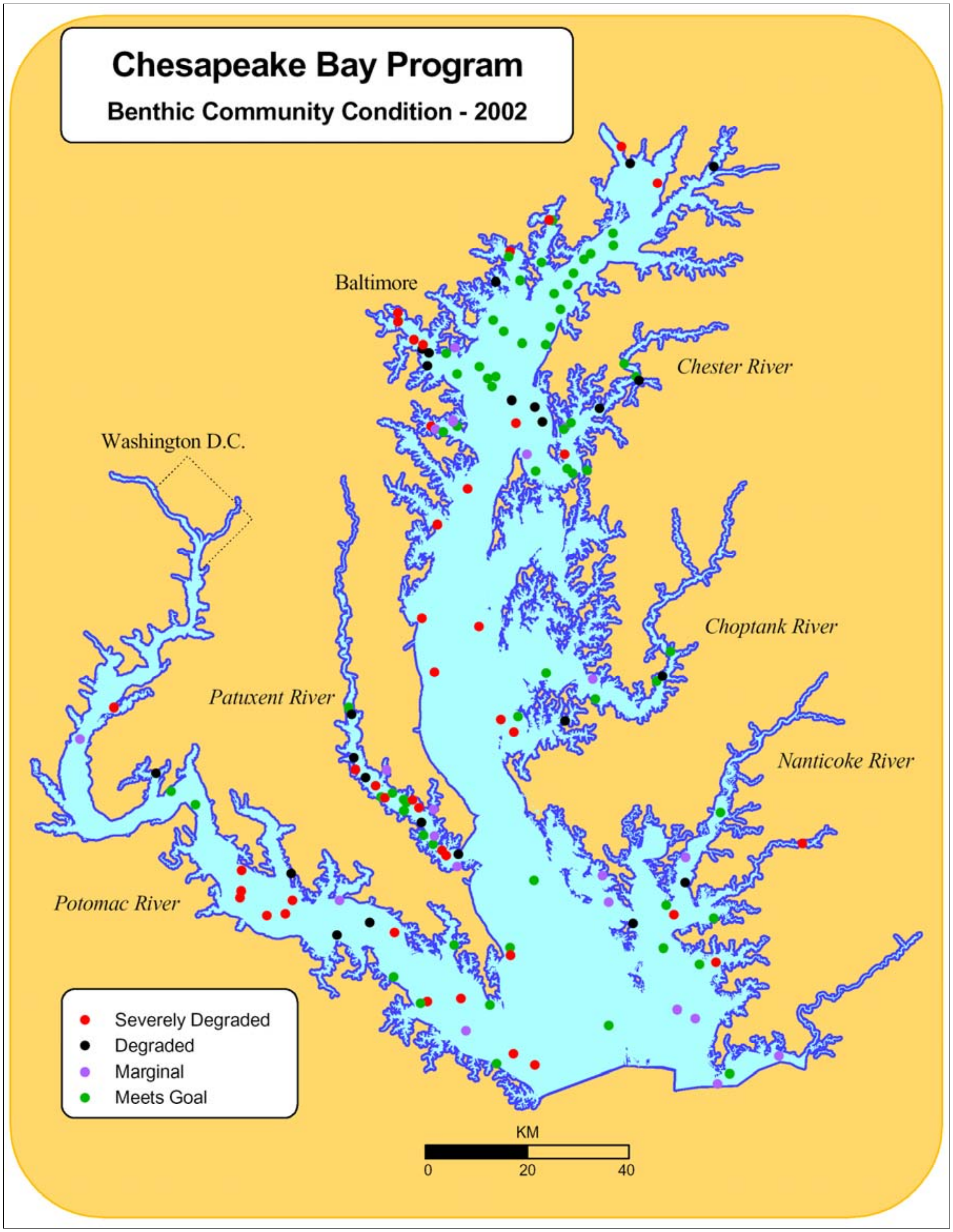

Figure 3-1. Results of probability-based benthic sampling of the Maryland Chesapeake Bay and its tidal tributaries in 2002. Each sample was evaluated in context of the Chesapeake Bay benthic community restoration goals.

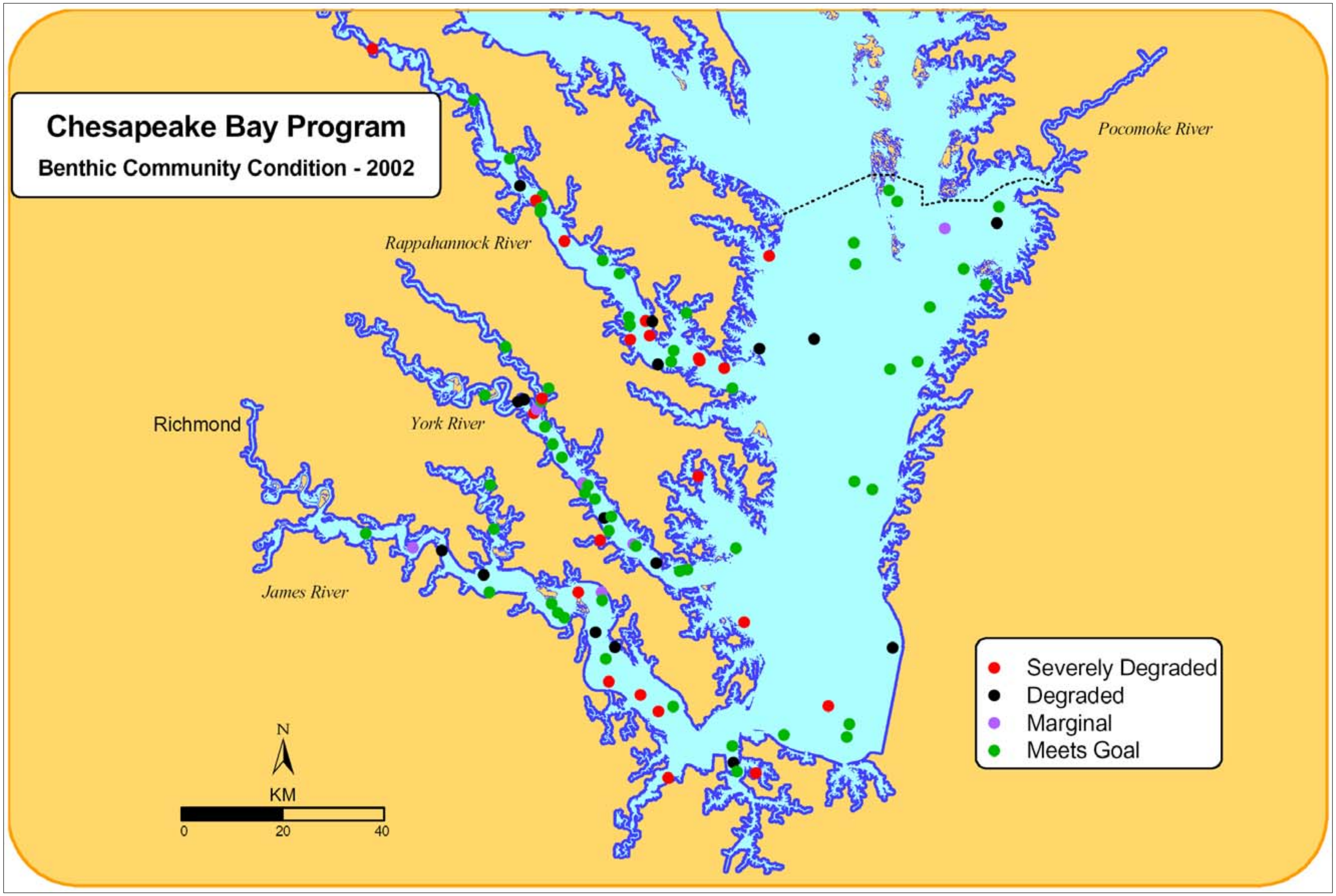

Figure 3-2. Results of probability-based benthic sampling of the Virginia Chesapeake Bay and its tidal tributaries in 2002. Each sample was evaluated in context of the Chesapeake Bay benthic community restoration goals.

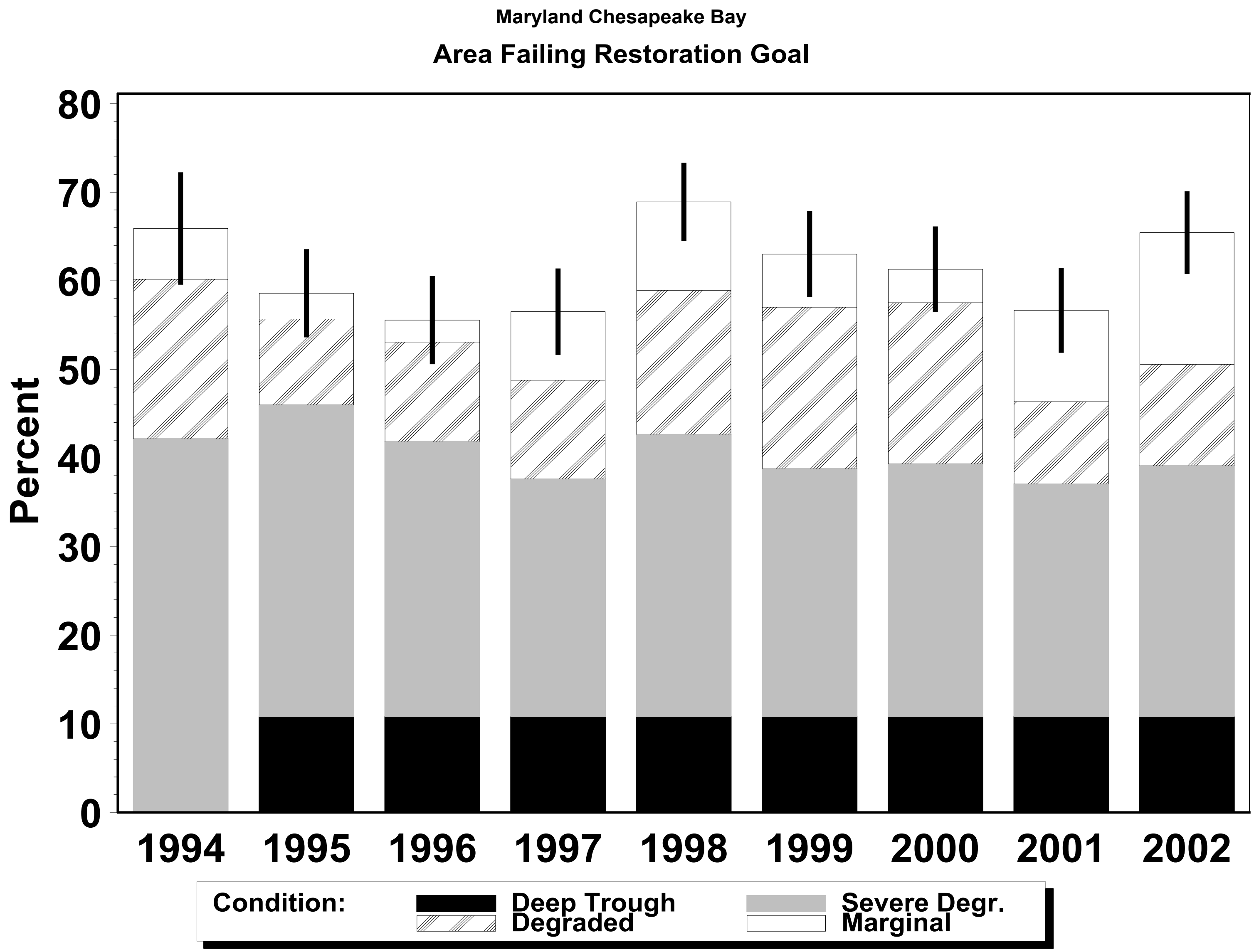

Figure 3-3. Proportion of the Maryland Bay failing the Chesapeake Bay benthic community restoration goals from 1994 to 2002. The error bars indicate $\underline{+}$ 1 standard error. The mainstem deep trough was sampled in 1994 and found to be mostly azoic; it is included in the severely degraded condition in 1994, but was excluded from sampling in subsequent years.

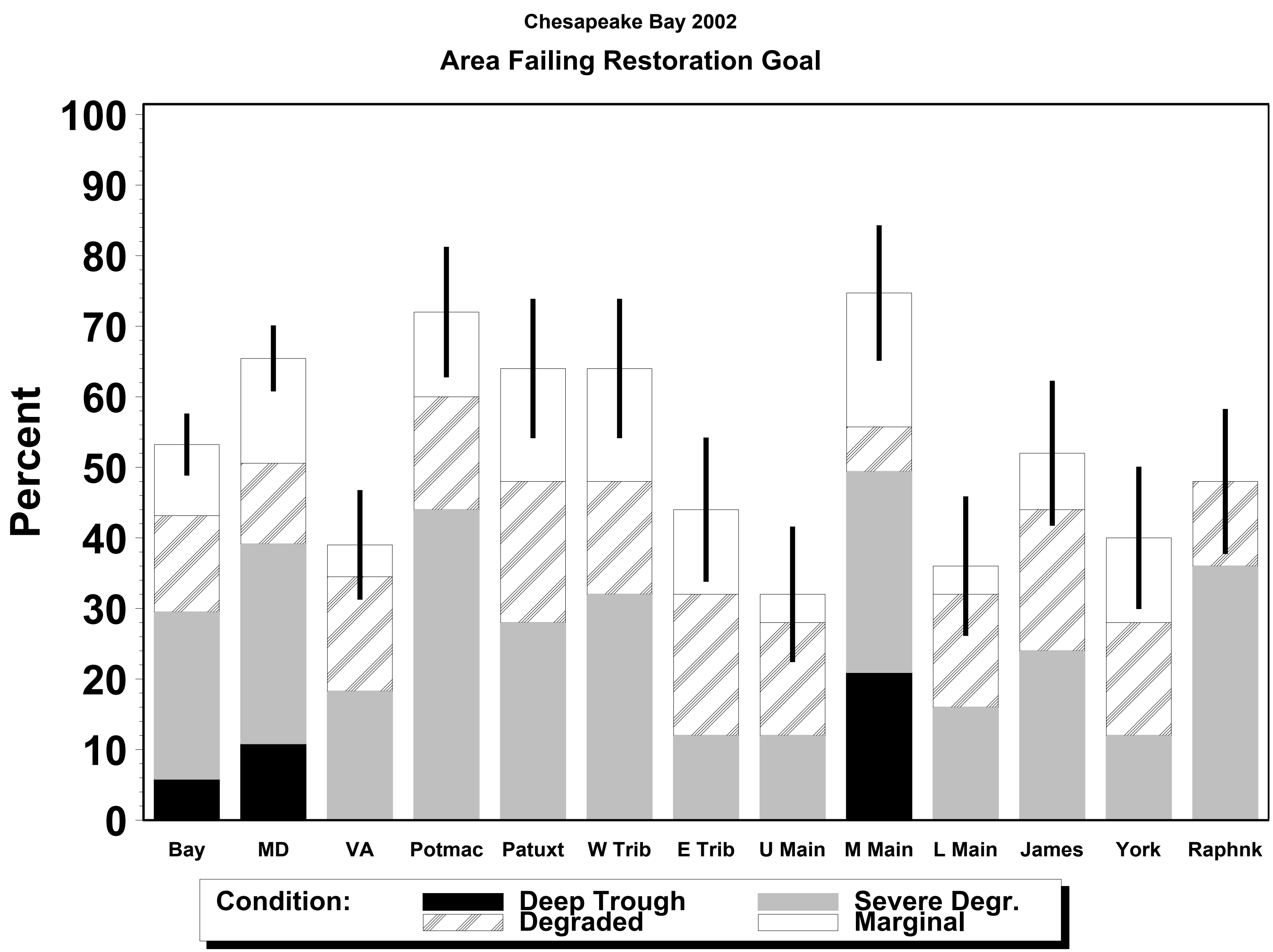

Figure 3-4. Proportion of the Chesapeake Bay, Maryland, Virginia, and the 10 sampling strata failing the Chesapeake Bay benthic community restoration goals in 2002. The error bars indicate ± 1 standard error.

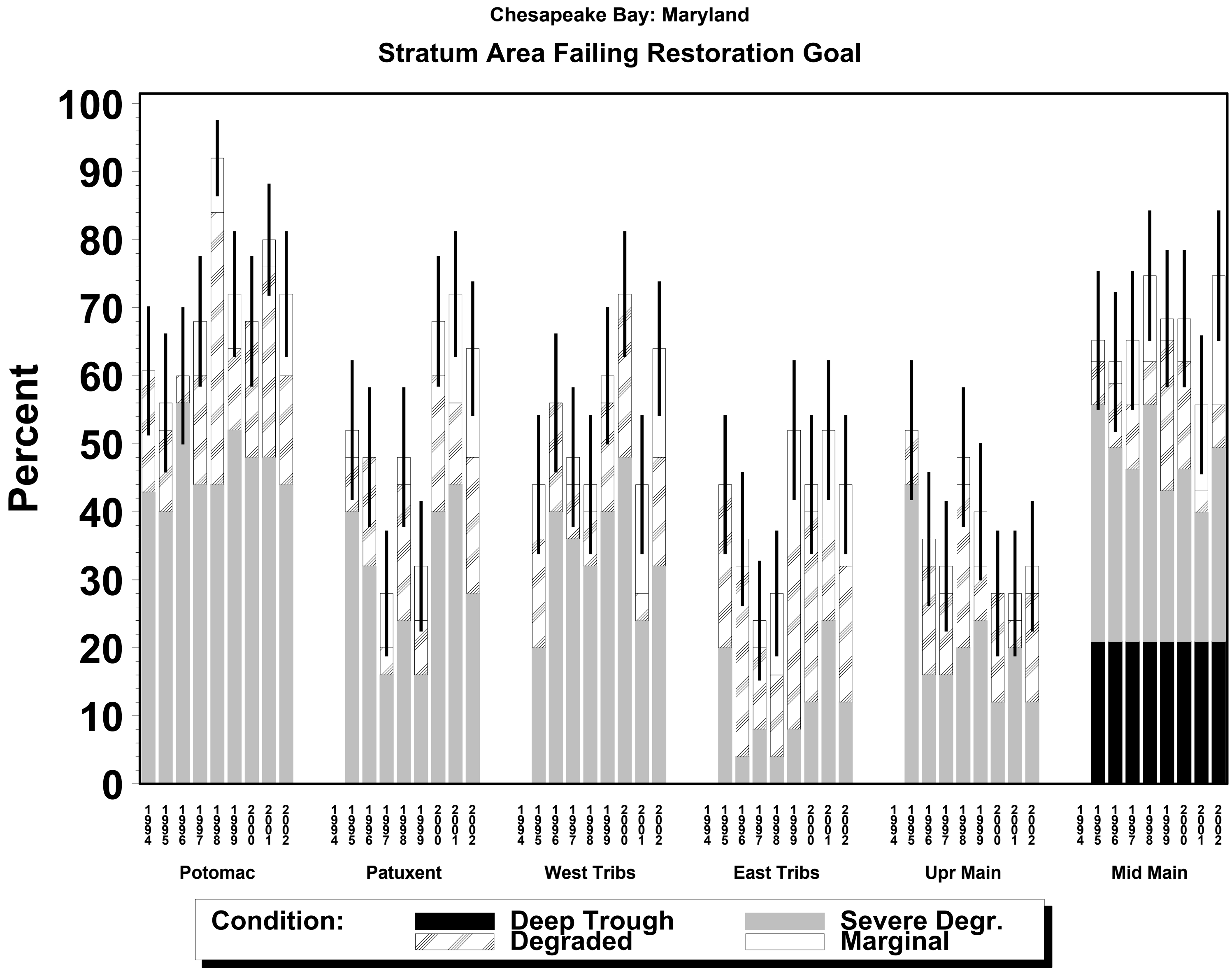

Figure 3-5. Proportion of the Maryland sampling strata failing the Chesapeake Bay benthic community restoration goals, 1994 to 2002. The error bars indicate ± 1 standard error.

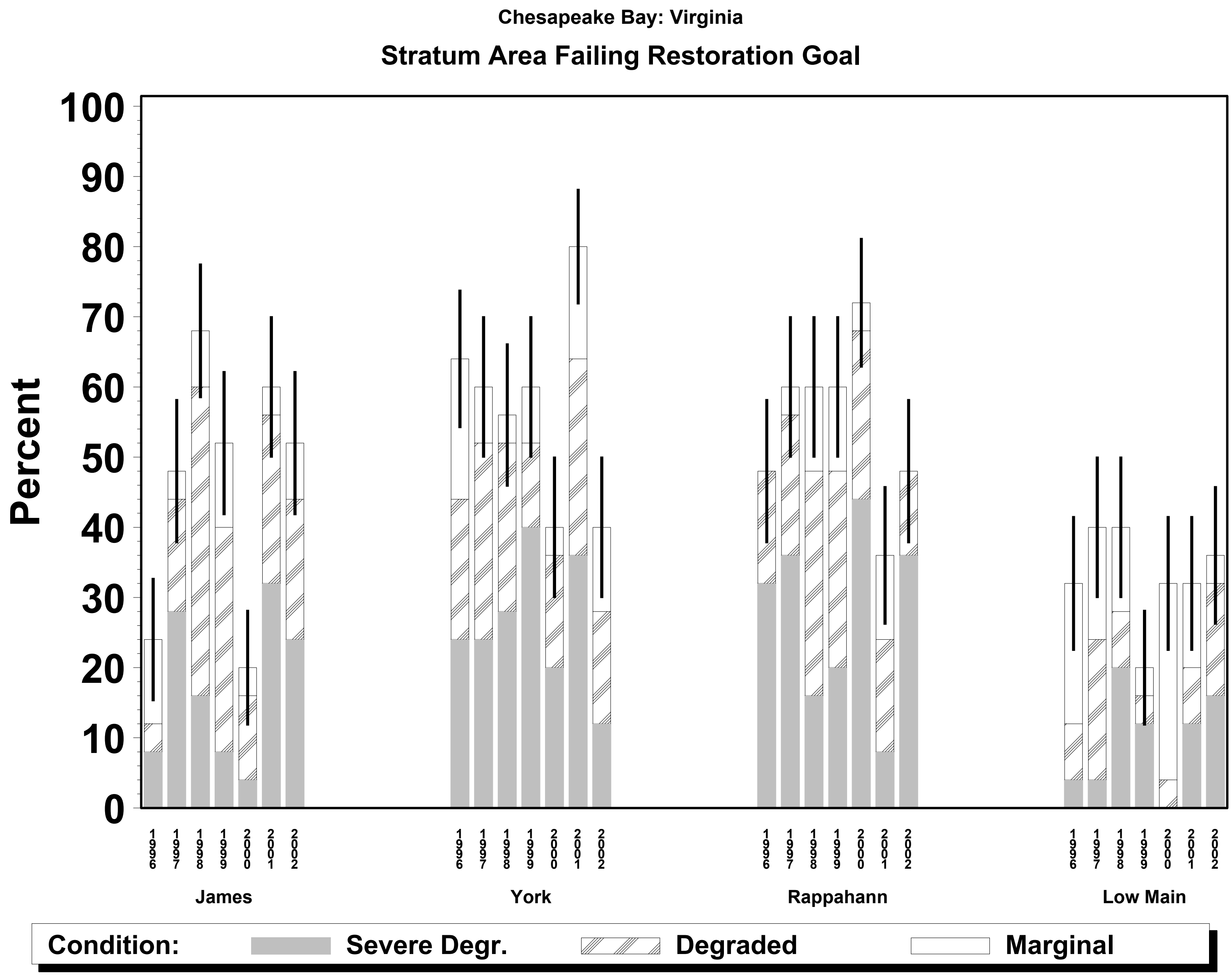

Figure 3-6. Proportion of the Virginia sampling strata failing the Chesapeake Bay benthic community restoration goals, 1996 to 2002. The error bars indicate $\pm$ 1 standard error.

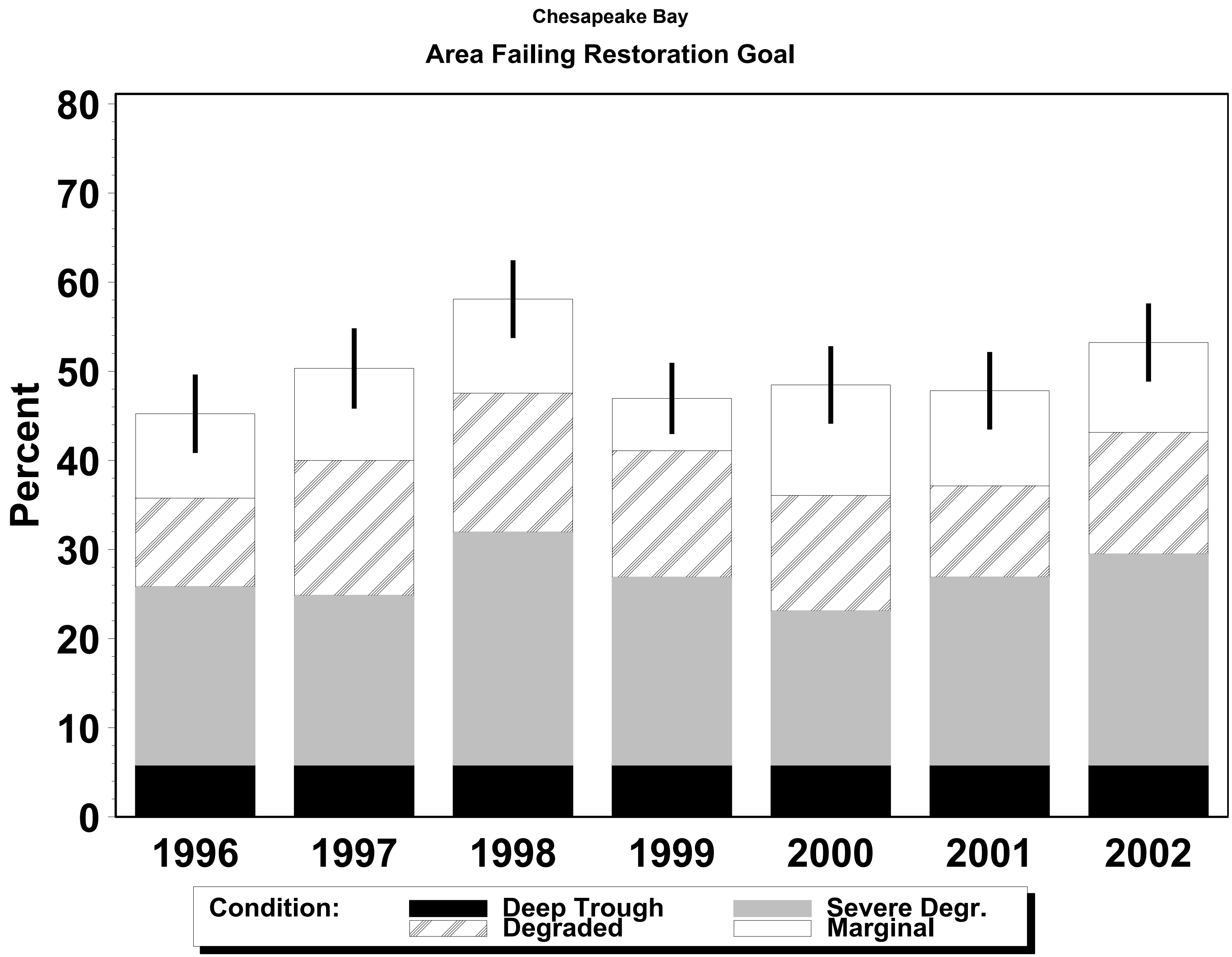

Figure 3-7. Proportion of the Chesapeake Bay failing the Chesapeake Bay benthic community restoration goals, 1996 to 2002. The error bars indicate ± 1 standard error.

4.0 DISCUSSION

Estimates of benthic community degradation for the Chesapeake Bay and the Maryland Bay in 2002 were slightly higher than those reported for 2001 (Llansó et al. 2002). However, the increase in the percent degraded area was within the margin of error of the estimate. Essentially, we see inter-annual changes in benthic condition that appear to be associated with spatial random patterns and changes in hydrology (dry vs. wet years). Substantial improvements in benthic community condition were not observed during the 1996-2002 time series. About half of the Chesapeake Bay and 65% of the Maryland tidal waters failed the Chesapeake Bay benthic community restoration goals in 2002. A large portion of the area failing the restoration goals in Chesapeake Bay had B-IBI values greater than 2.0, indicating mild degradation that should respond quickly to moderate improvements in water quality. Improving conditions were detected at some long-term monitoring fixed sites (see below); however, no obvious trends in the percentage of area with marginal or moderate degradation were observed. Forty-five percent of the degraded Chesapeake Bay bottom in 2002 (2,754 km^2) was marginally to moderately impaired. In the Maryland portion of the Bay, 40% of the degraded bottom (1,641 km^2) was marginally to moderately impaired. Of the additional 2,444 km^2 of Maryland Bay bottom supporting severely degraded benthic communities, 676 km^2 were located in the deep (>12m) mainstem that is perennially anoxic and probably beyond the scope of present mitigation efforts.

The estimates of degraded area for regions measured in multiple years were generally similar between years, with most estimates included within the confidence interval of other years. Some exceptions can be explained by the clumping of the random sites in either deep areas that are perennially hypoxic (e.g., the exceptionally high estimate of degraded area for the Potomac River in 1998) or shallow areas that are not typically affected by summer hypoxia (e.g., the low estimate of degraded area for the Patuxent River in 1997 and 1999). In addition, large annual changes in the percent area with benthic community degradation may be related to flow patterns. High spring flows, for example, have been theorized to cause earlier and spatially more extensive stratification within the Bay, leading to more extensive hypoxia (Tuttle et al. 1987). Patterns of degradation between years, although subtle, were in the direction expected from abnormally strong spring freshets in 1994, 1998, and 2000. Below we discuss the patterns of degradation and sources of stress affecting benthic communities in each of the Maryland's Bay six strata (see Figure 2-4) as inferred from the results of the water quality and the benthic monitoring programs.

4.1 PATUXENT RIVER

Benthic degradation in the Patuxent River is mainly related to adverse effects from low dissolved oxygen (DO). The intensity of summer hypoxic events varies annually, and this variability is reflected in the B-IBI. As indicated in Figure 4-1, there is a positive relationship between the percentage of samples with severely degraded condition (B-IBI scores of 2.0 or less) and summer DO, expressed as the percentage of time that bottom DO concentrations in the lower mesohaline Patuxent River were below 2 mg/L, as measured at water quality monitoring stations, June through September. This relationship, explaining 54% of the variability, is not as strong as that observed when the average DO concentration measured at the time of the benthic sampling is plotted against percent sites failing the restoration goals (Figure 4-2). This difference is probably due to the fact that the water quality monitoring stations are located in mid-channel and do not adequately reflect conditions in the shallower flanks of the lower Patuxent River. One factor linked to hypoxia is the amount of decaying organic matter from phytoplankton blooms. The lower Patuxent River suffers from poor water clarity and high algal concentrations. Years with large phytoplankton blooms are likely to result in more extensive hypoxia and increased benthic degradation. We observed a positive association between the percentage of samples with severely degraded condition and average chlorophyll *a* concentrations measured in Spring (April-June) at water quality monitoring stations in the lower Patuxent River. The strongest relationship is for average chlorophyll concentrations below the pycnocline (Figure 4-3).

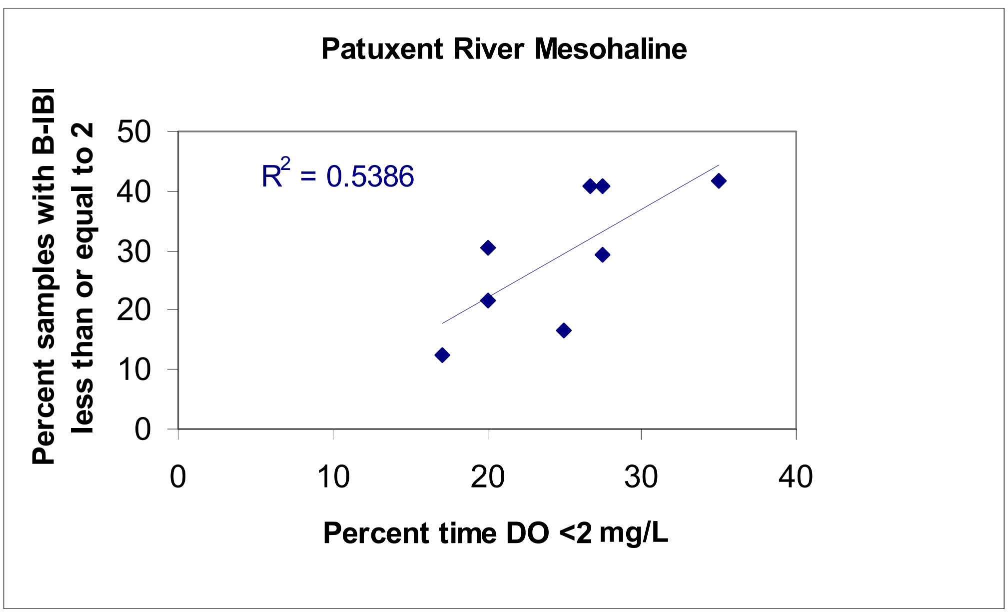

Figure 4-1. Relationship of benthic index of biotic integrity to percent time bottom dissolved oxygen below 2 mg/L (June-September) in the mesohaline Patuxent River. Each point represents a different year, 1995-2002. Dissolved oxygen data are fortnight near-bottom observations from Chesapeake Bay Water Quality Monitoring Program stations RET1.1, and LE1.1 through LE1.4.

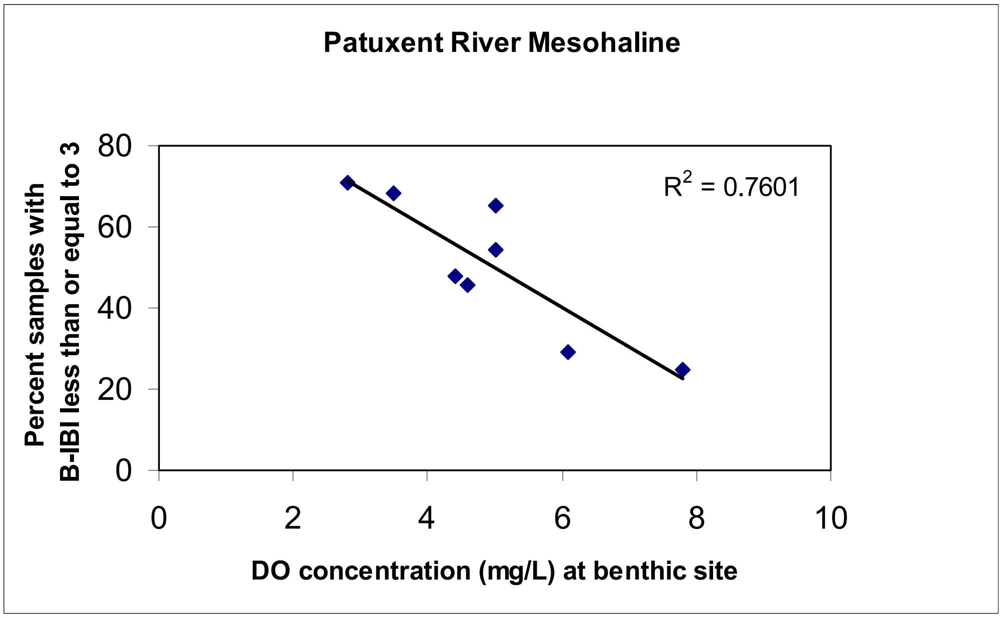

Figure 4-2. Relationship of benthic index of biotic integrity to dissolved oxygen concentration at the time of benthic sample collection in the mesohaline Patuxent River. Each point represents a different year, 1995-2002.

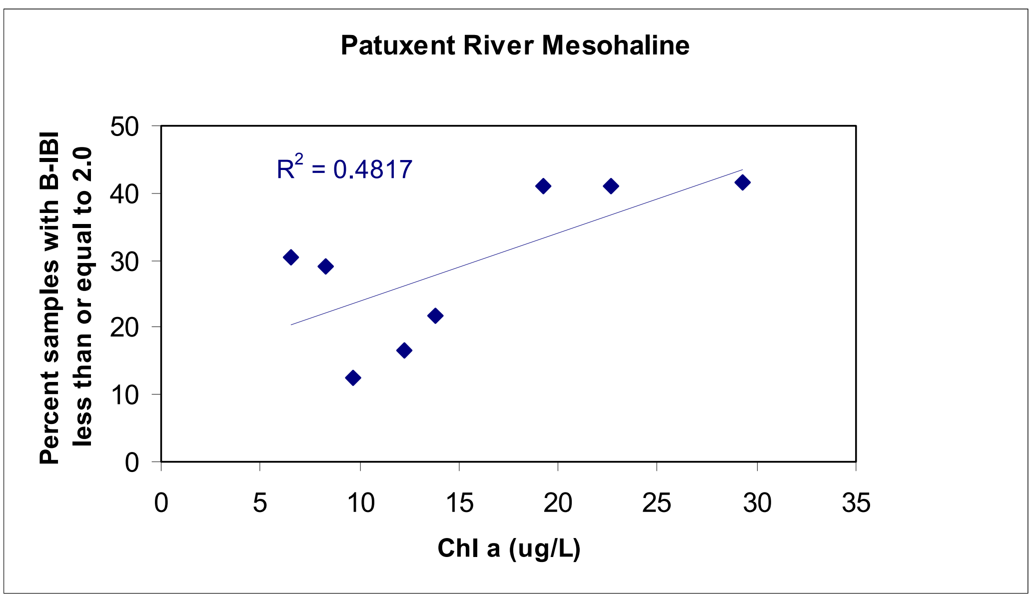

Figure 4-3. Relationship of benthic index of biotic integrity to average chlorophyll *a* concentration in the mesohaline Patuxent River. Each point represents a different year, 1995-2002. Chlorophyll data are below pycnocline, April through June fortnight observations from Chesapeake Bay Water Quality Monitoring Program stations RET1.1, and LE1.1 through LE1.4.

On average and for the entire Patuxent River stratum, the estimated degraded area in 2002 was similar to the estimated degraded area for the preceding two years. This result is surprising because 2002 was a drought year. Drought years are generally thought to be better for the bay because of the reduced flows and associated nutrient loads, which act together to alleviate the low DO problem. In the Maryland Bay, we observed increases in salinity of 2-4 psu in September 2002 and very few sites with DO concentrations below 2 mg/L. One possible interpretation of this result is that sediments in the Patuxent River, as well as other Bay tributaries, are nutrient saturated, and that excess particulate organic matter on the bottom is a strong factor controlling benthic community condition. The organic matter retained in the sediments represents a rich source of food for the benthic organisms, and primarily enhances growth and reproduction of the smaller, pollution-tolerant forms.

Of the four fixed monitoring stations in the Patuxent River, Station 74 (Chalk Point) and Station 77 (Holland's Cliff) show good benthic community status. Station 77 shows a degrading trend (declining B-IBI), but the magnitude of the decline has diminished in recent years, i.e., the condition of the benthic community has improved. With the addition of the 2002 data, the condition at Station 77 improved from degraded to meeting the goals. In the last three years, recovery at this station was associated with increases in biomass. The biomass metric is now scoring in the good range, reflecting increasing densities of the bivalves *Macoma balthica* and *Rangia cuneata*, and the crustacean *Cyathura polita*. In earlier years, trends in several community attributes contributed to the declining trend in the overall B-IBI. Large organisms were replaced by small, abundant opportunistic organisms indicative of pollution. For example, summer densities of the small polychaete *Streblospio benedicti* increased during the mid 1990s relative to the mid 1980s, while the abundance of the bivalve *M. balthica* decreased over the same period. In particular, *S. benedicti* densities increased from 100 individuals m^{-2} in 1984-1989 to over 5,000 individuals m^{-2} in August 1998. Spring densities also increased in recent years, peaking at over 10,000 individuals m^{-2} in May 2002.

It is hard to say whether the recent trends at Station 77 reflect changes in water quality. A variety of factors probably contribute to the observed trends. For example, the earlier declines of *M. balthica* were associated with a reported 57% flow increase in the Patuxent River during the 1990s (Tidal Monitoring and Analysis Workgroup, unpublished). Salinity limits the distribution of *M. balthica* in the Chesapeake Bay (Holland et al. 1987). Low salinity during the recruitment period increases mortality and reduces densities later in the year. The drier conditions of the last few years (Figure 4-4) are likely to have contributed to the recovery of the *M. balthica* population at Station 77.

In addition to the positive changes in benthic community condition noted for Station 77, a significant degrading trend through 2001 at Station 71 disappeared with the addition of the 2002 data. Station 71 near Broomes Island in the lower Patuxent River is influenced by severe low DO events. The status at this station is still degraded, but variable annual low DO events may influence B-IBI trends. Small organisms such as *S. benedicti* are main components of the community at this station. Species regarded as sensitive to low DO, such as the polychaete *Marenzelleria viridis*, the amphipod

Leptocheirus plumulosus, and the bivalves *M. balthica* and *Mulinia lateralis*, recruit to the benthos during the Spring but few individuals survive in Summer collections. Total community abundance and biomass have highly significant declining trends, factors that are usually linked to stress from low DO.

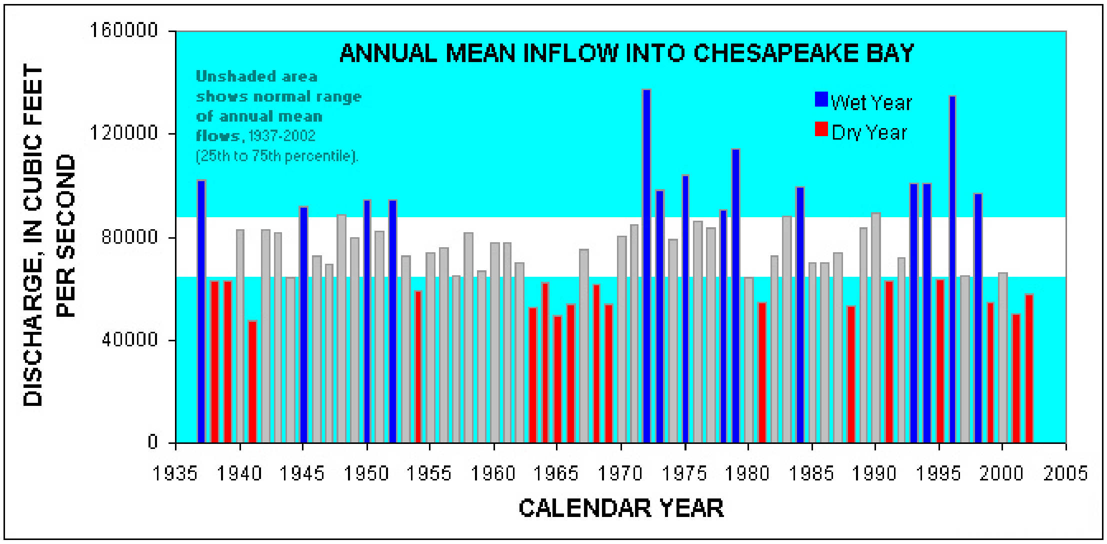

Figure 4-4. Annual mean flow into Chesapeake Bay, 1937-2002. This chart was obtained from the US Geological Survey website (http//md.water.usges.gov/monthy/ bay.html).

4.2 POTOMAC RIVER

The Potomac River has one of the highest areas with degraded benthic community in the Chesapeake Bay. Much of the problem in the Potomac River is severe oxygen depletion in the lower deep mainstem. Over the period 1996-2002, this stratum had one of the highest percentages of sites failing the restoration goals because of insufficient abundance or biomass. Unlike with the Patuxent River, no significant relationship is observed when the percentage of samples with severely degraded benthic condition is plotted against the percentage of time DO was below 2 mg/L (R^2 = 0.12). This is because hypoxia in the Potomac River is a perennial problem that affects waters below the pycnocline, with little inter-annual variability. Relationships between the B-IBI and DO in the Potomac River are best explored as a function of depth. The frequency of low DO events in the Potomac River is strongly associated with water depth (Figure 4-5), and so is the probability of observing severely degraded benthos (Figure 4-6). A positive relationship between percent samples with severely degraded condition and Summer average chlorophyll concentrations above the pycnocline was revealed, but the relationship was driven by one data point and was not particularly strong (R^2 = 0.40).

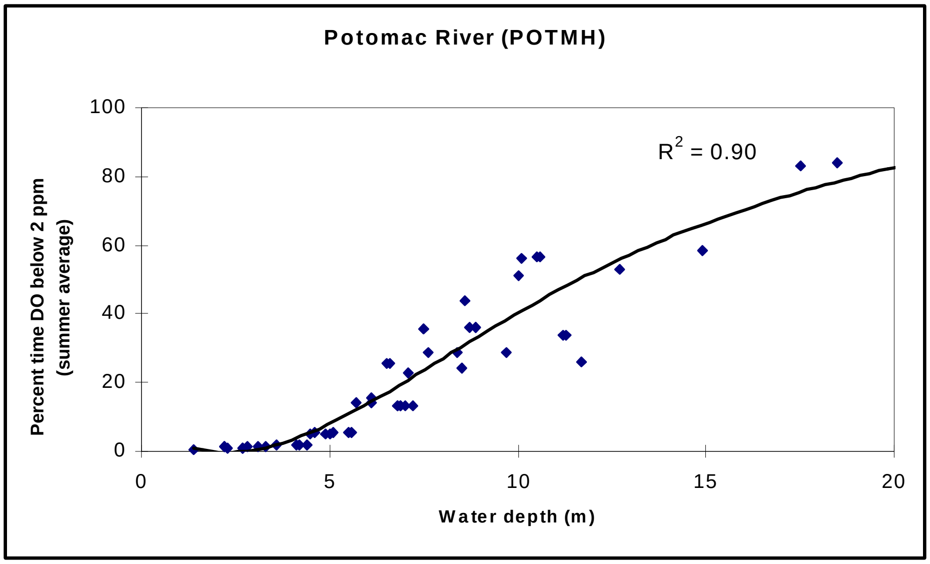

Figure 4-5. Relationship between percent time DO below 2 mg/L and water depth in the mesohaline Potomac River

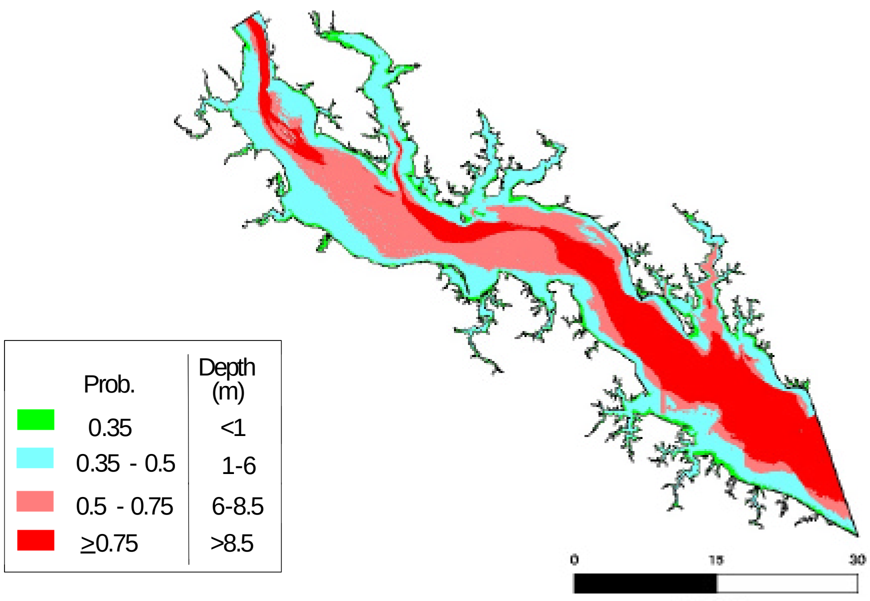

Figure 4-6. Probability of observing severely degraded benthos (B-IBI less than or equal to 2.0) as a function of water depth in the mesohaline Potomac River. A logistic regression model was used to obtain the probabilities.

Of the seven fixed monitoring stations in the Potomac River, only two showed trends in the B-IBI. Station 44 at Morgantown exhibited a degrading trend (significantly declining B-IBI) and Station 51 in shallow water near St. Clements Island exhibited an improving trend (significantly increasing B-IBI). The trend at Station 44 is new and marginally significant. Station 44 is on the slope of the deep channel (11-17 m) of the Potomac River and may be affected by tilts of the pycnocline bringing episodic fluctuations in DO and salinity. These are likely to exert severe stress on the benthic community, especially if abrupt changes in flow or salinity occur during the benthic reproductive season. For example, in May 1998 (a wet year) salinity at Station 44 was 1.5 psu, while in May 2002 (a dry year), salinity was 21 psu. The long-term summer salinity average is in the low mesohaline range. DO at the time of the benthic sampling was relatively high in 1999, 2000, and 2002 (5-7 mg/L), but bordering the 2 mg/L in 1996, 1997, and 2001. Although spatial (between replicate) and temporal variability at this station is high, the B-IBI has declined since 1998 from meeting the goal to a severely degraded condition, and total biomass has decreased significantly since 1999. The community is dominated by small organisms with species recruiting in the Spring persisting into the Summer. By virtue of its location between shallow and deep water, trends at Station 44 are expected to be sensitive measures of changing conditions in the mid Potomac River and of the effectiveness of management actions in the basin.

Improving trends at Station 51 were due to significant increases in diversity, pollution-sensitive abundance, and carnivore-omnivore abundance, and to significant decreases in pollution-indicative abundance, which may indicate improving water quality conditions in the lower shallow Potomac River. Densities of the small opportunist polychaete *S. benedicti* have decreased from a summer average of 370 individuals m^{-2} during the period 1985-1995 to an average of 60 individuals m^{-2} in subsequent years. Total community biomass, however, has been steadily decreasing since the 1980s.

An improving trend in the B-IBI at Station 36, in the upper tidal freshwater portion of the Potomac River, disappeared with the addition of the 2002 data. Benthic community status at this station is good (meeting the goal) and may have reached a plateau perhaps linked to significant reductions in nutrient loads in recent years as reported by the Tidal Monitoring and Analysis Workgroup (unpublished).

4.3 UPPER WESTERN TRIBUTARIES

The percent area with degraded benthic condition in the upper western tributaries of the Bay bounced back to nearly 65% from a low of 44% in 2001. The western tributaries suffer from various types of pollution, including toxic contamination, low dissolved oxygen, excess phytoplankton growth, lack of water clarity, and nutrient runoff, but these factors vary greatly among systems and the stress to the benthic communities varies accordingly. Generally, there is good agreement between the status and trends for water quality parameters and the benthic community condition. For example, summer DO status is poor in the Patapsco River but good in the Back River (Tidal Monitoring and Analysis Workgroup, unpublished). Back River mesohaline stations, however, show excess phytoplankton growth and poor Secchi depth. Benthic community condition is severely degraded in the upper part of the Patapsco River estuary, above the Francis Scott Key Bridge and at sites in Curtis Creek, Stony Creek, and along the deep channel south of Sparrows Point, areas that are affected by very low DO concentrations and by toxic contamination. The Back River shows moderately degraded benthic condition with total densities of organisms that are either within the good range or in excess of reference conditions, in agreement with pollution related to excess algal growth and high particulate organic deposition. Degraded sites in the Bush River are located in the upper reaches of the estuary and are numerically dominated by pollution tolerant organisms, mostly tubificid oligochaetes. This is consistent with poor water quality for chlorophyll *a* and Secchi depth in this region of the river. Good benthic community condition in the Middle River is also consistent with observations of good water quality status for this river.

An example where the benthic community provides valuable information on the condition of the estuary beyond what can be inferred from monitoring at water quality stations is the Severn River. All sites with degraded benthos in the Severn River were located in the upper portion of the estuary, above the long-term water quality monitoring station (WT7.1). Although the water quality at station WT7.1 indicates fair DO status, most of the failing benthic samples in the upper Severn River were azoic. A fixed long-term benthic monitoring station (Station 204) is also located mid-estuary in the Severn River. This station exhibited good benthic community condition in 2002 with no significant trend, suggesting that benthic degradation is limited to the upper part of the estuary where severe hypoxia or anoxia appears to be a problem.

4.4 EASTERN TRIBUTARIES

The Maryland eastern tributaries have some of the smallest extent of degraded area in the Chesapeake Bay. The severely degraded condition was exceptionally high in 2001 (24%), but, more typically, benthos is severely degraded in less than 15% of the area. Degradation in the eastern tributaries is mostly restricted to the lower Chester River and rivers emptying in Tangier Sound. Sixty percent of the sites with failing B-IBI in the Chester River are concentrated in the lower portion of the river, around Eastern Neck Island. Poor benthic community condition in this region could not be attributed to stress from low DO. Fifty percent of the sites in this region exhibited excess abundance of organisms, which is consistent with degrading trends in chlorophyll concentrations and water clarity. A positive trend in the B-IBI at Station 68 in the Chester River reported in 2001 was no longer significant with the addition of the 2002 data. The status at Station 68 is good (meets goal), but this station is located mid-river above the region where a majority of the random samples fail the B-IBI.

Maryland eastern tributaries have high agricultural land use, high nutrient input, high chlorophyll values but low frequencies of low dissolved oxygen events (Dauer et al. 2000). A high incidence of failure of restoration goals due to excess abundance of organisms is observed for these tributaries. However, in the lower eastern shore basin, low biomass relative to reference conditions is a problem, particularly in the Manokin River and Tangier

Sound. Sixty-three percent of all the sites sampled in the Manokin River between 1995 and 2002 scored 1 for biomass due to low values. In Tangier Sound, 65% of the sites scored 1 for biomass due to low values. Overall, 43% of the sites in the lower eastern tributaries (Nanticoke, Wicomico, Manokin, Big Annemessex, and Pocomoke) had low biomass. The major problem affecting water quality in the lower eastern shore basin is high sediment loads, which may reduce the amount of food that is available from the water column to the benthos. High amounts of sediments in suspension can interfere with the capturing of food particles by suspension-feeders. Suspension-feeders would normally account for a large portion of the biomass in these systems.

The fixed long-term monitoring station in the Nanticoke River (Station 62) exhibited a degrading trend in the B-IBI, and significantly declining trends in species diversity and biomass. Benthic community status at Station 62 is marginally degraded, but most of the biomass dominants at this station have decreased in abundance since the 1980s. The bivalves *M. balthica* and *M. mitchelli* decreased from average densities of approximately 100 and 300 individuals m^{-2} in September 1985-1988 to densities of 33 and 50 individuals m^{-2} in September 1995-2002, respectively. The bivalve *M. lateralis* was not recorded at this station between 1995 and 2001. Among the polychaete annelids, *Heteromastus filiformis* has not been recorded since 1995 and *M. viridis* densities decreased from approximately 30,000-55,000 individuals m^{-2} and 1,500-1,800 individuals m^{-2} in May and September 1996-1997, respectively, to 500 and 45 individuals m^{-2} in May and September 1998-2002. High sediment and nutrient loads are major problems in the Nanticoke River.

A fixed long-term monitoring station in the Elk River (Station 29) exhibited a significant, positive trend in the B-IBI and good benthic community condition. The improving trend was associated with a decrease in the abundance of pollution-indicative organisms (tubificid oligochaetes) since 1995 and an overall increase in densities of the bivalve *Rangia cuneata*. Improving trends in this region have been reported for nutrients, chlorophyll, and sediment concentrations. Likewise, Choptank River Station 64 exhibited a positive trend in the B-IBI in 2002 and good benthic community condition. This is a new trend but marginally significant. Inspection of the benthic community composition and abundance patterns at this station revealed no clear trends over the time series.

4.5 MARYLAND MID BAY AND UPPER BAY MAINSTEMS

Low DO events are common and severe in the mid-bay Maryland mainstem (Dauer et al. 2000). Anoxia is a common feature of the mid-bay deep channel. The Maryland mainstem stratum has the largest extent of severely degraded benthic community condition in the Bay. Two long-term monitoring stations are located in shallow, sandy habitats of the mainstem (Stations 01 and 06). These stations show significant improving trends in the B-IBI, as reported for the past several years. Benthic community condition in this shallow sandy habitat is good (meets goal).

The upper Maryland mainstem receives discharges from the Susquehanna River; therefore, water quality in this region should be a good indicator of inputs from the

Susquehanna River watershed. A high incidence of failure of restoration goals due to excess abundance or biomass of organisms is a common feature in the upper bay. This is indicative of effects on benthos resulting from nutrient enrichment. However, Station 26 further to the south shows a significant positive trend in the B-IBI, good benthic community condition, and no identifiable adverse effects.

4.6 VIRGINIA TRIBUTARIES

The James and the York rivers exhibited decreases in the estimated percent area with degraded benthic condition in 2002. During the period 1999-2002, the James, York, and Rappahannock Rivers exhibited some of the largest benthic condition changes in the Chesapeake Bay. The James and York rivers do not normally experience hypoxia, except for periods of intermittent hypoxia associated with spring-neap tidal cycles in the lower York River (Haas 1977). Therefore, stratum-wide changes in community condition for these two systems are not attributable to effects from low dissolved oxygen. In the James River, patterns in benthic community condition among years are partially explained by the clumping of samples in areas with local contamination problems. Because pollution sources are spatially variable in the James River stratum, comparisons in patterns of benthic community condition should be interpreted with caution and include assessments at various spatial scales of variability (Dauer and Llansó 2003). Patterns of degradation in the James River are driven by serious sediment contamination problems concentrated in the Elizabeth River (Dauer and Llansó 2003). Goal failure in the York River may be linked to both excess nutrients and physical disturbance of the sediments associated with strong erosional and depositional events (Schaffner et al. 2002).

4.7 CONCLUSIONS

Baywide estimates of degradation in 2002 were not substantially different from those of previous years. However, improvements in benthic condition were detected at some long-term monitoring stations, most notably in the Patuxent River estuary. Local areas with identifiable, point sources of pollution may be the first ones to respond to pollution abatement and are more likely to show recovery at fixed stations. Baywide, probability-based sampling will be critical for evaluating long-term changes in the areal extent of degradation.

The probability-based estimates developed for this report are the result of reviews conducted jointly by the Maryland and Virginia Chesapeake Bay benthic monitoring programs. A program review in 1996 examined program objectives, analysis techniques, and power to detect trends. One objective that emerged from the program review process was a goal of producing a baywide area estimate of degraded benthic communities with known and acceptable uncertainty. That goal is now an inherent part of benthic monitoring activities in Chesapeake Bay.

Baywide estimates are dependent on fully validated thresholds for assessing the condition of the benthic community in each sample collected. The thresholds were established and validated by Ranasinghe et al. (1994a) and updated by Weisberg et al. (1997). The B-IBI and the stratified random sampling design allow a validated, unambiguous approach to characterizing conditions in the Chesapeake Bay. The Chesapeake Bay B-IBI has been shown by Alden et al. (2002) to be sensitive, stable, robust, and statistically sound. The B-IBI is also applicable to a wide range of habitats, from tidal freshwater muds to polyhaline sands in the Chesapeake Bay, and this is an important and useful feature of the index because it allows characterization of local gradients of pollution and conditions across habitats. A study to develop diagnostic tools that differentiate between low dissolved oxygen impacts on benthos and those from toxic contamination was recently conducted by Dauer et al. (2002) and further augmented the usefulness of the B-IBI to management.

Although a continuing evolution of the B-IBI may lead to changes in estimates of the area of the Bay meeting the restoration goals, these revisions should amount to fine-tuning and not to significant changes in the estimates. One strength of the probability-based sampling element is that the amount of area meeting the goals can be recalculated as the index continues to be improved, so that trends in the area meeting the goals can be compared in a consistent and rigorous fashion.

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APPENDIX A

FIXED SITE COMMUNITY ATTRIBUTE 1985-2002 TREND ANALYSIS RESULTS

Appendix Table A-1. Summer trends in benthic community attributes at mesohaline stations 1985-2002. Shown is the median slope of the trend. Monotonic trends were identified using the van Belle and Hughes (1984) procedure. Shaded cells indicate increasing degradation; unshaded cells indicate improving conditions; (a): trends based on 1989-2002 data; (b): trends based on 1995-2002 data; (c): attribute trend based on 1990-2002 data; (d): attributes are used in B-IBI calculations when species specific biomass is unavailable; (e): attribute and trend are not part of the reported B-IBI.

Station	B-IBI	Abundance	Biomass	Shannon Diversity	Indicative Abundance	Sensitive Abundance	Indicative Biomass (c)	Sensitive Biomass (c)	Abundance Carnivore/ Omnivores
Potomac River									
43	0.00	-90.00	-0.55	0.004	0.25	-1.09 (d)	0.002 (e)	0.01	0.05 (e)
44	-0.03	-36.83	-0.12	0.03	-0.08	-0.52(d)	0.03 (e)	-6.85	0.80(e)
47	0.00	-47.75	1.05	0.02	0.32	-1.55 (d)	-0.003 (e)	-1.04	-0.19 (e)
51	0.05	-8.00	-0.23	0.03	-1.07	0.86	0.27 (e)	-0.70 (e)	0.91
52	0.00	0.00	-0.00	0.00	0.00 (d)	0.00 (d)	0.00	0.00	0.00
Patuxent River									
71	0.00	-45.97	-0.09	0.02	-2.23 (d)	0.00 (d)	-0.89	0.26	1.09
74	0.00	219.85	-1.12	-0.02	0.35	-1.67 (d)	0.01 (e)	-0.07	-0.52 (e)
77	-0.08	44.69	-0.22	-0.01	2.33	-0.72 (d)	-4.16 (e)	8.72	-0.43 (e)
Choptank River									
64	0.03	14.19	0.07	0.03	0.17 (d)	1.14 (d)	0.28	-0.71	0.13
Maryland Mainstem									
01	0.05	21.33	0.03	-0.001	-0.60	1.74	-0.13 (e)	0.21 (e)	1.18
06	0.06	50.91	0.001	0.01	-0.45	2.04	0.00 (e)	0.14 (e)	1.59
15	0.00	44.33	-0.04	-0.01	-0.96	0.11	0.11 (e)	-0.61 (e)	0.16
24	0.00	-50.14	-0.24	-0.03	-0.51 (d)	0.23 (d)	0.00	-1.15	1.83
26	0.03	36.22	0.63	0.02	0.07	0.25 (d)	0.00 (e)	-0.02	0.41 (e)
Maryland Western Shore Tributaries									
22	0.00	3.36	-0.03	-0.02	2.08	0.00 (d)	0.53 (e)	0.00	-0.50 (e)
23	0.00	-97.12	-0.02	0.01	-0.10	0.40 (d)	0.001 (e)	0.65	0.62 (e)
201(a)	0.00	-11.36	-0.001	0.01	0.00	0.00 (d)	4.86 (e)	0.00	0.00 (e)
202(a)	0.00	13.94	0.002	0.08	-1.28	0.00 (d)	-1.16 (e)	0.00	1.04 (e)
204(b)	-0.10	-184.15	-0.46	0.03	2.50 (d)	0.26 (d)	0.09	-2.96	0.28
Maryland Eastern Shore Tributaries									
62	-0.04	75.00	-0.08	-0.06	-0.18	-0.45 (d)	0.00 (e)	-4.15	-0.22 (e)
68	0.00	2.99	0.88	0.01	-0.10	2.09 (d)	-0.01 (e)	0.05	1.42 (e)

Appendix Table A-2. Summer trends in benthic community attributes at oligohaline and tidal freshwater stations 1985-2002. Shown is the median slope of the trend. Monotonic trends were identified using the van Belle and Hughes (1984) procedure. Shaded cells indicate increasing degradation; unshaded cells indicate improving conditions; (a): trends based on 1989-2002 data; NA: attribute not calculated.

Station	B-IBI	Abundance	Tolerance Score	Freshwater Indicative Abundance	Oligohaline Indicative Abundance	Oligohaline Sensitive Abundance	Tanypodinae to Chironomidae Ratio	Abundance Deep Deposit Feeders	Abundance Carnivore/ Omnivores
Potomac River									
36	0.00	-90.91	-0.01	0.27	NA	NA	NA	0.15	NA
40	0.00	-15.90	0.00	NA	-0.44	0.00	0.00	NA	0.51
Patuxent River									
79	0.00	241.14	-0.01	-1.04	NA	NA	NA	-0.76	NA
Choptank River									
66	0.00	122.42	0.12	NA	0.49	0.00	2.78	NA	1.21
Maryland Western Shore Tributaries									
203(a)	0.00	340.80	-0.00	NA	0.00	0.00	0.17	NA	0.00
Maryland Eastern Shore Tributaries									
29	0.03	-45.54	-0.13	NA	-3.39	0.05	0.00	NA	0.13

APPENDIX B

FIXED SITE B-IBI VALUES, SUMMER 2002

Appendix Table B-1. Fixed site B-IBI values, Summer 2002					
Station	**Sampling Date**	**Latitude (NAD83 Decimal Degrees)**	**Longitude (NAD83 Decimal Degrees)**	**B-IBI**	**Status**
001	9-Sep-02	38.41900	-76.41838	4.11	Meets Goal
006	9-Sep-02	38.44192	-76.44422	4.44	Meets Goal
015	9-Sep-02	38.71470	-76.51380	2.33	Degraded
022	16-Sep-02	39.25438	-76.58702	3.27	Meets Goal
023	16-Sep-02	39.20845	-76.52355	3.00	Meets Goal
024	9-Sep-02	39.12218	-76.35617	2.44	Degraded
026	9-Sep-02	39.27168	-76.29053	3.80	Meets Goal
029	20-Sep-02	39.47946	-75.94480	1.89	Severely Degraded
036	18-Sep-02	38.76937	-77.03663	2.50	Degraded
040	18-Sep-02	38.35729	-77.23060	2.56	Degraded
043	4-Sep-02	38.38418	-76.98837	3.80	Meets Goal
044	4-Sep-02	38.38512	-76.99600	1.93	Severely Degraded
047	4-Sep-02	38.36505	-76.98770	3.13	Meets Goal
051	4-Sep-02	38.20527	-76.73852	3.22	Meets Goal
052	4-Sep-02	38.19230	-76.74812	1.22	Severely Degraded
062	3-Sep-02	38.38388	-75.85068	2.73	Marginal
064	17-Sep-02	38.59053	-76.06983	3.67	Meets Goal
066	23-Sep-02	38.80112	-75.92173	2.20	Degraded
068	16-Sep-02	39.13333	-76.07580	2.87	Marginal
071	5-Sep-02	38.39467	-76.54925	2.78	Marginal
074	5-Sep-02	38.54840	-76.67560	3.67	Meets Goal
077	5-Sep-02	38.60433	-76.67475	3.80	Meets Goal
079	23-Sep-02	38.74924	-76.68992	3.50	Meets Goal
201	16-Sep-02	39.23450	-76.49747	1.13	Severely Degraded
202	16-Sep-02	39.21715	-76.56430	1.40	Severely Degraded
203	19-Sep-02	39.27497	-76.44441	1.56	Severely Degraded
204	17-Sep-02	39.00707	-76.50537	2.00	Severely Degraded

APPENDIX C

RANDOM SITE B-IBI VALUES, SUMMER 2002

Appendix Table C-1. Random site B-IBI values, Summer 2002

Station	Sampling Date	Latitude (NAD83 Decimal Degrees)	Longitude (NAD83 Decimal Degrees)	B-IBI	Status
MET-09401	3-Sep-02	38.12680	-75.88650	3.33	Meets Goal
MET-09402	3-Sep-02	38.13077	-75.84967	1.67	Severely Degraded
MET-09403	3-Sep-02	38.20908	-75.85567	3.33	Meets Goal
MET-09404	3-Sep-02	38.31572	-75.91917	2.67	Marginal
MET-09405	23-Sep-02	38.34268	-75.65754	1.67	Severely Degraded
MET-09406	3-Sep-02	38.39542	-75.84188	3.80	Meets Goal
MET-09408	17-Sep-02	38.59492	-76.12688	3.67	Meets Goal
MET-09409	17-Sep-02	38.62725	-75.98925	3.80	Meets Goal
MET-09410	17-Sep-02	38.62922	-76.13315	2.67	Marginal
MET-09411	17-Sep-02	38.63677	-75.97602	2.60	Degraded
MET-09412	17-Sep-02	38.68095	-75.95868	4.20	Meets Goal
MET-09413	16-Sep-02	38.99463	-76.18467	3.00	Meets Goal
MET-09414	16-Sep-02	38.99763	-76.26792	3.33	Meets Goal
MET-09415	16-Sep-02	39.00032	-76.15240	3.00	Meets Goal
MET-09416	16-Sep-02	39.00332	-76.19717	3.33	Meets Goal
MET-09417	16-Sep-02	39.02763	-76.20293	2.00	Severely Degraded
MET-09419	16-Sep-02	39.07233	-76.20565	3.00	Meets Goal
MET-09420	16-Sep-02	39.07702	-76.20153	2.67	Marginal
MET-09421	16-Sep-02	39.08388	-76.18995	3.33	Meets Goal
MET-09422	16-Sep-02	39.11038	-76.12505	2.33	Degraded
MET-09423	16-Sep-02	39.16000	-76.03668	2.60	Degraded
MET-09424	16-Sep-02	39.16645	-76.04285	3.00	Meets Goal
MET-09425	16-Sep-02	39.19033	-76.07058	3.40	Meets Goal
MET-09426	3-Sep-02	38.27108	-75.92032	2.33	Degraded
MET-09427	20-Sep-02	39.54121	-75.87126	2.20	Degraded
MMS-09501	24-Sep-02	37.91524	-75.84381	2.67	Marginal
MMS-09502	24-Sep-02	37.93304	-75.81629	3.67	Meets Goal
MMS-09503	4-Sep-02	37.94467	-76.25173	1.33	Severely Degraded
MMS-09504	3-Sep-02	38.01608	-76.08812	3.67	Meets Goal
MMS-09506	3-Sep-02	38.13910	-76.30912	1.67	Severely Degraded
MMS-09508	3-Sep-02	38.15475	-75.96768	3.33	Meets Goal
MMS-09509	3-Sep-02	38.19837	-76.03567	2.33	Degraded
MMS-09510	3-Sep-02	38.21437	-75.94518	2.00	Severely Degraded
MMS-09511	3-Sep-02	38.23172	-75.96153	3.67	Meets Goal
MMS-09512	3-Sep-02	38.23515	-76.09060	2.67	Marginal
MMS-09513	3-Sep-02	38.27147	-76.25935	3.67	Meets Goal
MMS-09514	3-Sep-02	38.28250	-76.10585	2.67	Marginal
MMS-09516	17-Sep-02	38.53395	-76.30927	1.67	Severely Degraded
MMS-09517	17-Sep-02	38.55545	-76.19373	2.33	Degraded
MMS-09518	17-Sep-02	38.55643	-76.33923	2.00	Severely Degraded

Appendix Table C-1. (Continued)

Station	Sampling Date	Latitude (NAD83 Decimal Degrees)	Longitude (NAD83 Decimal Degrees)	B-IBI	Status
MMS-09519	17-Sep-02	38.56210	-76.30022	3.00	Meets Goal
MMS-09520	9-Sep-02	38.63788	-76.48990	1.67	Severely Degraded
MMS-09521	17-Sep-02	38.63943	-76.23803	3.67	Meets Goal
MMS-09523	17-Sep-02	38.72062	-76.39075	1.67	Severely Degraded
MMS-09524	9-Sep-02	38.73337	-76.52077	2.00	Severely Degraded
MMS-09525	9-Sep-02	38.96400	-76.42147	1.67	Severely Degraded
MMS-09526	24-Sep-02	37.96553	-75.70725	2.67	Marginal
MMS-09527	3-Sep-02	38.15233	-76.31087	3.00	Meets Goal
MMS-09528	3-Sep-02	38.04585	-75.93480	2.67	Marginal
MMS-09530	3-Sep-02	38.03082	-75.89400	2.67	Marginal
MWT-09301	9-Sep-02	38.89993	-76.48832	2.00	Severely Degraded
MWT-09302	16-Sep-02	39.06490	-76.47870	3.00	Meets Goal
MWT-09303	16-Sep-02	39.06908	-76.49633	2.67	Marginal
MWT-09304	16-Sep-02	39.07480	-76.50667	2.00	Severely Degraded
MWT-09305	16-Sep-02	39.07548	-76.44810	3.33	Meets Goal
MWT-09306	16-Sep-02	39.08557	-76.45700	2.67	Marginal
MWT-09307	9-Sep-02	39.16777	-76.44967	3.67	Meets Goal
MWT-09308	16-Sep-02	39.18075	-76.51740	2.33	Degraded
MWT-09309	16-Sep-02	39.20418	-76.51410	2.33	Degraded
MWT-09310	16-Sep-02	39.20458	-76.47473	3.67	Meets Goal
MWT-09311	16-Sep-02	39.21097	-76.52925	2.33	Degraded
MWT-09312	16-Sep-02	39.21407	-76.45487	2.67	Marginal
MWT-09313	16-Sep-02	39.21825	-76.52832	1.00	Severely Degraded
MWT-09314	16-Sep-02	39.22677	-76.54875	2.00	Severely Degraded
MWT-09315	16-Sep-02	39.25828	-76.58600	1.33	Severely Degraded
MWT-09316	16-Sep-02	39.26035	-76.58510	4.00	Meets Goal
MWT-09318	16-Sep-02	39.27447	-76.58658	1.00	Severely Degraded
MWT-09319	19-Sep-02	39.33190	-76.36466	2.60	Degraded
MWT-09320	19-Sep-02	39.33535	-76.30920	3.00	Meets Goal
MWT-09321	19-Sep-02	39.36704	-76.26150	3.00	Meets Goal
MWT-09322	19-Sep-02	39.37672	-76.33594	3.40	Meets Goal
MWT-09323	19-Sep-02	39.38607	-76.33369	1.80	Severely Degraded
MWT-09324	19-Sep-02	39.44200	-76.23782	3.00	Meets Goal
MWT-09325	19-Sep-02	39.44255	-76.24584	1.40	Severely Degraded
MWT-09326	16-Sep-02	39.08295	-76.45692	2.67	Marginal
PMR-09101	4-Sep-02	37.94658	-76.33723	3.33	Meets Goal
PMR-09103	4-Sep-02	38.00432	-76.40637	2.67	Marginal
PMR-09105	4-Sep-02	38.04945	-76.35373	4.67	Meets Goal
PMR-09106	4-Sep-02	38.05113	-76.50918	3.67	Meets Goal
PMR-09107	4-Sep-02	38.06075	-76.41885	1.33	Severely Degraded

Appendix Table C-1. (Continued)					
Station	Sampling Date	Latitude (NAD83 Decimal Degrees)	Longitude (NAD83 Decimal Degrees)	B-IBI	Status
PMR-09108	4-Sep-02	38.09707	-76.56973	3.67	Meets Goal
PMR-09109	4-Sep-02	38.15553	-76.43577	4.00	Meets Goal
PMR-09110	4-Sep-02	38.16958	-76.69883	2.33	Degraded
PMR-09111	4-Sep-02	38.17557	-76.56945	1.00	Severely Degraded
PMR-09112	4-Sep-02	38.19270	-76.62617	2.33	Degraded
PMR-09113	4-Sep-02	38.20242	-76.85627	1.67	Severely Degraded
PMR-09114	4-Sep-02	38.20607	-76.81532	1.00	Severely Degraded
PMR-09115	4-Sep-02	38.23293	-76.91717	1.00	Severely Degraded
PMR-09116	4-Sep-02	38.22948	-76.79938	2.00	Severely Degraded
PMR-09117	4-Sep-02	38.23160	-76.69443	2.67	Marginal
PMR-09118	4-Sep-02	38.24413	-76.91537	1.00	Severely Degraded
PMR-09119	4-Sep-02	38.27747	-76.80422	2.33	Degraded
PMR-09121	4-Sep-02	38.39448	-77.02178	3.80	Meets Goal
PMR-09122	4-Sep-02	38.41797	-77.07760	3.40	Meets Goal
PMR-09123	18-Sep-02	38.44960	-77.11259	2.60	Degraded
PMR-09124	18-Sep-02	38.50754	-77.28519	2.67	Marginal
PMR-09125	18-Sep-02	38.56469	-77.21047	1.67	Severely Degraded
PMR-09126	4-Sep-02	38.05395	-76.49373	1.67	Severely Degraded
PMR-09127	4-Sep-02	38.28057	-76.91483	2.00	Severely Degraded
PMR-09128	4-Sep-02	37.96470	-76.29978	1.00	Severely Degraded
PXR-09201	5-Sep-02	38.29490	-76.43203	2.67	Marginal
PXR-09202	5-Sep-02	38.31405	-76.45732	2.00	Severely Degraded
PXR-09203	5-Sep-02	38.31648	-76.42935	2.33	Degraded
PXR-09204	5-Sep-02	38.32245	-76.46672	2.00	Severely Degraded
PXR-09205	5-Sep-02	38.33375	-76.48657	3.00	Meets Goal
PXR-09206	5-Sep-02	38.34767	-76.48412	2.67	Marginal
PXR-09207	5-Sep-02	38.35002	-76.50875	3.33	Meets Goal
PXR-09209	5-Sep-02	38.37133	-76.51393	2.33	Degraded
PXR-09210	5-Sep-02	38.39117	-76.55257	3.67	Meets Goal
PXR-09211	5-Sep-02	38.39115	-76.55395	3.33	Meets Goal
PXR-09212	5-Sep-02	38.39425	-76.48678	2.67	Marginal
PXR-09213	5-Sep-02	38.39708	-76.52028	1.00	Severely Degraded
PXR-09214	5-Sep-02	38.40670	-76.54833	3.33	Meets Goal
PXR-09215	5-Sep-02	38.41172	-76.55398	3.33	Meets Goal
PXR-09216	5-Sep-02	38.41392	-76.59670	2.00	Severely Degraded
PXR-09217	5-Sep-02	38.41512	-76.60502	3.33	Meets Goal
PXR-09218	5-Sep-02	38.42287	-76.58012	3.67	Meets Goal
PXR-09219	5-Sep-02	38.43487	-76.61797	2.00	Severely Degraded
PXR-09220	5-Sep-02	38.44987	-76.64097	2.33	Degraded
PXR-09221	5-Sep-02	38.46385	-76.59413	2.67	Marginal

Appendix Table C-1. (Continued)

Station	Sampling Date	Latitude (NAD83 Decimal Degrees)	Longitude (NAD83 Decimal Degrees)	B-IBI	Status
PXR-09222	5-Sep-02	38.46313	-76.66382	1.67	Severely Degraded
PXR-09223	5-Sep-02	38.48400	-76.66817	2.33	Degraded
PXR-09224	5-Sep-02	38.56140	-76.67490	2.20	Degraded
PXR-09225	5-Sep-02	38.57333	-76.68145	3.40	Meets Goal
PXR-09227	5-Sep-02	38.41103	-76.53418	1.67	Severely Degraded
UPB-09601	16-Sep-02	39.02702	-76.28823	2.67	Marginal
UPB-09602	9-Sep-02	39.08187	-76.31440	1.33	Severely Degraded
UPB-09603	9-Sep-02	39.08525	-76.25420	2.33	Degraded
UPB-09604	9-Sep-02	39.11095	-76.27245	2.33	Degraded
UPB-09605	9-Sep-02	39.12250	-76.32517	2.33	Degraded
UPB-09606	9-Sep-02	39.14560	-76.37005	4.00	Meets Goal
UPB-09607	9-Sep-02	39.16033	-76.37967	4.00	Meets Goal
UPB-09608	9-Sep-02	39.16340	-76.36177	3.67	Meets Goal
UPB-09609	9-Sep-02	39.18068	-76.39923	4.33	Meets Goal
UPB-09610	9-Sep-02	39.22210	-76.24897	3.33	Meets Goal
UPB-09611	9-Sep-02	39.22400	-76.30283	3.67	Meets Goal
UPB-09612	9-Sep-02	39.24450	-76.34550	3.00	Meets Goal
UPB-09613	9-Sep-02	39.25303	-76.23933	4.00	Meets Goal
UPB-09614	9-Sep-02	39.26433	-76.36972	3.00	Meets Goal
UPB-09615	9-Sep-02	39.28527	-76.21650	4.33	Meets Goal
UPB-09616	9-Sep-02	39.31245	-76.23203	3.80	Meets Goal
UPB-09617	10-Sep-02	39.32900	-76.20188	3.00	Meets Goal
UPB-09618	10-Sep-02	39.34893	-76.18813	4.20	Meets Goal
UPB-09619	10-Sep-02	39.37405	-76.16452	3.40	Meets Goal
UPB-09620	10-Sep-02	39.38362	-76.14975	3.80	Meets Goal
UPB-09621	20-Sep-02	39.39937	-76.09822	3.80	Meets Goal
UPB-09622	10-Sep-02	39.42085	-76.09982	3.00	Meets Goal
UPB-09623	20-Sep-02	39.51004	-75.99987	1.80	Severely Degraded
UPB-09624	20-Sep-02	39.54529	-76.06249	2.33	Degraded
UPB-09625	20-Sep-02	39.57371	-76.08257	1.67	Severely Degraded