Ref. No. [UMCES] CBL 07-044

Water Quality Monitoring Program for Mill Creek and its Tributaries Located in Southern Calvert County

Summer 2006

Final Report
Prepared for the Calvert County Board of County Commissioners

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April 19, 2007

Technical Report No. TS-524-07 of the University of Maryland
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Acknowledgements

We extend our gratitude to the following individuals and/or groups for their role in supporting the 2006 Water Quality Monitoring Program in the Mill Creek and its Tributaries Located in Southern Calvert County:

2. The Calvert County Board of County Commissioners provides funds and maintains interest in supporting research to better understand and preserve one of southern Calvert County's important natural resources.

3. The administration of the Chesapeake Biological Laboratory (CBL) consistently releases this grant from overhead charges and absorbs the operating costs of the research vessel. This substantial reduction in costs greatly enhances the scope of work that can be preformed for this yearly study.

4. Ms. Janet Barnes and Dr. Jon Anderson conducted field sampling.

5. The Nutrient Analytical Services Laboratory (NASL) provides valuable guidance and assistance with sample collection techniques and laboratory analyses thereby helping to ensure the integrity of the results presented in this report.

6. Mr. Buddy Millsaps provides yearly precipitation data.

7. Mr. James Manning at the United States Geological Survey (USGS) provided historical river flow data. However, USGS data for station number 01594440 is now available on the web:

   http://va.water.usgs.gov/chesbay/RIMP/01594440.html
   Data retrieval: 1985 – 2006 for station 01594440 Patuxent River at Bowie, MD:
   http://va.water.usgs.gov/chesbay/RIMP/dataretrieval.html
   Recent provisional daily data can be obtained online via an interactive system at:
   http://waterdata.usgs.gov/nwis/sw

Executive Summary

Overall, this year represented average water quality conditions, despite a very abnormal rainfall event in June 2006. For example, both mean surface chlorophyll and bottom dissolved oxygen concentrations were similar to the 20 year average. In addition, bottom water dissolved oxygen concentrations were generally higher than previous years. In the context of the past few years, these conditions in Mill Creek and its surrounding tributaries illustrate improving conditions.

As in all years of this monitoring study, measurements included water column temperature, salinity, dissolved oxygen, chlorophyll-*a* concentrations and water clarity. These variables were measured at 10 fixed stations on 8 occasions during 2006 (once in May, bimonthly in June, July, August, and once in September). Station locations, sampling frequencies and analytical methodologies were identical to those used in previous years.

Concentrations of active chlorophyll-*a* serve as a measure of the size of the algal populations in the water column. Active chlorophyll-*a* concentrations at the surface ranged from 4.96 to 57.10 micrograms per liter ($\mu g\ L^{-1}$) at the fixed stations. Concentrations greater than 20 $\mu g\ L^{-1}$ indicate the presence of an algal bloom (severe bloom concentrations in the Patuxent River have exceeded 300 $\mu g\ L^{-1}$). The average surface active chlorophyll-*a* concentration for 2006 was 14.68 $\mu g\ L^{-1}$, compared to the 20 year average of 16.8 $\mu g\ L^{-1}$. The number of surface blooms recorded during the sampling season was 10, one higher than the 20 year average (9).

Although true anoxic conditions (=depleted dissolved oxygen) have not been recorded on the sampling dates of any harbor system cruise, in 2006 we recorded 7 observations when DO was less than 2.0 $mg\ L^{-1}$, with the lowest reading recorded as 1.18 $mg\ L^{-1}$. In comparison, 17 measurements were recorded below 2.0 $mg\ L^{-1}$ in 2005 and the lowest reading was 0.3 $mg\ L^{-1}$. The percentage of bottom water hypoxic readings during the 2006 season was 9.7%, lower than the past three years (12% for 2005, 25% for 2004, 30% for 2003), and suggests improving water quality.

Water clarity is affected by runoff, resuspension of bottom sediment, algal blooms and submerged aquatic vegetation. The minimum light necessary for algal growth is estimated to be 1% of surface radiation, while the minimum light necessary for SAV growth is estimated to be 30% of the surface radiation. At the lowest Secchi reading of 0.4 meters (kd = 3.62), light sufficient for algal growth penetrates to 1.3 meters; for SAV sufficient light penetrates to only 0.33 meters. At the highest Secchi reading of 1.7 meters (kd = 0.85), 1% of the surface radiation penetrates to 5.4 meters and 30% surface radiation penetrates to 1.4 meters. Since the average mean depth of the system is about 2.0 meters, light sufficient for algal growth throughout most of the water column was present on most sampling dates. However, light sufficient for SAV growth throughout an average depth of 2 meters was not present on the sampling dates.

Precipitation and river flow patterns exert substantial influence on water quality conditions. Average precipitation within the harbor system drainage basin during the 2006 sampling season (March – September) was 0.14 inches day^{-1}, slightly higher than the average recorded precipitation for the past 20 years of monitoring. The lowest average recorded during the monitoring program was 0.07 inches day^{-1} in 1986, and the highest was 0.22 inches day^{-1} in 2004.

The January-May 2006 mean flow of the Patuxent River (at Bowie, MD) was 351 cubic feet per second (cfs), well below the 20 year average of 503 cfs. This mean flow was lower than the past three years (560 cfs in 2005, 602 cfs in 2004, 699 cfs in 2003). The highest flow recorded was in 1998 (786 cfs).

Herein, we also focus on water quality in relation to the large storm in late June. This rain event, created by the remnants of tropical storm Alberto and a stalled jet stream, produced up to 5 inches of rain in the Patuxent watershed (TMAW 2006). The rain also produced a large discharge event (a “freshet”) in the Patuxent that was as large as the previous 80 days of river flow combined (USGS 2006). It is generally believed that large storm events can deliver significant sediments and nutrients that may stimulate algal blooms, cause seagrass dieoff, and depress bottom water dissolved oxygen. Therefore, local agencies, such as Maryland Department of Natural Resources, the EPA Chesapeake Bay Program, Morgan State Estuarine Research Center, and the University of Maryland Center for Environmental Science (including Chesapeake Biological Laboratory), assessed its impact on Chesapeake Bay seagrasses, algal blooms, and bottom water dissolved oxygen. Their analyses showed that despite an increase in chlorophyll (=algal biomass) after the freshet, there was no measurable long-term effects in regards to bottom water dissolved oxygen, and seagrass abundance/health (TMAW 2006).

Conclusions and Recommendations:

Monitoring of Mill Creek and its surrounding tributaries has been conducted for the past twenty years. During 2006, the water quality of the system was average. Still, algal blooms and the resulting bottom water hypoxia are common, especially in late summer. Continued monitoring is important.

Interannual variability in precipitation and river flow greatly influences water quality trends. However, it appears that winter and spring conditions tend to affect water quality more so than ephemeral storm events (e.g. the June freshet).

In the context of the past few years, it appears that the system is slowly improving after two very wet years (2003 and 2004) produced suboptimal conditions.

Continued monitoring is necessary so that both negative and positive trends in the system's health can be recognized in a timely fashion.

It is also recommended that the county continue to support planning and eventual implementation of sewer upgrades, BNR, riparian and vegetative buffer zones, and encourage the use of pump-out facilities by boaters within the Mill Creek system.

Continue to support the local county and state environmental educational programs as an educated person is our hope for a cleaner future.

1. Introduction

As development adjacent to coastal and estuarine waters increases so does the risk that water quality of these areas will degrade. Water quality degradation is a concern not only in the large estuaries, such as Chesapeake Bay, but also in the smaller coves and tributary rivers adjoining these estuaries. In many cases these areas can be considered small estuaries or sub-estuaries. They are subjected to similar natural and anthropogenic influences as the larger estuaries. However, due to their smaller size and restricted flushing, the potential for dilution of pollutants is limited and the potential for algal blooms and general water quality deterioration is enhanced.

Mill Creek, St. John Creek, Back Creek, The Narrows and Solomons Harbor located within the Dowell, Drum Point, Lusby, Olivet and Solomons portion of southern Calvert County, Maryland (referred to as the ***Mill Creek system*** in this report), is one of these smaller sub-estuarine systems. The number of houses and town houses surrounding the Mill Creek system is increasing, as are the number of boat slips within the Mill Creek system. Additionally, many forms of recreation enjoyed by the local population and by visitors are becoming increasingly popular.

The aquatic resources and the population growth in this area must be managed to preserve this system for the use and enjoyment of future generations. In response to these management concerns, the Calvert County Board of County Commissioners provides the University of Maryland System, Center for Environmental Science, Chesapeake Biological Laboratory (UMCES CBL) with funding for monitoring water quality conditions in the Mill Creek system. Past monitoring grants were awarded in 1987-1988 and 1990-2005. The focal point of these studies was to measure the variables that best indicate stress to an estuarine system due to increased development and recreational activity. Between 1987 and 2005 variables measured included particulate and dissolved nutrients, chlorophyll-*a*, fecal coliform concentrations, temperature, water column clarity, dissolved oxygen concentrations and salinity.

The 2006 Mill Creek study followed the scaled-down format used in recent years that focuses on temperature, salinity, dissolved oxygen, water column clarity and chlorophyll-*a* concentrations. An investigation into the effects of Patuxent River flow, precipitation, Mill Creek system chlorophyll-*a* concentrations, water column stratification on bottom water dissolved oxygen levels was also conducted. In addition, we focus on the results of two sampling dates, June 22nd and July 11th, that straddle the rainfall event to examine the effect of the June 2006 freshet on water quality in the Mill Creek system.

2. Sampling Procedures

2.1 Station Locations and Sampling Frequency

Water column data were collected at ten fixed stations in the Mill Creek system on eight different cruises beginning May 23, 2006 and ending on September 6, 2006. The data from these eight cruises characterized the water quality of the Mill Creek system during the spring and summer periods of 2006 and were compared to findings of all previous monitoring studies.

As in previous years, sampling stations were distributed throughout the Mill Creek system to ensure coverage of the area (Figure 2-1 and Table 2-1). Four stations were positioned along Mill Creek (stations 3, 4, 6 and 7); two along St. John Creek (stations 8 and 9) and two located in Back Creek (stations 15 and 17). One station was located in The Narrows (station 11) and one at the mouth of the Mill Creek system (station 2). Data from stations 2 and 11 provide insight into main stem Patuxent River – Mill Creek System interactions.

Each sampling cruise was conducted aboard the R/V Pisces, a 25-ft CBL research vessel, between the hours of 0700 and 1200.

2.2 Water Quality Observations

Water column temperature, conductivity, salinity and dissolved oxygen were measured at each station using a submersible water quality monitoring instrument (YSI model 6920 or 600). Surface (0.5 meters) and bottom (0.5 meters above the sediment surface) measurements were taken at each site. At station 9 only surface measurements were recorded. The total depth was less than 2 meters with no water column stratification observed. (Evidence for stratification was checked on each cruise.) Water column turbidity was measured using a Secchi disk. Weather and sea-state conditions including temperature, percent cloud cover, wind speed and direction, total water depth and wave heights were recorded.

2.3 Chlorophyll-*a* Analyses

Samples of near-surface and near-bottom water were collected for chlorophyll-a in separate, sample rinsed, one-liter polyethylene jugs using a small submersible pump (Rule model 1500). For each depth, aliquots of 25 to100 ml were immediately filtered through a 0.7 μm glass fiber filter, wrapped in a labeled foil packet, then kept in the dark on ice blocks. After the cruise, the samples were transported to the CBL Nutrient Analytical Services Laboratory (NASL) and immediately frozen. Analyses of all samples were conducted by NASL using the standard operating protocols described in Keefe et al. (2004).

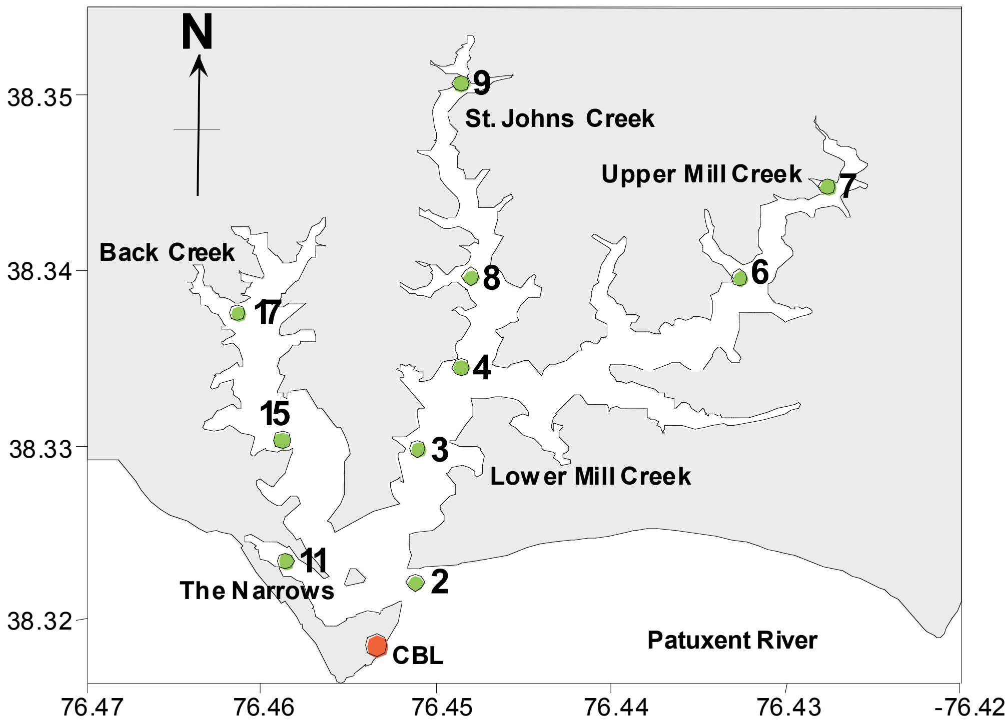

Figure 2.1. Map of the sampling sites within the Mill Creek system.

Table 2-1. Location and average depth of sampling sites within the Mill Creek system.

Station Number	Station Name	Average Depth* (meters)	Latitude (degrees - decimal minutes)	Longitude
2	Boat Shop	5.68	38^o 19.43'	76^o 26.16'
3	Bow Cove	4.56	38^o 19.61'	76^o 27.13'
4	Pancake Point	4.52	38^o 20.10'	76^o 27.01'
6	Cole's Creek	2.30	38^o 20.40'	76^o 26.03'
7	Ranch Club	1.33	38^o 20.77'	76^o 25.70'
8	Hutchin's Cove	2.80	38^o 20.46'	76^o 26.92'
9	Lore's Creek	1.05	38^o 21.13'	76^o 26.98'
11	Pilot Transport Station	3.61	38^o 19.50'	76^o 27.58'
15	Calvert Marina	3.75	38^o 19.95'	76^o 27.53'
17	Solomon's Landing	2.95	38^o 20.34'	76^o 27.71'

* Average depth calculated using total station depth data measured in 2006.

3. Water Quality Results and Discussion

Water quality data collected during the 2006 Mill Creek System monitoring study are listed by station and date in Table I (Appendix I).

3.1 Temperature and Salinity

Surface temperatures ranged from 18.07°C (station 11, May 23) to 29.52°C (stations 8 and 15, August 10). 2005 surface temperatures ranged from 16.93°C to 31.20°C.

Average Surface Temperatures:

May 22 2004	May 26, 2005	May 23, 2006
24.44°C	18.57°C	19.07°C

The bottom temperature range of 17.9°C (station 2 , May 23) to 29.54°C (station 15, August 10) was much larger than the previous year (2004; 21.62°C – 29.21°C).

Average Bottom Temperatures:

May 22 2004	May 26, 2005	May 23, 2006
22.64°C	17.67°C	18.89°C

Warmer water temperatures encourage epiphtyic growth on SAV and increased respiration (oxygen consumption). Both surface and bottom temperatures increased from May through the beginning of August, reaching their highest values in early August. Temperatures then dropped 4 to 6 degrees through the rest of the sampling period. As in the past, neither surface nor bottom temperatures exhibited any significant spatial trends within this system (Figure 3.1).

Surface water salinity ranged from 9.8 ppt (station 7 on July 24) to 14.93 ppt (station 2 on June 22). All salinities were highest on June 22, dropping an average of 3 - 4 ppt by July 11 never to recover to June salinities. This unusual salinity decrease was due to a record high flow event occurring in late June.

Surface Salinity Ranges (ppt):

2003	2004	2005	2006
6.00-12.21	6.12-11.89	5.05 - 14.66	9.8 - 14.93

Bottom water salinity in 2006 showed slightly more saltwater present, ranging from 10.35 ppt (station 7, August 10) to 15.28 ppt (stations 3 and 4, June 22). As with surface salinities, a significant drop occurred between June 22 and July 11. During the sampling season, bottom salinities were greater than or equal to surface salinities. The average difference between the two depths, 0.6 ppt, was small and similar to most years,<0.5 ppt..

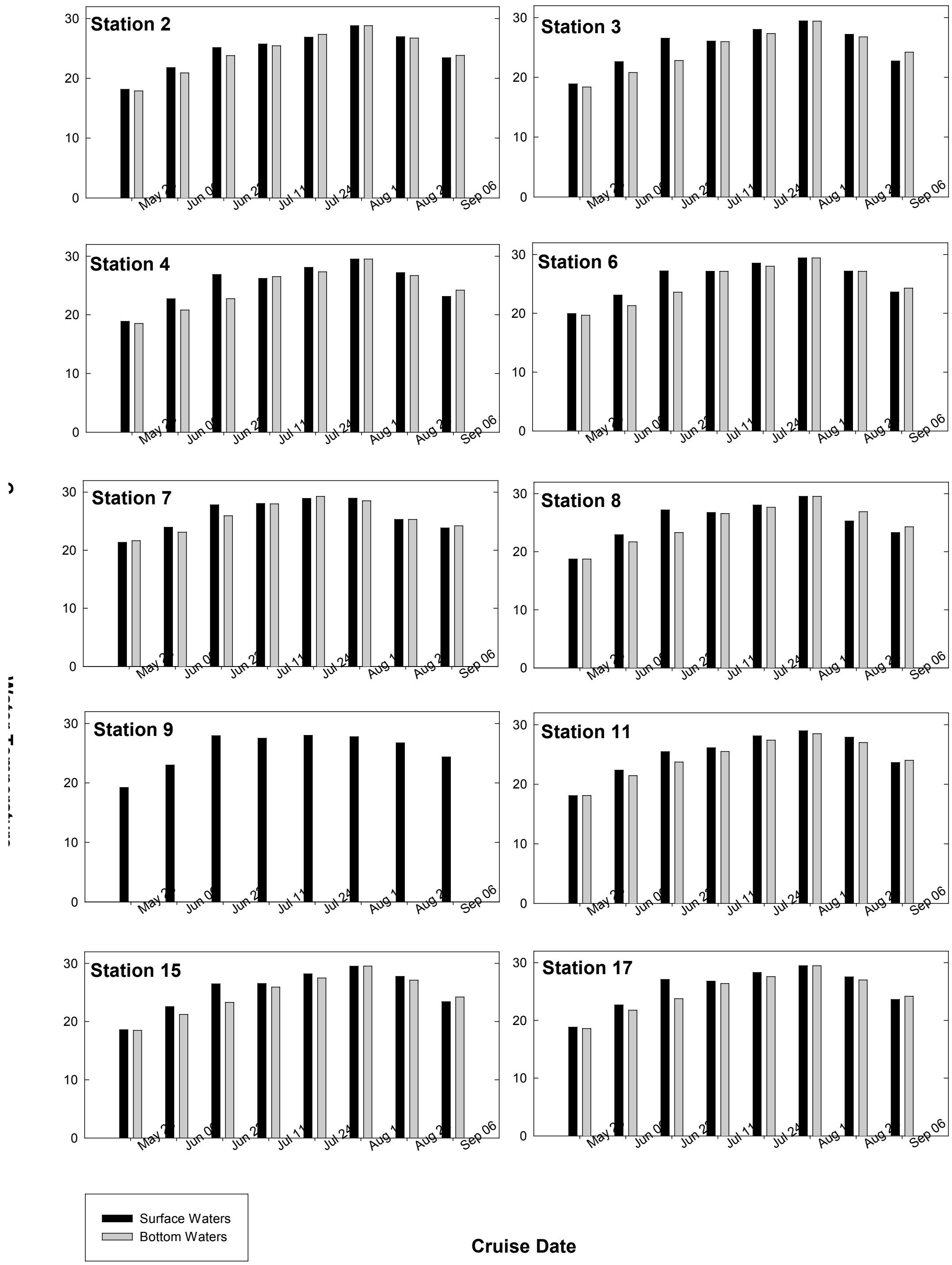

Figure 3.1. Bar graphs of surface and bottom water temperature measured at each station from May 23 through September 6, 2006.

No bottom water temperatures were measured at station 9.

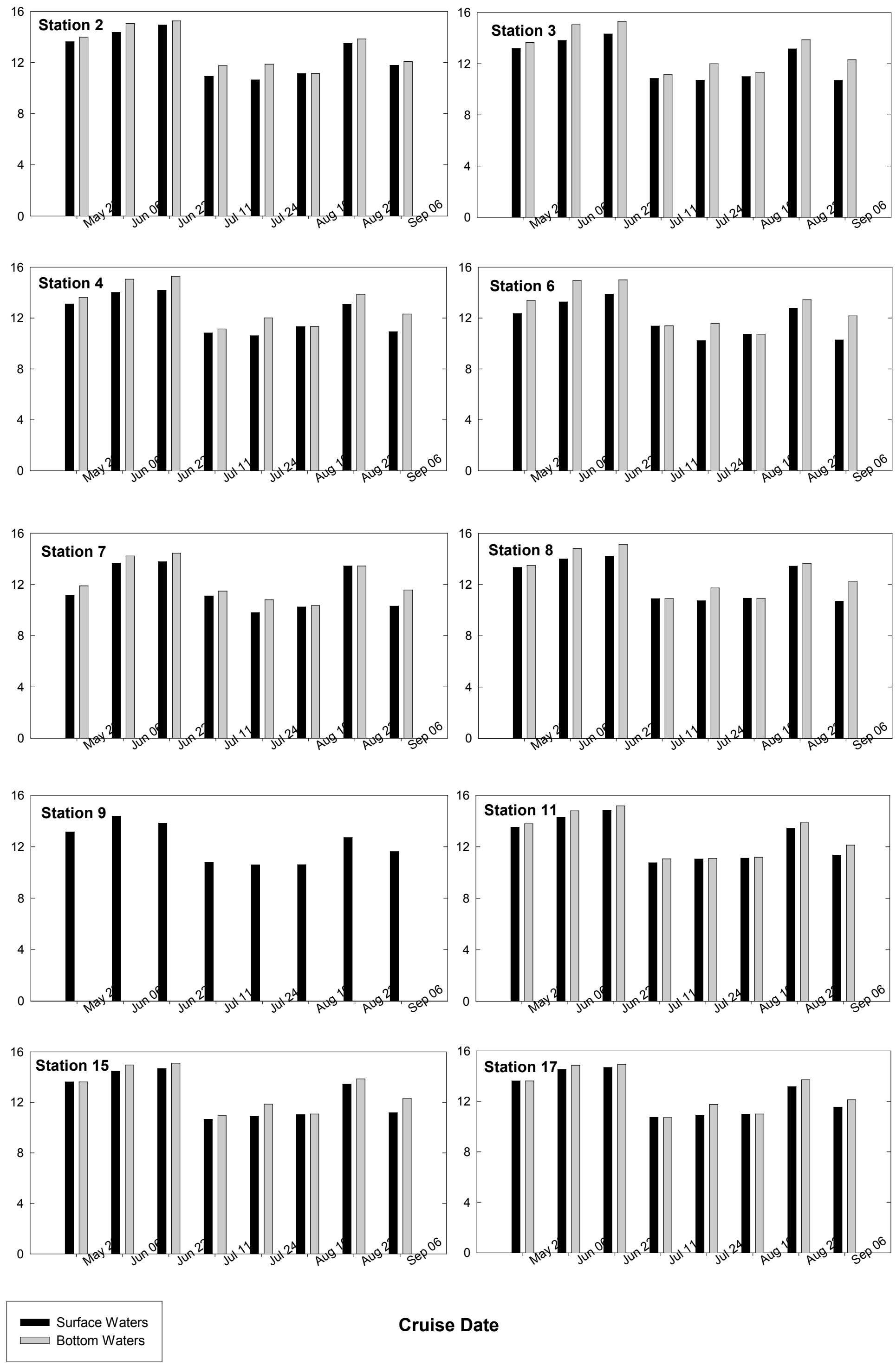

Figure 3.2. Bar graphs of surface and bottom water salinity values measured at each station from May 23 through September 6, 2006.

No bottom water salinities were measured at station 9.

Sigma-t (specific gravity of water computed using water temperature and salinity) of the surface and bottom waters was calculated for each station and sampling date. Bottom water sigma-t was higher than surface water sigma-t at all stations except on August 10 at 4 stations (sigma-t was 0.00) and on August 22 at Station 8 (sigma-t was slightly negative).. The difference between surface and bottom sigma-t values provides an indication of the stratification strength of the water column (Figure 3.3). Stratification strength was highly variable, with peaks occurring before the late June fresh water inflow and a slight recovery in late July. In general stratification is weak, driven by wind and freshwater inflow.

3.2 Dissolved Oxygen

The dissolved oxygen concentration of surface waters ranged from 2.10 milligrams per liter (mg L^{-1}) at station 9 (August 10) to 9.47 mg L^{-1} (station 15, June 22). Bottom water dissolved oxygen concentrations ranged from 1.18mg L^{-1} (station 6, June 22) to 7.91mg L^{-1} (station 8, July 11). Figure 3.4).

Surface water concentration ranges (mg/l):

2004	2005	2006
0.79 - 10.10	1.86 - 11.92	2.10 - 9.47

Bottom water concentration ranges (mg/l):

2004	2005	2006
0.18 - 7.31	0.3 - 9.56	1.18 - 7.91

Only 1 % of the bottom water dissolved oxygen levels were below 2.0 mg L^{-1} during the 2006 study as compared to (24% in 2005, 30.6% of 2003, and 8% of the 2002 readings (Figure 3.5A). Levels below 2.0 mg L^{-1} are considered hypoxic and are stressful to organisms. The percent of hypoxic readings during the 2005 season is lower than average and is equal to 2002 (1%) as opposed to wet years, such as 2004 (25%), 2003 (30.6%) and 1990 (21.3%).

True anoxic conditions (0.0 mg L^{-1} dissolved oxygen) have not been recorded on the sampling dates of any Mill Creek system cruise. It may be that only high frequency monitoring will record any short-term (less than 2 weeks in duration) anoxic events. During the 2006 sampling season, 0% of the bottom water observations under 2.0 mg L^{-1} were < 1.0 mg L^{-1} (2005 recorded 40%.)

3.2.1 Percent Saturation of Dissolved Oxygen

Oxygen from the air dissolves in the water column in proportion to water temperature and salinity. When oxygen dissolved in water is in equilibrium with that in air, the water is 100% saturated with dissolved oxygen. Oxygen is replenished in water by direct exchange with air at the surface and through the efforts of photosynthesizing phytoplankton in the water column. Respiration by organisms in the water and in the mud, as well as some chemical processes, consumes oxygen in the water, causing the oxygen content to fall below the 100% saturation level.

Bottom water dissolved oxygen saturation levels less than 50% saturation were observed 36% of the time (26 out of 72 observations) similar to 2002 (32%), Figure 3.5B. Wetter years ranged from 44% in 2001 and 2005, 50% in 2004 and 65% in 2003.

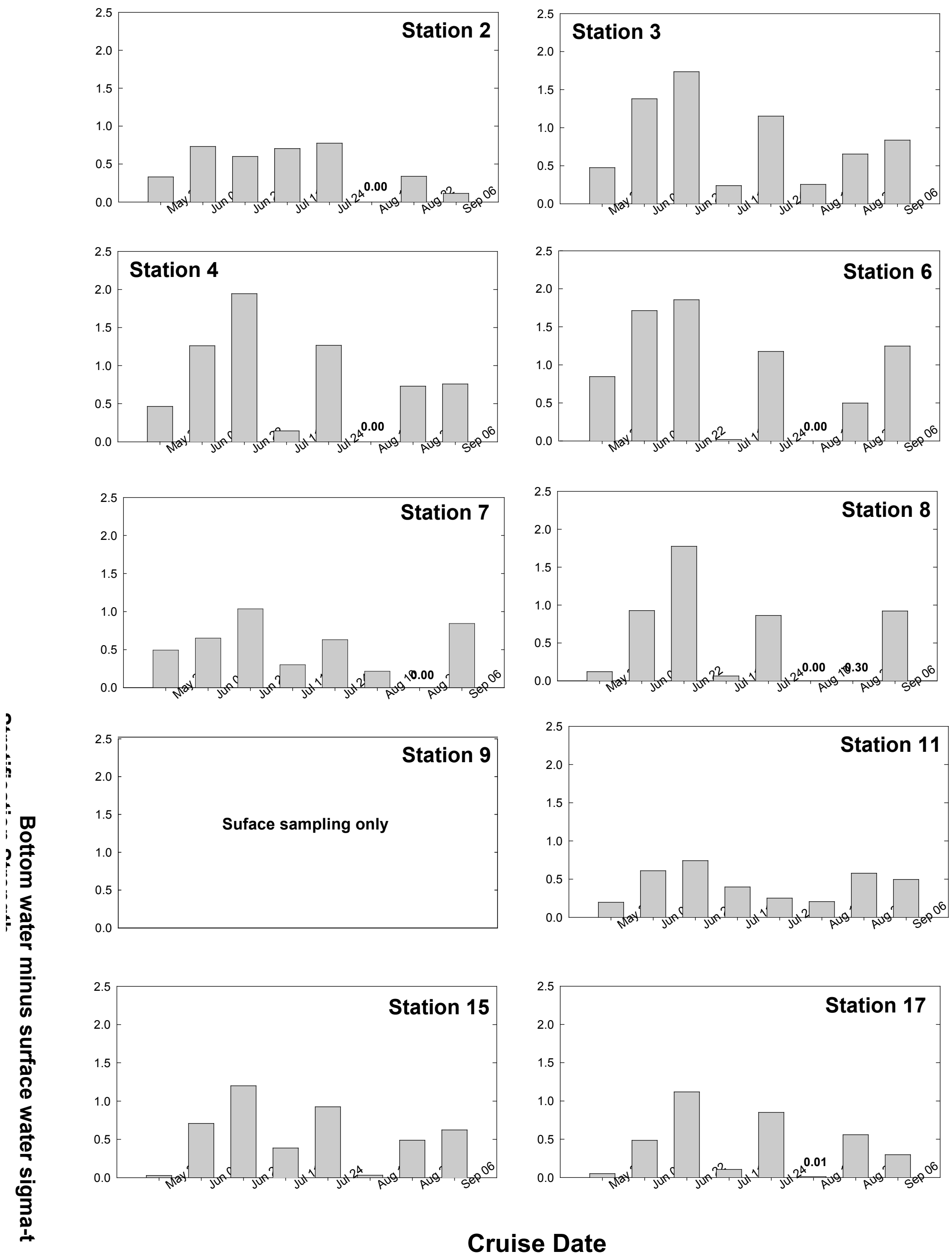

Figure 3.3. Bar graphs of water column stratification represented as the difference between surface and bottom water sigma-t values calculated for each station from May 23 through September 6, 2006.
No bottom water measurements were taken at station at station 9.

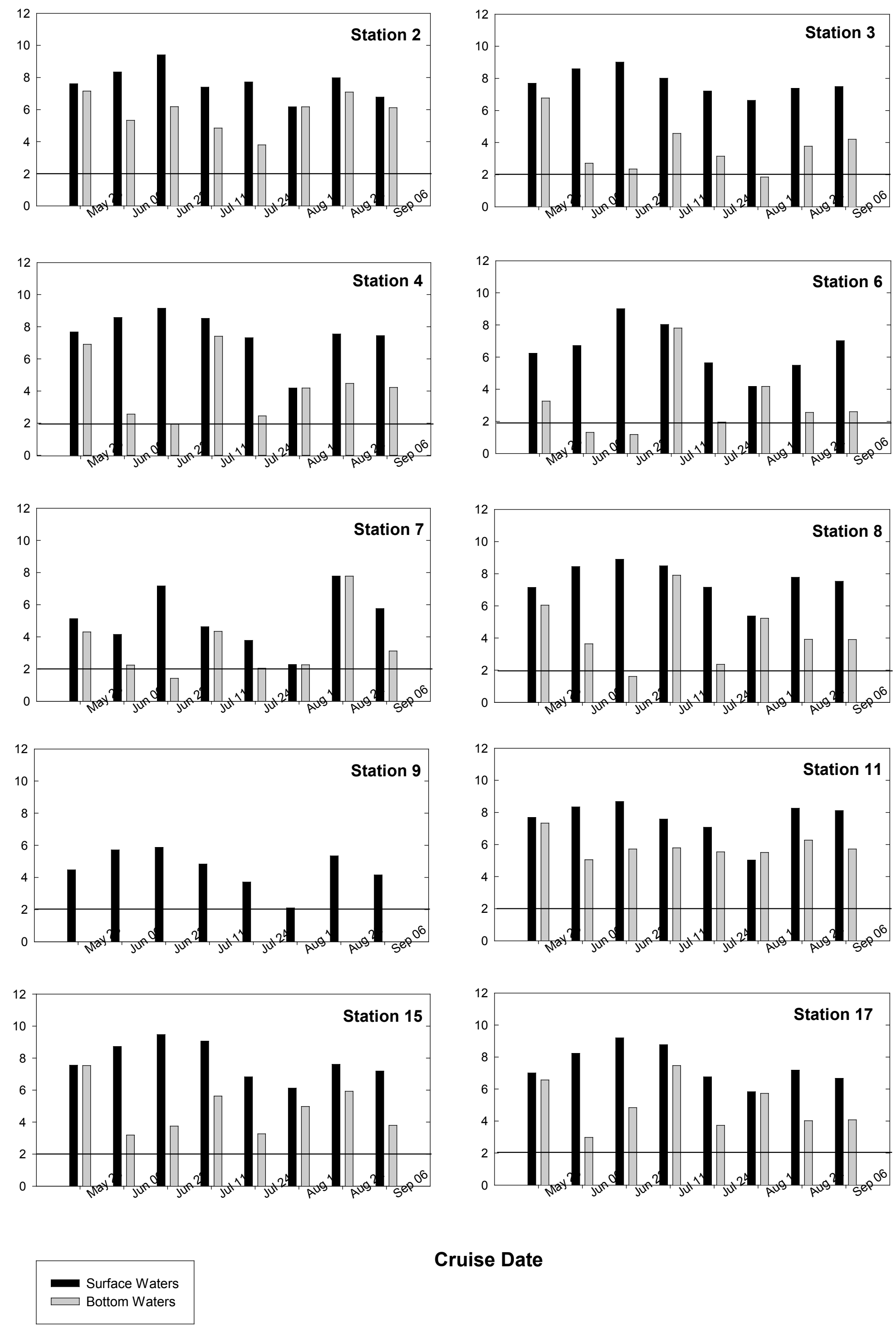

Figure 3.4. Bar graphs of surface and bottom water dissolved oxygen concentrations measured at each station from May 23 through September 6, 2006.
No bottom water measurements were taken at station at station 9.

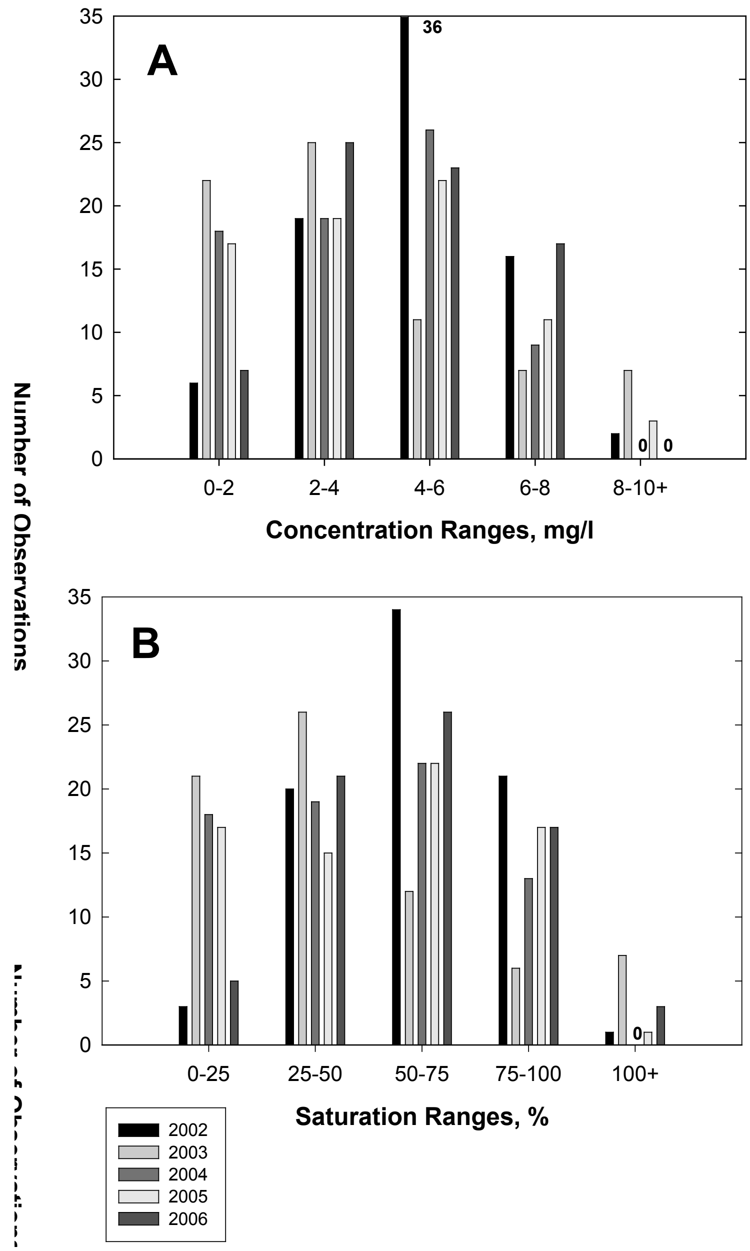

Figure 3.5.A&B. Bar graphs showing the distribution of bottom water dissolved oxygen (A) and bottom water percent oxygen saturation (B) observations comparing 2002 and 2006. Note 2002 was a dry year, while 2003 and 2004 were relatively wet years. 2005 and 2006 were near average.

3.3 Chlorophyll-*a*

Concentrations of active chlorophyll-*a* serve as a measure of the size of algal populations in the watercolumn. Active chlorophyll-*a* concentrations in surface waters ranged from 4.96 micrograms per liter ($\mu g\ L^{-1}$) (station 9, Sept. 6) to 57.10$\mu g\ L^{-1}$ (station 9, May 23). Bottom water concentrations ranged from 2.15 $\mu g\ L^{-1}$ (station 2, Sept 6) to 68.07 $\mu g\ L^{-1}$ (station 15, June 22; Figure 3.6).

Surface active chlorophyll-*a* ranges:

2004	2005	2006
5.47 - 88.39	3.54 - 224.88	4.96 - 57.10

Bottom active chlorophyll-*a* ranges:

2004	2005	2006
3.45 - 41.48	2.69 - 42.17	2.15 - 68.07

Active chlorophyll-*a* concentrations were exceptionally low, with scattered small bloom events throughout the summer; especially on June 22.

Even though Station 7 in upper Mill Creek is shallow (1.4 meters), some significant differences in surface and bottom chlorophyll-*a* readings in past years point to the importance of shallow water stratification. Thus, we will continue to monitor both surface and bottom readings at stations 7.

Concentrations of greater than 20 $\mu g\ L^{-1}$ indicate the presence of an algal bloom (severe bloom concentrations in the Patuxent River have exceeded 300 $\mu g\ L^{-1}$). During the 2006 sampling season, 10 small surface blooms were observed; about the average (9) of the 20 year dataset. The average surface active chlorophyll-*a* concentrations:

2004	2005	2006
20.46	17.64	16.69

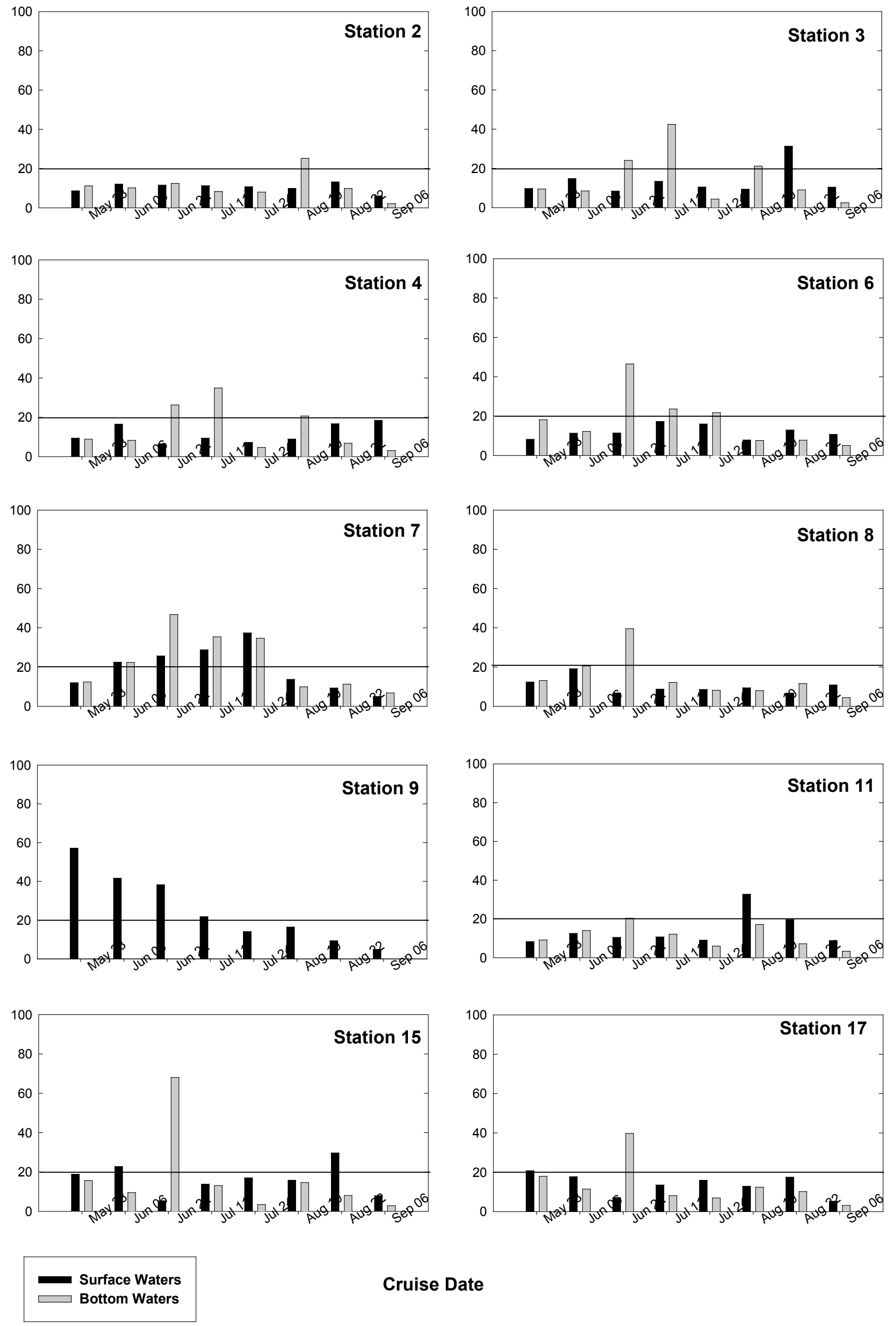

Figure 3.6. Bar graphs of surface and bottom water active chlorophyll-*a* values for each station from May 23 through September 6, 2006.

Bottom water chlorophyll-*a* was not measured at station 9.

3.4 Water Column Clarity

Water clarity, measured with a Secchi disc (Figure 3.7), appeared similar to 2005 and was higher compared to 2004 and 2003.

The highest 2006 Secchi measurement (indicating the clearest water) was 1.7 meters measured on May 26 at stations 4 and 11 (in 2005, it was 2.0 meters). The lowest 2006 recording was 0.4 meters at the station 7 on July 11 and July 24 (in 2005, it was 0.2 meters).

The extinction coefficient (kd) was calculated based on the Secchi depth using the equation kd = 1.45/ Secchi (Figure 3.8). We can use this calculation to determine the depth that sufficient light penetrates for both algal growth (1% of surface radiation) and submerged aquatic vegetation or SAV (at 30% of surface radiation).

At the lowest Secchi reading of 0.4 meters (kd = 3.62)**,** light sufficient for algal growth penetrates to 1.3 meters; for SAV sufficient light penetrates to only 0.33 meters. At the highest Secchi reading of 1.7 meters (kd = 0.85), 1% of the surface radiation penetrates to 5.4 meters and 30% surface radiation penetrates to 1.4 meters. Since the average mean depth of the system is about 2.0 meters, light sufficient for algal growth throughout most of the water column was present on most sampling dates. However, light sufficient for SAV growth throughout an average depth of 2 meters was not present on the sampling dates.

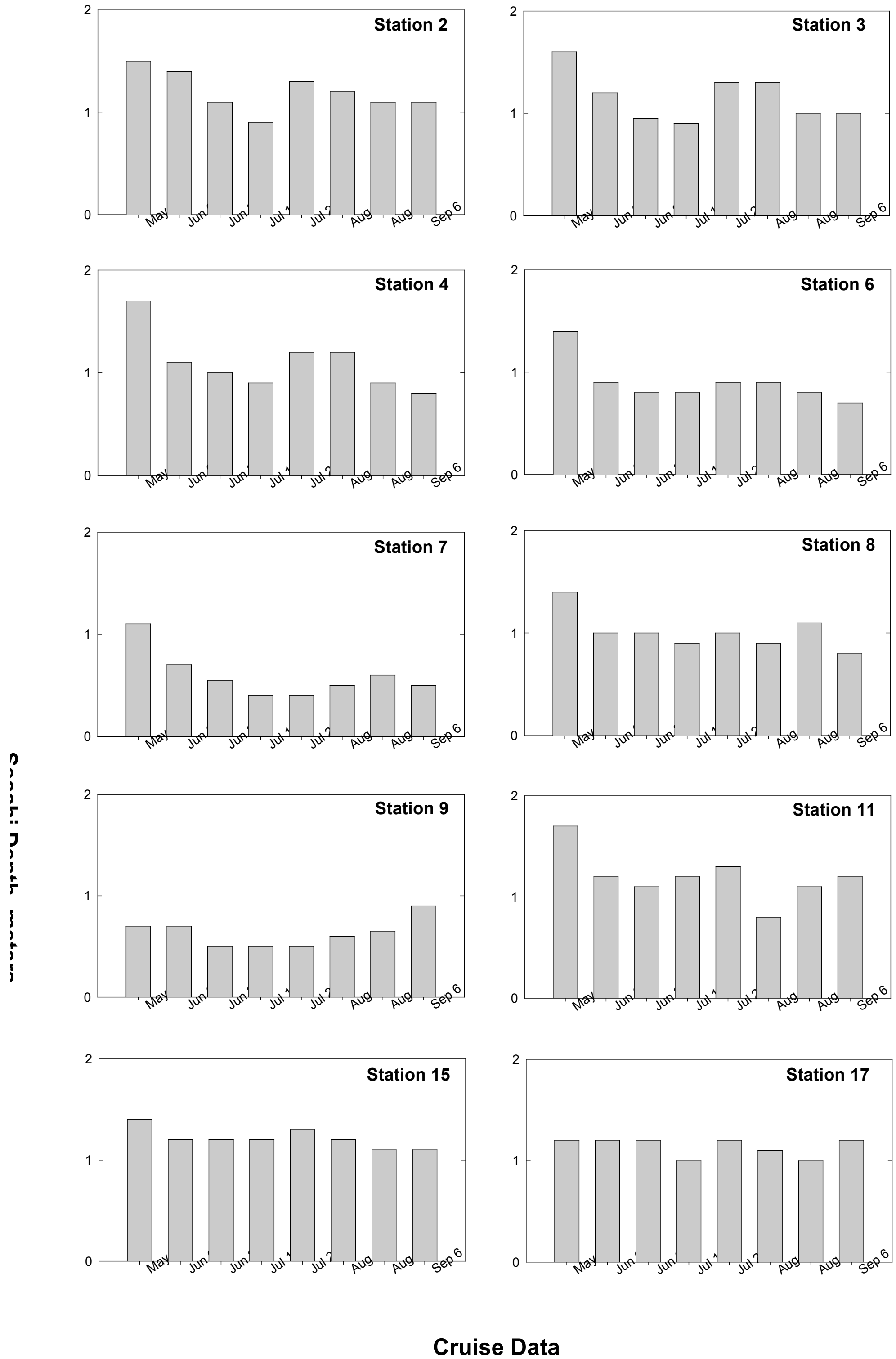

Figure 3.7. Bar graphs of water column Secchi disk measurements for each station from May 23 through September 6, 2006.

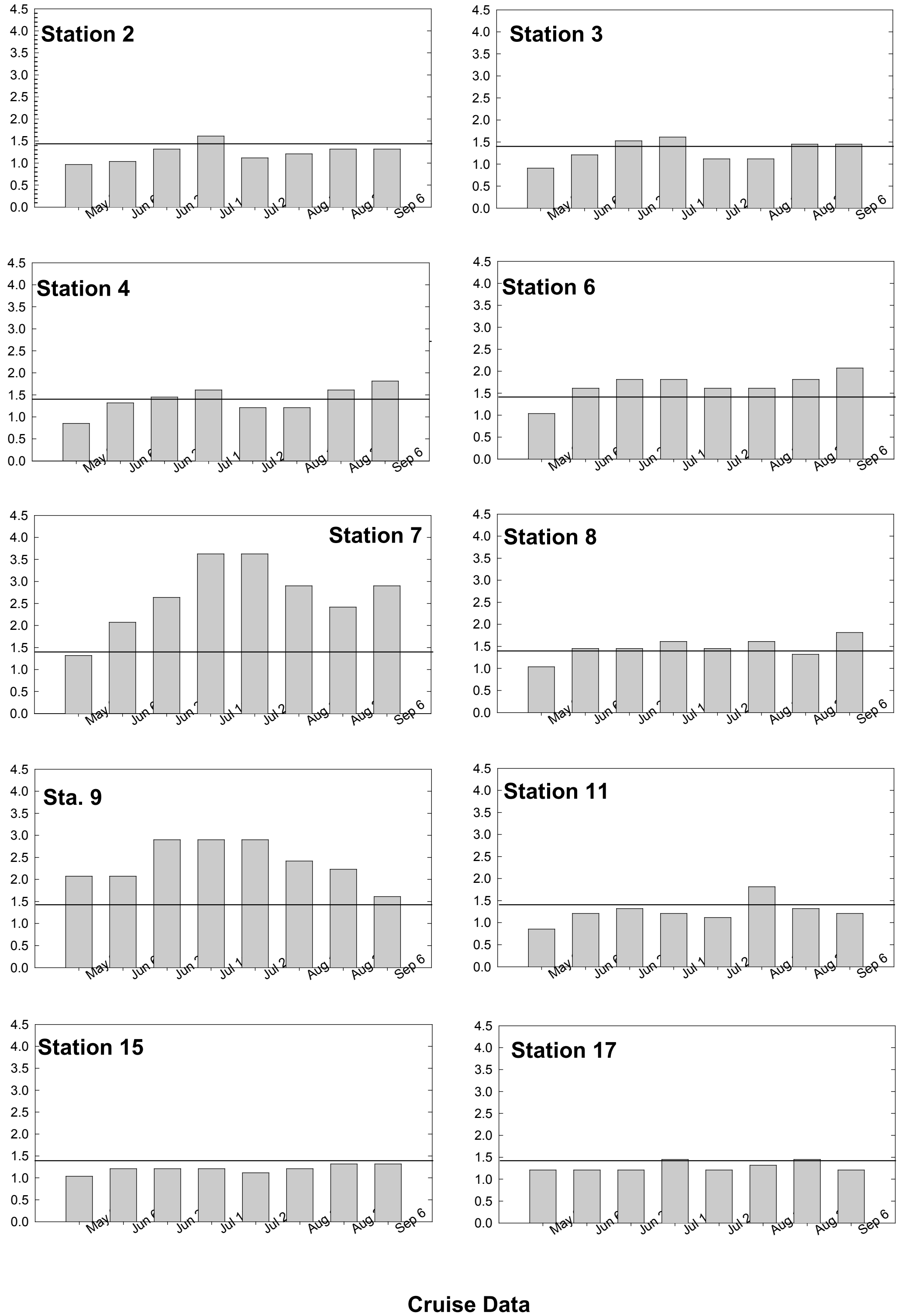

Figure 3.8. Bar graphs of light attenuation measurements (Kd) for each station from May 23 through September 6, 2006.

Line in each graph indicates Tier I SAV restoration goal of 1.5 meters.

4. Precipitation Patterns and River Flow

4.1 Precipitation

Precipitation in the spring and summer is an important factor to consider in understanding the water quality in the Mill Creek system. This section describes when and how materials enter the system from the surrounding land and from the Patuxent River.

In general, the level of precipitation provides an index of the potential amount of nitrogen and phosphorus (as well as other materials), which could enter the Mill Creek system as diffuse source run-off. While there is not a simple relationship between precipitation and diffuse source nutrient loading (Summers 1989), loading generally increases in proportion to precipitation. As a result, nutrient loads to the Mill Creek system can be expected to be larger in wet than in dry years. The magnitude of spring river flow reflects the intensity of spring rainfall. Since river water is ultimately of terrestrial origin, it is responsible for the import of a significant amount of nutrients to the estuary (Kemp and Boynton, 1992). This supply of nutrients can then generate spring algal blooms.

This relationship between river flow and algal biomass has been documented in a number of estuaries (Nichols and Cloern, 1985; Malone *et al.*, 1988; Christian *et al.*, 1991; Kemp and Boynton, 1992), and was a point of concern when a major storm event produced a large freshet this past June. Typically, with increased river input in the spring, the amount of nutrients imported to the system increases and therefore the potential for more intense algal blooms increase. Furthermore, decay of an algal bloom and its subsequent sinking to the bottom can stimulate bacteria which draw down dissolved oxygen and decrease habitat quality for fish, seagrass, and other organisms.

For the Mill Creek system, average daily precipitation for the period of March through September has been collected over the past twenty-two years (1984 – 2006) from a precipitation monitoring station located at CBL. The time interval (March - September) was chosen to correspond with sampling dates of the present and previous Mill Creek system studies (Figure 4.1A).

Average precipitation within the Mill Creek system drainage basin during the 2006 sampling season (March – September) was 0.14 inches day^{-1} (Fig 4.1B), slightly higher than in 2005 (0.12 inches d^{-1}), but much lower than in 2003 and 2004 (Figure 4.1A). The average precipitation is slightly higher than the average (0.13 in d^{-1}), most likely reflecting rainfall events in both June and September.

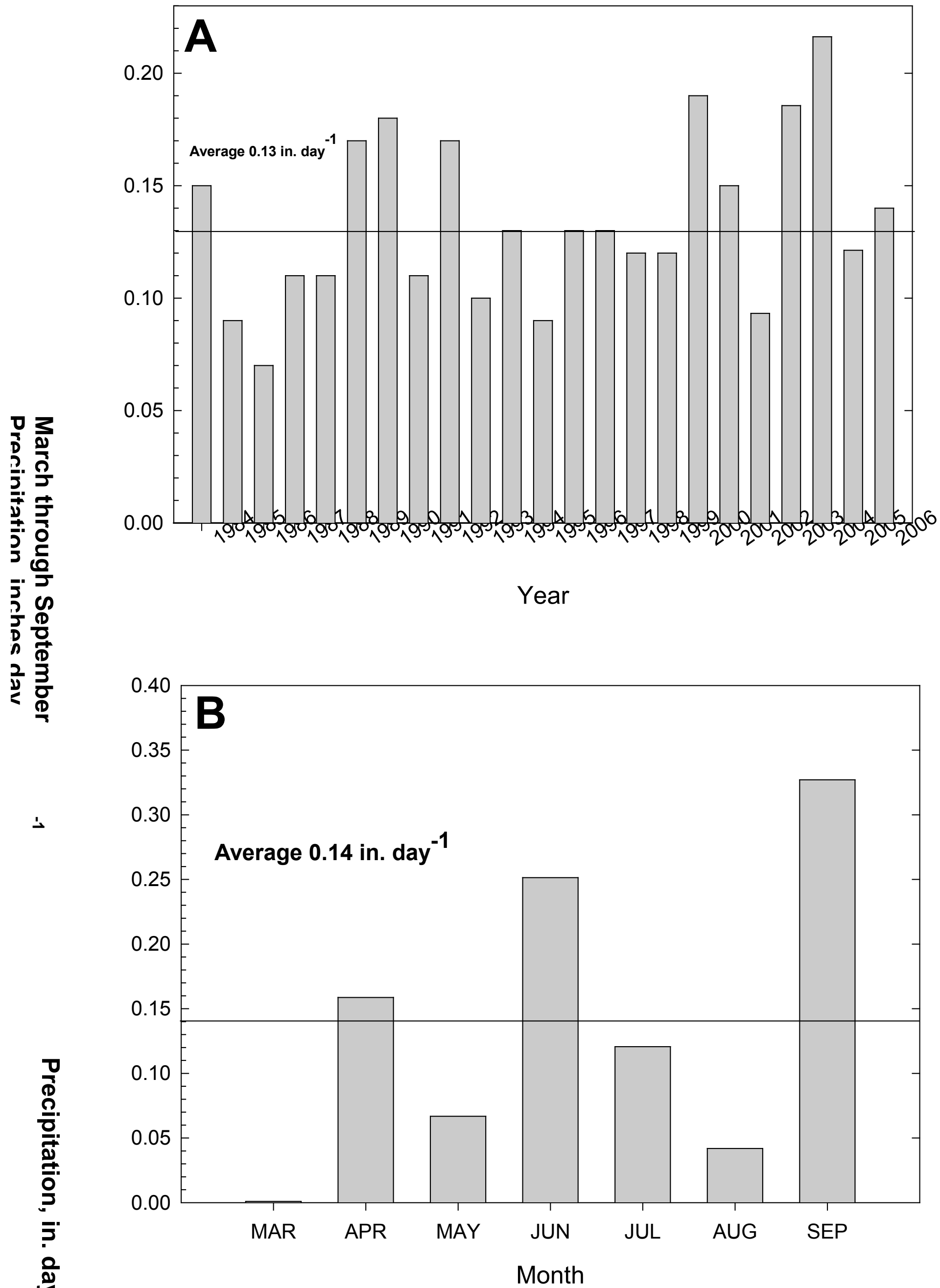

Figure 4.1.A&B. Bar graphs showing (A) the mean daily seasonal precipitation (March through September) for 1984 to 2006 and the mean daily precipitation for these same months during 2006. The solid horizontal line in both graphs indicates the average daily precipitation for these months during the period of 1984 to 2006.

4.2 River Flow

Mean Patuxent River flow for each month from January through May for 2006 was obtained from a flow gage (station 01594440 Patuxent River at Bowie, MD) maintained by the United States Geological Survey (USGS) located near Bowie, Maryland (Figure 4.2B).

The January-May 2006 mean flow for the year, 351 cfs, is well below the twenty year average of 503 cfs. Like most of the Chesapeake Bay region, the Patuxent river watershed experienced a wetter than normal winter and drier than normal spring (Figure 4.2).

As seen in Figure 4.3, the June "freshet" was large and relatively short-lived, but provided as much freshwater to the Patuxent River as the previous 80 days combined. The inset graphic shows the total year's stream flow measured at Bowie, MD, and illustrates the lack of major flow events just prior to the freshet. The arrows in the figure show the two closest sampling dates (June 22nd and July 11th).

Figure 4.4 illustrates the measured surface chlorophyll and bottom water dissolved oxygen conditions on those sampling dates (June 22nd, and July 11th). In general, chlorophyll appeared to decrease, and bottom water dissolved oxygen improved. This pattern is consistent with a turnover and mixing event that can occur after a large storm. However, it is difficult to say that changes observed were due to the storm or freshet alone and not the "usual" summer progression. Therefore, regression analyses were used to examine if the freshet caused changes above and beyond changes observed during the same period for all other monitoring years. Results were consistent with findings from state and local agencies. In other words, the changes observed were not significantly different than what is typically observed in the Mill Creek system between late June and early July in the absence of such storms.

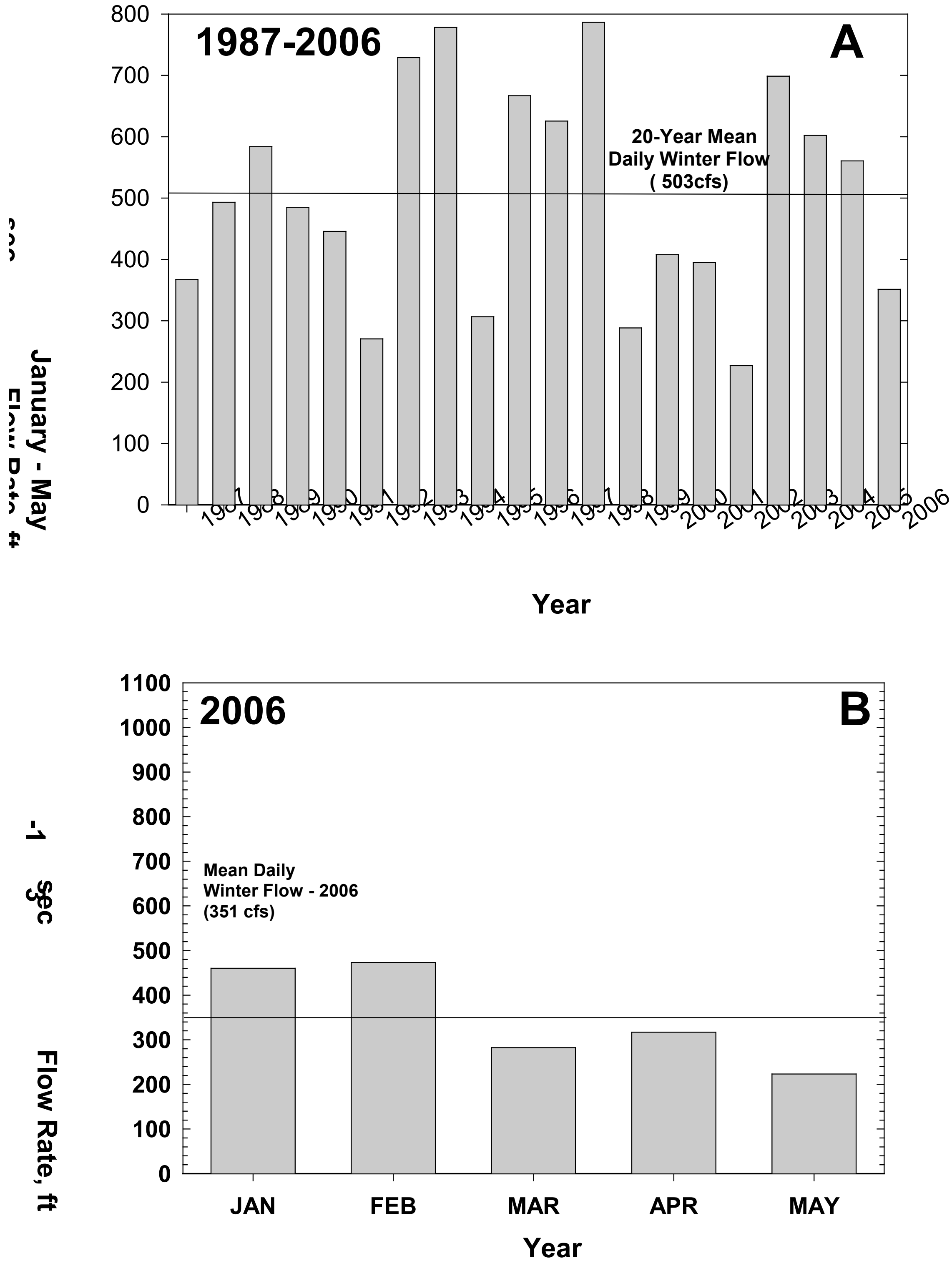

Figure 4.2.A&B. **Bar graphs showing (A) Patuxent River mean winter-spring flow (January through May) for 1987 to 2006 and the (B) mean monthly winter-spring flow for 2006. Average flows during the history of the study are indicated.**

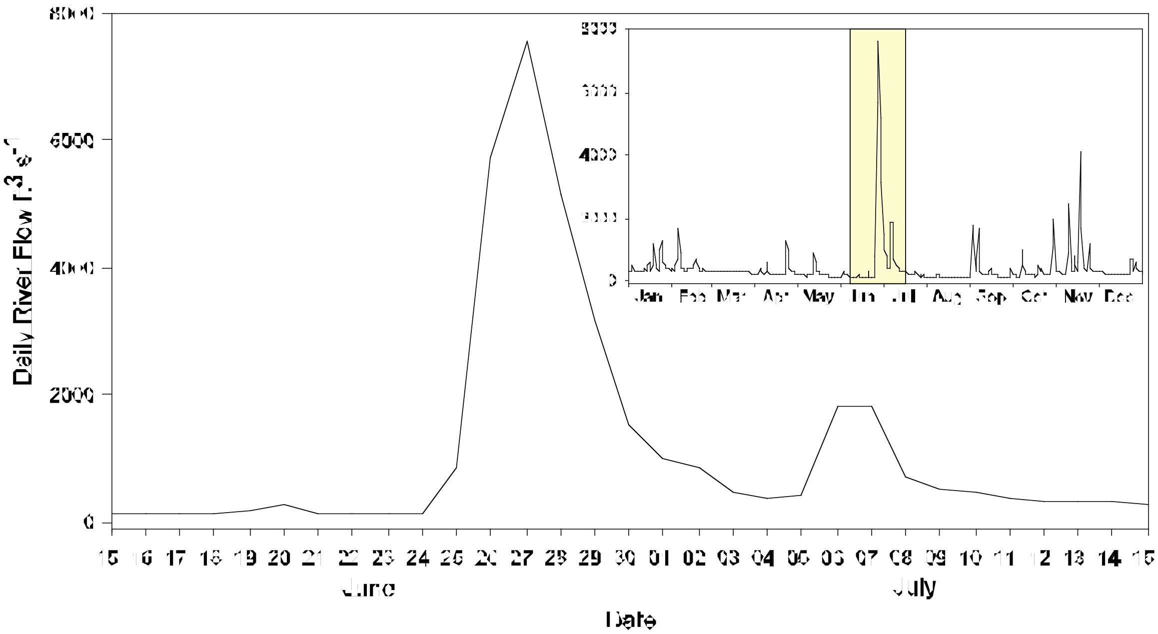

Figure 4.3. Time series of daily stream flow from USGS gauge at Bowie, MD highlighting the June 22-24th storm event and subsequent freshet. The inset graphic shows stream flow for the all of 2006. Arrows in the main figure show the two routine water quality monitoring conducted before and after the freshet.

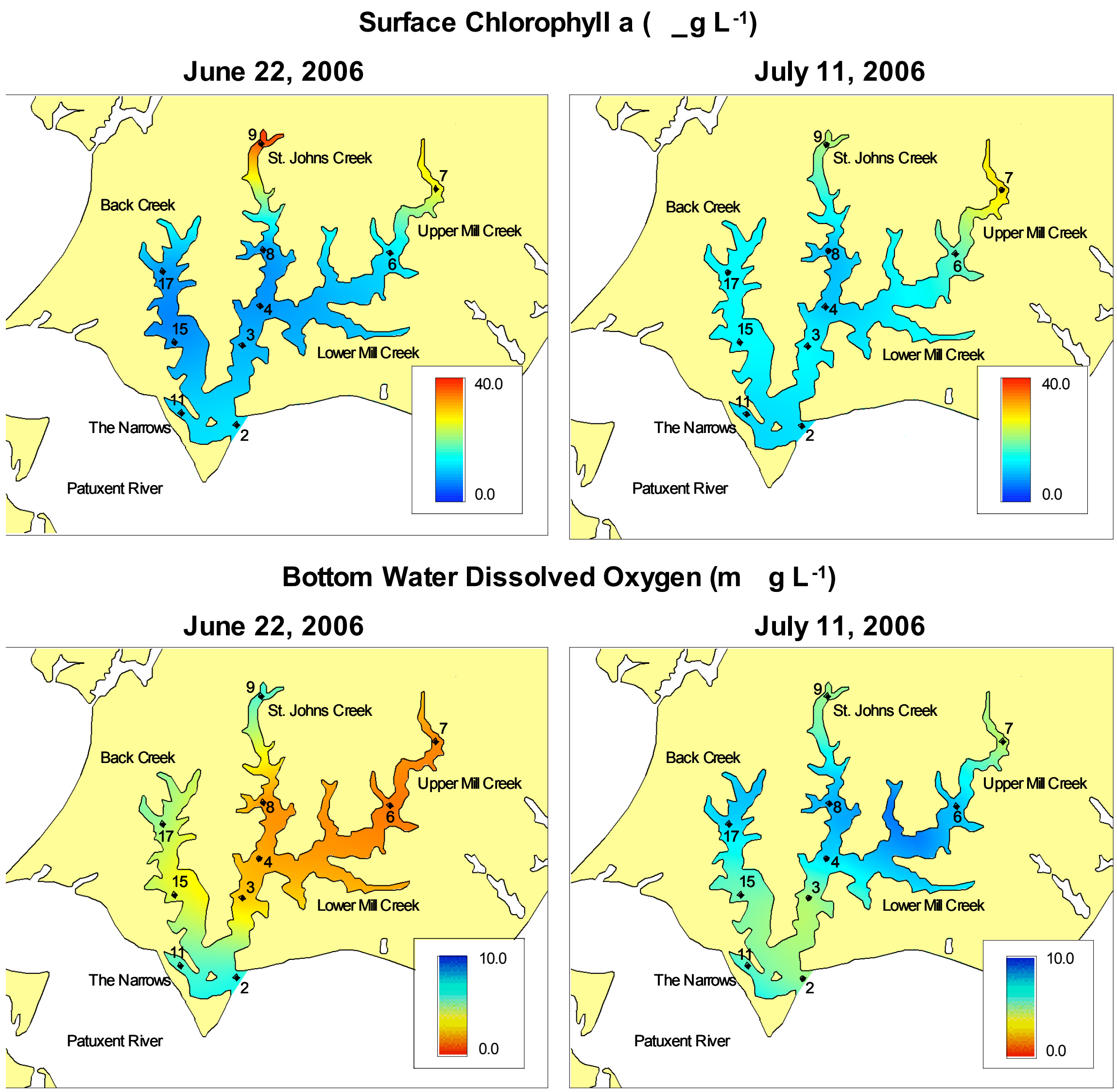

Figure 4.4. Spatial representation of surface chlorophyll concentrations and bottom water dissolved oxygen just before (June 22nd) and just after the June freshet (July 11th). Note the color bar is inverted for the dissolved oxygen figures, with reds and yellows indicating lower dissolved oxygen.

5. Long Term Water Quality Trends

Data from the following representative stations were examined to determine if trends were evident in water quality conditions: stations 2 (Mill Creek system mouth), 6 (mid Mill Creek), 7 (Ranch Club), 9 (Lore's Creek), and 15 (mid Back Creek). Two variables were examined, bottom water dissolved oxygen concentrations and surface water active chlorophyll-*a* concentrations. These variables are good indicators of the water quality status of estuarine systems.

5.1. Dissolved Oxygen Trends

The average mean bottom water dissolved oxygen concentrations for stations 2 (Mill Creek system mouth), 6 (mid Mill Creek), 7 (Ranch Club), 9 (Lore's Creek) and 15 (mid Back Creek) for the summer periods for 1987, 1990-2006 are summarized in Figure 5.1A. The average long-term bottom water dissolved oxygen concentration is 4.35 mg L^{-1}. In the context of the past four years, dissolved oxygen concentrations are increasing, indicating improving bottom water quality. However, even though anoxic conditions (dissolved oxygen concentrations of zero milligrams per liter) have never been observed, hypoxic conditions (less than 2.0 mg L^{-1}) are observed frequently enough to continue monitoring these trends.

5.2. Chlorophyll and Algal Bloom Trends

Surface active chlorophyll-*a* concentration means for stations 2, 6, 7, 9, and 15 from 1987 through 2006 are depicted in Figure 5.1B. Ranking the past 10 years according to mean surface chlorophyll-*a* concentration gives the following pattern:

1999 < 2002 < 2000 < 1997 < 2001 < **2006** < 2005 < 2004 < 1998 < 2003

Surface mean active chlorophyll-*a* concentrations are returning to average concentrations (~17 µg L^{-1}) from the highest concentrations observed in 2003 (45.21 µg L^{-1}).

Occurrences of algal blooms (concentrations of active chlorophyll-*a* greater than 20 µg L^{-1}) at the five inter-annual comparison stations were tallied using the norm of eight cruises per year (Figure 5.2). No blooms occurred during 1999, while 2003 produced the maximum of 29 blooms. This year produced 11 blooms, which was just higher than the average (9 blooms). Ranking occurrences of algal blooms gives the following pattern:

1999 < 2002 < 2005 < 1997,2000 < **2006** < 2001 < 2004 < 1998 < 2003

In general the trends of numbers of algal blooms between years follow the same trends as active chlorophyll-*a*. That is, if the mean active chlorophyll-*a* concentration rose or fell, so did the number of blooms.

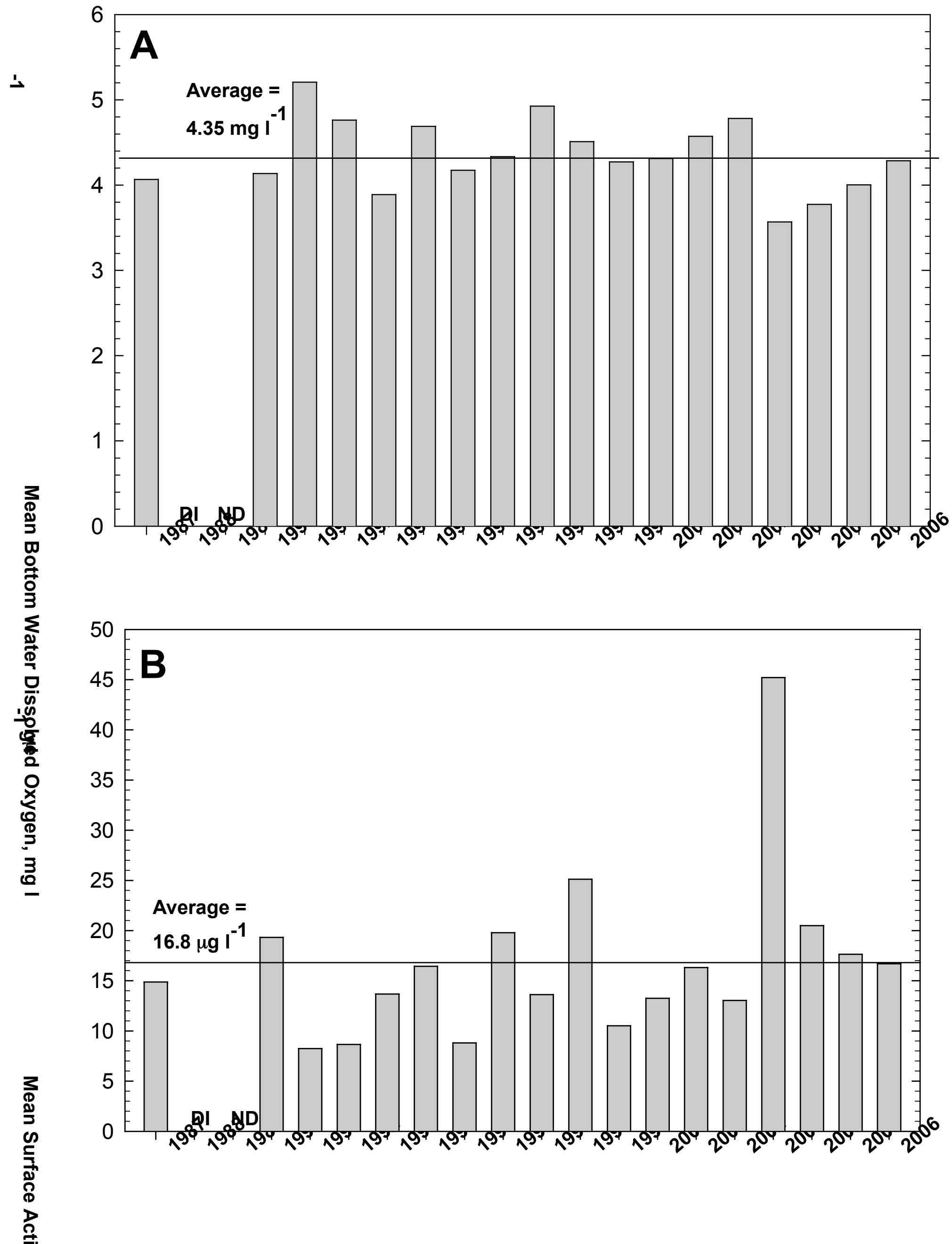

Figure 5.1.A&B. Bar graphs of (A) bottom water mean dissolved oxygen concentrations at the inter-annual comparison sites (stations 2, 6, 7, 9 and 15) from 1987 through 2006, and (B) mean surface water active chlorophyll-*a* concentrations at the inter-annual comparison sites (stations 2, 6, 7, 9 and 15) from 1987 through 2006.
DI = Data set for 1988 was incomplete.
ND = No study was funded 1989.

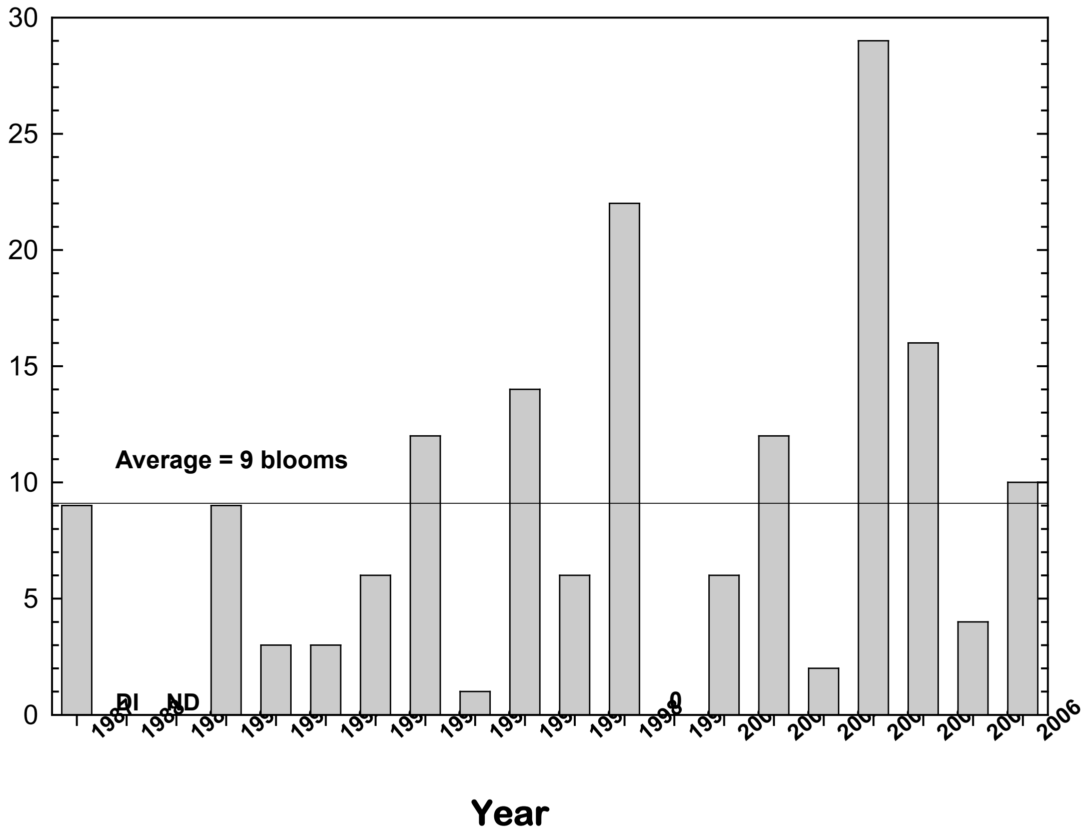

Figure 5.2. Bar graph of surface chlorophyll-*a* blooms at the inter-annual comparison stations 2, 6, 7, 9 and 15 from 1987 through 2006. Note: chlorophyll-a concentrations greater than 20 μg L^{-1} were defined as blooms.
DI = Data set for 1988 was incomplete.
ND = No study was funded in 1989.

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