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Ken Moore

Betty Neikirk
Virginia Institute of Marine Science

Britt Anderson
Virginia Institute of Marine Science

Jessie Campbell
Virginia Institute of Marine Science

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WATER QUALITY CONDITIONS AND RESTORATION OF SUBMERGED AQUATIC VEGETATION (SAV) IN THE TIDAL FRESHWATER JAMES RIVER: 2003-2004

Kenneth A. Moore, Betty Neikirk, Britt Anderson and Jessie Campbell

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The Virginia Institute of Marine Science,
College of William and Mary
Gloucester Point, Virginia 23062

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EXECUTIVE SUMMARY

In 2003-2004 wild celery (*Vallisneria americana*) whole shoots and seeds were transplanted into four sites in the Hopewell region of the tidal James River. The SAV transplants were sampled by the Virginia Institute of Marine Science (VIMS) for survivorship and growth at bi-weekly to monthly intervals throughout the growing season. Concurrently, water quality sampling was conducted at bi-weekly intervals throughout the year for water column nutrients, chlorophyll a, suspended solids, water transparency and other chemical and physical constituents important for SAV growth. Objectives of the study were to: 1) expand the SAV transplanted plots within the study sites previously transplanted; 2) conduct water quality sampling using both fixed station and continuous underway Dataflow sampling; 3) evaluate techniques for assessing visual surface water algal conditions and water color characteristics; 4) evaluate the relationships between SAV transplant performance and water quality.

SAV growth and survival were evident at all sites when the plants were protected from herbivory. Seeds obtained from wild stock and planted within the exclosures germinated and produced adult plants at each of the sites. The transplanted beds demonstrated limited impacts from hurricane Isabel with losses only evident at one transplant site.

Water quality conditions in 2003 and 2004 were characterized by relatively low chlorophyll concentrations in comparison to 2002. River flow appeared to be inversely related to chlorophyll levels with a precipitous drop in chlorophyll evident for 2003 and 2004 (higher flow years) in comparison to 2002 (low flow year). Chlorophyll concentrations in 2003 and 2004 were well below the SAV habitat criteria (15µg/l) that have been associated with SAV growth to 1m. Proposed seasonal numeric chlorophyll limits under consideration by the Va. DEQ for the tidal freshwater James River (10 to 20 µg/l) would have been met in most areas in 2003 and 2004, but not in 2002. Turbidity levels were comparable among both high flow and low flow years. Water column nutrient concentrations did not vary greatly as river flow increased in 2003 and 2004 from lower flows in 2002. High ammonium concentrations found throughout this region in 2002 have not been evident since.

Algal condition assessments conducted in 2004 showed little visual algal impairment. Several visual water color assessment techniques using the Flore-Ule color systems and Munsell color charts were also investigated. None were very suitable for quantifying algal and phytoplankton concentrations in this environment. This was partly due to the relative low phytoplankton concentrations present during most of this study period, the confounding effects of the varying ambient conditions, and partly due to the subjective nature of the assessment techniques themselves.

1.0 INTRODUCTION

1.1 Background and Objectives

This report summarizes the 2003-2004 results of a continuing shallow water quality monitoring and submerged aquatic vegetation (SAV) restoration project that began in 1999, funded by the Hopewell Regional Wastewater Treatment Facility (HRWTF) in partnership with the Chesapeake Bay Foundation (CBF.

Beginning in 1999, four test sites in shallow water areas of the tidal freshwater James River (Powell's Creek, Tar Bay, Shirley Plantation and Turkey Island) were selected for test transplanting in the Hopewell region of the estuary. The sites chosen were based upon historical photographs showing previous SAV presence and appropriate water depths (<0.5m MLW; Moore et al. 2000). A fifth shallow water site (Westover) was added in 2001 (Moore et al. 2002). Replicated SAV transplantings of a variety of native SAV species were undertaken at the various sites during the spring and early summer of each of the years (Moore et al. 2000, 2001, 2002, 2003). VIMS personnel monitored each site for growth and survival as well as shoot epiphyte abundance throughout the growing season. Results indicate that founder colonies of wild celery could be established within three years (Fig. 1.1) if the transplant plots were enclosed with a fence to reduce herbivory of the plantings. A preliminary SAV-herbivore study at the Shirley Cove site (Meier 2002) suggests that the principal herbivore on the SAV may be the Chesapeake Bay blue crab, *Callinectes sapidus*. Only wild celery (*Vallisneria americana*), among the six native species of SAV tested, appeared to be able to survive and reproduce from one year to the next. Water quality conditions at each of these shallow water (<1.0m) transplant sites were monitoried at bi-weekly intervals. Typically, water quality did not appear to be limiting SAV growth and survival. During unusually dry years, such as 2002, salinity intrusions during the growing season may have caused a dieback in growing vegetation.

The 2003-2004 SAV restoration and water quality monitoring project was a continuation of the previous SAV transplanting studies. In 2004 we also evaluated several methodologies in an effort to quantify the aesthetic impacts of algae on water surface condition and water color. The specific objectives of the 2003-2004 studies were:

1) Expand the SAV plots at the transplant sites to serve as habitat as well as a source of propagules for enhanced recovery of SAV in these areas.
2) Work with the Alliance for the Chesapeake Bay (ACB), as well as the CBF to expand other restoration activities in this region of the river.
3) Monitor the transplant sites for water quality and SAV growth and survival.
4) Relate the responses of the transplants to water quality conditions monitored at bi-weekly intervals in the shallows during the growing season.
5) Evaluate techniques for quantify surface algae conditions and water color characteristics and compare these to actual chlorophyll measurements.
6) Conduct continuous monitoring of surface water quality along the axis of the James River during three quarterly cruises to quantify the spatial distribution of water quality in the James River tidal freshwater segments.

2.0 METHODS

2.1 Study Sites

Five shallow water sites (Fig. 2-1) were used for SAV transplanting and/or water quality monitoring in the Hopewell region of the James River estuary in 2003-2004.

Turkey Island	Lat. 37.3826 N	Long. 77.2527 W
Shirley Cove	Lat. 37.3326 N	Long. 77.2631 W
Tar Bay	Lat. 37.3075 N	Long. 77.1902 W
Powell's Creek	Lat. 37.2929 N	Long. 77.1622 W
Westover Plantation	Lat. 37.3105 N	Long. 77.1558 W

Due to a dredge disposal operation at the Shirley Cove site, no transplants have been placed there since 1999. However, water quality monitoring was continued in 2003-2004 to assess any long-term water changes at that location. As a result of the success of CBF transplants at the Westover site and our review of previous water quality monitoring data at this site, SAV were transplanted by VIMS to that site in the spring of 2003 and 2004 and the transplants were monitored for survival throughout 2004. In addition, technical assistance was provided to the Alliance for the Chesapeake Bay and the U.S. Fish and Wildlife Service for the development of a SAV restoration nursery area at the Harrison Lake National Fish Hatchery.

2.2 SAV Transplanting and Monitoring

Transplanting activities at all of the James River sites were undertaken in spring and summer 2003 and 2004 using bare-rooted wild celery donor plants. Transplants were surveyed by diver at bi-weekly to monthly intervals throughout the growing season for percent survival and growth of planting units. Observations were also made on the relative condition of the transplants, including any evidence of herbivory.

Wild celery seeds were obtained from native beds in the Potomac River, Md. in October 2003 by harvesting seed pods by hand. Seed pods were kept in river water and were refrigerated in the dark at 4 °C until planting in April 2004. Just prior to planting the seeds pods were gently broken apart by hand and 10-15 pods, with accompanying seeds were lightly patted into the sediments within 1 m^2 areas in the exclosures at each of the transplant sites. Germinated seedlings were checked by diver for relative abundance at monthly intervals.

Technical assistance was also provided to other restoration efforts in the region. Herbivory exclosures had been constructed in June 2002 by VIMS, CBF and ACB at the Harrison Lake National Fish Hatchery in Charles City, Virginia, in collaboration with the U.S. Fish and Wildlife Service. Wild celery shoots were then transplanted into these by ACB, CBF, VIMS and citizen volunteers. These ponds were checked for growth and survivorship in 2003 and again in 2004. Hatchery grown plants will be used for transplanting into the tidal James River in 2005.

2.3 Water Quality Monitoring

2.3.1 Fixed Station Monitoring

VIMS personnel conducted water quality sampling at bi-weekly intervals at each of the five James River restoration sites from June 2003 to December 2004. This resulted in a continuous record of water quality conditions from previous monitoring starting in 1999. Water quality measurements included: air and water temperatures, secchi depth, light attenuation profiles (K_d), pH, conductivity, organic and inorganic nitrogen and phosphorus, chlorophyll, suspended solids, dissolved oxygen, total organic carbon and nitrogen. Samples were obtained at the shallow water transplant sites at water depths of approximate one meter. Water samples were obtained a depth of one-half meter below the surface.

2.3.2 Algal Condition and Water Color Assessments

In conjunction with water quality monitoring conducted by VIMS and HRWTF for nutrients, chlorophyll a, suspended solids, water transparency and other chemical and physical constituents, several procedures suggested by HRWTF and Malcom Pirnie and Associates for visual assessment of algal condition were investigated at each of the James River SAV transplant sites.

Algal Condition: Field personnel recorded the presences/absence of:

- Surface films/scums
- Partially dispersed clouds
- Flecks
- Balls
- Filaments
- Mats

In some cases, these effects above may have been of non-algal origin. Field personnel took additional descriptive notes about form and color to help determine if such effects are of algal origin. Field personnel rated the overall *algal condition index* on an ordinal scale as follows:

Algal Index Value	**Category**	**Description**
0	Clear	Conditions vary from no algae to small populations visible to the naked eye.
1	Present	Some algae visible to the naked eye but present at low to medium levels.
2	Visible	Algae sufficiently concentrated that filaments and/or balls of algae are visible to the naked eye. May be scattered streaks of algae on water surface.
3	Scattered Surface Blooms	Surface mats of algae scattered. May be more abundant in localized areas if winds are calm. Some odor problems.
4	Extensive Surface Blooms	Large portions of the water surface covered by mats of algae. Windy conditions may temporarily eliminate mats, but they will quickly redevelop as winds become calm. Odor problems in localized areas.

Source: Coastnet, 1996, *Sampling Procedures: A Manual for Estuary Monitoring*, prepared for the Coastnet Water Quality Monitoring Project administered by the Oregon State University Extension Sea Grant Program, http://secchi.hmsc.orst.edu/coastnet/manual/index.html

Color: Water color was assessed using two separate standards.

- Forel-Ule Color System
- Munsell Soil Color Charts

The Forel-Ule color was determined by using a Lamotte Forel-Ule comparator. On the shady side of the vessel, field personnel lowered the Secchi disk to a depth of one-half meter and then compared the Forel-Ule color scale to the color of water as seen against the white portion of the Secchi disk. The Forel-Ule color number that was the closest match was then recorded.

The Munsell color number was determined by comparison of the surface water color on the shady side of the vessel to the Munsell Soil color chart. A second assessment was made by filling a clean test tube with sample water. Under natural light, in the shade, and against a white background, the sample test tube was held next to the appropriate Munsell color chart and assigned the appropriate Munsell number. The Munsell color chart was also used to assess the color of algal blooms (filaments, films, flecks) that might be different than the color of the surrounding water.

Photography: Photographs were taken at every sampling station during every sampling event, regardless of whether algal effects were visible. Photographs were taken with an Olympus Stylus 400 digital camera with 4.0 effective megapixels. High-angle photographs of the water surface were taken both on the shady and non-shady sides of the vessel; these photographs included a floatable color wheel for scale. Near shore and far shore photographs were taken at each site as well as other photographs if necessary to document visible algal effects or the lack thereof. Upon return from the field, pictures were downloaded onto the computer and labeled with appropriate date and site identification.

2.3.3 Continuous Monitoring Using DATAFLOW Technology

DATAFLOW is a compact, self-contained surface water quality mapping system, suitable for use in a small boat operating at speeds of about 25 KT. The system collects water through a pipe ("ram") deployed on the transom of the vessel, pumps it through an array of water quality sensors, then discharges the water overboard. The entire system, from intake ram tube to the return hose, is shielded from light to negate any effect high intensity surface light might have on phytoplankton in the flow-through water that is being sampled. A blackened sample chamber is also used to minimize any effect of light on measurements by the fluorescence probe. The system records measurements once every 2-4 seconds. The resulting distance between samples is therefore a function of vessel speed. An average speed of 25 knots results in one observation collected every 40-60 m. Verification samples for DO and chlorophyll are sampled at regular intervals along the cruise track to insure accuracy of the sensor readings.

The DATAFLOW system has a YSI 6600 sonde equipped with a flow-through chamber. The sensors include a Clark-type 6562 DO probe, a 6561 pH probe, a 6560 conductivity/temperature probe, a 6026 turbidity probe, and a 6025 chlorophyll probe. The sonde transmits data collected from the sensors directly to a laptop computer using a data acquisition system created with LabView software (National Instruments, Inc.). Custom software written in the Labview environment provides for data acquisition, display, control, and storage. Real-time graphs and indicators provide feedback to the operator in the field, ensuring quality data is being collected. All calibrations and maintenance on the YSI 6600 sondes are completed in accordance with the YSI, Inc. operating manual methods (YSI 6-series Environmental Monitoring Systems Manual; YSI, Inc. Yellow Springs, OH).

The system is also equipped with a Garmin GPSMAP 168 Sounder. This unit serves several functions including chart plotting, position information, and depth. The unit is WAAS (Wide Area Augmentation System) enabled providing a position accuracy of better than three meters 95 percent of the time.

Three continuous DATAFLOW sampling cruises were conducted in May, September and November 2004. The cruise tracks were run along the center axis of the James River estuary from the mouth of the Chickahominy River to the upper limit of tidal water in Richmond. Cruises occurred from approximately 10:00 am to 3:00 pm. During each cruise five calibration stations were sampled for chlorophyll, dissolved oxygen, suspended solids and light attenuation.

3.0 RESULTS

3.1 Water Quality Monitoring

3.1.1 Fixed Station Monitoring

Results of water quality measurements are presented for all years of shallow water SAV habitat monitoring. Sampling was initiated at Westover Plantation on April 10, 2001. Water temperatures (Fig. 3-1) demonstrated similar annual patterns over the 1999-2004 sampling period at all the stations with daytime minimums ranging from approximately 5 °C to maximums of 30-32 °C. During the winter of 2002-2003 however, water temperatures were near zero on one occasion. Conductivity (Fig. 3-2) demonstrated marked differences among the years reflecting variations in river discharge rates and low freshwater inputs in 1999, 2001 and 2002. In this region of the James conductivities were generally in the range of 100-300 µmhos (0 psu salinity). During low flow years shallow water salinities began to increase in July to nearly 1000 µmhos (0.5 psu salinity) in the fall of 1999, 2000 µmhos (1.0 psu salinity) in the fall of 2001 and 3500 µmhos during the late summer and fall of 2002 (>6.0 psu salinity), and did not return to freshwater conditions until the late fall. When salinity levels increased in the fall of 1999, 2001 and 2002, highest levels were reached at the most downstream stations of Westover Plantation, Powell's and Tar Bay. At other times there were no differences among the stations. Generally, the very high salinity levels did not reach the upriver Turkey Island site where transplant survival was highest. Conductivities have remained low throughout 2003 and 2004.

Daytime dissolved oxygen (DO) concentrations (Fig. 3-3) at the transplant sites are typically above 6 mg/l even during the summer with no differences among the stations. Seasonal maximums exceeding 13 mg/l are regularly measured during the winter. Water column pH levels (Fig. 3-4) paralleled changing DO levels. However pH is affected by many factors including the buffering capacity of the water, which is related to salinity. The highest salinities observed here typically buffer pH between 7.5 and 8.0. pH dropped markedly in the fall of 2002 as river flow increased and levels were unusually low at Westover during the winter of 2002. This was not repeated during the winters of 2002 and 2003

Suspended particle loads (TSS) have been remarkably consistent among years regardless of river flow and salinity. Concentrations were consistently lowest at the Shirley Cove station (Fig. 3-5) where the protected conditions allow for particle settlement. The Westover and Tar Bay sites had the greatest proportion of short-term increases in TSS likely reflecting wind or wave re-suspensions of bottom sediments. Table 1 presents median annual TSS concentrations throughout the SAV growing season (April 1- October 31) for each of the transplant sites. Levels were consistently lower by 5-10 mg/l in 2003, a high flow year, compared to 2002 a low flow year. Much of the summertime suspended material may therefore be composed of material already within the system that is being reworked and resuspended.

A pattern of generally increasing chlorophyll levels from initiation of the monitoring in 1999 through mid 2002 is followed by a decrease through 2004 (Fig. 3-6). SAV growing season median chlorophyll concentrations are presented in Table 1. Flow appears inversely related to chlorophyll with a precipitous drop in chlorophyll evident from 2002 (low flow year) to 2003 (high flow year). These lower levels continued in 2004. Concentrations in 2003 and 2004 were well below the diagnostic habitat criteria (15 µg/l) that have been associated with SAV growth to 1m (EPA 2002).

Table 2 presents the mean chlorophyll concentrations for the March-May (spring) and July-September (summer) periods for the SAV transplant stations within each of the two James River Tidal Freshwater segments (JMSTF1 and JMSTF2). In 2002 the mean concentrations exceeded the proposed numeric chlorophyll limits in 2002 but were near or met the limits in 2003 and 2004 at most of the sites. Again, during the low flow summer of 2002 chlorophyll concentrations were considerably higher than 2003 and 2004. Proposed numeric chlorophyll limits would have been met at most stations during most seasons in 2003 and 2004 but not in 2002. The Turkey Island and Shirley Cove transplant sites are located near the downstream end of JMSTF2 where conditions are typically very similar to JMSTF1. Upstream areas in JMSTF2 closer to Richmond will typically be lower. This spatial variability is reflected in the continuous DATAFLOW monitoring presented later in this report.

Water transparencies measured as secchi depth (Fig. 3-7) demonstrated little year-to-year variability over the past several years, regardless of river flow. Generally, secchi depths were always greatest (i.e. clearer water) at the Shirley Cove site. This site is located off the main section of the river. It is more sheltered from wave and current action than the other sites and TSS levels were usually lowest.

Total organic carbon (TOC) concentrations demonstrated some seasonality with higher levels during the summer (Fig 3-8). Concentrations were also highest in 2002 followed by decreases in 2003 and 2004. Total kjeldahl nitrogen (TKN) and total phosphorus (TP) levels (Figs. 3-9, 3-10) were relatively consistent among the years. Elevated late summer TKN concentrations in 2002 paralleled increased salinity suggesting a source unrelated to watershed inputs. Concentrations were usually, but not always, highest during the summers. Generally TP followed TSS patterns as much of the total phosphorus load is bound to suspended sediments although levels were quite variable. Concentrations appeared to be below detection (0.05 mg/l) on many occasions after the fall of 2002 compared to before suggesting a possible long-term decrease.

Throughout the study period nitrate + nitrite levels (Fig. 3-11) have been quite variable, both over time and among stations. Nitrate and nitrite generally represent “new” nitrogen entering the system. Concentrations were generally highest in the late fall and winter. Winter concentrations have been similar among the years. Nitrate + nitrite levels were very low in the summer of 2002 and higher in the summers of 2003 and 2004 and this likely reflected higher watershed inputs due to higher river flow. High levels of ammonium (Fig. 3-12) that were observed for all stations during the fall of 2001 have not re-occurred. Concentrations during the high flow summer of 2003 were below detection. These increased to 0.2 mg/l in 2004.

Dissolved inorganic phosphorus (DIP) concentrations (Fig. 3-13) met the SAV growing season habitat criteria threshold of 0.02 mg/l for 1999 through 2002, and exceeded it slightly in 2003 and 2004 (Table 1). The long-term trend is one of increasing growing season median concentrations from 1999 to 2003-2004. These increases may be related to the relatively higher river flows in 2003 and 2004.

3.1.2 Algal Condition and Water Color Assessments

Algal Condition: The evaluation of this parameter was straightforward but not very informative for this region of the James. Most often Algal Index Values were given the value of "0" (clear) but on occasion received a value of "1" (data not presented in this report). Values of "1" were generally indicative of surface films/scums and occasionally small flecks of material. Partially dispersed clouds, balls, filaments, and mats have not been observed as of yet. These observations suggest that in 2004 this region of the river was largely free of negative aesthetic impacts of phytoplankton including nuisance conditions such as floating algal mats and films. This lack of surface visual impairment is consistent with the relatively low water column chlorophyll concentrations in 2004 (Fig. 3-6; Tables 1and 2).

Forel-Ule Color System: A Lamotte Forel-Ule Color Scale kit was used to access water color. The Forel-Ule color scale, a system originally developed by European lake scientists, classifies water color into 22 categories ranging from blue, green, yellow to brown. This method was found to be unsuitable for the Hopewell sampling sites. The James River water color was never able to be matched to any of the given choices of colors provided by the Forel-Ule Color Scale. The closest possible match was “XV” and was the most often recorded regardless of chlorophyll level.

Munsell Soil Color Charts: While this measurement was somewhat subjective depending on the user, it proved to be more suitable at the Hopewell transplant sites than the Forel-Ule system. The Munsell color system has three components: hue (a specific color), value (lightness and darkness), and chroma (color intensity). The mean chlorophyll concentrations for combined 2004 data for all sites corresponding to each of the observed Munsell color categories are presented in Fig. 3-14. Highest chlorophyll concentrations were associated with 5y 4/3 and 5y 5/4 designations and lowest with 2.5y 5/6 and 2.5y 6/6. All water samples in this region had a yellow hue that may have largely reflected the mineral as well as the organic matter composition of the suspended sediments in the water. Water with higher chlorophyll concentrations (>20 ug/l) nevertheless had a distinctly different hue (5y) than waters with less than 10ug/l (2.5y). However, no algae blooms were observed at any of the stations in 2004, therefore the range of chlorophyll values observed was not large enough to adequately asses this method. Given a broader range of chlorophyll and less suspended sediments such a scale may have some utility for qualitatively assessing bloom events. A second assessment of this color monitoring approach was attempted by first filling a clean test tube with sample water, holding the filled test tube against a white background in the shade, and then comparing it to the color chips provided in the Munsell charts. This assessment proved to be unsuitable, as colors were too faint to be successfully compared to the colors offered by the Munsell charts. Perhaps an optical device with a longer path length for viewing might provide a more detectable color, however visible differences in water color were difficult to quantify by eye.

Photography: Photography of the surface water of the sampling sites using a Olympus Stylus 400 digital camera with 4.0 effective megapixels have been archived, however no algal effects were observed throughout 2004. Close-up, high angle photographs of the water surface including a floatable color wheel at each of the Hopewell sampling sites were also inconclusive. Representative pictures taken on both the shady side and the sunny side of the boat on each sampling cruise are presented here (Figs. 3-15 to 3-18). The assessment of algal condition and water color using a comparison to the color wheel was inconsistent as the water color appeared related to sun angle, time of day, viewer angle and atmospheric conditions. On clear sunny days during the spring and summer (higher sun angle), pictures of the water surface on the sunny side of the boat gave the appearance of being very dark and color determination was impossible (Figs. 3-15 and 3-16). In the winter (low sun angle) more color could be seen (Fig. 3-17). Pictures taken of the water surface in the shade under sunny conditions demonstrated the opposite effect: greater color in the summer and less in the winter (Figs. 3-15, 3-16, 3-17). On days with heavily overcast skies, color was indistinguishable on either the sunny and shady sides of the boat. The water generally appeared to be black or dark gray. The most accurate means of measuring water color using comparison to the wheel appeared to be direct visual in-situ observation. However, temporal or spatial variation in water color among the Hopewell sites was not apparent using even this technique. Visual estimation of water color by observer always appeared to be the darkest of the yellow band on the color wheel.

3.1.3 Continuous Monitoring Using DATAFLOW Technology

Continuous Dataflow mapping cruises of the tidal freshwater James River from the mouth of the Chickahominy River to the fall line at Richmond were conducted on May 19, September 23 and November 11, 2004. Levels of turbidity, chlorophyll and dissolved oxygen along with the May 2004 cruise track are presented in Fig. 3-19. Dissolved oxygen (Fig. 3-20) generally exceeded 6 mg/l throughout the James River Tidal Freshwater (JMSTF) segments with several areas of high D.O. observed. These generally corresponded with areas of high chlorophyll especially in the middle reaches of the sampling area (Fig. 3-21). Spatially averaged chlorophyll and turbidity concentrations for each of the JMSTF segments are presented in Table 3. During the May cruise integrated mean chlorophyll measured by fluorescence was 10.2 and 7.6 µg/l for segments JMSTF1 and JMSTF2, respectively. This compares to proposed numeric chlorophyll limits of 15 and 10 µg/l for these two segments of the James River. These results suggest that when integrated over the entire reach of the segments, proposed numeric limits would be met. Highest chlorophyll levels were observed in the SAV transplant region (Westover to Turkey Island) with several peaks or blooms of phytoplankton extending for distances of two miles or more. Lower concentrations of chlorophyll were observed in the Shirley plantation cove and highest levels in the bend of the James River where the Turkey Island transplant site is located. The distribution of turbidity demonstrated a similar pattern with highest turbidities in the upper JMSTF1 and lower JMSFT2 regions (Fig. 3-22). Several of the highest regions of turbidity were also associated with the highest regions of chlorophyll suggesting some contribution of phytoplankton to overall turbidity in these areas. Integrated turbidities measured in NTUs were 22.1 and 15 NTU for JMSTF1 and JMSTF2 segments respectively. Conversion of NTU to water clarity goal for SAV growth to 0.5 m was made using the following approach. First, growth of SAV to 0.5 m was assumed to require a water clarity secchi depth of 0.4 m or light attenuation coefficient (K_d) of approximately 3.6 (EPA 2003). DATAFLOW NTU corresponding to this water clarity was estimated using the following relationship that was developed from in vivo DATAFLOW calibrations of NTU to K_d (Moore unpublished):

$$\text{Dataflow NTU} = (K_d - 1) / 0.072$$

This conversion suggests that for tidal freshwater SAV growth to 0.5 m (0.4 m secchi), a turbidity of 36 NTU or less should be the goal. Overall, both segments would meet this goal with some regions, especially near the I-295 bridge and above, where the water was much clearer.

The September 23, 2004 cruise track along with turbidity, chlorophyll and D.O. levels are presented in Fig. 3-23. Surface D.O. concentrations during this cruise exceeded 6 mg/l throughout and were above 8 mg/l for most of the JMSTF2 segment (Fig. 3-24). Chlorophyll concentrations were quite low throughout, never exceeding 10 µg/l (Fig. 3-25). Proposed seasonal chlorophyll limits of 20 and 15 µg/l for the JMSTF1 and JMSTF2 segments would have been met. Integrated chlorophyll concentrations were also quite low at 5.3 and 3.4 µg/l for these same two segments (Table 3). Turbidity levels were also lower than the May cruise and typically never exceeded 25 NTU (Fig 3-26; Table 3).

The November 9, 2004 cruise track along with turbidity, chlorophyll and D.O. levels are presented in Fig. 3-27. Declining water temperatures resulted in D.O. concentrations exceeding 8 mg/l for most of the JMSTF segments (Fig. 3-28). Chlorophyll concentrations were consistently low throughout, generally staying below 5 µg/l (Fig. 3-29). Intergrated mean concentrations were 4.2 and 3.3 µg/l for the JMSTF1 and JMSTF2 segments, respectively. These low September and November chlorophyll levels observed using the Dataflow system reflected the low seasonal chlorophyll but expand these site specific measurements to highlight the wide spatial distribution of the low phytoplankton abundance in the late summer and fall. Turbidity distribution (Fig. 3-30) demonstrated decreasing turbidity with distance upriver in November. Levels were generally below the approximate 36 NTU threshold for SAV growth to 0.5 m.

3.2 Transplant Survival

Transplant survival and growth in 2003 and 2004 was high (Fig. 3-31) in spite of the relatively high flow conditions of these years and the occurrence of hurricane Isabel in September 2003. Additional exclosures of wild celery transplants were added to the Turkey Island site and exclosures were rebuilt and expanded at the Westover, Powell's Creek and Tar Bay sites. Wild celery seeds obtained from natural beds in the Potomac River in the fall of 2003 were planted into exclosures at each of the sites in April 2004. Their germination, growth, and survival paralleled that of the transplanted whole shoots. Future work in 2005 will focus on the expanded use of seeds for SAV restoration. Thousands of wild celery seeds were collect in October 2004 from existing beds in the Potomac River and will be used for transplanting in 2005. Seedpods containing seeds have been kept refrigerated at 4 °C in the dark since collection for planting in April-May 2005.

As in previous years SAV transplanted to the Turkey Island site continued to have the greatest survival and growth of all the restoration areas. A fifth exclosure was added to this site and survival of transplants by the end of 2004 was approximately 80%. Typically three years with no herbivory is required for growth to 100% coverage. The Westover site had the poorest transplant survival but losses here appeared not to be related to water quality in 2003 and 2004. Shoot herbivory has been the greatest problem at this site. Perhaps this is due to the relatively exposed location causing gaps in the exclosures. A preliminary study by Meier (2002) implicates the blue crab as a significant herbivore. It may be that this downriver site has greater blue crab abundance due to its somewhat higher salinity or proximity to the river channel. The effects of hurricane Isabel on the transplants were relatively minor compared to the adjacent shoreline damage. There were some loss of plants and damage to the exclosures, however most of the sites recovered in the spring of 2004. Only the Westover site demonstrated significant losses in the spring of 2004 with loss of all plants by mid summer. This area was again replanted in late summer of 2004. The Tar Bay site also experienced herbivory and was replanted. Both the expanded Powell's Creek and Turkey Island sites demonstrated no significant losses post hurricane and expanded through 2004.

Although epiphytes were not quantitatively measured in 2004, expanded growth of an unidentified, encrusting, invasive colonial tunicate was observed throughout 2004 on both the exclosure mesh and the leaves of wild celery shoots at all sites. This tunicate has been observed in the past, but qualitatively it was more abundance in 2004. It did not appear to be causing an extensive died back of the vegetation but its presence will be followed in 2005.

Wild celery transplants at the Harrison Lake National Fish Hatchery in Charles City, Virginia, which were initially planted in 2003 by VIMS, ACB and CBF personnel, were continued in 2004. One of the shallow water ponds used for grow out of transplants was subject to an extensive algal bloom in the summer of 2003. This continued for at least several weeks until the water in the pond could be exchanged. All of the growing transplants died as a result of the very high turbidity. SAV in the second pond planted by ACB was not so affected and growth and expansion of the SAV continued throughout 2004. ACB will provide some of these plants for transplantation into the James in 2005.

4.0 DISCUSSION AND CONCLUSIONS

Algal condition and water color assessments of the Hopewell region of the JMSTF segments in 2004 revealed little visual impairment. Surface algal conditions were generally categorized with no or low algae evident. Attempts to adapt established color systems including the Forel-Ule and Munsell color charts to the surface waters of the James were generally not successful. Few color differences were observed among the stations or throughout the year. Water with higher chlorophyll concentrations (>20 ug/l) during the summer could be differentiated with a distinctly different hue than waters with less than 10ug/l found earlier or later during the year on the Munsell color scale but, overall, the value of this approach in 2004 was limited. This was due in part to the relatively low chlorophyll observed in this region through most of the year. Photographs taken of the water surface both on the shady and sunny sides of the vessel in order to document water condition were not quantifiable due to the effects of atmospheric variability and sun angle. Perhaps all these data will provide a useful background if water quality conditions were to deteriorate in the James but continued monitoring using these approaches is probably not warranted at this time.

Water quality conditions and SAV survival in 2003 and 2004 demonstrated that during these relatively high runoff years both were better in this region that during the low flow year of 2002. Chlorophyll concentrations measured using both fixed station sampling and continuous underway sampling with Dataflow were quite low for most of the growing season. Although mid-summer concentrations reached 30-40 µg/l, seasonal levels were only 5-15 µg/l. Comparisons to SAV habitat requirements or proposed chlorophyll numeric limits suggest most areas in the JMSTF segments would meet these goals in 2003-2004. In contrast, chlorophyll levels in the low flow year of 2002 were much higher. This highlights the probable importance of water residence time in the development of phytoplankton blooms in this region of the James. Turbidity levels during the SAV growing season, in contrast, were not affected greatly by river flow and consequently SAV survival was not related to the slight differences in light availability apparent among the years.

Exceptional storm events, such as hurricane Isabel, which stuck this region in September 2003, appeared to have little effect on water quality conditions or SAV survival. Acute effects, such a erosion, scouring or uprooting of the existing vegetation were generally not evident. In addition, turbidity increases or other water quality effects were only short-lived and did not appear to be related to SAV persistence.

5.0 LITERATURE CITED

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APPENDIX A

TABLES

Table 1. SAV Growing Season (April – October) median water quality. Shaded indicates SAV criteria met for SAV growth to 1 m.

Water Quality Parameter	SAV Habitat Criteria	Turkey Island					
		1999	2000	2001	2002	2003	2004
Light Attenuation (Kd; m^{-1})	< 3.6	-	-	-	3.28	3.28	3.9
Secchi Depth (m)	> 0.40	0.30	0.45	0.38	0.40	0.40	0.35
TSS (mg/l)	<15	33.5	26.0	32.0	30.0	26.0	35.0
Chl a (ug/l)	<15	11.1	30.8	30.8	44.8	6.6	9.2
DIP (mg/l)	<0.02	0.01	0.02	0.02	0.02	0.03	0.03

Water Quality Parameter	SAV Habitat Criteria	Shirley Cove					
		1999	2000	2001	2002	2003	2004
Light Attenuation (K_d; m^{-1})	< 3.6	-	-	-	3.40	2.38	2.83
Secchi Depth (m)	> 0.40	0.40	0.55	0.40	0.40	0.50	0.45
TSS (mg/l)	<15	21.00	19.00	22.00	24.00	16.00	21.00
Chl a (ug/l)	<15	13.70	27.55	37.90	56.00	8.80	5.65
DIP (mg/l)	<0.02	0.01	0.01	0.01	0.02	0.03	0.03

Water Quality Parameter	SAV Habitat Criteria	Tar Bay					
		1999	2000	2001	2002	2003	2004
Light Attenuation (K_d; m^{-1})	< 3.6	-	-	-	4.20	4.03	3.66
Secchi Depth (m)	> 0.40	0.35	0.40	0.35	0.40	0.40	0.35
TSS (mg/l)	<15	31.00	28.00	30.00	34.50	24.00	32.00
Chl a (ug/l)	<15	12.00	26.75	39.35	41.90	4.90	5.30
DIP (mg/l)	<0.02	0.02	0.02	0.02	0.02	0.03	0.03

Water Quality Parameter	SAV Habitat Criteria	Powell’s Creek					
		1999	2000	2001	2002	2003	2004
Light Attenuation (K_d; m^{-1})	< 3.6	-	-	-	4.07	3.41	4.42
Secchi Depth (m)	> 0.40	0.30	0.50	0.30	0.40	0.40	0.30
TSS (mg/l)	<15	37.50	29.00	32.00	35.50	31.00	38.00
Chl a (ug/l)	<15	12.60	43.25	35.80	42.55	6.40	5.90
DIP (mg/l)	<0.02	0.01	0.02	0.02	0.02	0.03	0.03

Water Quality Parameter	SAV Habitat Criteria	Westover					
		1999	2000	2001	2002	2003	2004
Light Attenuation (K_d; m^{-1})	< 3.6	-	-	-	4.03	3.07	4.26
Secchi Depth (m)	> 0.40	-	-	0.40	0.40	0.40	0.30
TSS (mg/l)	<15	-	-	30.00	30.00	26.00	32.00
Chl a (ug/l)	<15	-	-	32.40	40.85	5.60	7.20
DIP (mg/l)	<0.02	-	-	0.02	0.02	0.03	0.03

Table 2. Mean (March-May and July-September) chlorophyll concentrations at SAV transplant sites for 2002, 2003 and 2004. Shaded indicates proposed limits met.

Season by Year	JMSTF2[1]		JMSTF1[1]		
	Turkey Island (µg/l)	Shirley Cove (µg/l)	Tar Bay (µg/l)	Powell's Creek (µg/l)	Westover (µg/l)
Mar-May 2002	23.5	24.0	18.8	20.5	27.0
Mar-May 2003	8.0	12.8	5.6	6.0	5.5
Mar-May 2004	6.0	6.7	5.4	6.7	6.4
Jul-Sep 2002	50.5	62.9	49.9	48.4	45.0
Jul-Sep 2003	16.0	10.3	15.4	17.1	14.1
Jul-Sep 2004	15.6	14.2	15.3	16.4	14.4

[1] JMSTF 1 - Proposed Chlorophyll Limits: March 1-May 31 (15 µg/l); July 1-Sept 30 (20 µg/l)
JMSTF 2 - Proposed Chlorophyll Limits: March 1-May 31 (10 µg/l); July 1-Sept 30 (15 µg/l)

Table 3. 2004 Dataflow Spatially Averaged Turbidity and Chlorophyll for James River Tidal Freshwater Segments

	May 19, 2004				September 23, 2004				November 9, 2004			
	Chlorophyll[1]		Turbidity[2]		Chlorophyll[1]		Turbidity[2]		Chlorophyll[1]		Turbidity	
Segment	Mean (µg/l)	S.E	Mean (NTU)	S.E.	Mean (µg/l)	S.E.	Mean (NTU	S.E.	Mean (µg/l)	S.E.	Mean NTU)	S.E.
JMSTF 1	10.2	0.1	22.1	0.1	5.3	0.0	21.6	0.1	4.2	0.0	26.5	0.1
JMSTF 2	7.6	0.1	15.0	0.2	3.4	0.0	16.6	0.1	3.3	0.0	11.7	0.1

[1] Measured directly through DATAFLOW in vivo fluorescence

[2] Secchi goal of 0.4 m for SAV growth to 0.5 m estimated as <36 NTU. See conversion in text.

APPENDIX B

FIGURES

Figure 1-1. Turkey Island *Vallisneria* Transplant Survivorship
Showing 3-year Grow Out

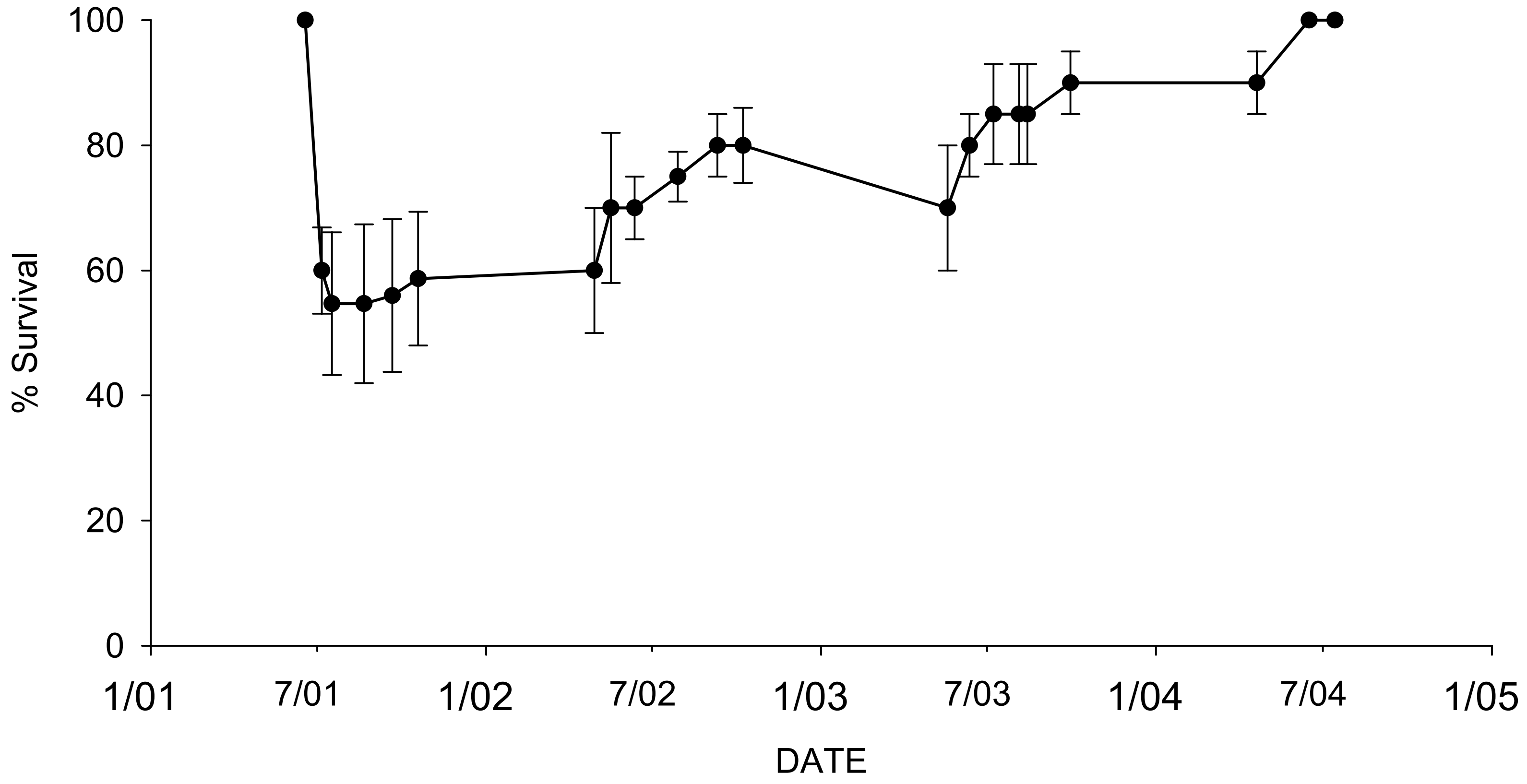


Figure 2-1. Location of SAV Transplant and Water Quality Monitoring Sites

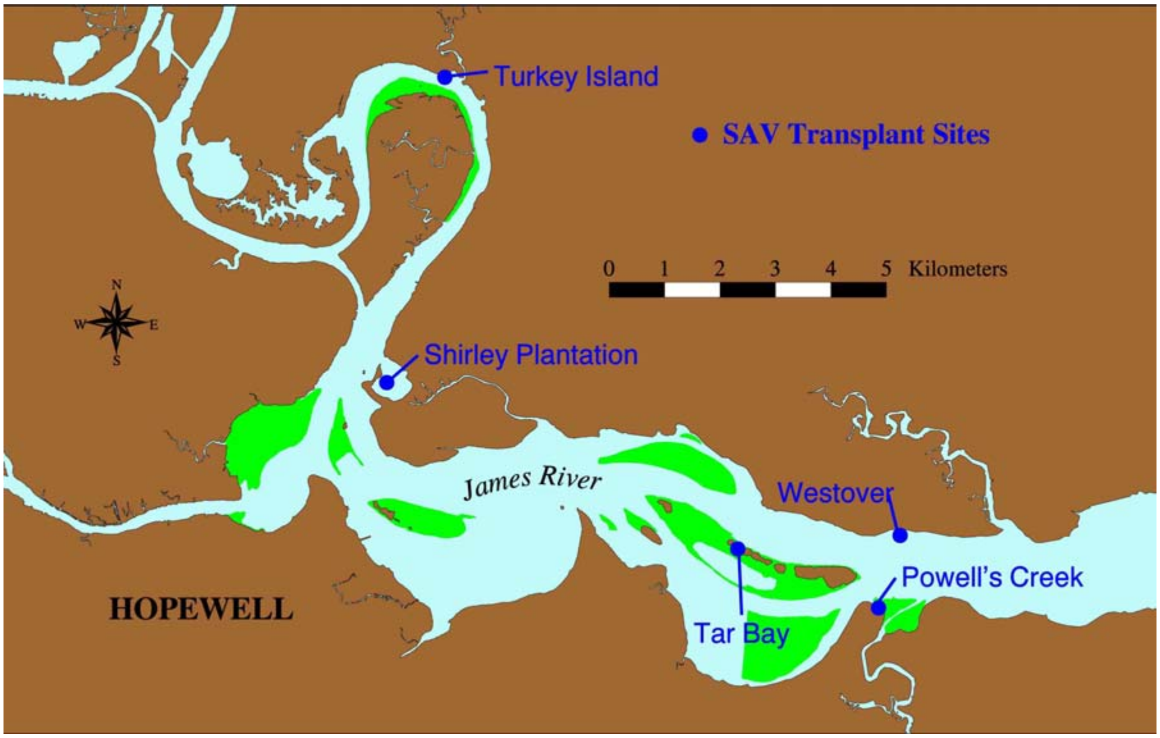


Figure 3-1. Water Temperature

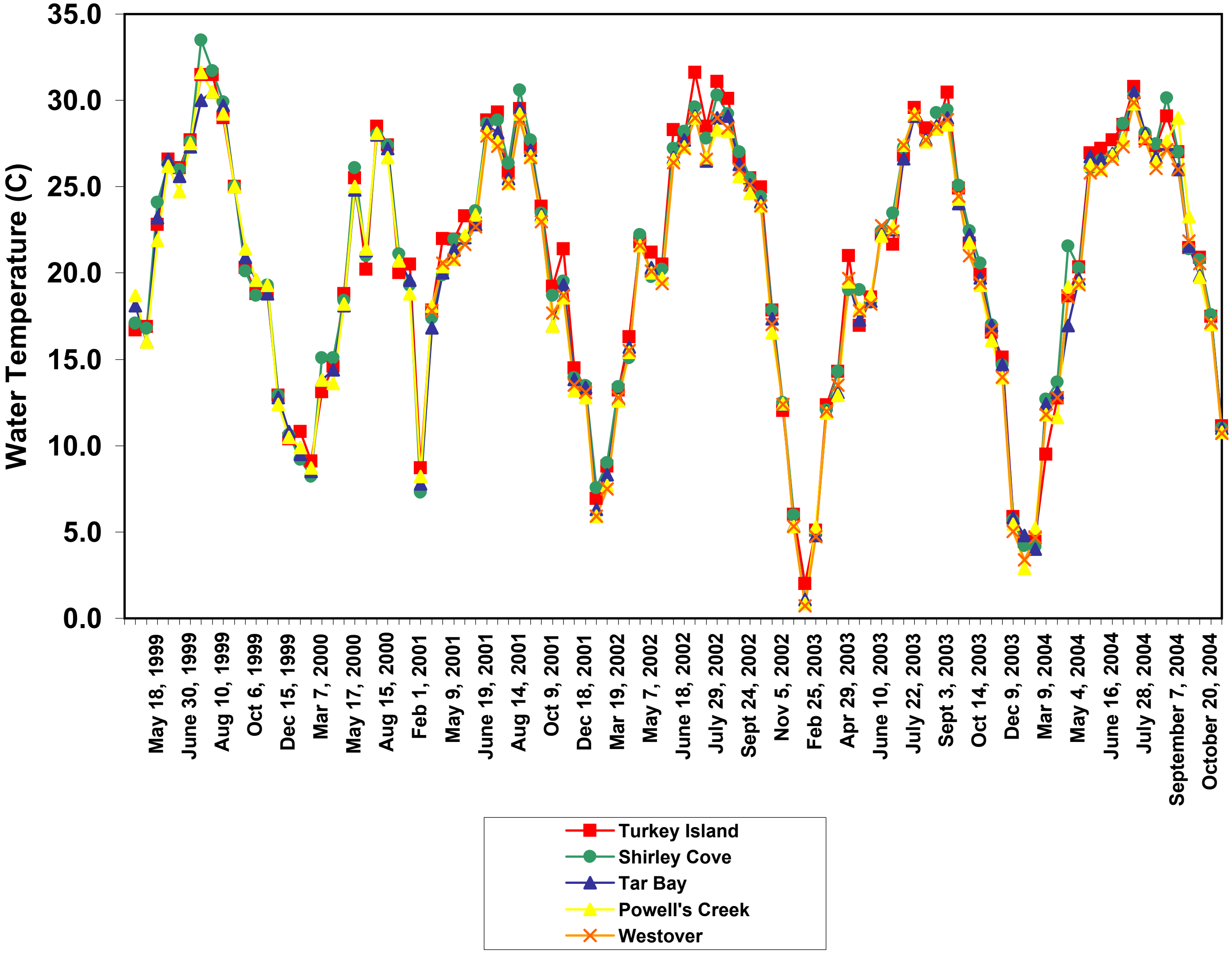


Figure 3-2. Conductivity

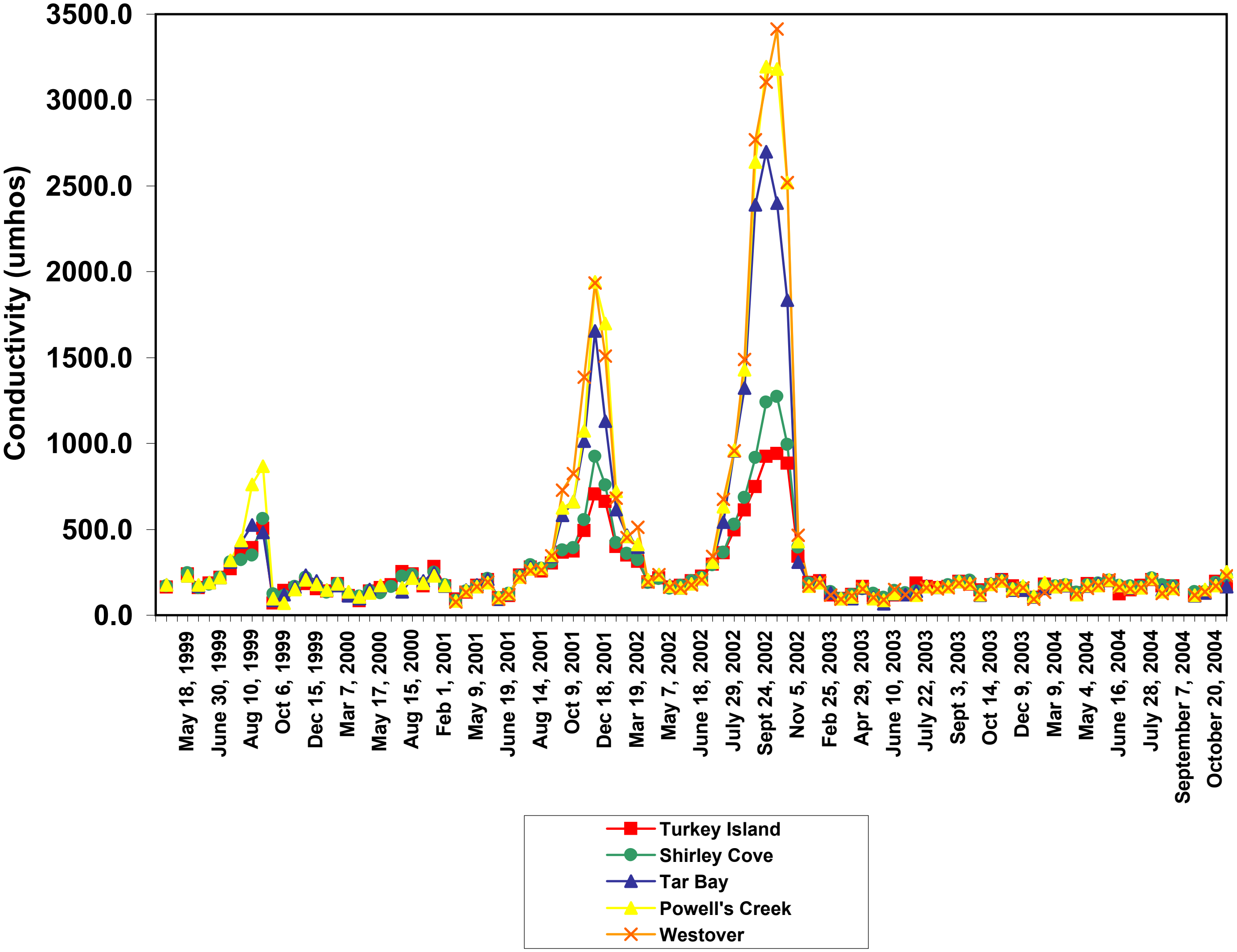


Figure 3-3. Dissolved Oxygen

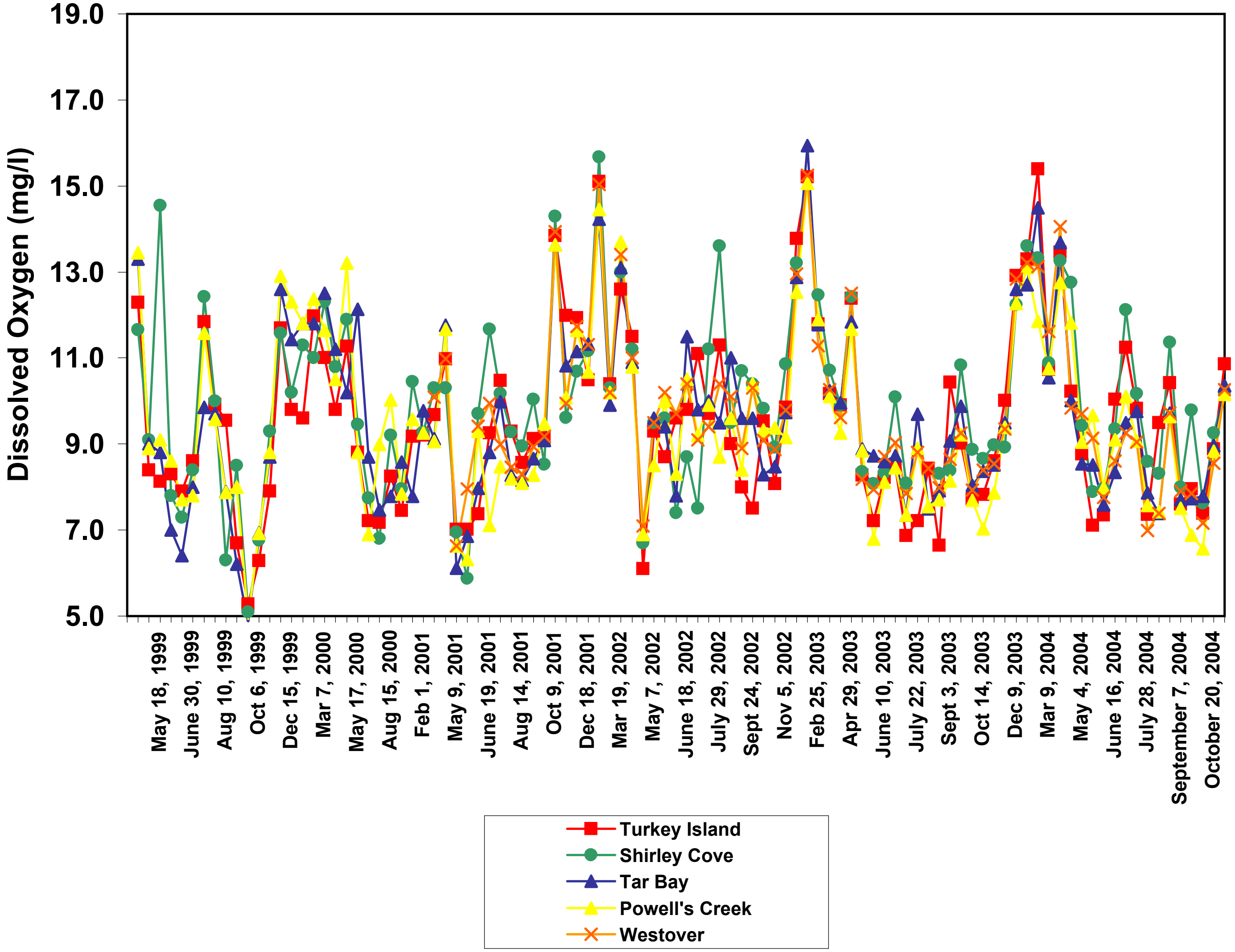


Figure 3-4. Water Column pH

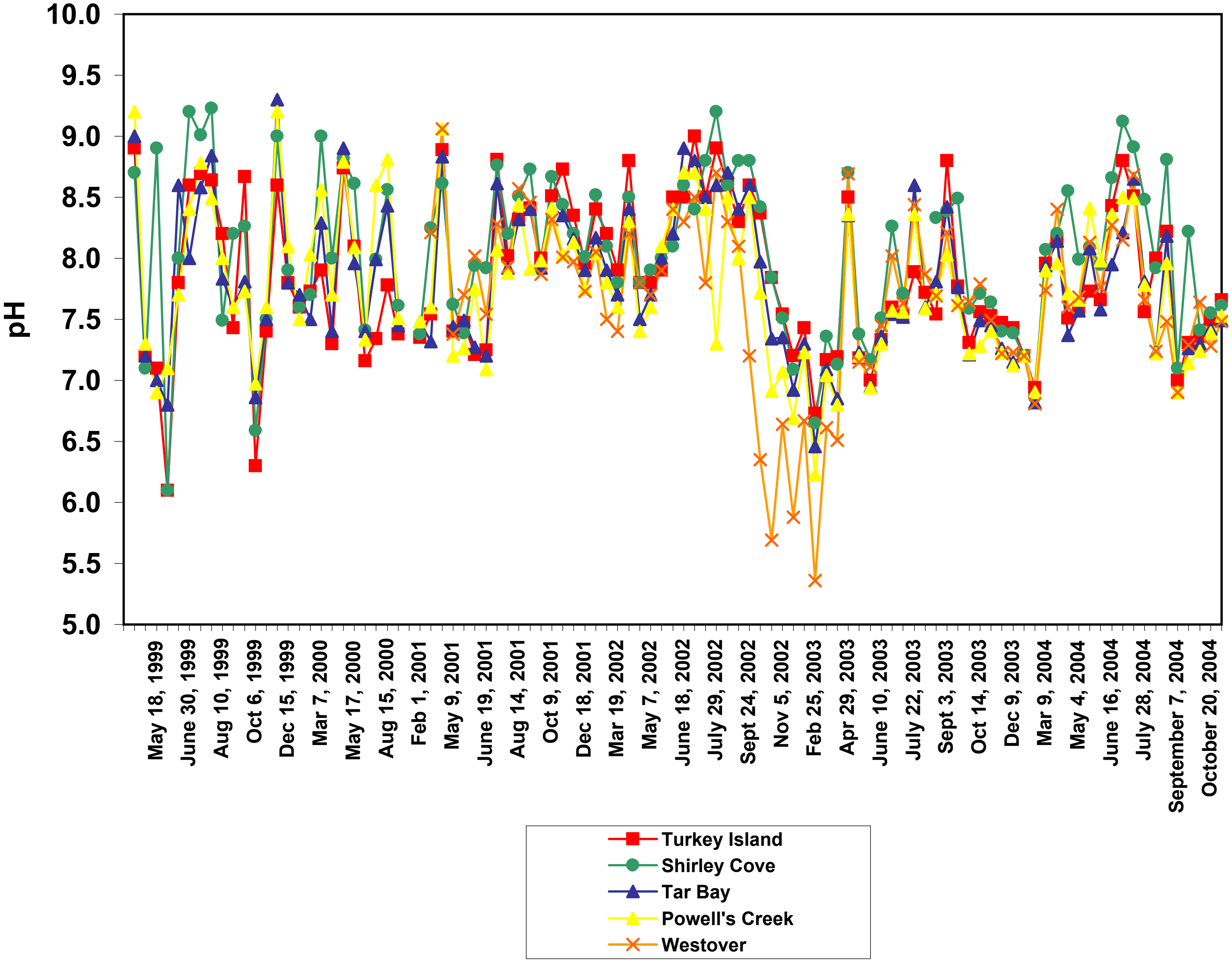


Figure 3-5. Total Suspended Solids

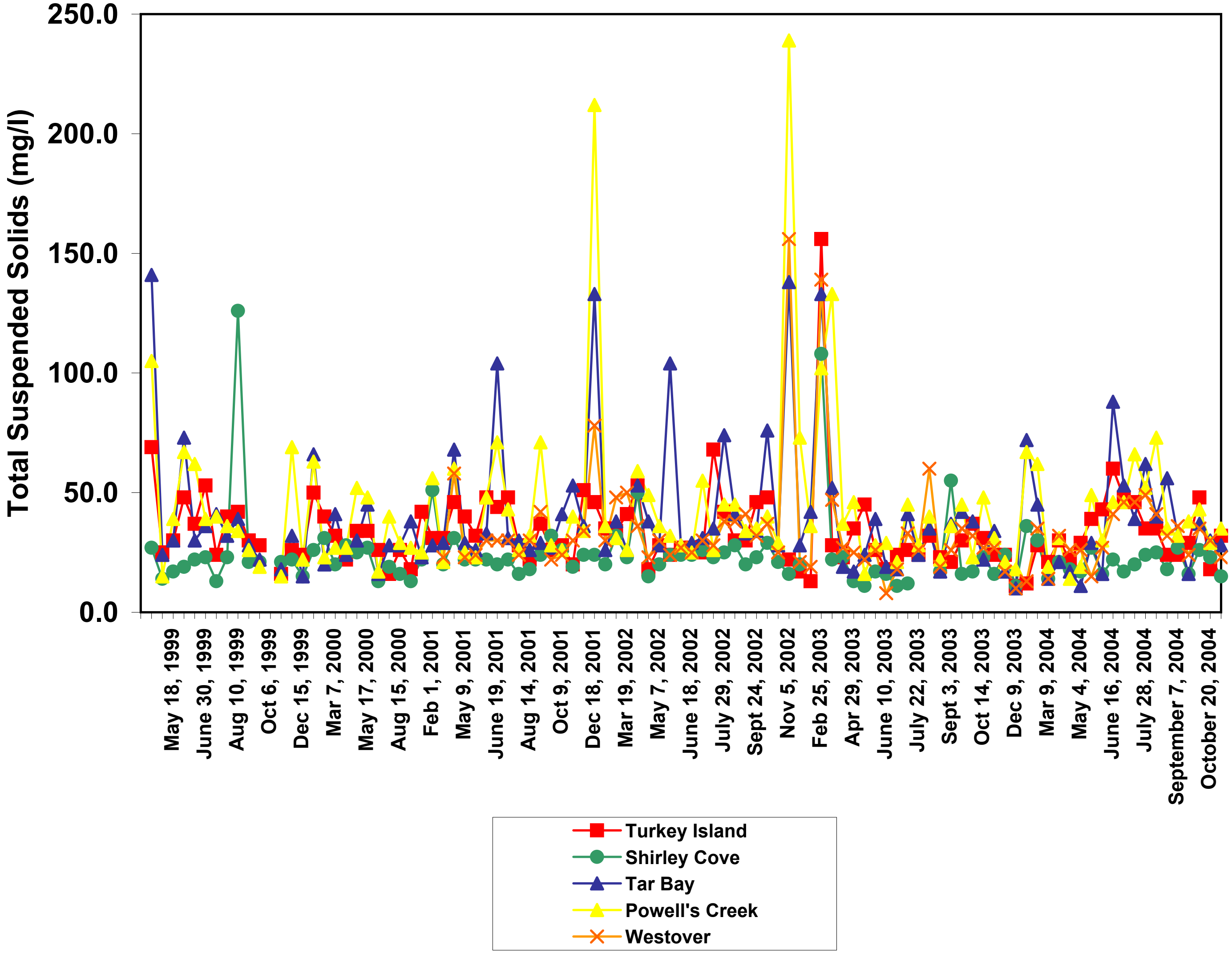


Figure 3-6. Phytoplankton as Chlorophyll a

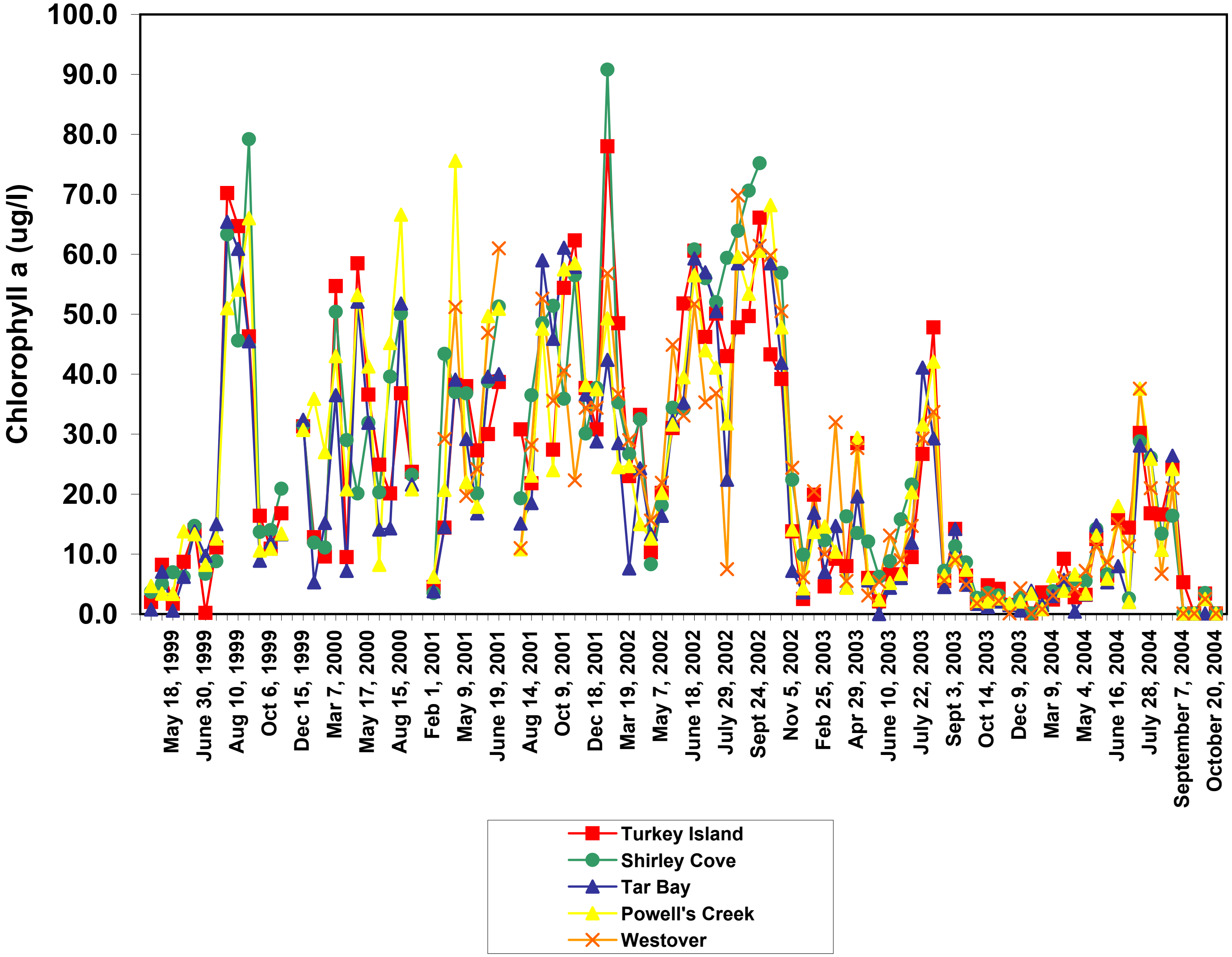


Figure 3-7. Secchi Depth

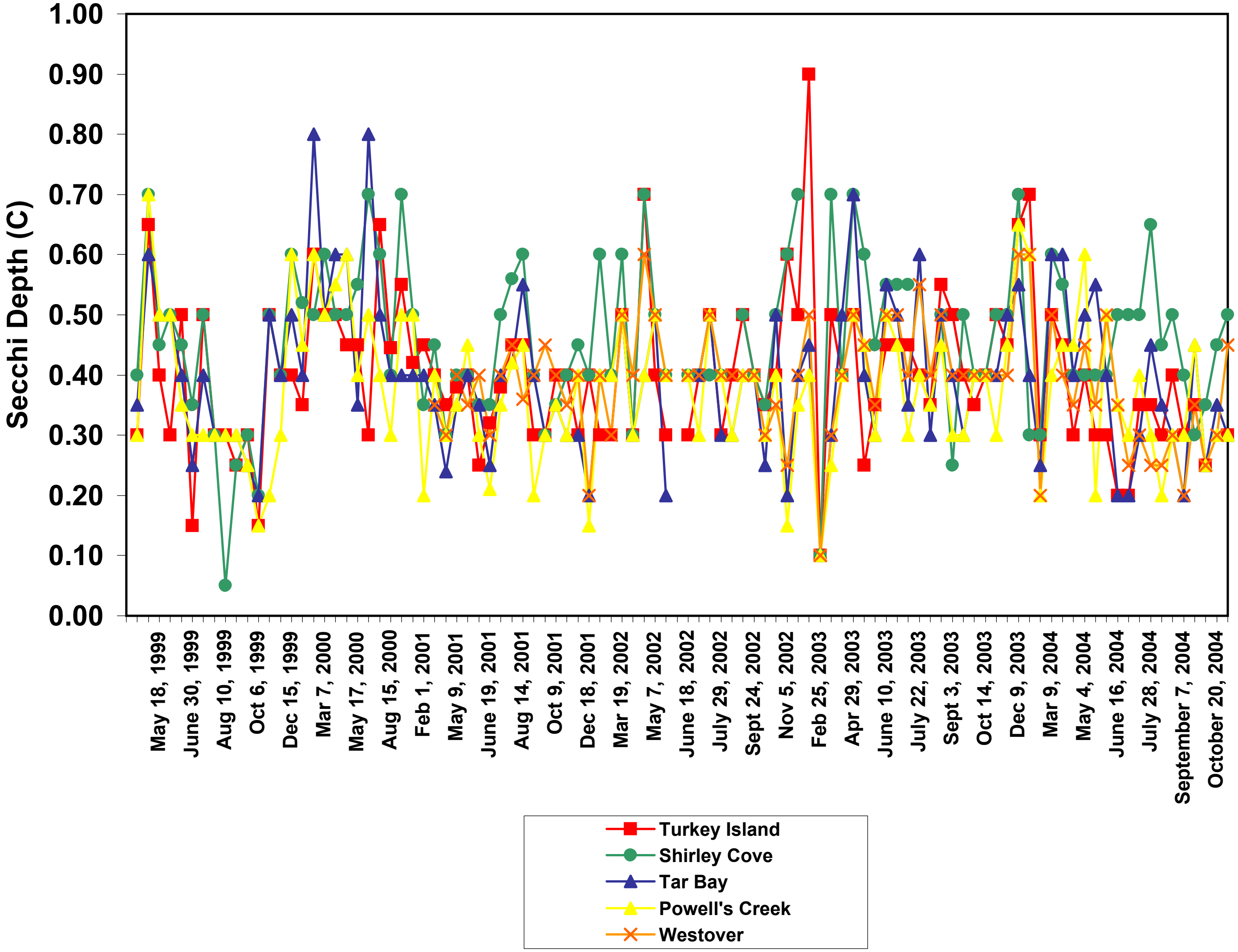


Figure 3-8. Total Organic Carbon

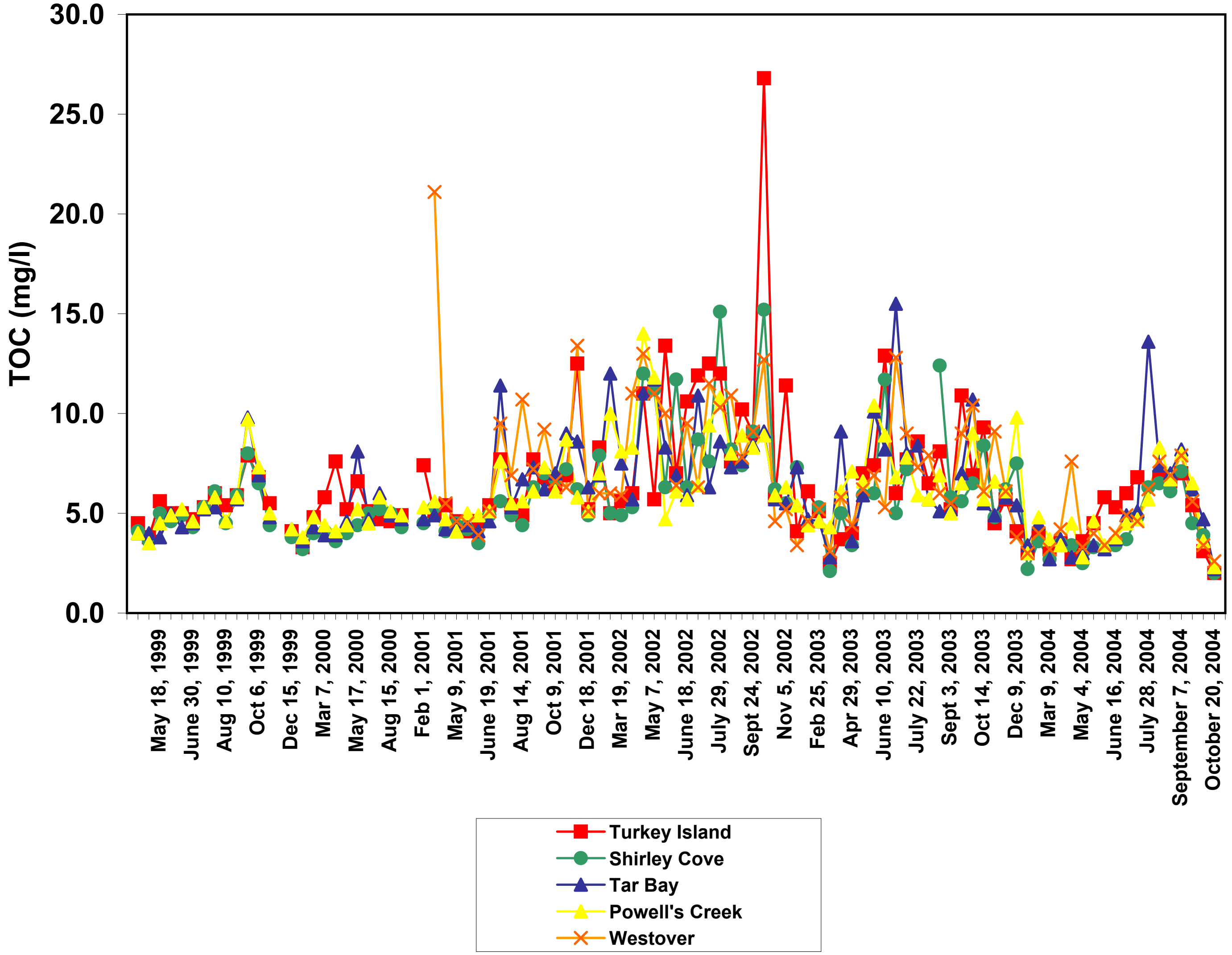


Figure 3-9. Total Kjeldahl Nitrogen

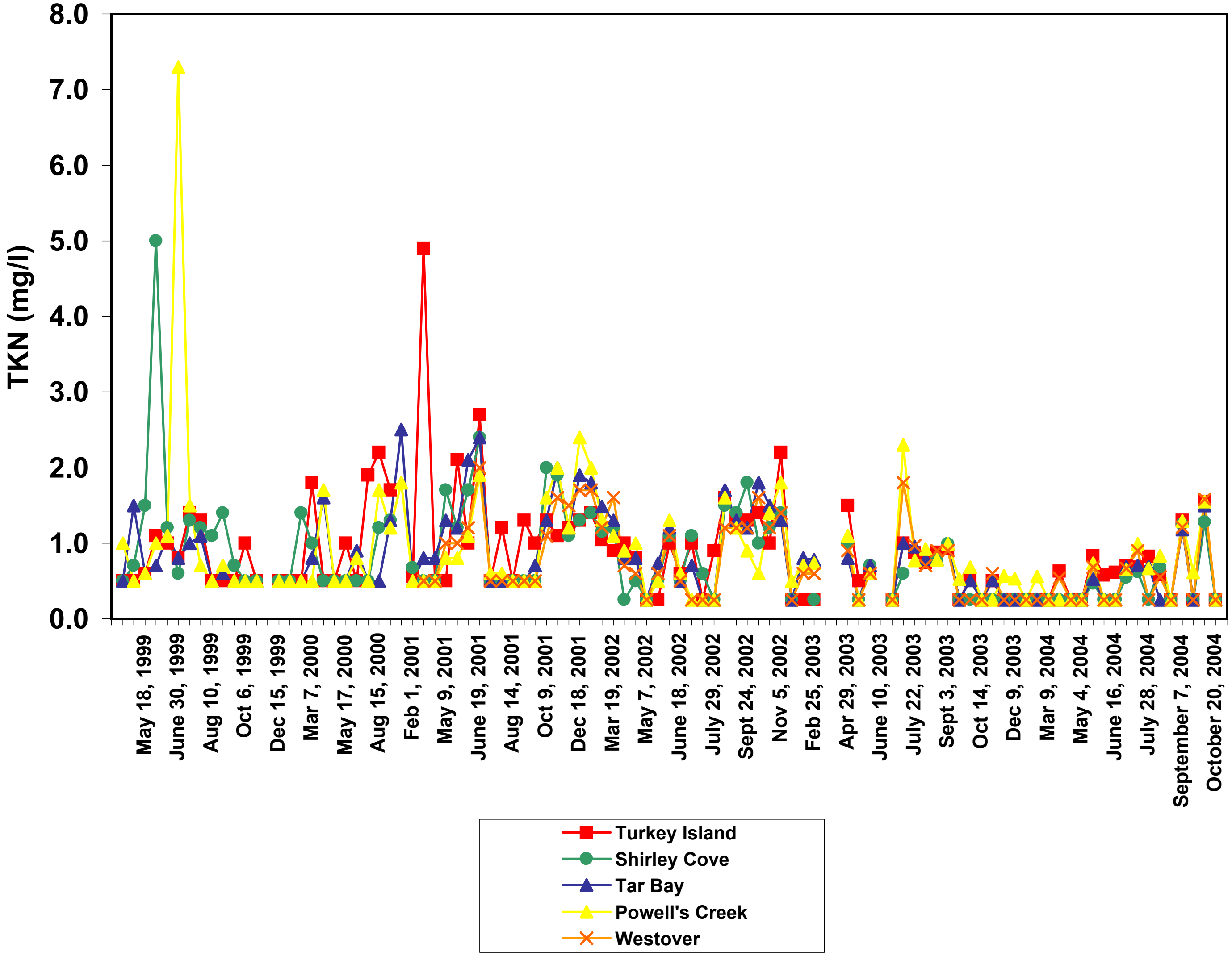


Figure 3-10. Total Phosphorus

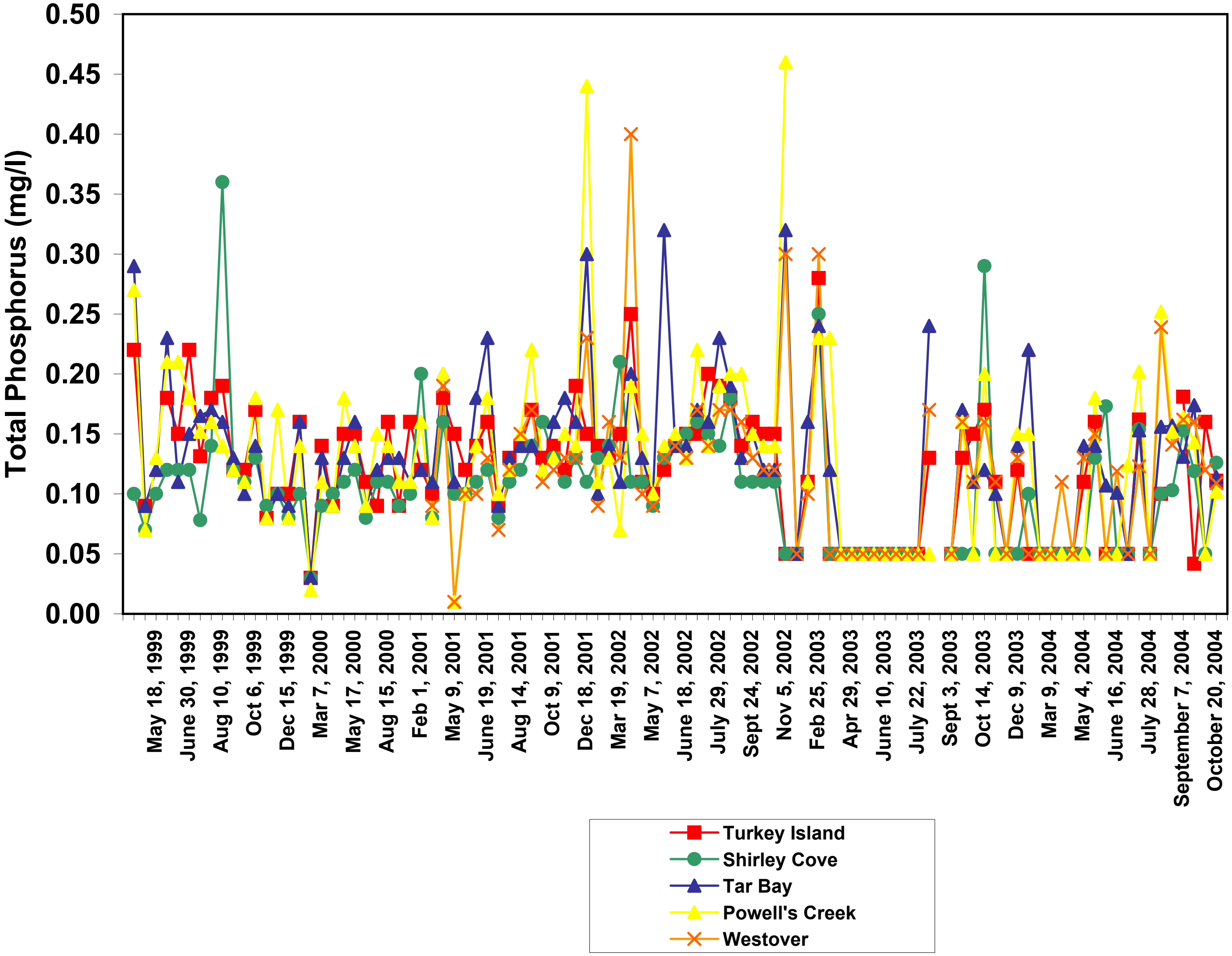


Figure 3-11. Dissolved Nitrate + Nitrite

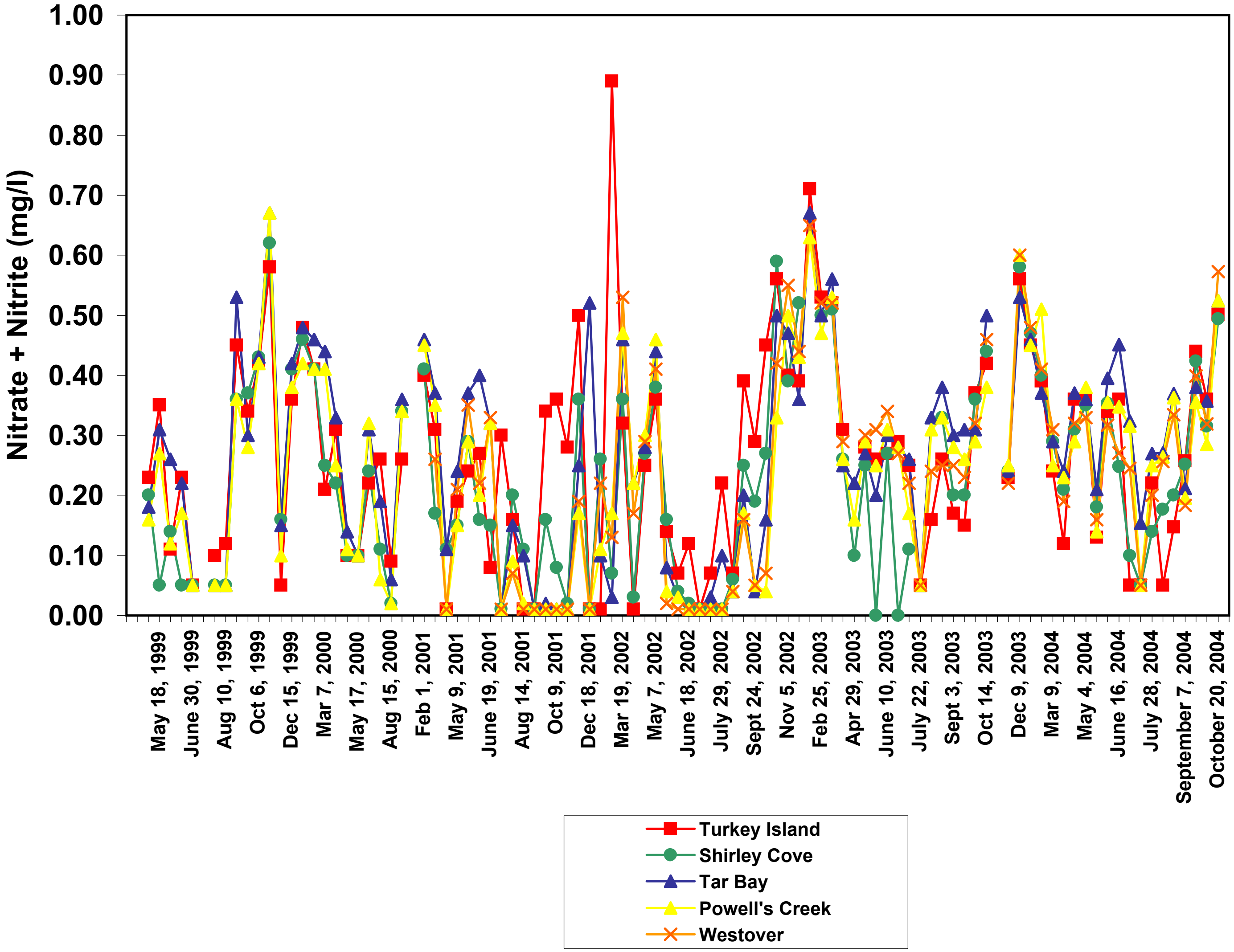


Figure 3-12. Dissolved Ammonium

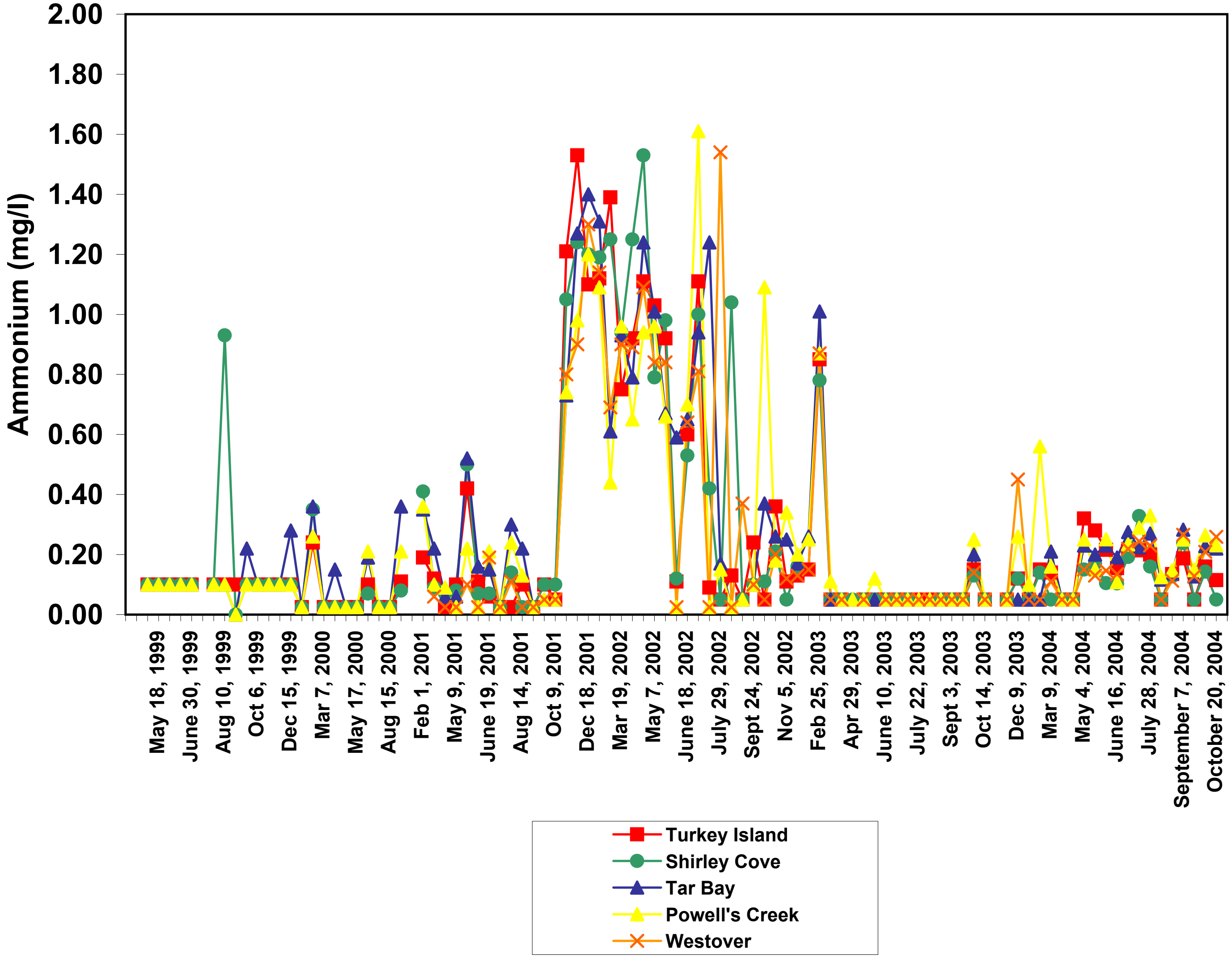


Figure 3-13. Dissolved Inorganic Phosphate

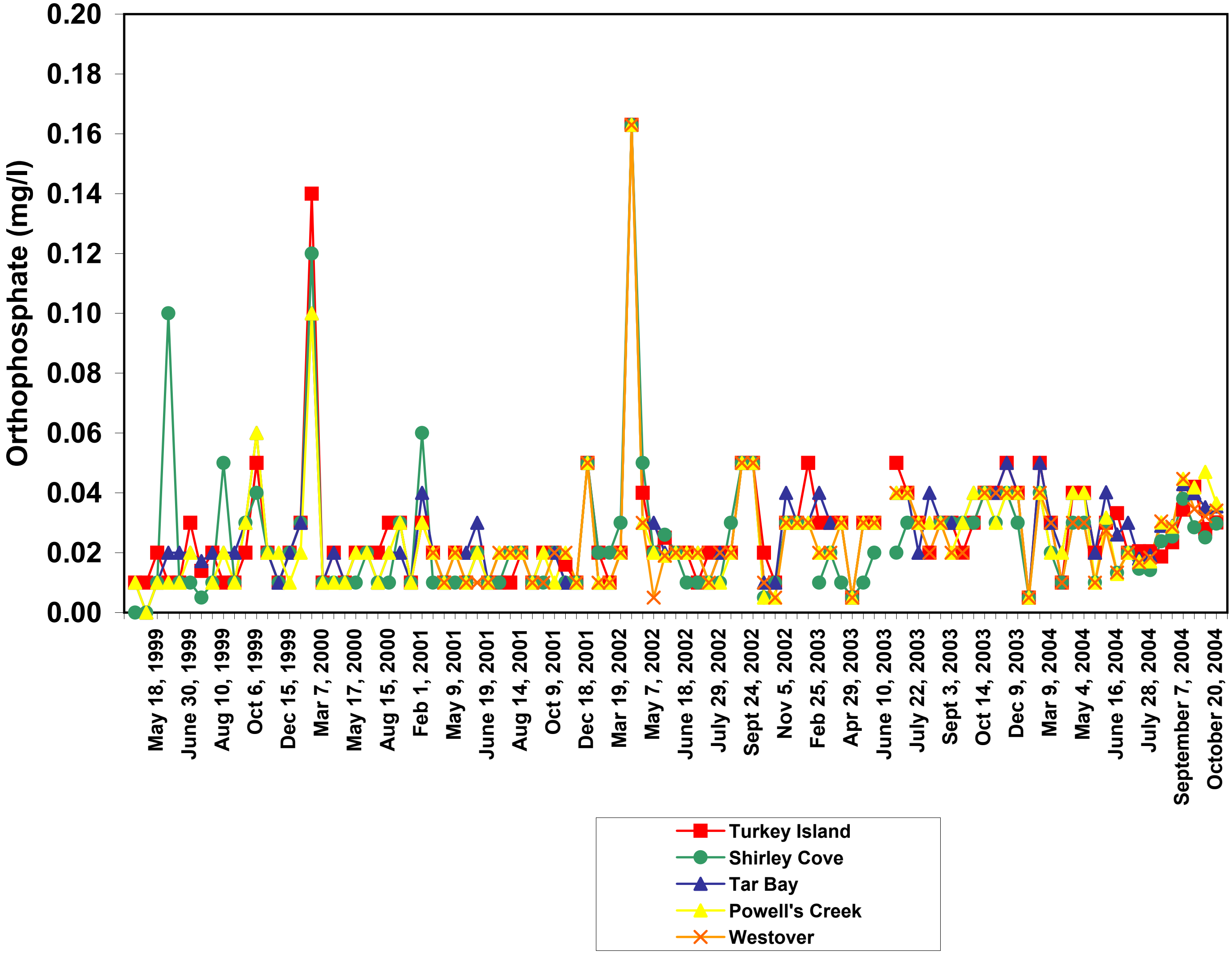


Figure 3-14. Munsell Color Category vs. Chlorophyll a

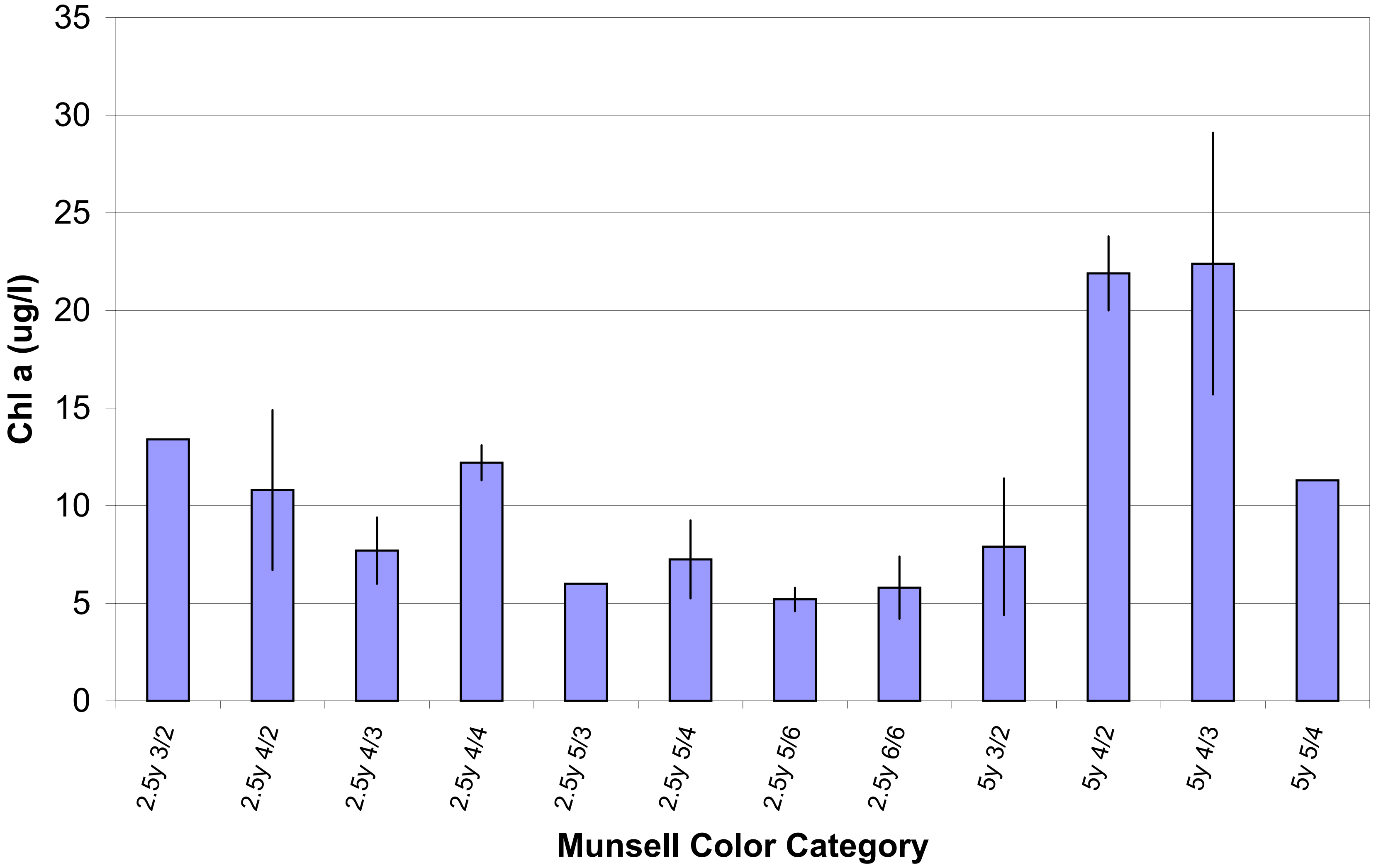


Figure 3-15. High Angle Water Color Photography; May 4, 2004; Sunny Mid-day; Shade Side (top); Sun Side (bottom)

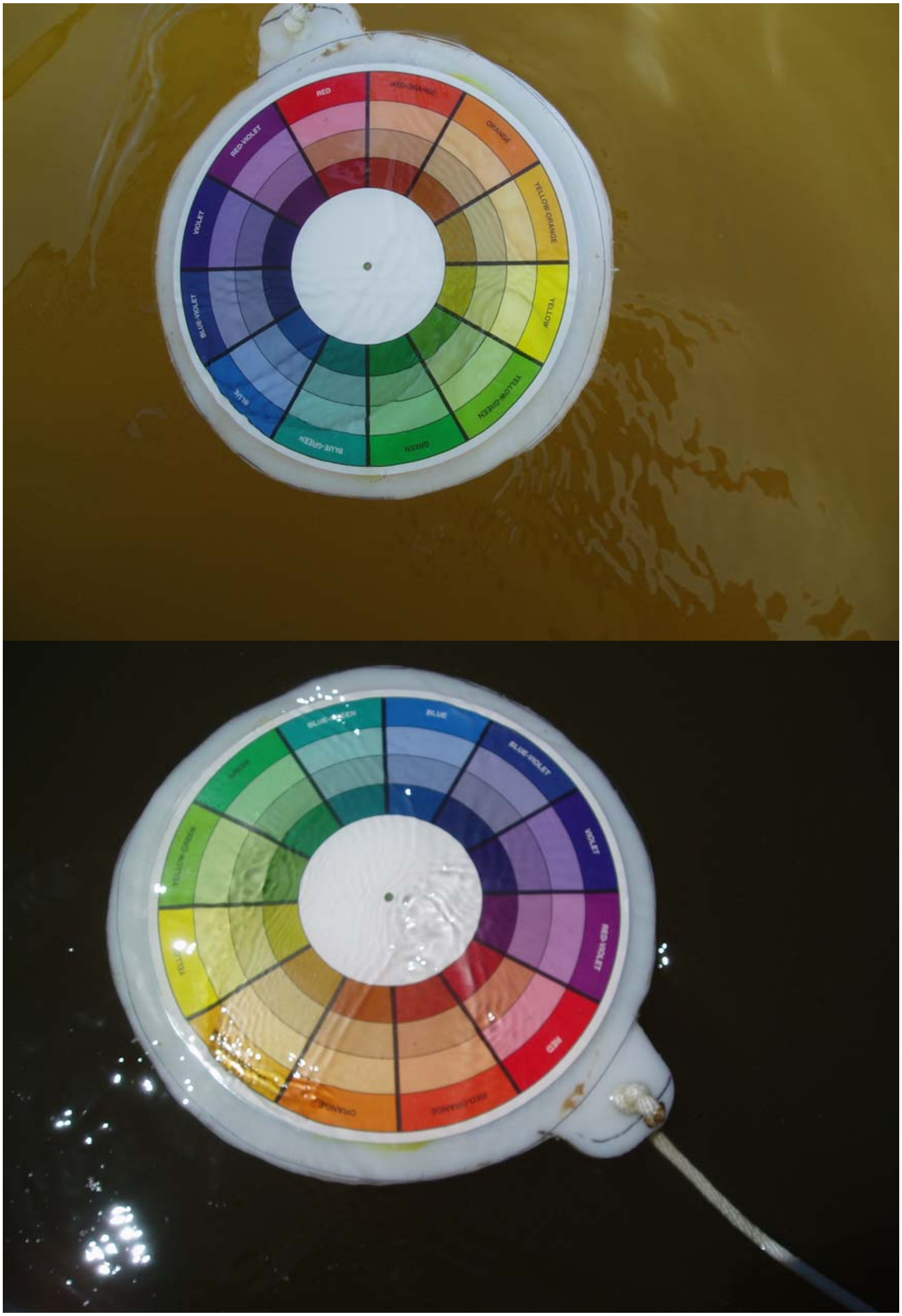


Figure 3-16. High Angle Water Color Photography; April 6, 2004; Sunny Afternoon; Shade Side (top); Sun Side (bottom)

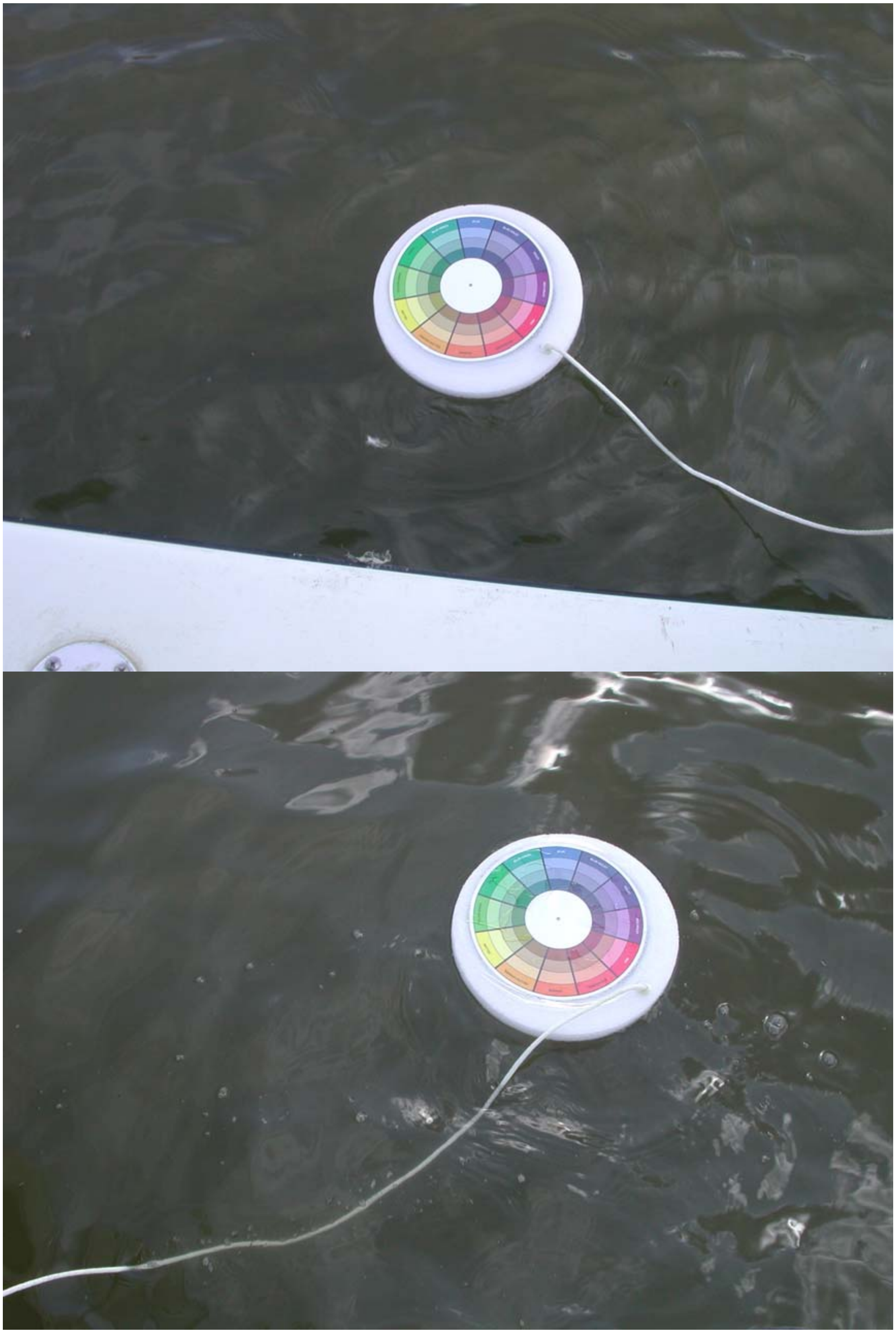
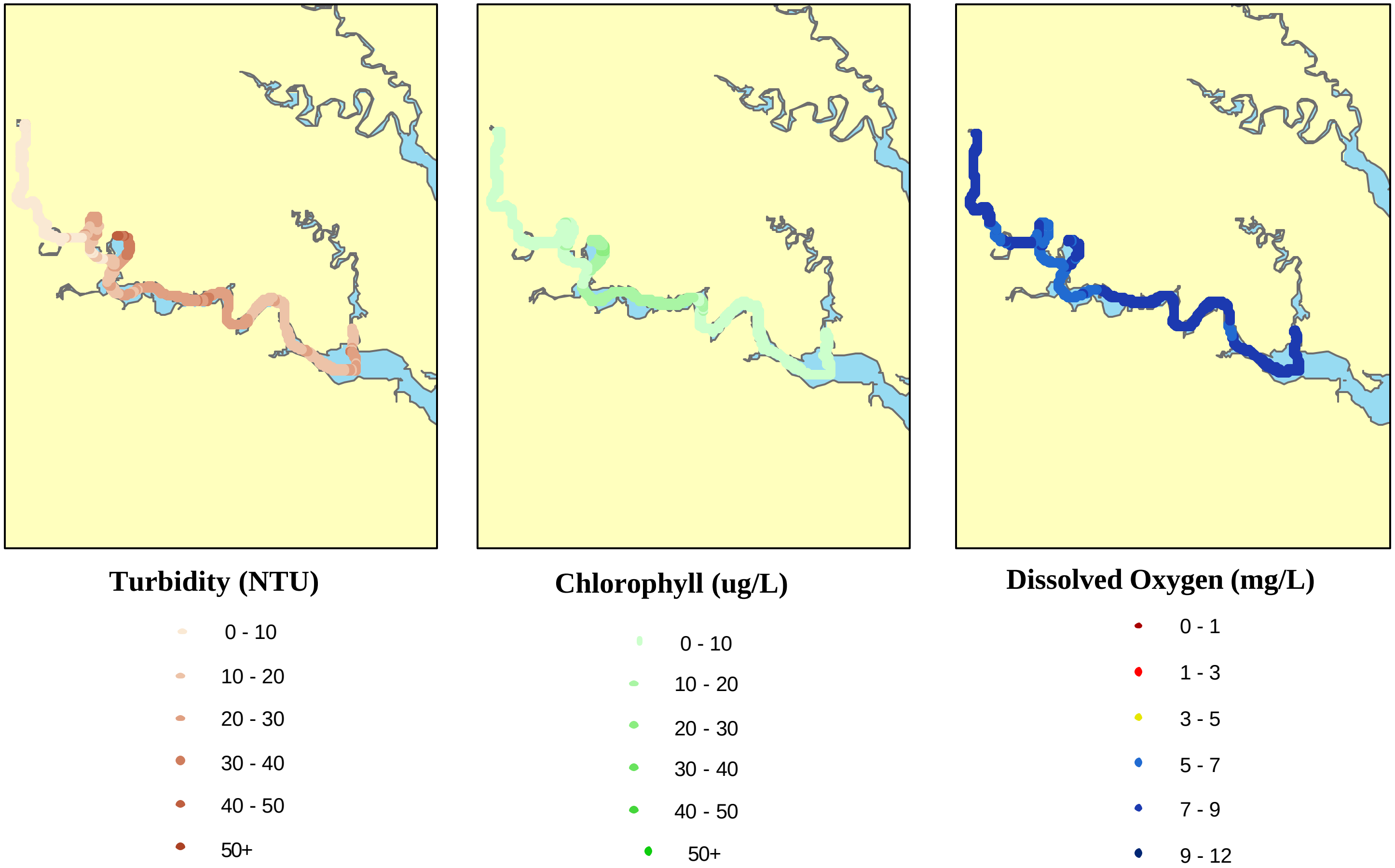


Figure 3-17. High Angle Water Color Photography; December 14, 2004; Sunny Mid-day; Shade Side (top); Sunny Side (bottom)

Figure 3-18. High Angle Water Color Photography; March 9, 2004; Cloudy Mid-day; Shade Side (top); Sunny Side (bottom)

Figure 3-19. James River DATAFLOW Cruise Track, May 19, 2004

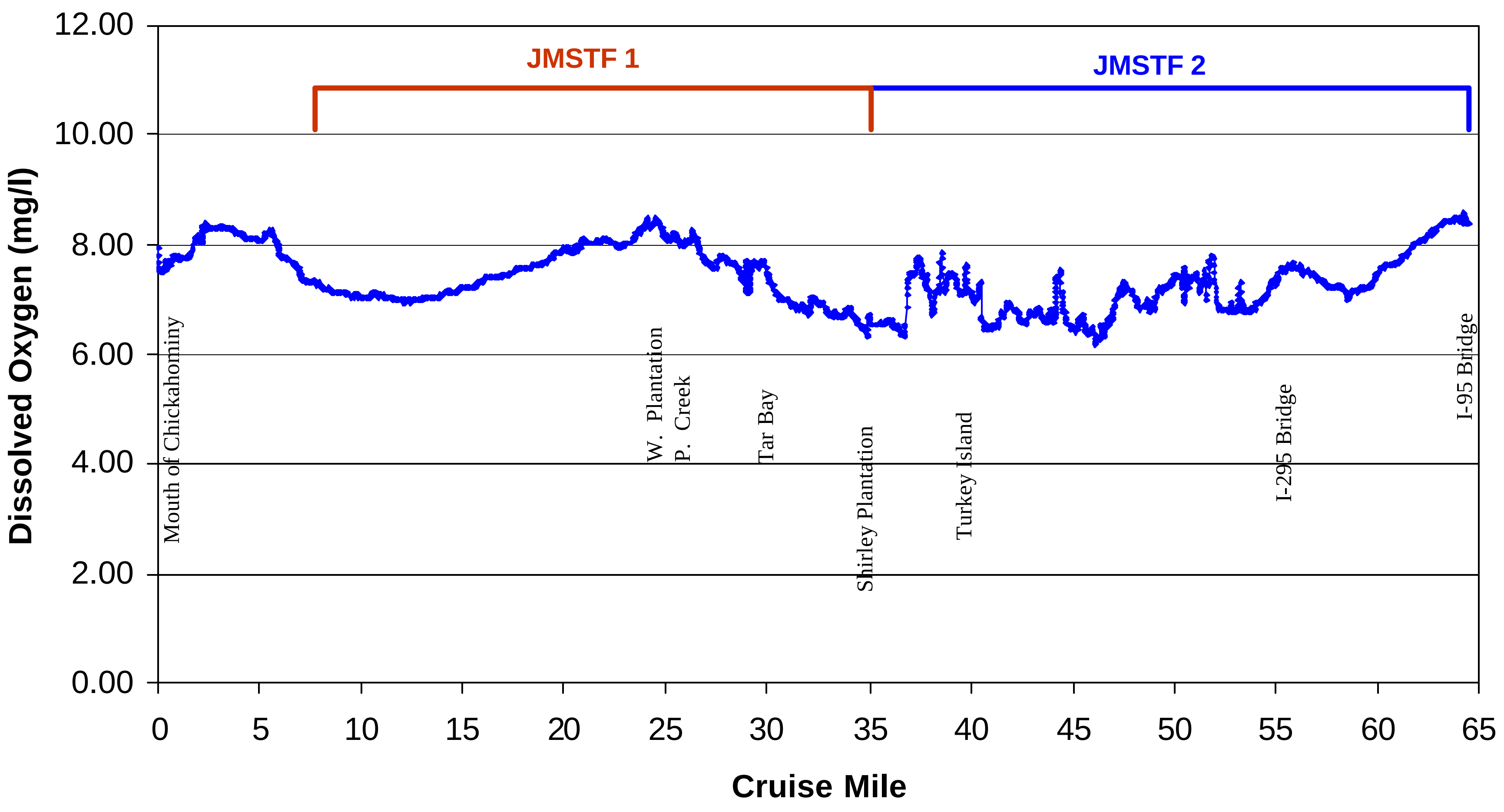


Turbidity (NTU)

Chlorophyll (ug/L)

Dissolved Oxygen (mg/L)

Figure 3-20. James River DATAFLOW Dissolved Oxygen, May 19, 2004



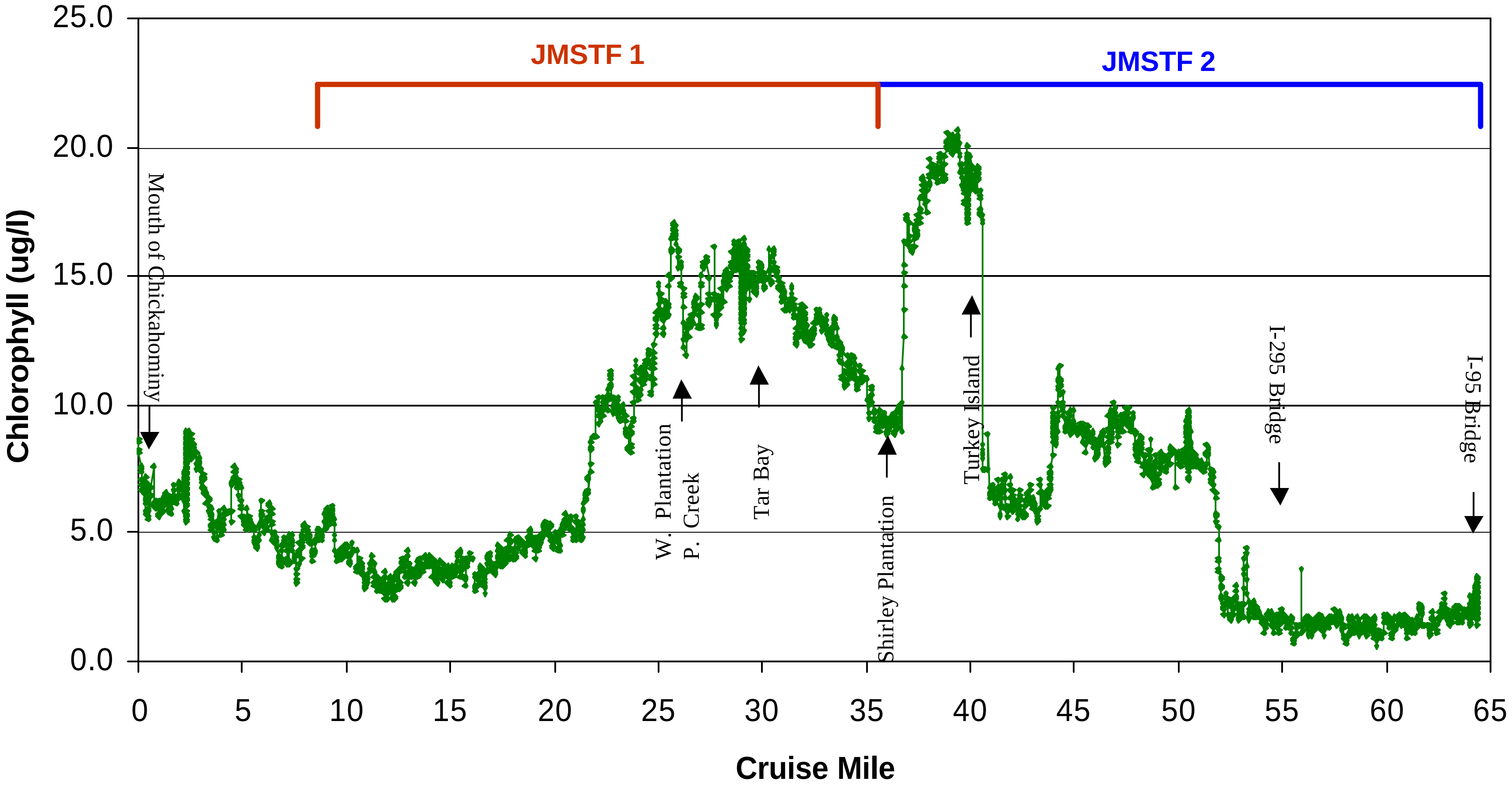


Figure 3-22. James River DATAFLOW Turbidity, May 19, 2004

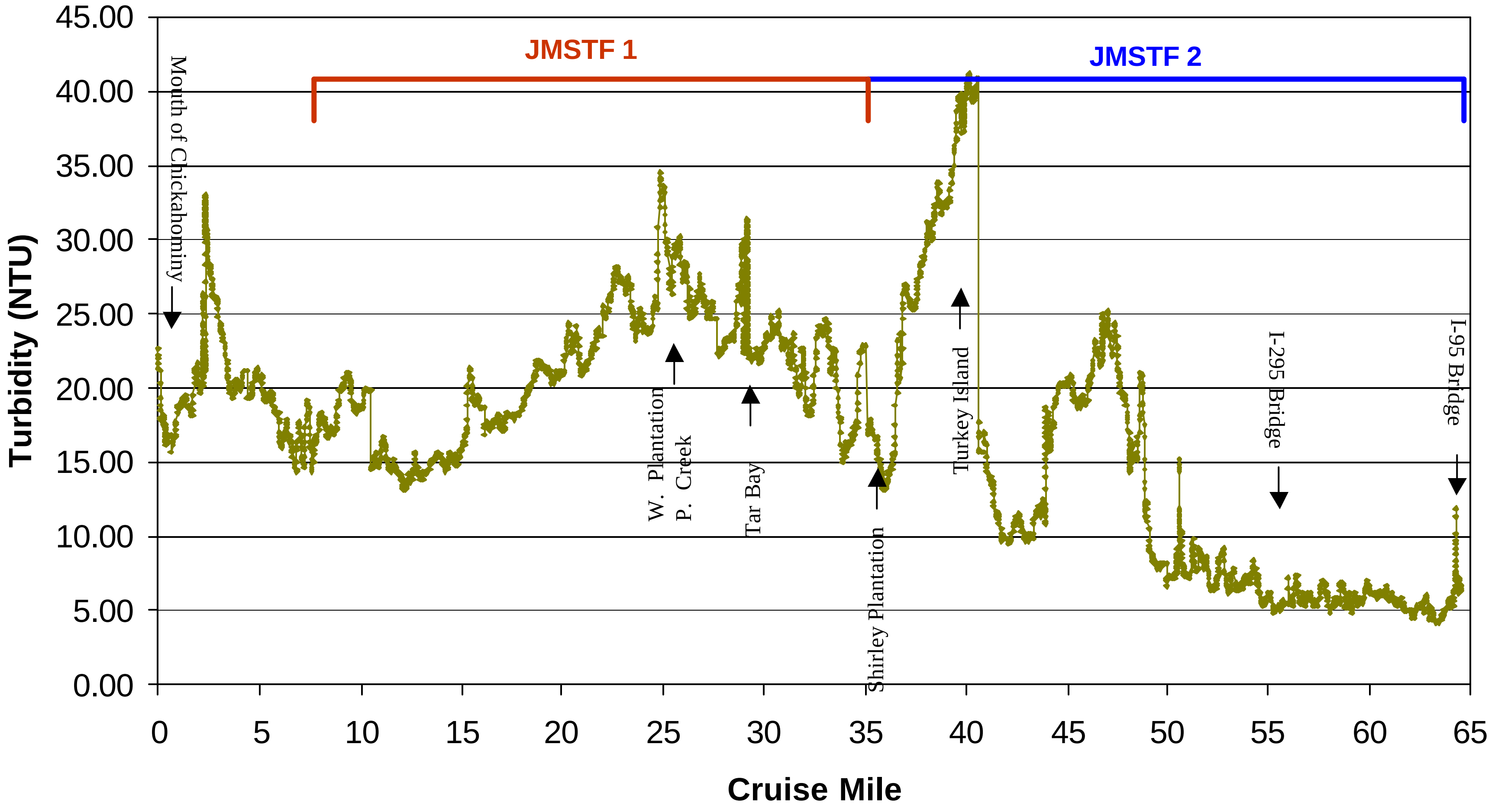
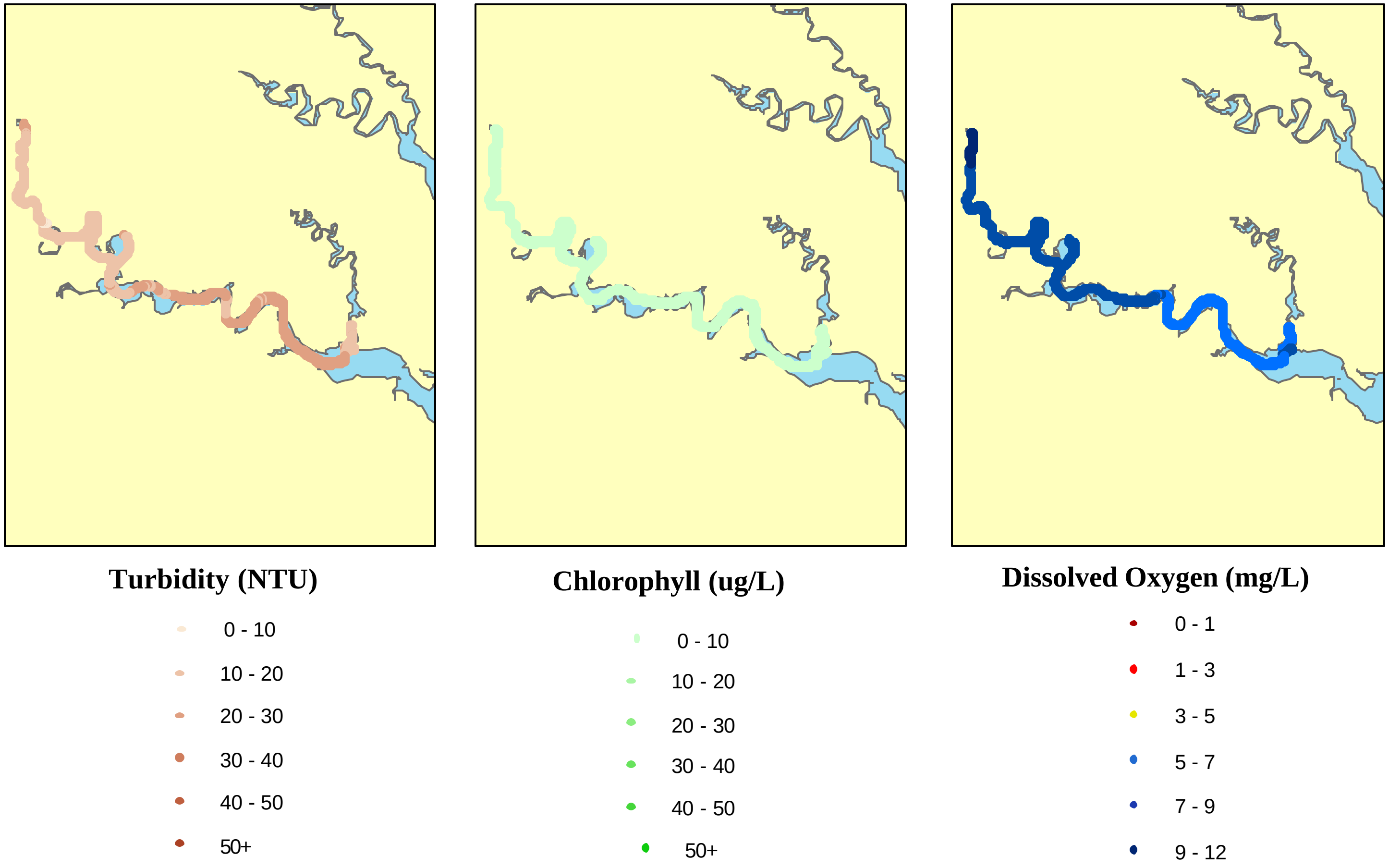


Figure 3-23. James River DATAFLOW Cruise Track, September 23, 2004

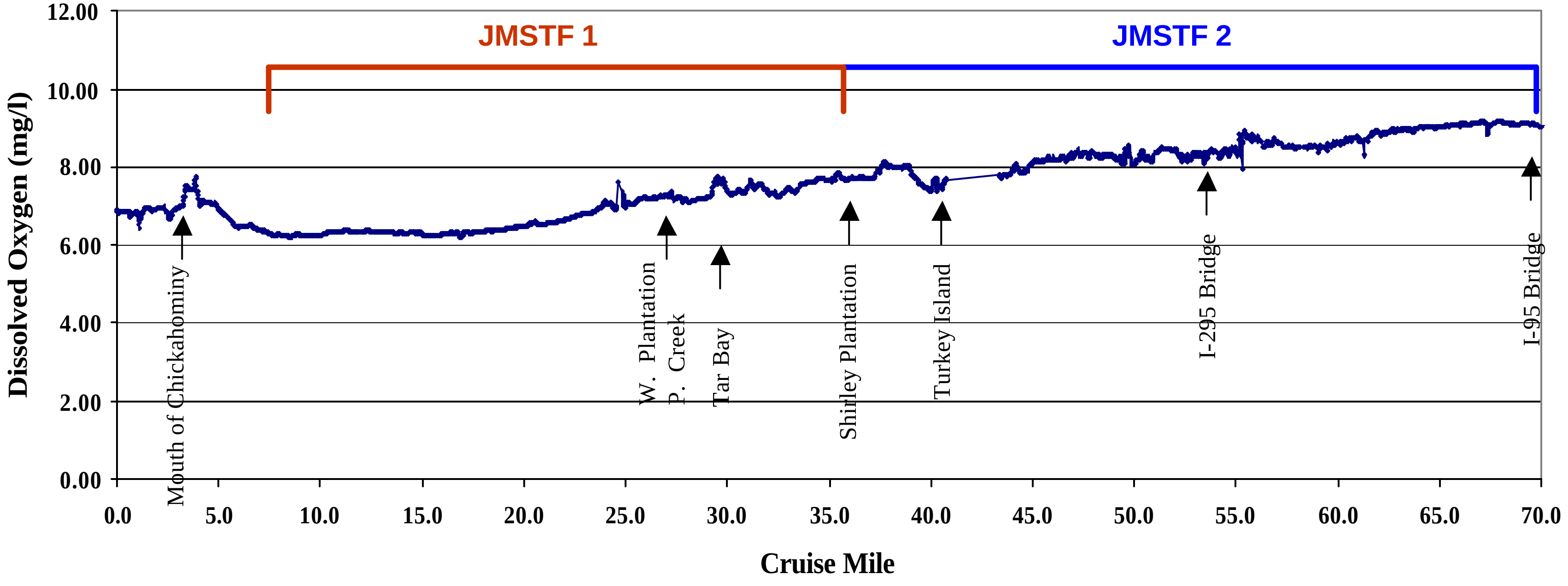


Turbidity (NTU)

Chlorophyll (ug/L)

Dissolved Oxygen (mg/L)

Figure 3-24. James River DATAFLOW Dissolved Oxygen, September 23, 2004



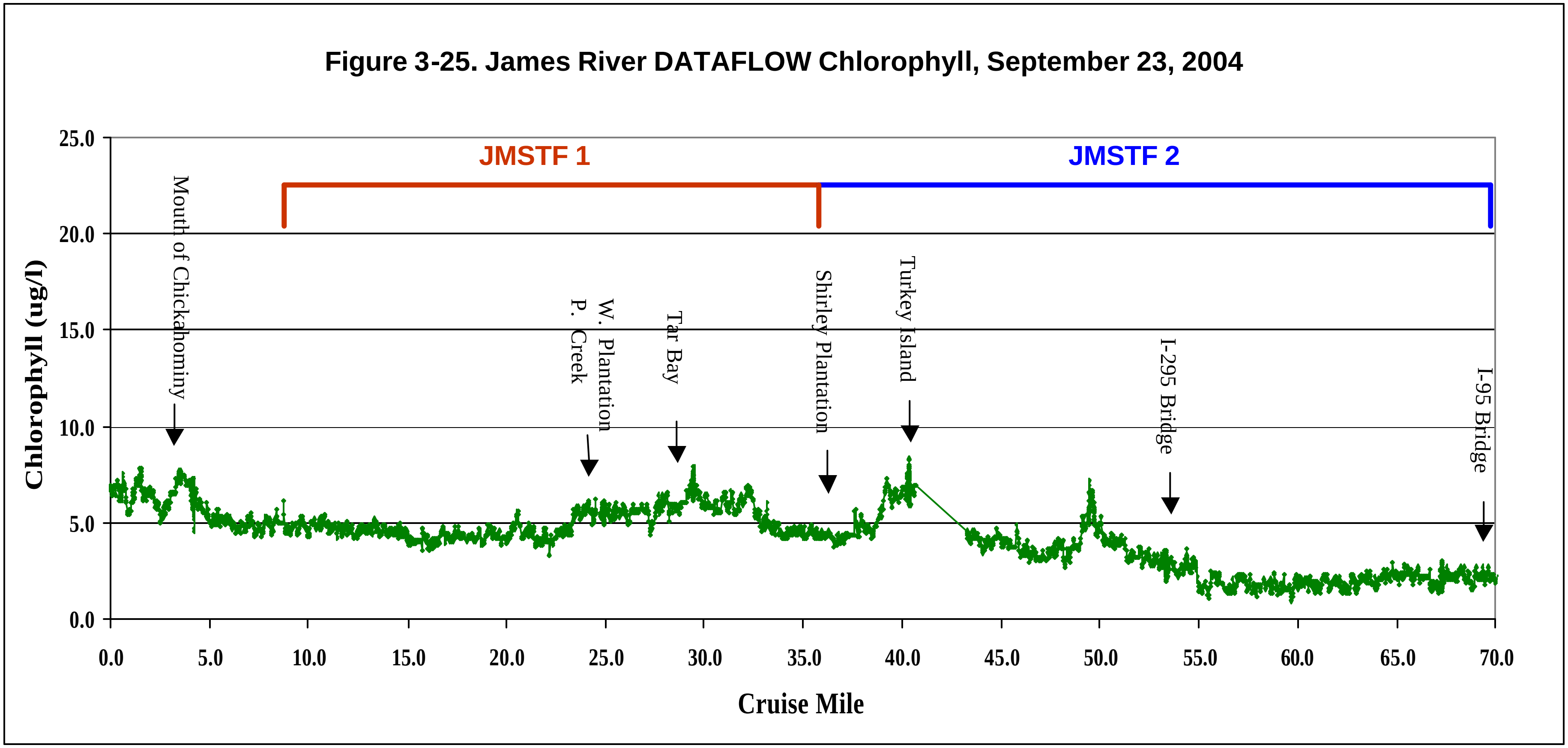


Figure 3-25. James River DATAFLOW Chlorophyll, September 23, 2004
JMSTF 1
JMSTF 2
Mouth of Chickahominy
W. Plantation
P. Creek
Tar Bay
Shirley Plantation
Turkey Island
I-295 Bridge
I-95 Bridge
Chlorophyll (ug/l)
25.0
20.0
15.0
10.0
5.0
0.0
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
40.0
45.0
50.0
55.0
60.0
65.0
70.0
Cruise Mile

Figure 3-26. James River DATAFLOW Turbidity, September 23, 2004

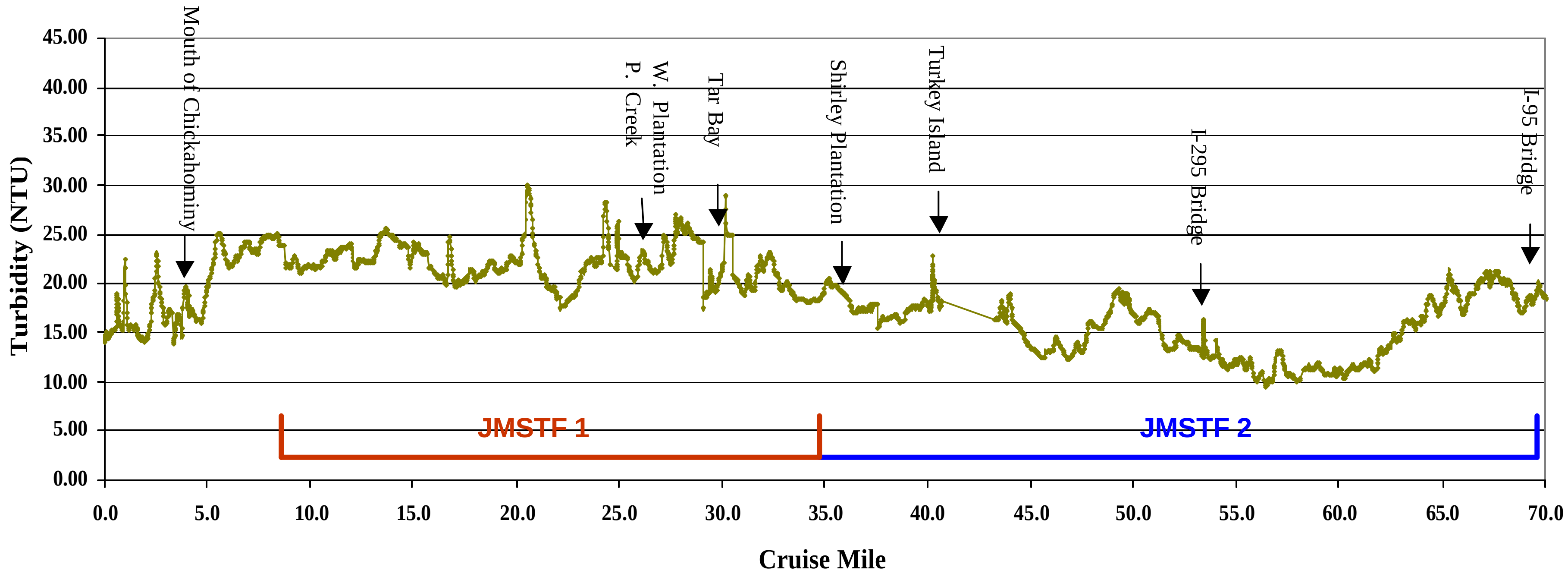


Figure 3-27. James River DATAFLOW Cruise Track, November 9, 2004

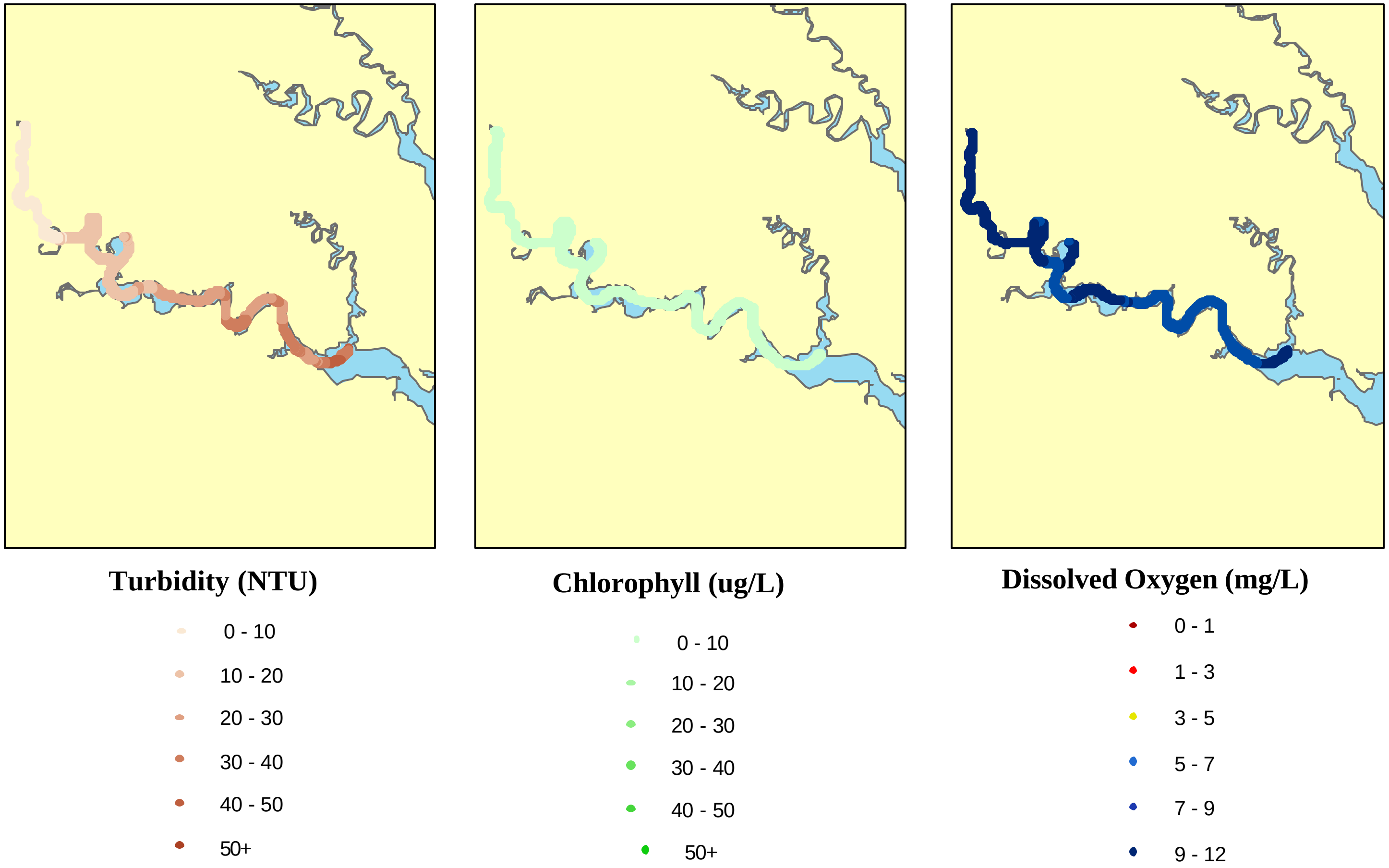


Figure 3-28. James River DATAFLOW Dissolved Oxygen, November 9, 2004

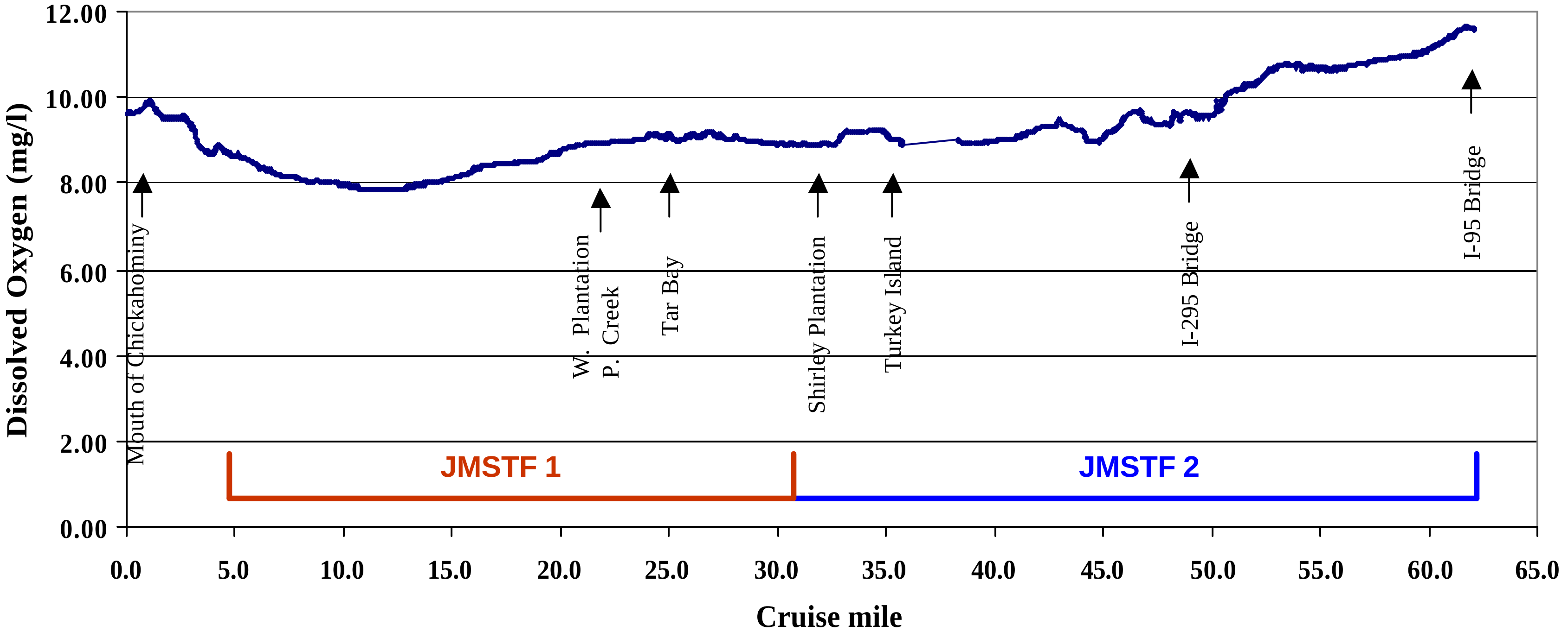


Figure 3-29. James River DATAFLOW Chlorophyll, November 9, 2004

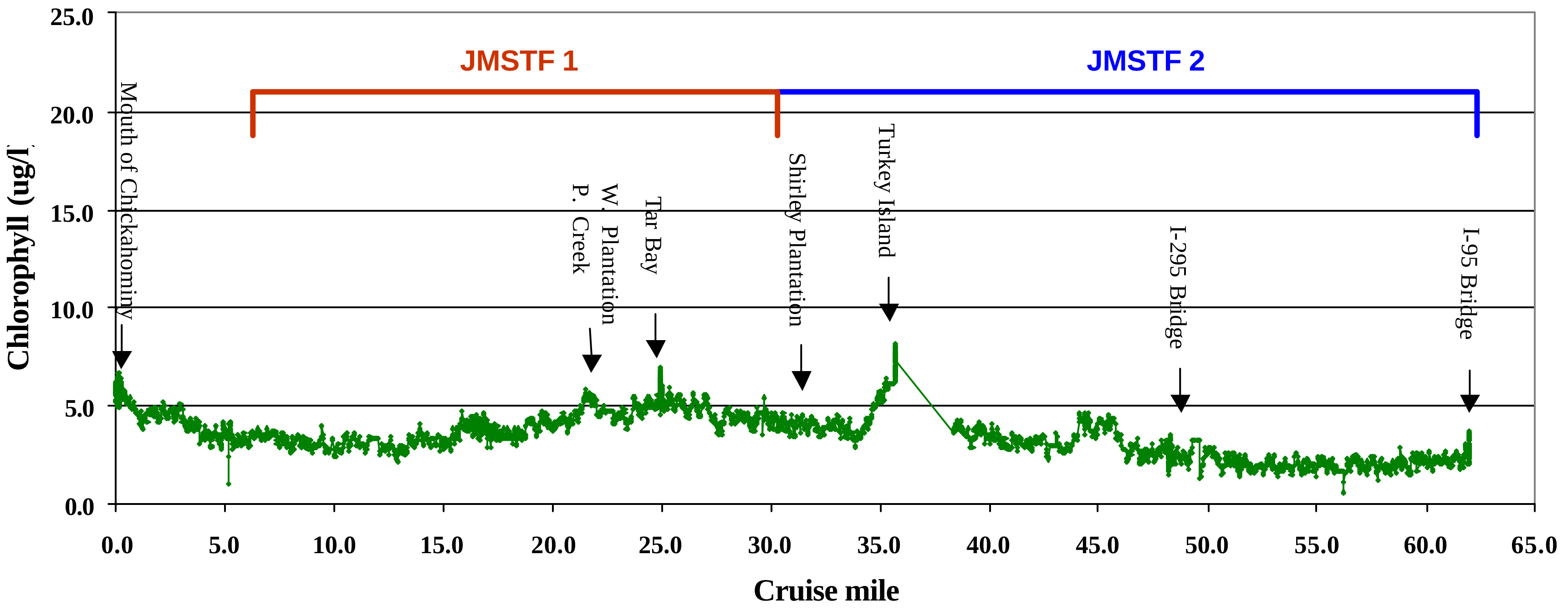


Figure 3-30. James River DATAFLOW Turbidity, November 9, 2004

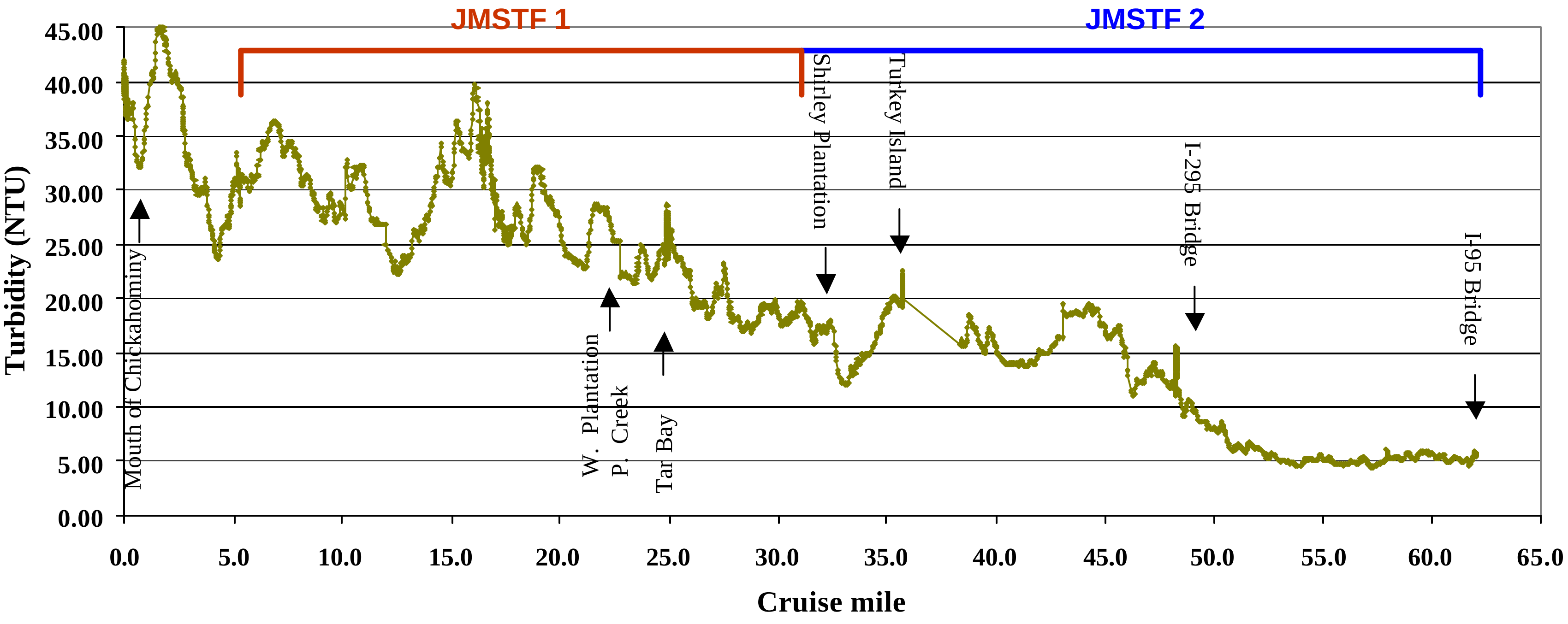


Figure 3-31. James River 2003-2004 SAV Transplant Survivorship