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**WATER QUALITY CONDITIONS AND RESTORATION OF
SUBMERGED AQUATIC VEGETATION (SAV) IN THE TIDAL
FRESHWATER JAMES RIVER 2005**



Dr. Kenneth Moore, Betty Neikirk and Britt-Anne Anderson

Special Report No. 392 in Applied Marine Science and Ocean Engineering

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EXECUTIVE SUMMARY

In 2005, wild celery (*Vallisneria americana*) whole shoots, seeds and intact seed pods with 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. Continuous underway sampling was also conducted along the James River tidal freshwater segments from the mouth of the Chickahominy River to the upstream limits of tidal water at Richmond. 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 the relationships between SAV transplant performance using seeds and whole plants and water quality.

SAV transplant growth and survival were evident at all sites at depths of approximately 0.4 m below low water, when the plants were protected from herbivory by exclosures. Seeds obtained from wild stock and planted within the exclosures germinated and produced adult plants at each of the sites. The use of seeds of wild celery harvested from reproductive shoots collected in the Potomac River during the fall of 2004 proved successful. Seedlings sprouted within one month of planting at all transplant sites. The whole shoot transplants suffered some initial losses but survivorship was approximately 40% to 70%. Both seedlings produced from seed, and seed pod plantings, as well as transplanted whole shoots that were not protected by protective fencing were heavily grazed and did not survive throughout the summer.

Water quality monitoring in the tidal James River in 2005 indicated continued adequate water quality for SAV growth. Turbidity levels, while highest in the upper JMSTF1 segment and lower JMSTF2 segment, were suitable for SAV growth to depths of 0.5 m in most areas. In part this is likely due to the availability of light at low tidal periods when shoot leaves can reach the water's surface. Phytoplankton levels, measured as chlorophyll, were largely within surface water chlorophyll standards and water quality criteria for SAV growth in most areas. When integrated across the entire segments using continuous underway spatial sampling, average concentrations were found to generally be within criteria limits, except during the mid-summer. Phytoplankton did appear to contribute to reduced water clarity, although this proportion was much smaller than that caused by suspended sediments. Nutrient levels generally were comparable with earlier years' monitoring results and long term increasing or decreasing trends since 1999 were not evident. Summertime chlorophyll levels in 2005 were higher than 2004, but much lower than those observed in 2001 and 2002. These differences may be related to water residence time in this tidal freshwater region of the James River, with highest concentrations generally observed during lower flow years. Higher salinities, and therefore lower flow and reduced flushing, in 2005 may have caused the slightly higher chlorophyll levels observed during the summer of 2005.

1.0 Background and Objectives

The James River tidal freshwater estuary is listed on the 303(d) list as an impaired waterbody for aquatic life use attainment. Historic aerial photographs document the presence of submerged aquatic vegetation (SAV) in the tidal freshwater James during the 1940s. Since SAV is one measure of the health of the river, its absence suggests that the water quality of the river is in question. However, despite high nutrient and chlorophyll levels, the James River does not exhibit the typical signs of eutrophication that would be expected. In addition, while low dissolved oxygen levels have been recorded, the James does not exhibit the acute or chronic conditions reported in other estuaries.

In November 2005 the Virginia Water Control Board adopted site specific numerical chlorophyll *a* criteria for the periods of March 1 – May 31 and July 1 – September 30 [as seasonal means] to the tidal James River segments JMSTF2, JMSTF1, JMSOH, JMSMH, JMSPH which are implemented in accordance with subsection D of 9 VAC 25-260-185. Excessive phytoplankton growth, measured as chlorophyll, can have adverse effects on the estuarine system in a variety of ways. High phytoplankton levels can especially contribute to reduced light availability for SAV growth. In addition, high chlorophyll levels may be associated with noxious or harmful algae species and organic matter derived from the decomposition of the algae may contributed to low oxygen levels.

The EPA Water Quality Model provides an indication of how SAV is likely to respond to changes in water quality. Even at the limits of technology, the model predicts limited increases in SAV in the James River. The model has a number of factors that provide a conservative prediction on how living resources will respond to changes in water quality. In particular, the model:

- does not contain a strong feedback mechanism to predict the localized water quality benefits that would result from SAV establishment;
- estimates SAV growth at the one meter contour level, yet most SAV establishment in the James River could be expected at the half meter level or shallower;
- uses a single species to predict response and that species only responds under fairly favorable conditions.

In 1999, the Hopewell Regional Wastewater Treatment Facility (HRWTF) along with the Virginia Institute of Marine Science (VIMS) began a study to transplant and re-introduce two species of underwater grasses to the tidal freshwater James River. Results of this initial study demonstrated that SAV could grow and reproduce in this area of the river. However, until 1999 no transplants of SAV had been attempted in the tidal freshwater region of the James River. Further plantings since that time have been necessary and additional information is needed in order to better demonstrate the cause/effect relationships between James River water quality conditions and SAV and to determine if SAV can survive, reproduce, propagate, and succeed in the tidal freshwater James River. Results of the preceding five years of work have been very encouraging. SAV transplants have been established at four shallow water sites in the Hopewell region of the James River. At one site transplanted beds have persisted for over three years. At each of these sites however, cropping of SAV shoots by animals (such as fish, turtles or blue crabs) has been a problem and those transplants unprotected by fencing have not as yet been successful. However, some initial re-growth of SAV species has been identified in various tidal tributary creeks, as well as the Chickahominy River, in this region, so there is demonstrated potential for large-scale recovery in the main body of the James River.

1.1 Statement of Problem

The Commonwealth of Virginia Draft Tributary Strategy, “Goals for Nutrient and Sediment Reduction in the James River”, identifies reduced light penetration preventing the growth of SAV as one of the key issues regarding water quality and living resource impacts. The strategy states, “ Restoration of grass beds to the upper tidal river will greatly expand existing recreational fishing opportunities for largemouth bass and other tidal fresh sport fish. Once grass beds gain a foothold, they will also begin to improve water quality themselves by stabilizing shorelines, minimizing resuspension of sediments into the water due to wind and waves, and filtering nutrients out of the water.” In addition, EPA listed the James River on the 303(d) List as impaired for aquatic life use attainment. Since SAV is a vital resource that produces oxygen, provides a nursery, food and protection for a variety of aquatic organisms, reduces the erosion effect of wave energy, absorbs nutrients and other pollutants, traps sediments, and serves as an important indicator of the health of the James River. Therefore, restoration efforts are closely tied to water quality and water quality improvements.

Analysis of historical aerial photographs and ground survey reports for SAV in the James River revealed evidence that shallow water areas of the James River near the City of Hopewell supported SAV growth until the mid-1940’s. Since then SAV has been found only in scattered patches in a few small tributary creeks in this region of the tidal, freshwater James River (Moore et al. 1999) although expansive growth in the Chickahominy River is now evident (Orth et al. 2005). The current lack of re-growth of SAV in many of these shallow water areas may be related to a number of possible factors (Batiuk et al. 1992) including:

- poor water quality due to high turbidity and high nutrient levels,
- poor sediment characteristics (high organic content),

- physical limitation due to biological or physical disturbance,
- limited SAV propagule supply.

Freshwater SAV are a potentially important component of the ecosystem because of their value to fish and waterfowl, and their recovery can be an important catalyst for positive ecosystem change throughout the region as they have been in the upper Potomac River. Chesapeake Bay Model evaluations of the continuing improvements to point source discharges in this region of the James suggests that water quality in many areas may now be suitable for SAV growth. One way to assess these various hypotheses is to use SAV transplants to test the current suitability of the areas for SAV. Using SAV plants directly can provide an integrated measure of habitat suitability that cannot be determined solely by discreet monitoring of physical and chemical habitat conditions. In addition, once established they can provide a local source of propagules to hasten recovery.

1.2 Project Description

During the previous years' SAV restoration and water quality monitoring efforts, funded by HRWTF, in partnership with Virginia Institute of Marine Science (VIMS) and assisted by Chesapeake Bay Foundation (CBF) and the Alliance for the Chesapeake Bay, the objectives were to:

- 1) Develop, evaluate and refine effective methodologies for the development, growth and transplantation of SAV propagules into the tidal freshwater James River ecosystem.
- 2) Evaluate if under current conditions, SAV transplants can survive in selected sites in the Hopewell Region of the James River estuary.
- 3) Determine the relative performance of different species of freshwater SAV commonly found in the Chesapeake Bay region to conditions in the Hopewell Region.

- 4) Determine if the response of the transplants is related to specific water quality conditions at the sites, site characteristics, or physical disturbance.

Four test sites had been selected for spring transplanting in the Hopewell region of the estuary based upon historical photographs showing previous SAV presence and appropriate water depths. Plants were either harvested from native stock in the York River, or were supplied by the Chesapeake Bay Foundation from nursery grown material. A number of the wild celery plants were sprouted and grown by citizen volunteers and in Virginia schools under the guidance of the CBF in their initial year of Virginia's "Grasses in Classes" program.

After observing natural predation and disruption of the plots planted in May 1999, the restoration plots planted in subsequent years were surrounded by 4-6 foot high plastic mesh fencing to assure initial survival. Maintenance of the fencing was required throughout the summer. Similar restoration efforts using wild celery in Maryland suggested that once established and developed the beds might become less subject to disruption.

VIMS personnel monitored each site for growth and survival at monthly intervals, and water quality measurements made at biweekly intervals throughout the summer by VIMS personnel. During 2004 additional planting exclosures were established to include a variety of substrate types. Water quality monitoring determined that although suspended sediments and therefore light attenuation at the transplant sites were high, planting at shallow depths (<0.5m) allowed the shoots (which rapidly grew up to 1 m long) to reach the waters surface at mid to low tides. The sediments, which exceeded 5% organic content in some locations, did not appear to be limiting SAV growth. However in the soft mud that characterized several of the sites, borrowing or foraging by animals could disturb initial plant growth.

1.3 Objectives for 2005

This SAV water quality and restoration project was an expansion of the previous SAV transplanting and monitoring efforts conducted prior to 2005. The objectives of the year 2005 study were:

- 1) Plant SAV at four sites in currently unvegetated shallow water sites in the freshwater, tidal James River in the vicinity of Hopewell, VA, using whole plants and seeds 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 and the USFWS Harrison lake Fish Hatchery to develop donor SAV beds for use as propagule source for James River transplanting
- 3) Conduct twice monthly fixed station water quality sampling at 5 shallow water sites (1m depth) in the James River from April through October and monthly from November to March.
- 4) Conduct monthly continuous water quality monitoring cruises during the SAV growing season (April-October) using Dataflow technology, along the axis of the James River along both the Tidal Fresh 1 (JMSTF1) and Tidal Fresh 2 (JMSTF2), Chesapeake Bay Program Segments.
- 5) Monitor the sites for water quality and SAV growth and survival. Relate the response of the transplants to changing water quality conditions in the shallows during the growing season to evaluate the cause/effect relationships between water quality and SAV habitat recovery, and to use this information to assist in the continuing development of tributary nutrient reduction strategies.

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 2005.

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 2005 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 2005 and the transplants were monitored for survival throughout 2005. 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 2005 using bare-rooted wild celery donor plants and seeds. Transplants were surveyed by a 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 2004 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 2005. At each of the four transplant sites (Westover, Powell's Creek, Tar Bay and Turkey Island) 5m x 10 m areas both inside and outside of fenced enclosure areas were planted with treatments consisting of whole bare rooted plants, intact seeds pods, and seeds that had been removed from the pods. Just prior to planting the seeds pods were gently broken apart by hand and the seeds removed. Both the intact seed pods and separated seeds were randomly dispersed onto the bottom by divers and lightly patted into the sediments within each treatment area at each study site. The whole plants were planted directly into the sediments at approximately 0.2 m intervals. Germinated seedlings and whole plants were checked by divers for growth and abundance at monthly intervals.

Technical assistance was also provided to other restoration efforts in the region. Herbivory enclosures had been constructed in June 2002 and expanded in 2005 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 2005. Wild Celery seeds were also transplanted into these enclosures in spring 2005.

2.3 Water Quality Monitoring

2.3.1 Fixed Station Monitoring

VIMS personnel conducted water quality sampling at bi-weekly to monthly intervals at each of the five James River restoration sites from January to December 2005. 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 in water depths of approximately one meter. Water samples were collected at a depth of one-half meter below the surface. Water samples were placed in clean, pre-labeled containers provided by HRWTF personnel and stored on ice in the dark until the end of each sampling cruise. At that time the samples were returned to HRWTF personnel for subsequent laboratory analyses.

2.3.2 Continuous Monitoring Using Dataflow Technology

The Dataflow system 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 light attenuation, dissolved oxygen 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 dissolved oxygen (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.

Seven continuous Dataflow sampling cruises were conducted from May to October 2005. The cruise tracks were run along the center axis of the James River tidal freshwater region from the mouth of the Chickahominy to the upper limit of tidal waters in Richmond. The individual cruises were completed between 10:00 am to 3:00pm. On each Dataflow cruise day, five stations situated along a salinity gradient were sampled for verification data. These samples, which included water samples for extracted chlorophyll, total suspended solids, and dissolved oxygen by Winkler titration, secchi depth, and light attenuation profiles of photosynthetically available radiation (PAR), were used to verify the data from the YSI 6600 in the Dataflow unit. Once on station, the vessel was anchored and station conditions (wind speed and direction, cloud cover, air temp, station depth, and wave height) were recorded. A YSI 600 minisonde was placed in the water at the depth of the Dataflow intake to get real time verification of DO, pH, and salinity. A secchi disk was used to obtain a secchi depth, which is a measurement of water

clarity. Water samples were taken from the outflow of the Dataflow for chlorophyll, total suspended solids and Winkler titration. Exact time was recorded so that the verification data could then be matched back to exact Dataflow readings. The chlorophyll sample was immediately filtered and then the filter was placed on ice. The sample for Winkler titration was run immediately and the results recorded on the field data sheet. The water sample for total suspended solids was put on ice and filtered upon return to the laboratory. Personnel then measured a light attenuation profile of PAR, using a LiCor LI-1400 data logger, deck sensor and quantum underwater sensor. Measurements were taken at 0.10m, 0.25m, 0.50m, 0.75m, and 1.00m. This profile was then replicated three times and light attenuation (K_d) was determined.

3.0 RESULTS

3.1 Water Quality Monitoring

3.1.1 Fixed Station Monitoring

Water temperatures (Fig. 3-1) demonstrated similar annual patterns over the 1999-2005 sampling period at all the stations with daytime minimums ranging from approximately 5 °C to maximums of 30-32 °C. Higher than usual temperatures (approximately 2-3°C) have been observed for shallow water areas in the lower bay during the months of July and August 2005 and similarly, water temperatures were higher than all years except for 1999. These high summertime temperatures have been associated with a dieback in the seagrass, eelgrass, in the high salinity regions of the lower bay and lower James River. Eelgrass is a cool temperature adapted species that suffers from summertime diebacks in the warm, southern limits of its distribution along the east coast of North America. In contrast, the freshwater SAV species in the Chesapeake Bay region, such as wild celery, found in the upper James River, flourish throughout the summer and are not severely affected by water temperatures exceeding 30 °C.

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. During 2005 the SAV restoration sites demonstrated a gradual increase in salinity throughout the March-October growing season to a maximum of 500 μ mhos (approximately 0.3 psu salinity). During low flow years shallow water salinities increased to nearly 1000 μ mhos (0.5 psu salinity) in the fall of 1999, 2000 μ mhos (1.0 psu salinity) in the fall of 2001 and 3500 μ mhos during the late summer and fall of 2002 (>6.0 psu salinity), and did not return to freshwater conditions until the late fall. In 2002, increases to 6.0 psu were associated with diebacks in SAV transplants at the most downstream stations of Westover Plantation, Powell's Creek and Tar Bay where salinities were highest. No such effects of the much lower salinities in 2005 were evident.

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. During 2005 several low DO observations were made, however, no levels were observed below 5 mg/l.

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, in part, related to salinity. The highest salinities observed here typically buffer pH between 7.5 and 8.0. The pH dropped markedly in the fall of 2002 as river flow increased and salinity decreased. Levels were unusually low at Westover during the winter of 2002. This was not repeated during the winters of 2003, 2004 or 2005.

Suspended particle loads (TSS) have been remarkably consistent among years regardless of river flow and salinity. In 2005 TSS levels were again higher during the summer even though river flow is lower than the spring. This suggests that much of the suspended material is

reworked or retained within this region of turbidity maximum. Concentrations have been consistently lowest at the Shirley Cove station (Fig. 3-5) where the protected conditions allow for particle settlement. Table 1 presents median annual TSS concentrations throughout the SAV growing season (April 1- October 31) for each of the transplant sites. Suspended sediment concentrations in 2005 during the SAV growing season were similar to previous years and ranged from 24-38 mg/l. These are above the bay-wide 15 mg/l targets for SAV growth to 1m.

Chlorophyll levels in 2005 demonstrated increases over 2004 and increased from the spring into the summer (Fig. 3-6). Levels declined in the fall but occasional high spikes were observed in September and October. This may reflect decreased river flow and increased phytoplankton residence time in this region of the James. Much higher levels were observed in 2002 when the river flow water greatly reduced and somewhat lower levels in 2003 and 2004 when river flows were higher. SAV growing season median chlorophyll concentrations are presented in Table 1. Although levels in 2005 were higher than 2003 and 2004 concentrations met the targets (<15 µg/l) associated for established SAV growth (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) for the years 1999-2005. During the spring of 2005 levels at all the transplant sites met the numeric chlorophyll standards for that season and the trend over time has been for increasing standards attainment since 2003. Summertime phytoplankton concentrations in 2005 were higher than 2003 or 2004 and exceeded numeric chlorophyll standards at all but one site in 2005.

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. SAV growing season secchi depths for SAV growth to 0.5m have been generally close to the goal of 0.4m secchi depth although mean depths were slightly below these levels during 2005 at many of the sites (Table 1). This suggests that light continues to be marginal for SAV growth at depths shallower than 0.5m in this region.

Total organic carbon (TOC) concentrations demonstrated some seasonality with higher levels during the summer as in previous years (Fig 3-8). Over the past 5 years concentrations were 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 up to the present compared to before 2002 suggesting a possible long-term decrease.

Throughout the study period nitrate + nitrite levels (Fig. 3-11) have been quite variable, although levels have been highest in the fall and winter. Nitrate and nitrite generally represent “new” nitrogen entering the system. 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. Levels during 2005 were lower than average during the summer increasing again in the fall and winter. In general there is no trend evident over time. High levels of ammonium (Fig. 3-12) that were

observed for all stations during the fall of 2001 have not re-occurred since that time and only a few concentrations above detection were observed in the fall of 2005.

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 and met the criteria in 2005 at all sites (Table 1). The long-term trend of increasing growing season median concentrations from 1999 to 2003-2004 ended in 2005. These increases may be related to the relatively higher river flows in 2003 and 2004 and lower flows in 2005. In general DIP concentrations do not appear excessive for SAV growth in this region.

3.1.2 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 at approximately monthly intervals from April through October 2005. Levels of turbidity, chlorophyll and dissolved oxygen along with the July 2005 cruise track are presented in Fig. 3-14 to illustrate the sampling area. Continuous surface dissolved oxygen (DO) concentrations from the mouth of the Chickahominy River (mile 0.0) to the limits of tidal influence in Richmond (Figs. 3-15a-g) are presented in chronological order. Open areas in the data plots are due to losses of data as a result of equipment malfunction. Seasonally, DO levels decreased from April through August (Figs 3-15a-e), then rebounded slightly in September and October (Figs 3-15f-g). A DO sag was evident in the lower JMSTF1 segment just upriver from the Chickahominy River and down river from the chlorophyll maximum. This DO sag increased throughout the spring and summer when surface DO levels were observed to be below 4 mg/l for approximately 8 km during the August 15, 2005, cruise (Fig 3-15e). Except for this region of the river during July, August and

September (Figs. 3-15d-f) surface DO levels were above 6 mg/l throughout the JMSTF1 segment and only occasionally below 6 mg/l in the upriver JMSTF2 segment.

Continuous surface measurements of chlorophyll for every cruise are presented in Figures 3-16a-g. Spatially averaged monthly cruise chlorophyll concentrations for each of the JMSTF segments are presented in Table 3. The in vivo Dataflow fluorescence measurements were corrected relative to the extracted chlorophyll pigment values taken at the Dataflow calibration sites by first developing a regression of extracted chlorophyll to fluorescence chlorophyll using all the paired (extracted to in vivo) 2005 verification station data. This regression was then used to convert the in vivo Dataflow chlorophyll data to corrected values comparable to those obtained at the fixed, restoration stations. Highest chlorophyll levels were generally observed in the SAV transplant region (Westover to Turkey Island; cruise miles 20-40) with several peaks of phytoplankton extending for distances of two miles or more. Lowest concentrations of chlorophyll were usually observed in the most upriver reaches of the James between the I-95 and I-295 bridges (cruise miles 50-60) and the lower reaches of the bay segment JMSTF2 just upriver from the Chickahominy River (cruise miles 5-20). Concentrations of chlorophyll were highest in the upper JMSTF1 and lower JMSTF2 segments (cruise miles 20-50) where they increased steadily from lows in April to highs in July, decreasing again to low levels in October. Patchiness of the phytoplankton was evident with bloom patches ranging for less than a mile to 10 miles in length. Overall these results demonstrate the considerable spatial variability in chlorophyll concentration along the tidal freshwater James.

The distribution of turbidity was relatively consistent throughout most of the tidal freshwater segments (Figs. 3-17a-g) with highest levels observed in April (Fig. 3-17a). Lowest turbidities generally occurred in the region above the I-295 bridge (above cruise mile 50).

Isolated peaks in turbidity were often associated with peaks in chlorophyll suggesting some contribution of phytoplankton to overall turbidity in these bloom areas. Individual patches of higher (1-5 NTU) turbidity water were found all along the river. These generally varied from <1 to 5 mile in length. Dataflow NTU corresponding to SAV water clarity goals (13% of light to the bottom; 9 VAC 25-260 – Virginia Water Quality Standards, May 2004) for SAV growth to 0.5m (JMSTF1) was calculated using calibration station simultaneous measurements of Dataflow NTU and light attenuation profiles to K_d :

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

This relationship indicates that for tidal freshwater SAV growth to 0.5 m (3.6 K_d or 0.4 m secchi), a turbidity of 36 NTU or less should be the goal. Overall, both segments would meet this goal throughout most of the year, except during the April 2005 cruise when some areas were above this level.

Table 3 presents the spatially integrated in vivo turbidities and in vivo corrected chlorophyll for the JMSTF1 and JMSTF2 segments for each of the sampling cruises. Integrated chlorophyll levels that met the numeric standards (9 VAC 25-260, Virginia Water Quality Standards, November 2005) for either the spring (JMSTF1, 15 $\mu\text{g/l}$; JMSTF2, 23 $\mu\text{g/l}$) or summer (JMSTF1, 10 $\mu\text{g/l}$; JMSTF2, 15 $\mu\text{g/l}$) are shaded in gray. June and October 2005 cruises did not fall in either season. Both the April and July cruises measured average levels of chlorophyll that were above the criteria for the spring and summer respectively in both segments.

Integrated turbidity levels for the JMSTF1 and JMSTF2 segments are presented in Table 3 for each monthly cruise. Spatially averaged turbidity levels corresponding to the SAV water clarity criteria of 36 NTU (13% of light to the bottom at 0.5m; 9 VAC 25-260 – Virginia Water Quality Standards, May 2004) were found to meet this standard overall. This supports our SAV

transplant results that water clarity in 2005 was generally suitable for SAV growth to very shallow depths of 0.5m in this region.

3.2 SAV Transplant Survival

The use of wild celery seeds and seed pods proved to be an effective method of transplanting wild celery propagules. Seeds harvested in the fall of 2004, held at 4 °C and then dispersed into the bottom in the spring of 2005, germinated and sprouted successfully. Germination percentage could not be determined due to the low visibility and small size of the seedlings, however recent work by Campbell (2005) using seed stock from the same donor site determined that percent germination can range from 10-80% depending on environmental conditions. Figure 3-18 provides a comparison of transplant success with whole shoots compared to seedling bottom cover for each of the transplant sites. Densities of each treatment were dependent on initial planting densities so seedling cover measurements are presented as the proportion of bottom area in the transplant area with seedling present. Previous work here (Moore et al. 2005) has found that whole plants of wild celery will reach near natural bed densities after approximately three growing seasons when initially transplanted at 20 cm spacing. Both the seeds and the seed pods appeared to remain in the bottom areas where they were dispersed and required approximately one month or less of time to sprout and produce seedlings. There were no apparent site differences significantly affecting the seed germination. Campbell (2005) found that seeds of wild celery typically had higher germination rates in sandy sediments vs. more muddy sediment types. She also found that the time to germination increased as temperatures increased. A temperature threshold for germination was found to be approximately 15 °C. At temperatures between 20-30 °C the mean time to germination was found to decrease from 12 days to 7 days. Water temperatures during transplanting were below this threshold, so the period of several

weeks to a month required for germination and sprouting observed here is consistent with her results. By the mid summer, approximately 20% to 50% of the seeded area had viable seedlings. Transplanted whole shoots suffered some initial mortality resulting in 40% to 70% survival. Significant growth was evident however, and flowering and reproductive shoots were observed in August. Shoots reached over 1 m in length by mid-summer.

Herbivory of shoots and seedlings proved to be a problem in 2005 for unprotected plants as it had in earlier years (Figure 3-19). Whole shoots were rapidly grazed with only 20% to 40% survival by July and no plant survival was observed outside of the exclosures by the end of the summer. Although initial germination of seeds outside of the exclosures was comparable to those inside the exclosures, once the seedlings reached approximately 10 cm in height they were found to be cut off to a height of 1-2 cm. One strategy for successful growth and survival of wild celery in these high turbidity but historically vegetated regions of the James River is the capacity of the plants to elongate such that the leaves can reach closer to the water surface to gather adequate light for growth. When subject to continual cropping the plants rapidly use up stored reserves and die.

Transplants efforts at the Harrison Lake Fish Hatchery using seeds and seed pods were generally not successful in 2005. One major issue with the use of the hatchery ponds in 2005 was the development of large masses of freshwater algae, including muskgrass (*Chara*), which smothered the SAV. After the growth of the algae, salt was added to the pond to bring the salinity up to 2-3 psu to kill the algae and allow for growth of the wild celery. Although growth of wild celery is reduced with increasing salinity, levels below 5 psu do not not inhibit survival (French and Moore 2003). These levels are, however, sufficient to kill the freshwater algae. The addition of salt was not possible until the end of the growing season in 2005 so the effects on

survival of the wild celery in 2005 was limited. Transplanting using seeds will therefore be attempted again in 2006.

4.0 CONCLUSIONS

Water quality monitoring in the tidal James River in 2005 indicated continued adequate water quality for SAV growth. Turbidity levels, while highest in the upper JMSTF1 segment and lower JMSTF2 segment, were suitable for SAV growth to depths of 0.5m. In part, this is due to the availability of light at low tidal periods when shoot leaves can reach the water's surface. Phytoplankton levels, measured as chlorophyll, were largely within surface chlorophyll standards and criteria for SAV growth in most areas. When integrated spatially across the entire segments using Dataflow continuous measurements, concentrations were found to generally be within criteria, except during the mid summer. Phytoplankton did appear to contribute to reduced water clarity, however, this proportion was much smaller than that related to suspended sediments. Nutrient levels generally paralleled those of earlier years and no increasing trends since 1999 were evident. Summertime chlorophyll levels in 2005 were higher than in 2004, but much lower than those observed in 2001 and 2002. These differences may be related to water residence time in the tidal freshwater region of the James River, with highest concentrations generally observed during lower flow years. Higher salinities, and therefore lower flow and reduced flushing in 2005 may have resulted in slightly higher chlorophyll levels during the summer of 2005.

Wild celery transplanting using seeds and seed pods was generally successful. Both methods produced seedlings that were able to grow and become established. Since the seedlings became established within a few meters of where the seeds were distributed, seeding of specific locations may be possible. Given the potential for flooding in the James during the winter and spring, and the chance for excessive scour of the bottom during these floods, it is not recommended that

seeds be transplanted during the fall immediately after collection. Since they will not germinate until water temperatures increase above 15 °C in the following spring, over-winter storage at 4 °C until seeding in the spring seems prudent. Storage is no problem since the seeds are very small (1-2mm in length) and each seed pod (5-10 cm in length) holds 100-150 seeds. Therefore thousands of seeds can be held in a small, refrigerated space.

Constraints on SAV restoration in this region continue to be herbivory of shoots by blue crabs and possibly other animals including turtles, fish and birds. Restoration using seeds provides the potential to establish larger SAV beds than those possible using whole shoots. This may reduce the effective grazing pressure on these larger recolonization beds, as has been observed in regions such as the upper Potomac river where SAV recovery has occurred. In the spring 2006 we will be dispersing seeds collected in the fall of 2005 over much larger areas to test this effect. In addition, a companion species, water stargrass (*Heteranthera dubia*), was collected during the fall of 2005 from the non-tidal James River where it co-occurs with wild celery. Grow-out ponds at VIMS were planted with this species to provide another potential SAV species for restoration use in this tidal freshwater James River region in 2006.

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APPENDIX A

TABLES

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

Water Quality Parameter	SAV Habitat Criteria	Turkey Island						
		1999	2000	2001	2002	2003	2004	2005
Light Atten.(Kd; m ⁻¹)	< 3.6	-	-	-	3.6	3.26	3.91	3.48
Secchi Depth (m)	> 0.40	0.30	0.45	0.39	0.40	0.40	0.30	0.35
TSS (mg/l)	<15	33.5	26.0	31.5	30.0	26.0	35.0	32.0
Chl a (ug/l)	<15	11.1	30.8	30.4	44.8	6.6	9.2	12.5
DIP (mg/l)	<0.02	0.01	0.02	0.02	0.02	0.03	0.03	0.02

Water Quality Parameter	SAV Habitat Criteria	Shirley Cove						
		1999	2000	2001	2002	2003	2004	2005
Light Atten.(Kd; m ⁻¹)	< 3.6	-	-	-	3.54	2.38	2.83	3.33
Secchi Depth (m)	> 0.40	0.40	0.55	0.40	0.40	0.50	0.45	0.45
TSS (mg/l)	<15	21.0	19.0	22.0	24.0	16.0	21.0	24.0
Chl a (ug/l)	<15	13.7	27.5	37.0	56.0	8.80	5.65	9.3
DIP (mg/l)	<0.02	0.01	0.01	0.01	0.02	0.03	0.03	.01

Water Quality Parameter	SAV Habitat Criteria	Tar Bay						
		1999	2000	2001	2002	2003	2004	2005
Light Atten.(Kd; m ⁻¹)	< 3.6	-	-	-	4.20	3.96	3.65	3.68
Secchi Depth (m)	> 0.40	0.35	0.40	0.35	0.40	0.40	0.35	0.40
TSS (mg/l)	<15	31.00	28.00	29.5	34.50	24.0	32.0	28.0
Chl a (ug/l)	<15	12.00	26.7	39.1	41.90	4.90	5.30	15.3
DIP (mg/l)	<0.02	0.02	0.02	0.02	0.02	0.03	0.03	.02

Water Quality Parameter	SAV Habitat Criteria	Powell's Creek						
		1999	2000	2001	2002	2003	2004	2005
Light Atten.(Kd; m ⁻¹)	< 3.6	-	-	-	4.07	3.41	4.41	4.20
Secchi Depth (m)	> 0.40	0.30	0.50	0.33	0.40	0.40	0.30	0.40
TSS (mg/l)	<15	37.5	29.0	36.0	35.5	31.0	38.00	38.0
Chl a (ug/l)	<15	12.6	43.2	24.0	42.5	6.40	5.90	13.6
DIP (mg/l)	<0.02	0.01	0.02	0.02	0.02	0.03	0.03	.01

Water Quality Parameter	SAV Habitat Criteria	Westover						
		1999	2000	2001	2002	2003	2004	2005
Light Atten.(Kd; m ⁻¹)	< 3.6	-	-	-	4.03	3.07	4.26	3.68
Secchi Depth (m)	> 0.40	-	-	0.40	0.40	0.40	0.30	0.35
TSS (mg/l)	<15	-	-	30.00	30.00	26.00	32.00	36.0
Chl a (ug/l)	<15	-	-	32.40	40.85	5.60	7.20	11.2
DIP (mg/l)	<0.02	-	-	0.02	0.02	0.03	0.03	.01

Table 2. Mean (March-May and July-September) chlorophyll concentrations at SAV transplant sites for 1999 through 2005. Shaded indicates seasonal criteria 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 1999	4.0	5.2	2.8	3.8	-
Mar-May 2000	36.8	30.3	28.4	33.3	-
Mar-May 2001	32.6	28.4	23.0	19.9	22.0
Mar-May 2002	23.5	24.0	18.8	20.8	27.0
Mar-May 2003	10.8	12.0	8.9	10.5	14.7
Mar-May 2004	6.0	6.7	5.4	6.7	6.4
Mar-May 2005	4.3	4.0	5.8	6.5	5.3
Jul-Sep 1999	41.7	42.1	39.1	38.9	-
Jul-Sep 2000	26.9	37.6	29.2	44.2	-
Jul-Sep 2001	26.7	38.9	34.6	26.4	31.8
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
Jul-Sep 2005	27.7	26.0	26.3	21.3	25.1

¹ JMSTF 1 – Seasonal Chlorophyll Criteria: March 1-May 31 (15 µg/l); July 1-Sept 30 (23 µg/l)
 JMSTF 2 – Seasonal Chlorophyll Criteria: March 1-May 31 (10 µg/l); July 1-Sept 30 (15 µg/l)

Table 3. 2005 Spatially Averaged Dataflow Turbidity and Chlorophyll for the James River Tidal Freshwater Segments.
 Shaded indicates SAV turbidity or chlorophyll criteria limits met. No Chlorophyll Criteria Applicable for June or October.

	April 7, 2005				May 4, 2005				June 3, 2005			
	Chlorophyll ¹		Turbidity ²		Chlorophyll ¹		Turbidity ²		Chlorophyll ¹		Turbidity ²	
	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.
JMSTF1	4.10	0.02	34.30	0.03	17.47	0.20	21.35	0.10	14.60	0.16	16.30	0.15
JMSTF2	2.93	0.05	35.69	0.14	9.88	0.20	15.20	0.10	25.40 ³	0.19	17.50 ³	0.27

	July 1, 2005				August 15, 2005				September 13, 2005			
	Chlorophyll ¹		Turbidity ²		Chlorophyll ¹		Turbidity ²		Chlorophyll ¹		Turbidity ²	
	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.
JMSTF1	32.40	0.57	20.80	0.12	18.90	0.30	21.00	0.13	28.00	0.38	17.70	0.29
JMSTF2	29.10	0.54	12.50	0.22	12.20	0.27	9.00	0.15	24.60	.38	10.00	0.14

	October 27, 2005			
	Chlorophyll ¹		Turbidity ²	
	Mean (µg/l)	S.E.	Mean (NTU)	S.E.
JMSTF1	8.20	0.06	22.00	0.10
JMSTF2	6.00	0.09	11.00	0.09

¹ Measured directly through DATAFLOW in vivo fluorescence and corrected by extracted chlorophyll.

JMSTF 1 – Seasonal Chlorophyll Standards: March 1-May 31 (15 µg/l); July 1-Sept 30 (23 µg/l)

JMSTF 2 – Seasonal Chlorophyll Standards: March 1-May 31 (10 µg/l); July 1-Sept 30 (15 µg/l)

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

³ Incomplete data for JMSTF2 on June 3, 2005 due to technical issues

APPENDIX B
FIGURES

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

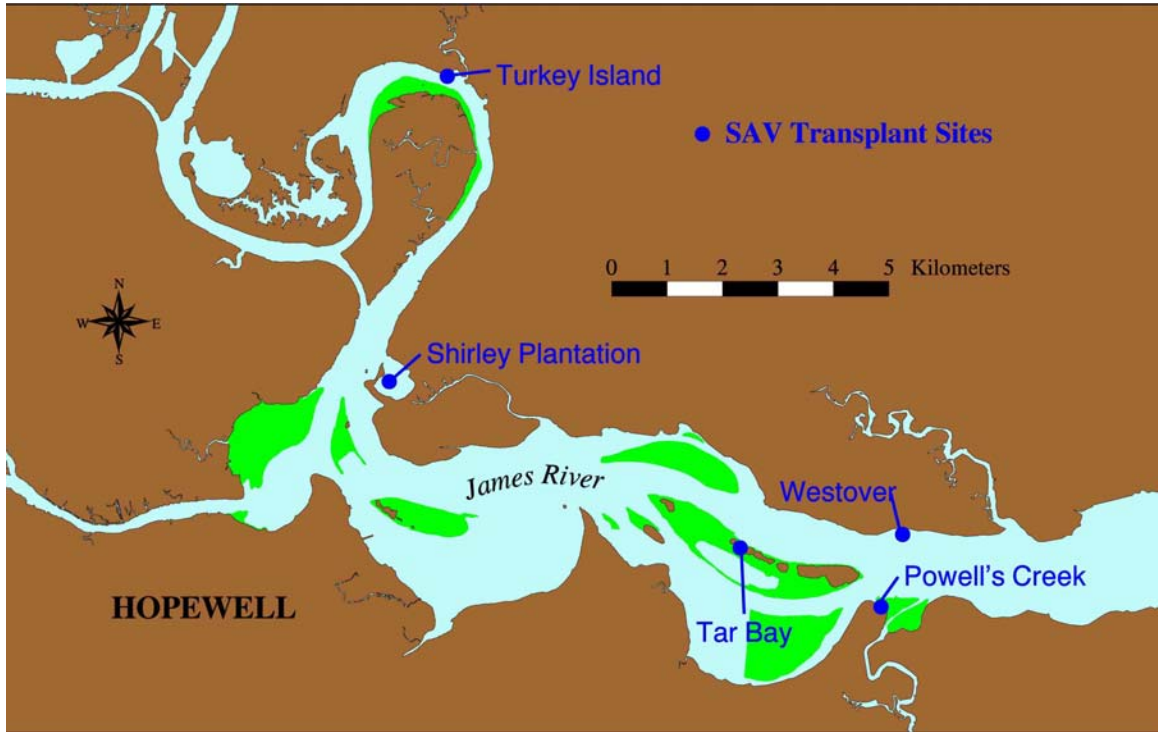


Figure 2-2. Westover SAV Transplant Site With Exclosures



Figure 2-3. Wild Celery Seed Pod With Seeds



Figure 2-4: Wild Celery Seeds Used for Transplanting



Figure 3-1. Water Temperature

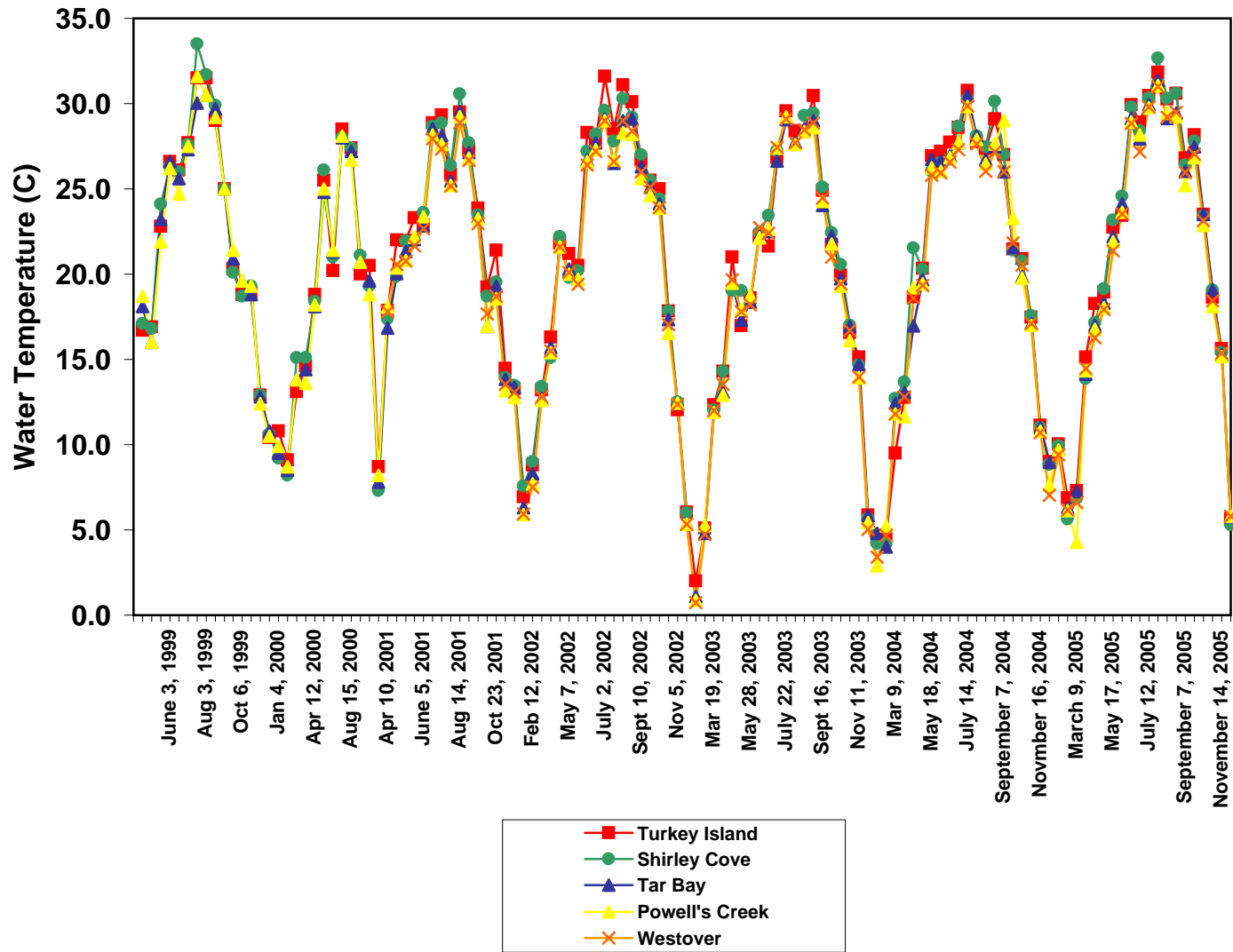


Figure 3-2. Conductivity

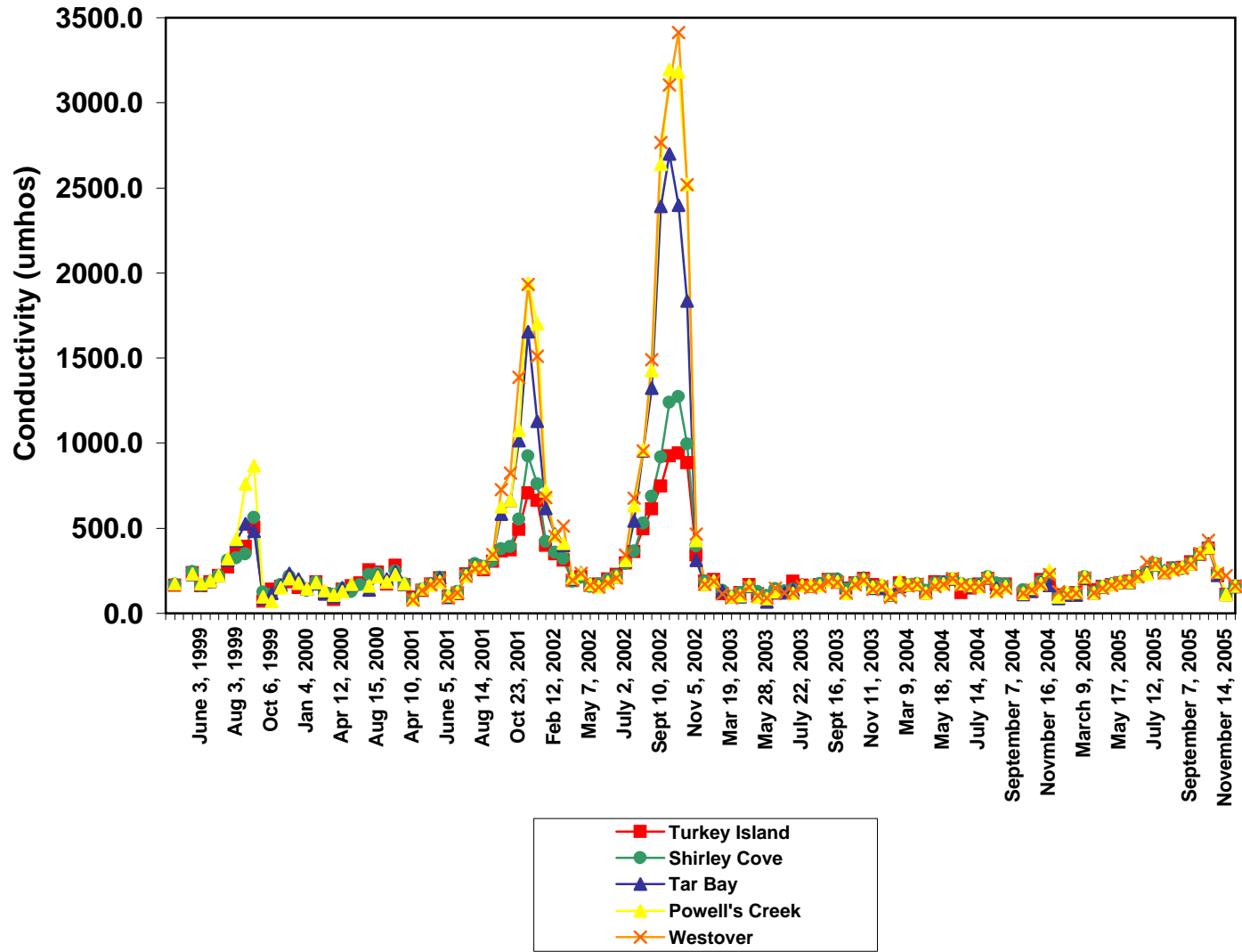


Figure 3-3. Dissolved Oxygen

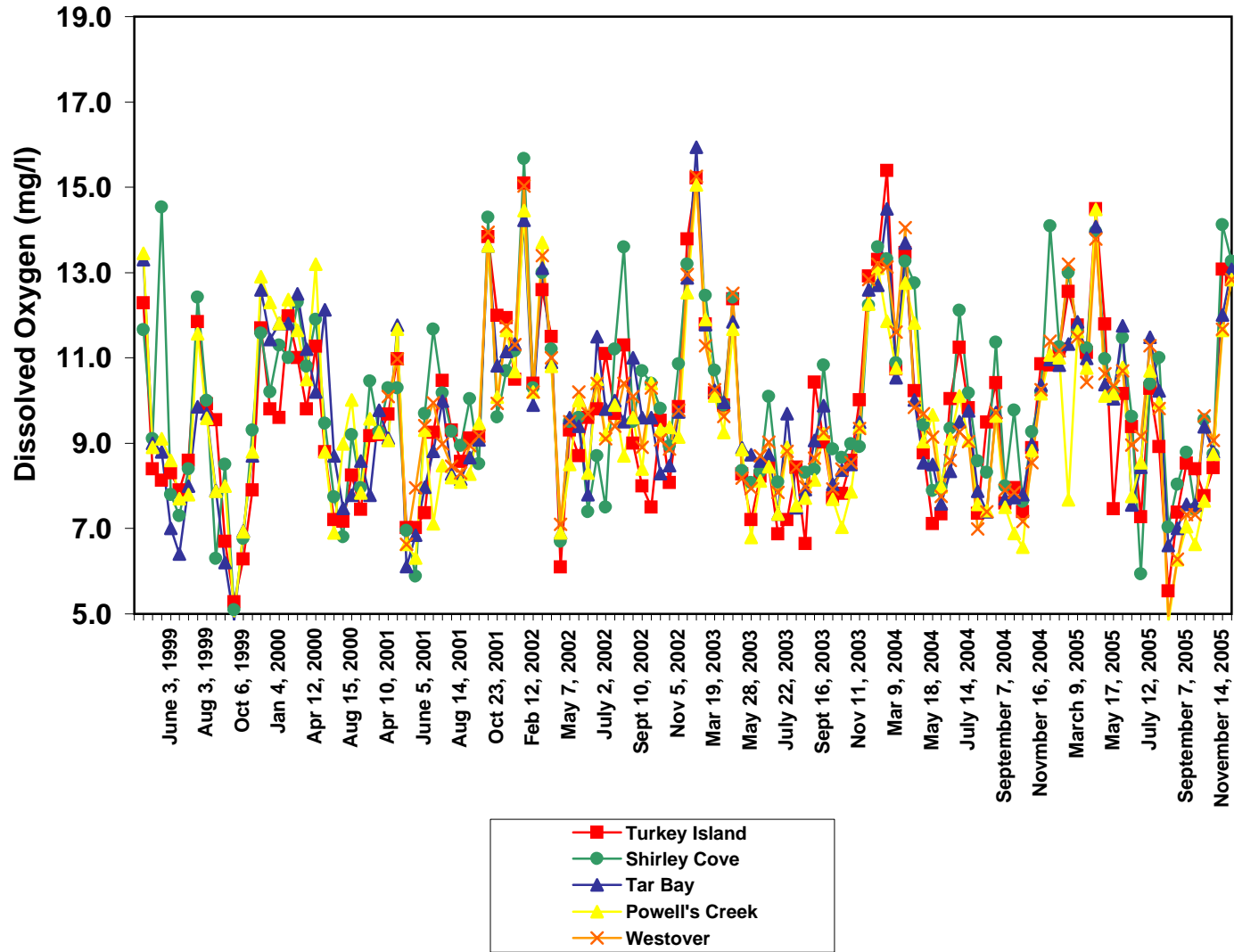


Figure 3-4. Water Column pH

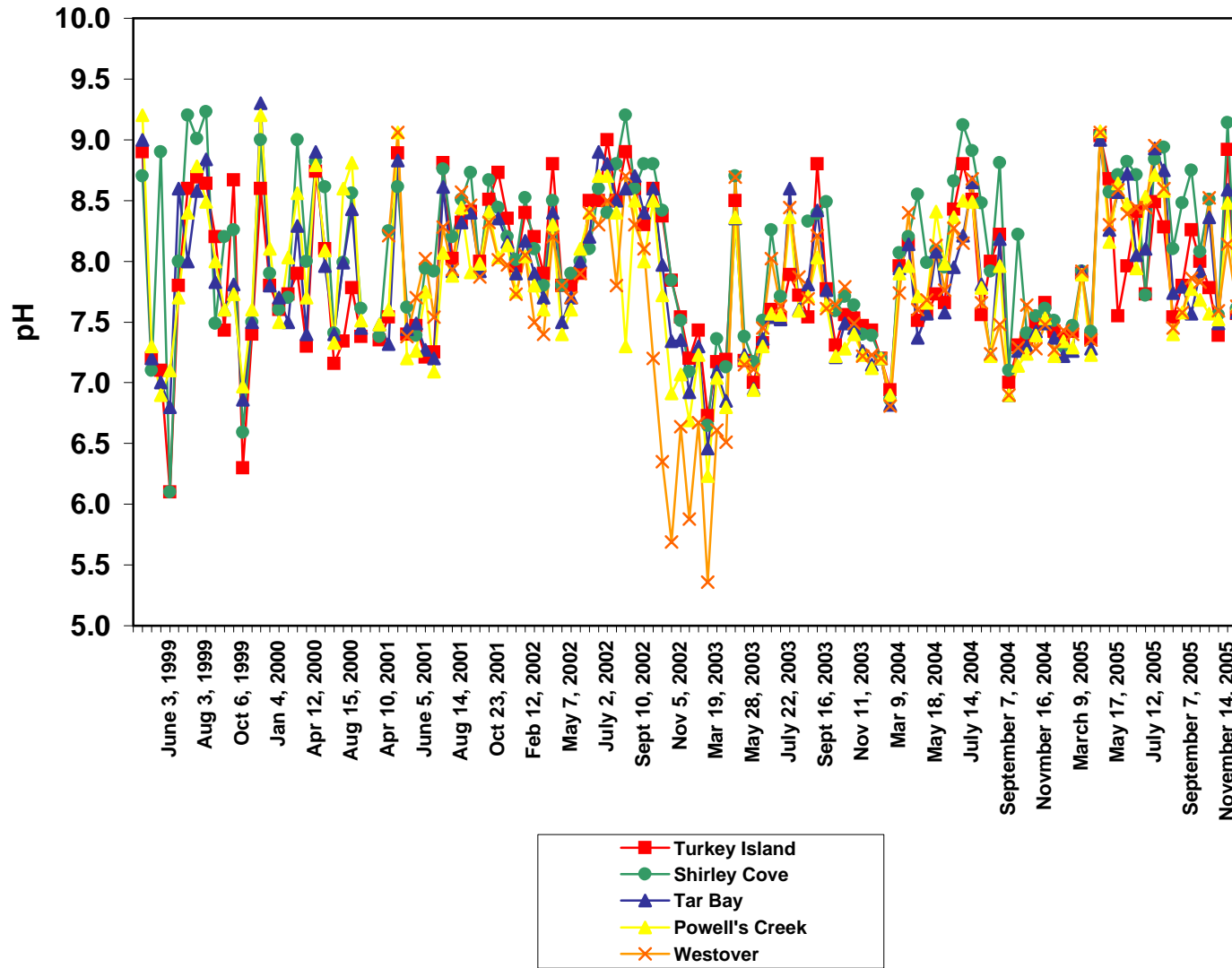


Figure 3-5. Total Suspended Solids (TSS)

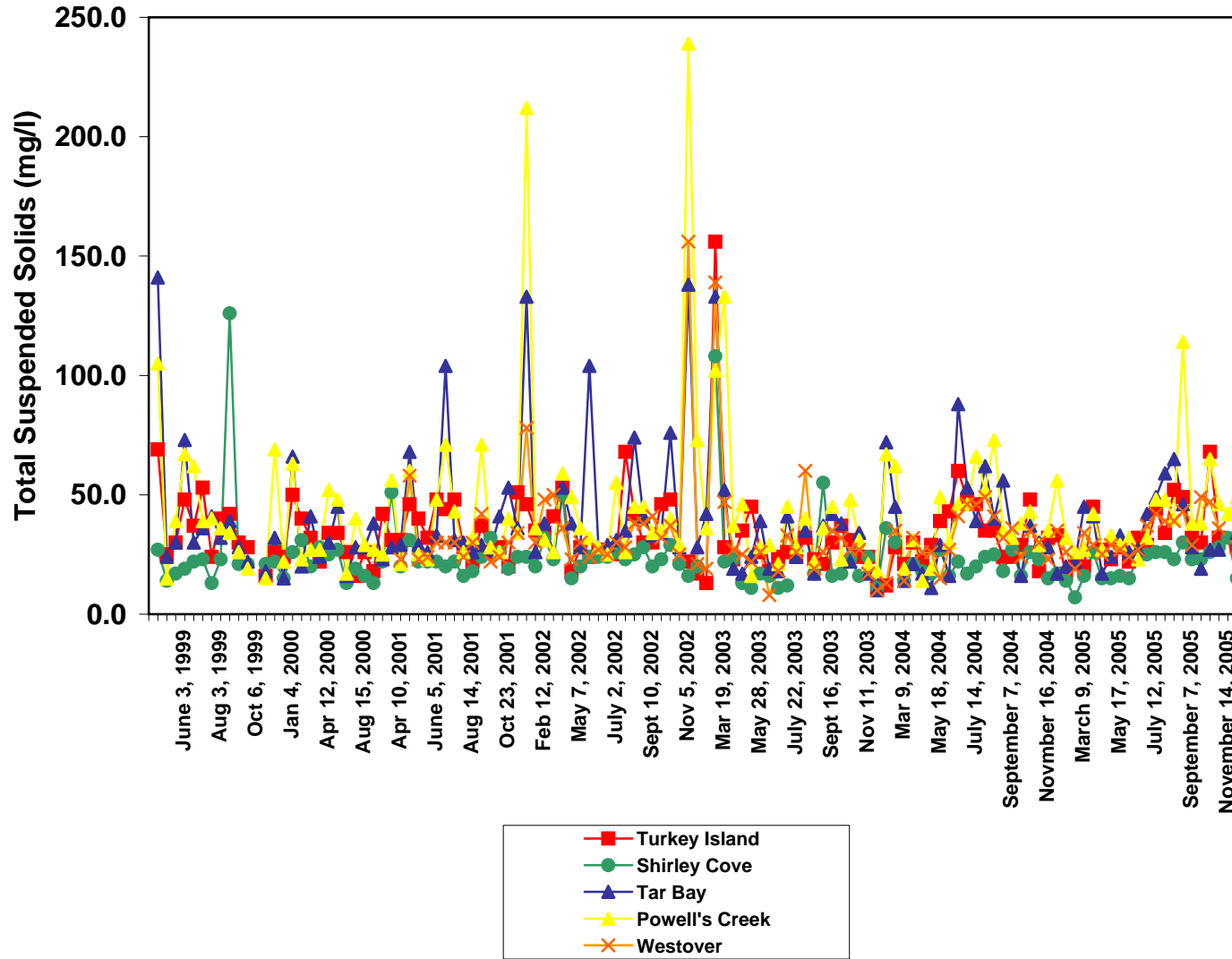


Figure 3-6. Phytoplankton as Chlorophyll a

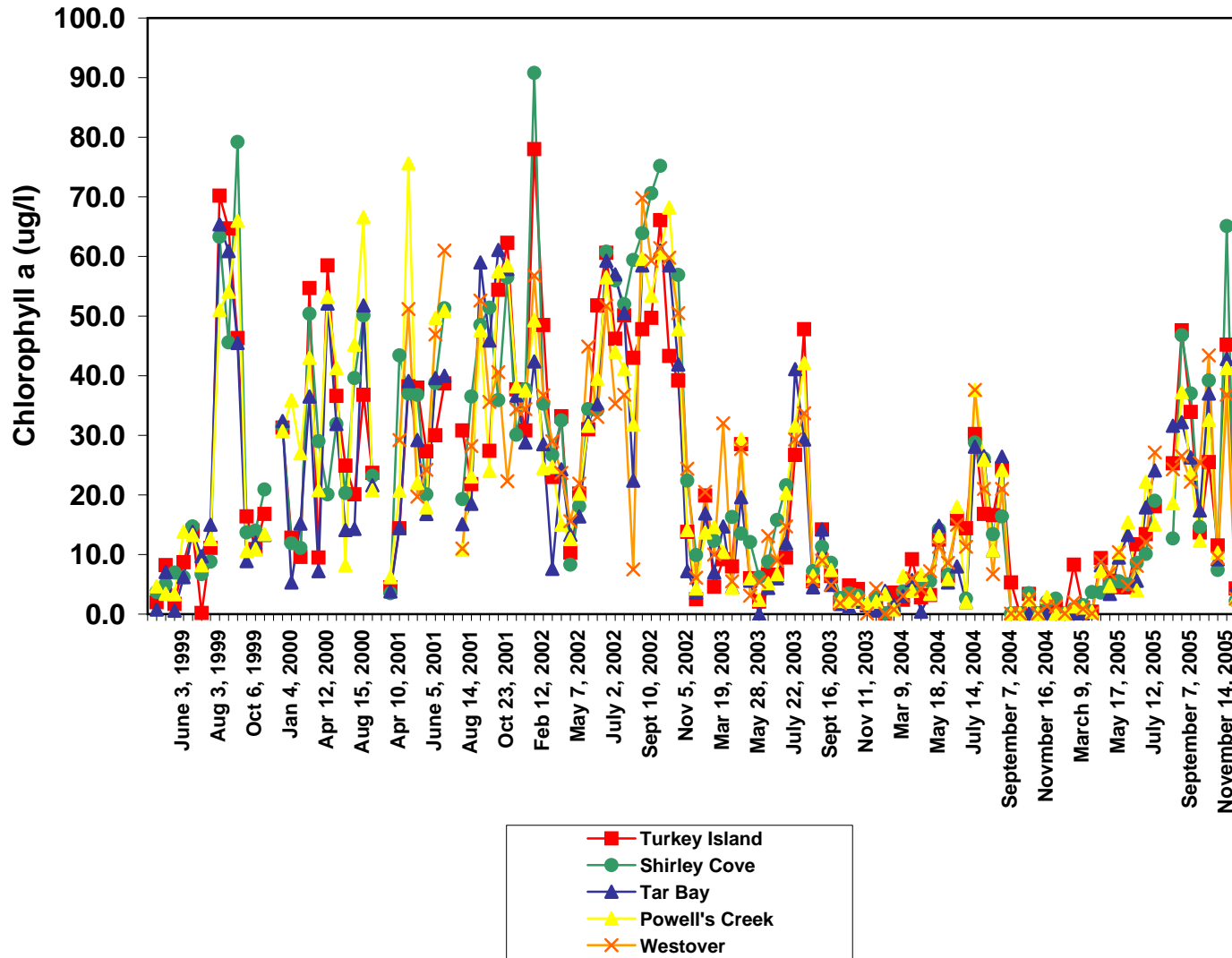


Figure 3-7. Secchi Depth

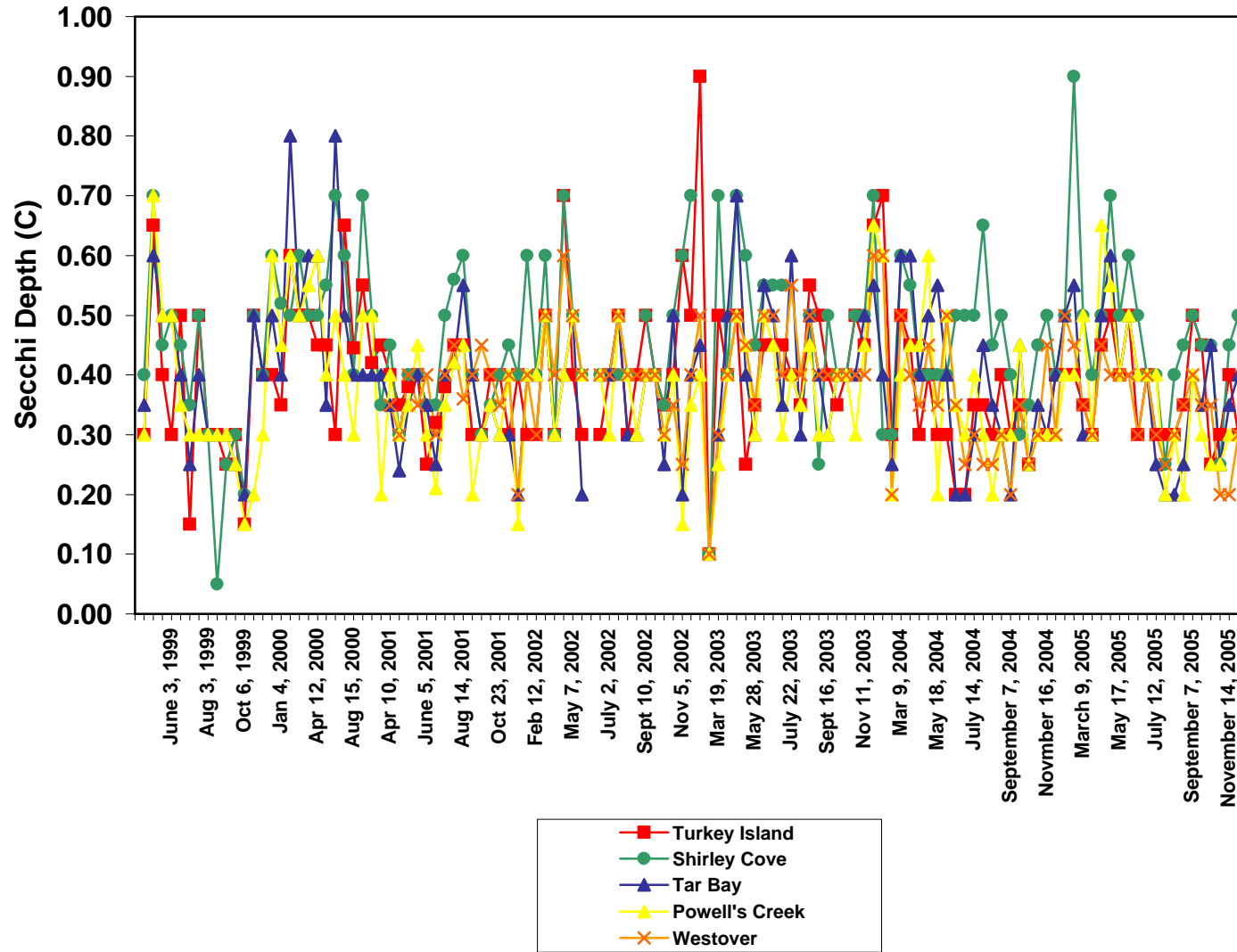


Figure 3-8. Total Organic Carbon (TOC)

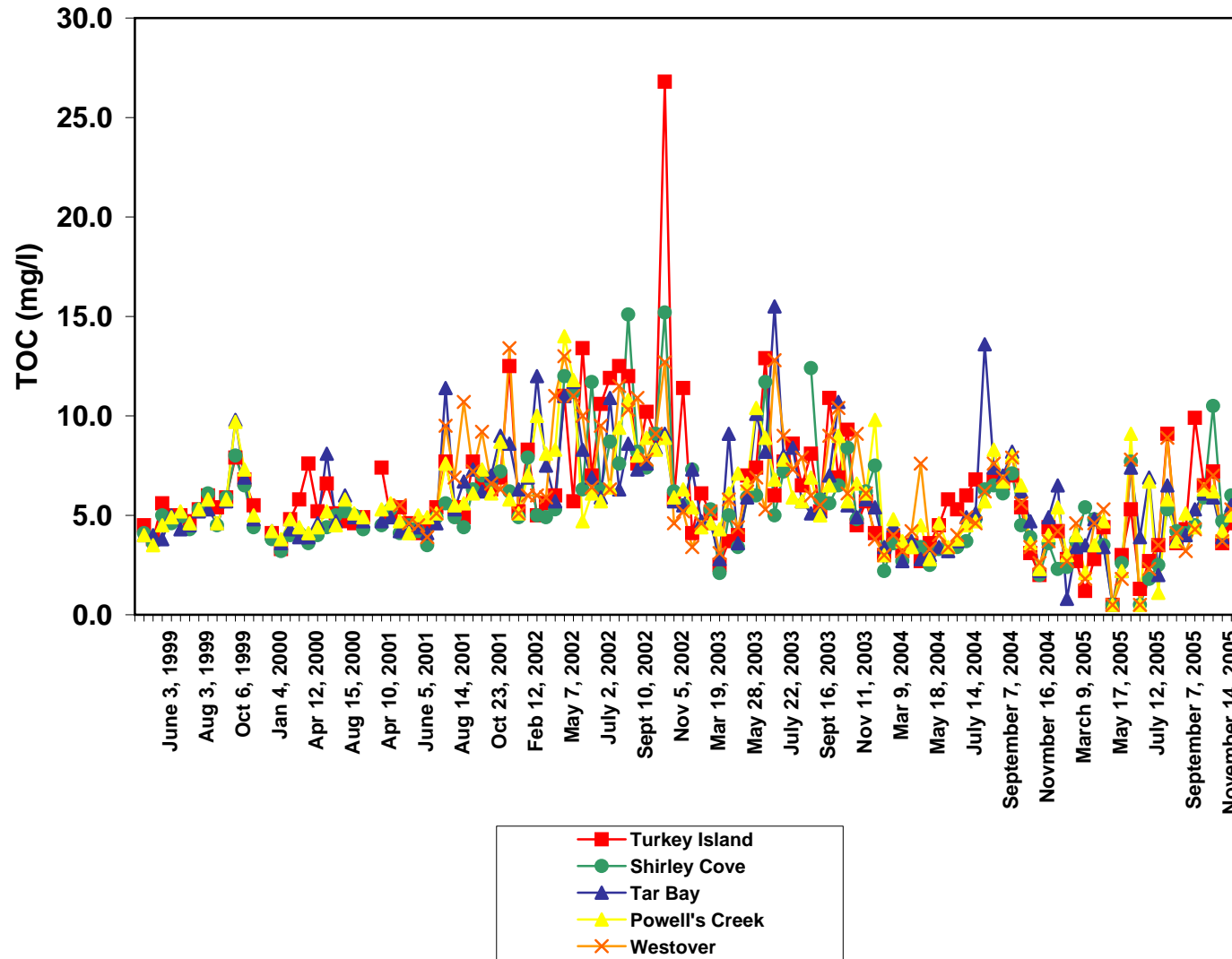


Figure 3-9. Total Kjeldahl Nitrogen (TKN)

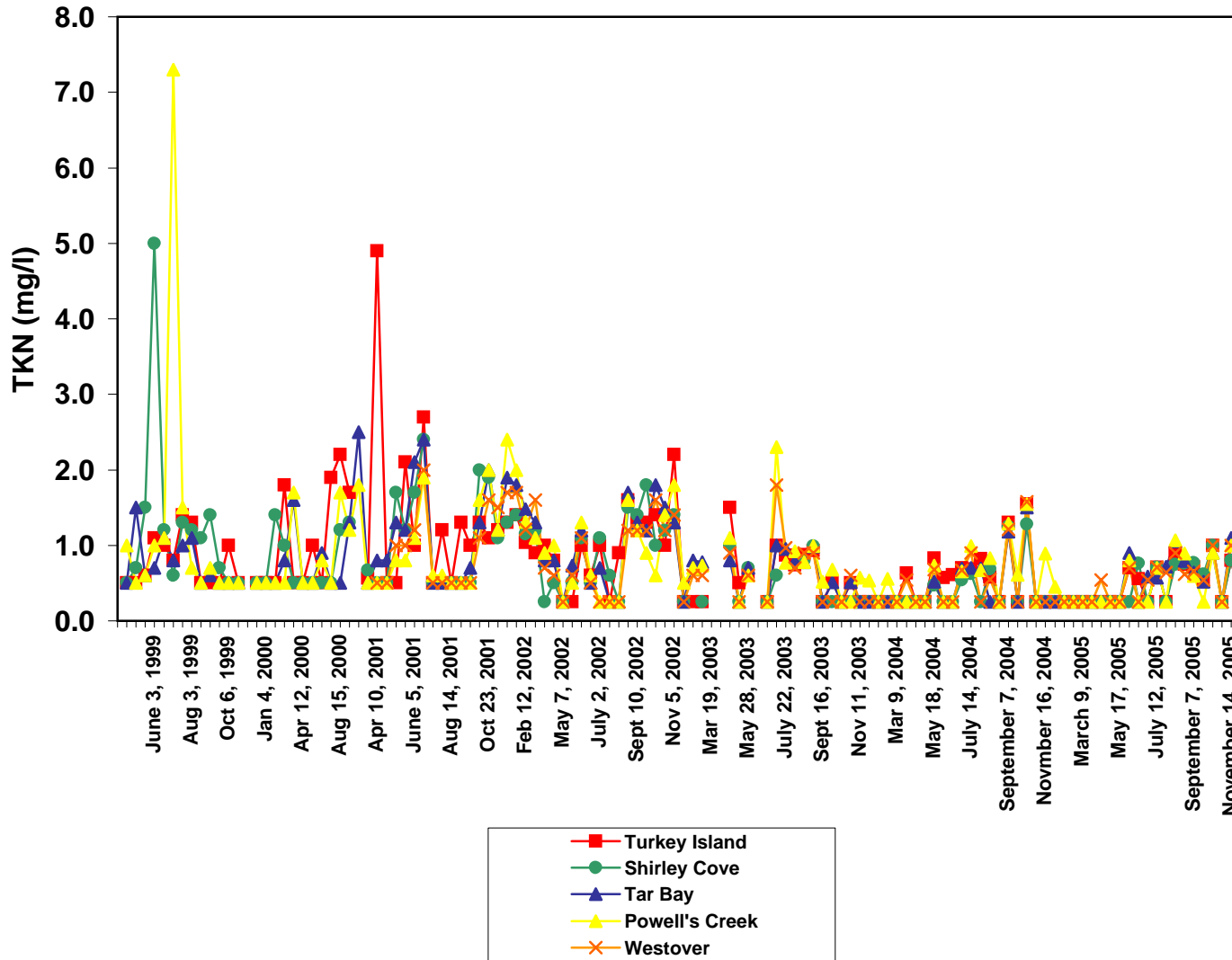


Figure 3-10. Total Phosphorus (TP)

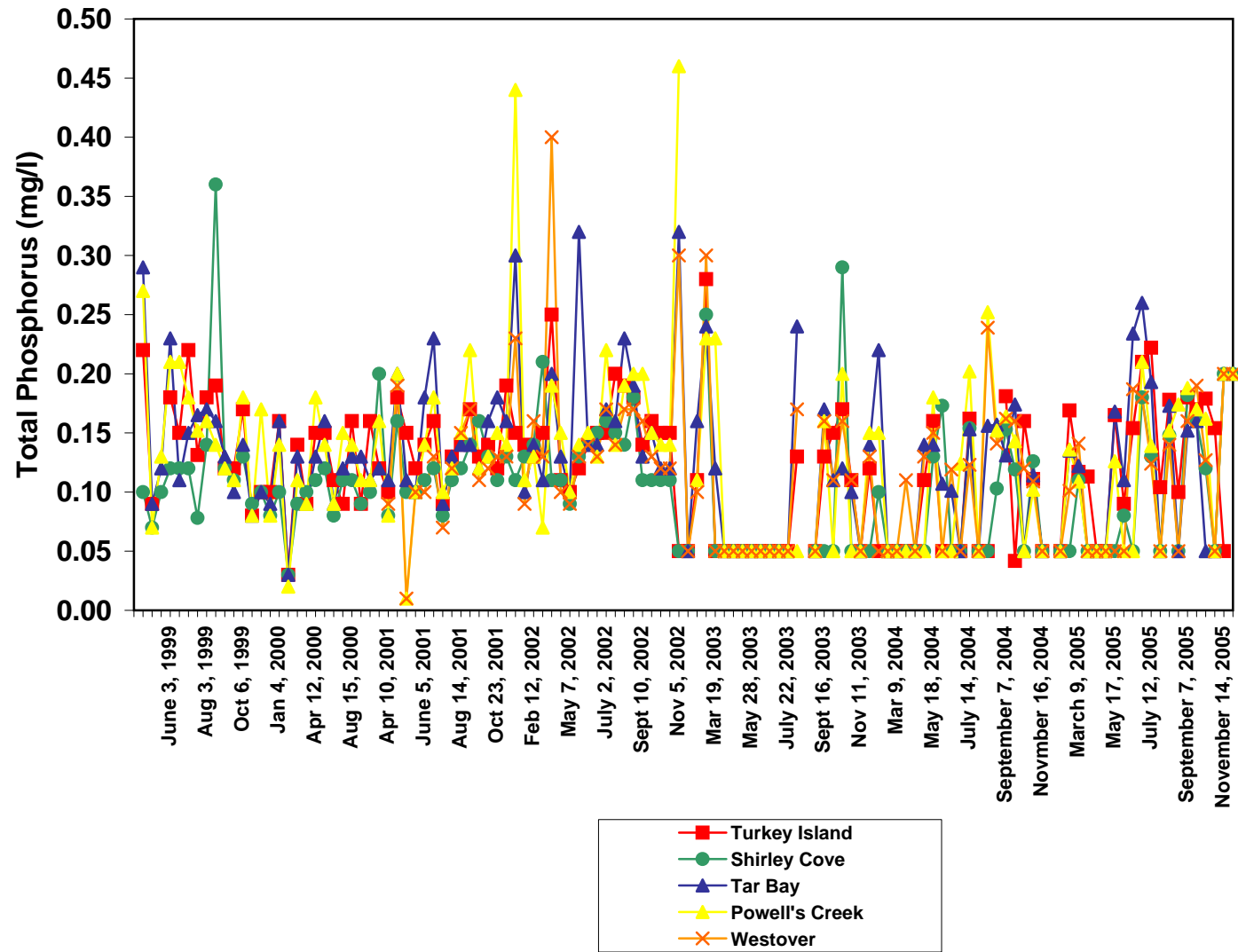


Figure 3-11. Dissolved Nitrate + Nitrite

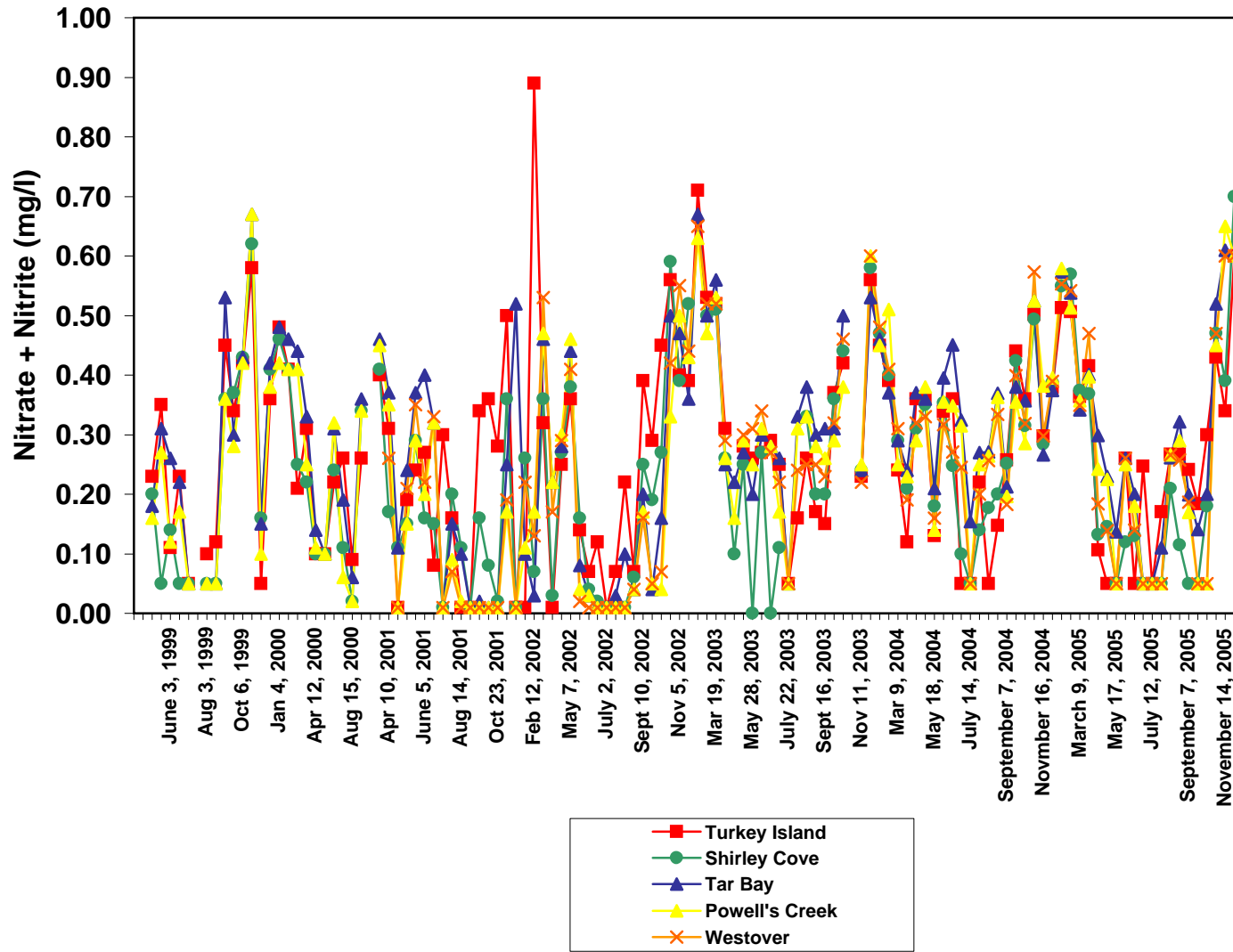


Figure 3-12. Dissolved Ammonium

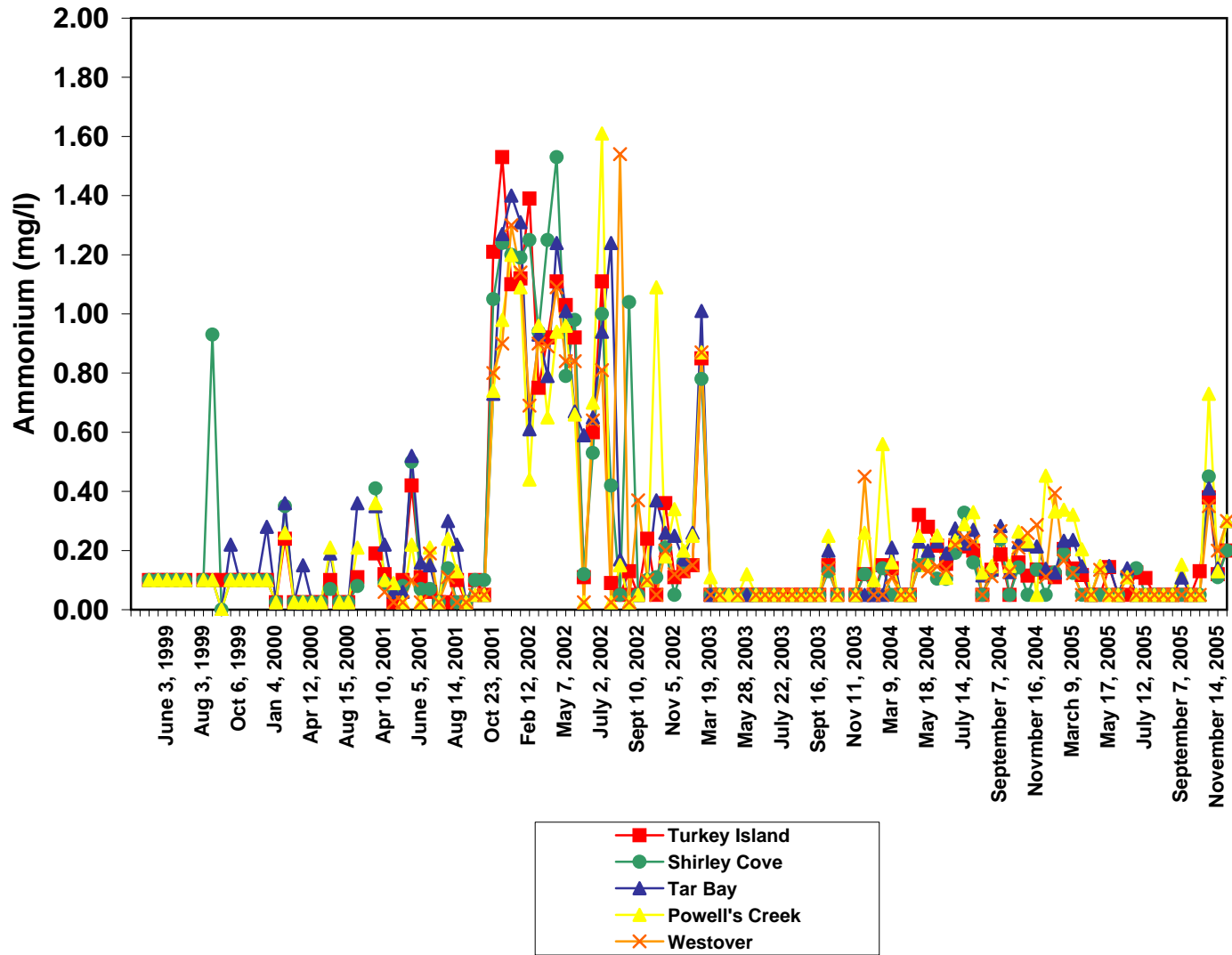


Figure 3-13. Dissolved Inorganic Phosphate (DIP)

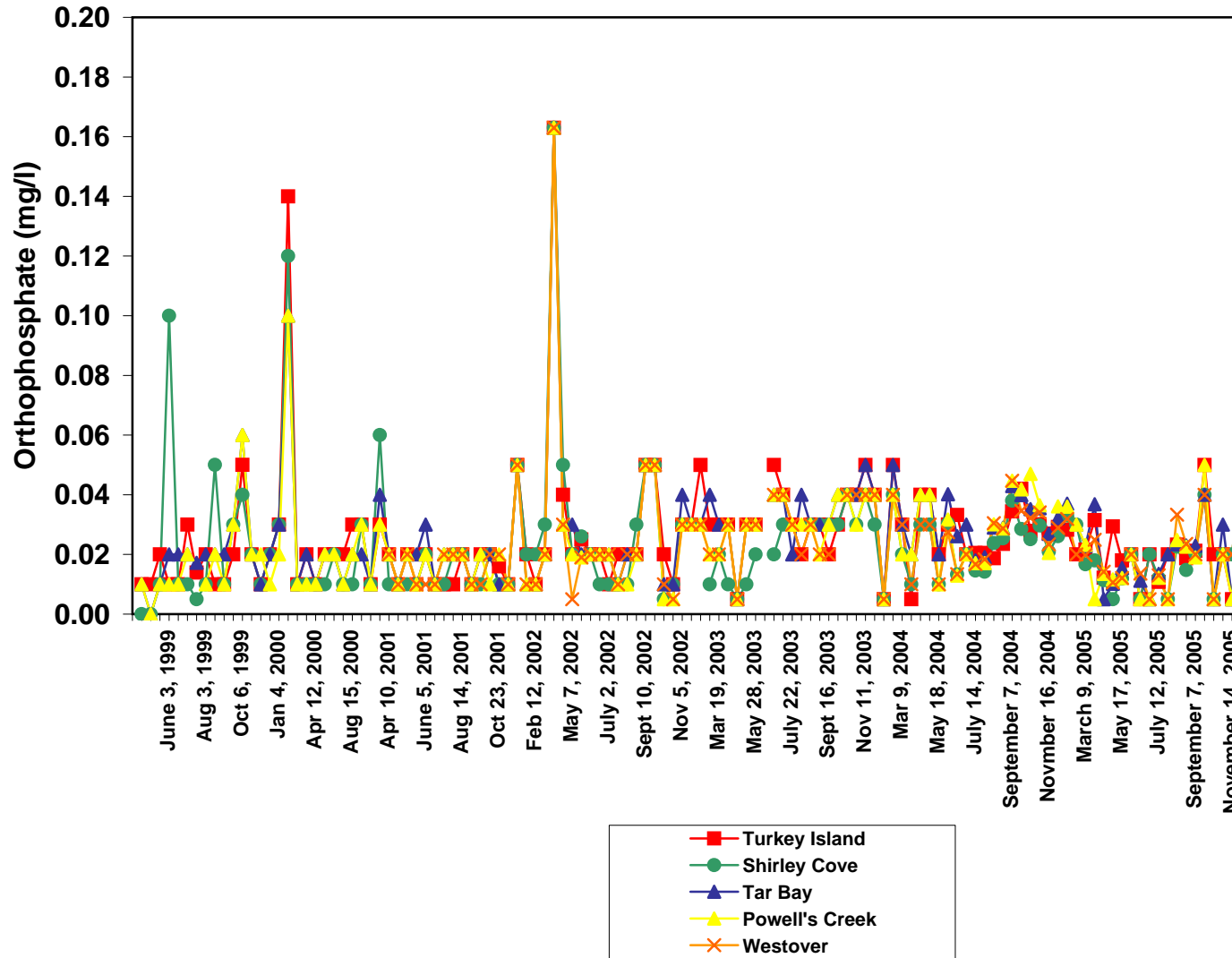


Figure 3-14. Upper James River Dataflow Cruise Track July 1, 2005

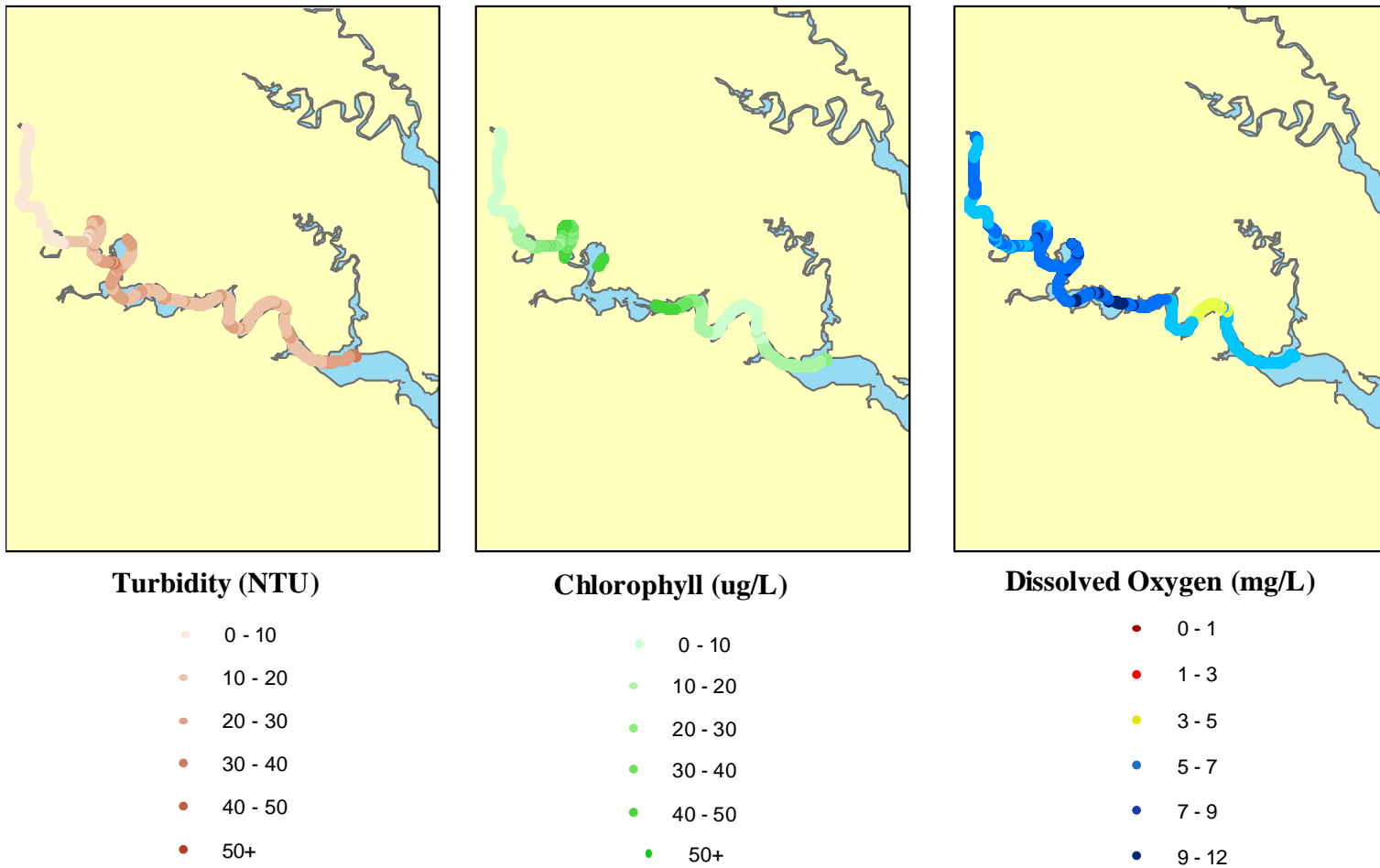


Figure 3-15a. Upper James River 04-07-05
Dataflow Dissolved Oxygen

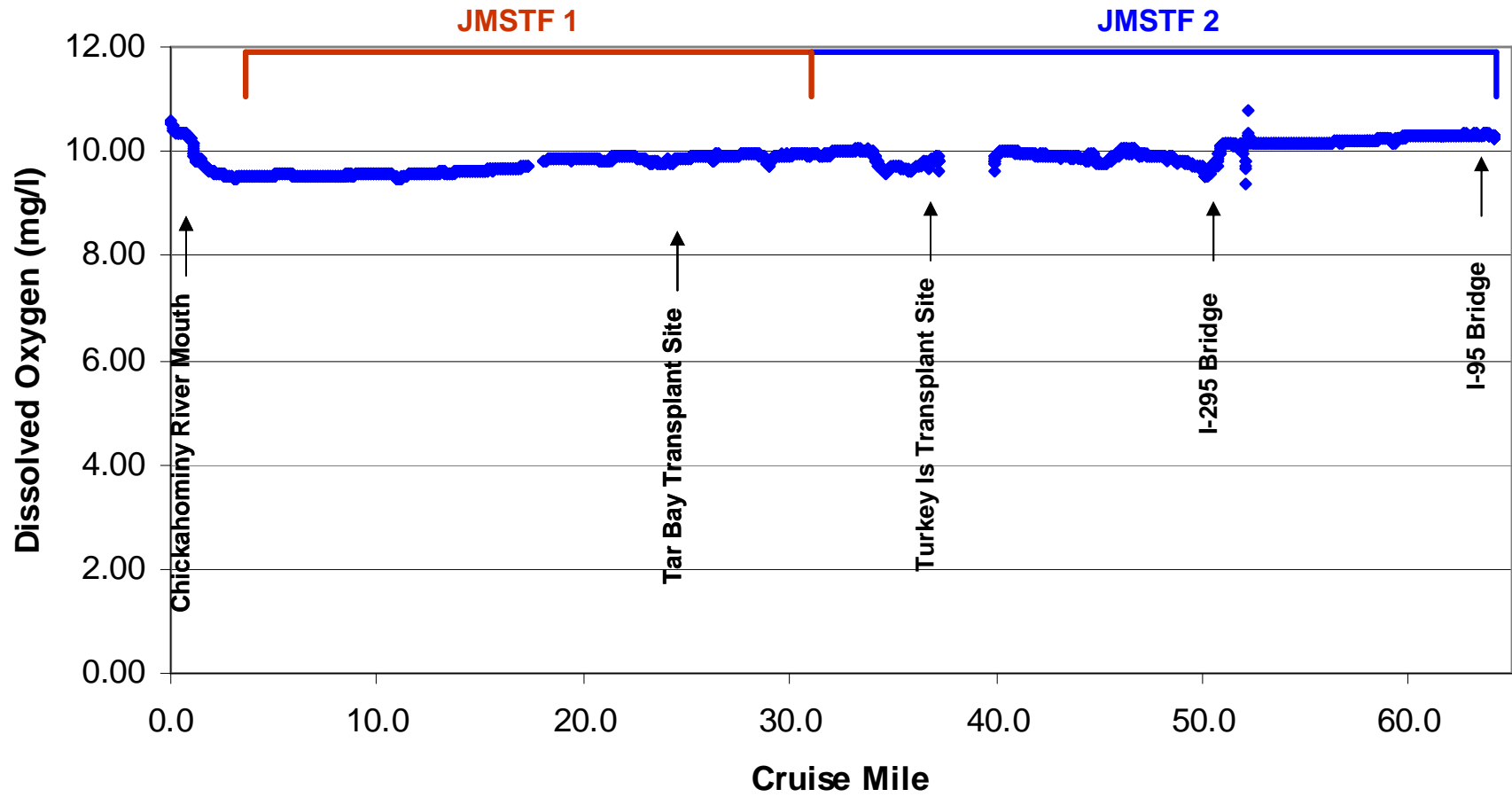
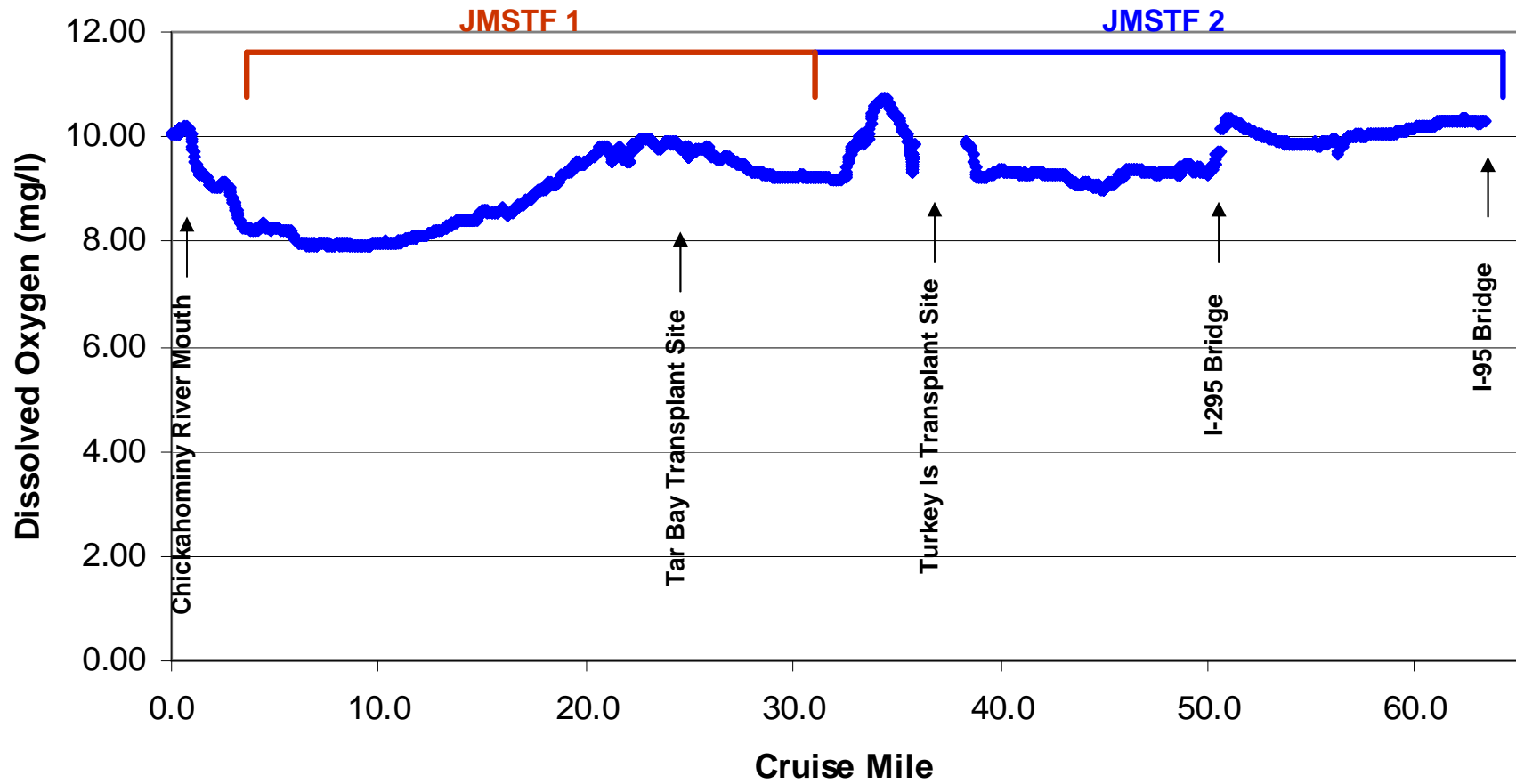


Figure 3-15b. Upper James River 05-04-05
Dataflow Dissolved Oxygen



**Figure 3-15c. Upper James River 06-03-05
Dataflow Dissolved Oxygen**

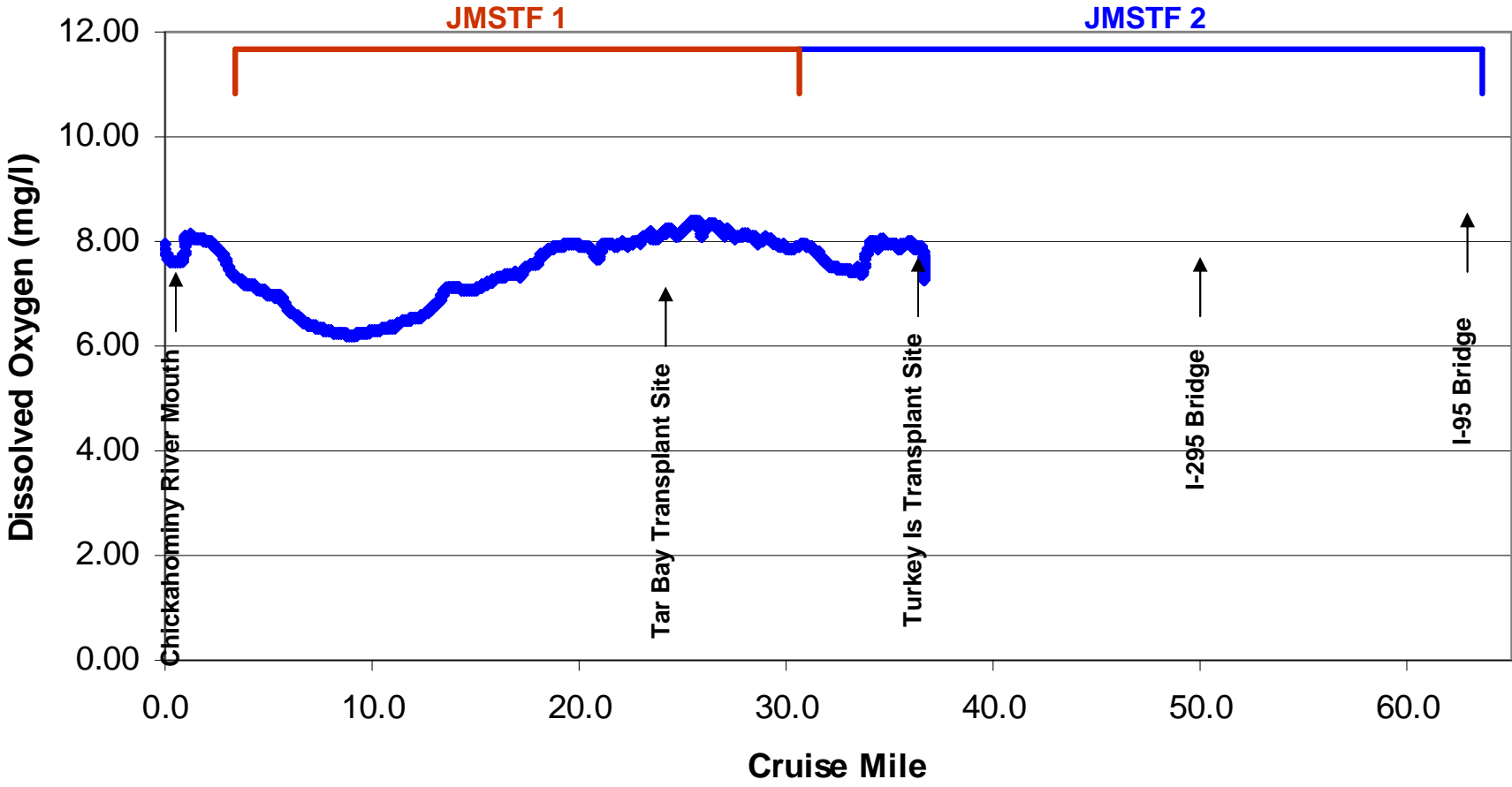


Figure 3-15d. Upper James River 07-01-05
Dataflow Dissolved Oxygen

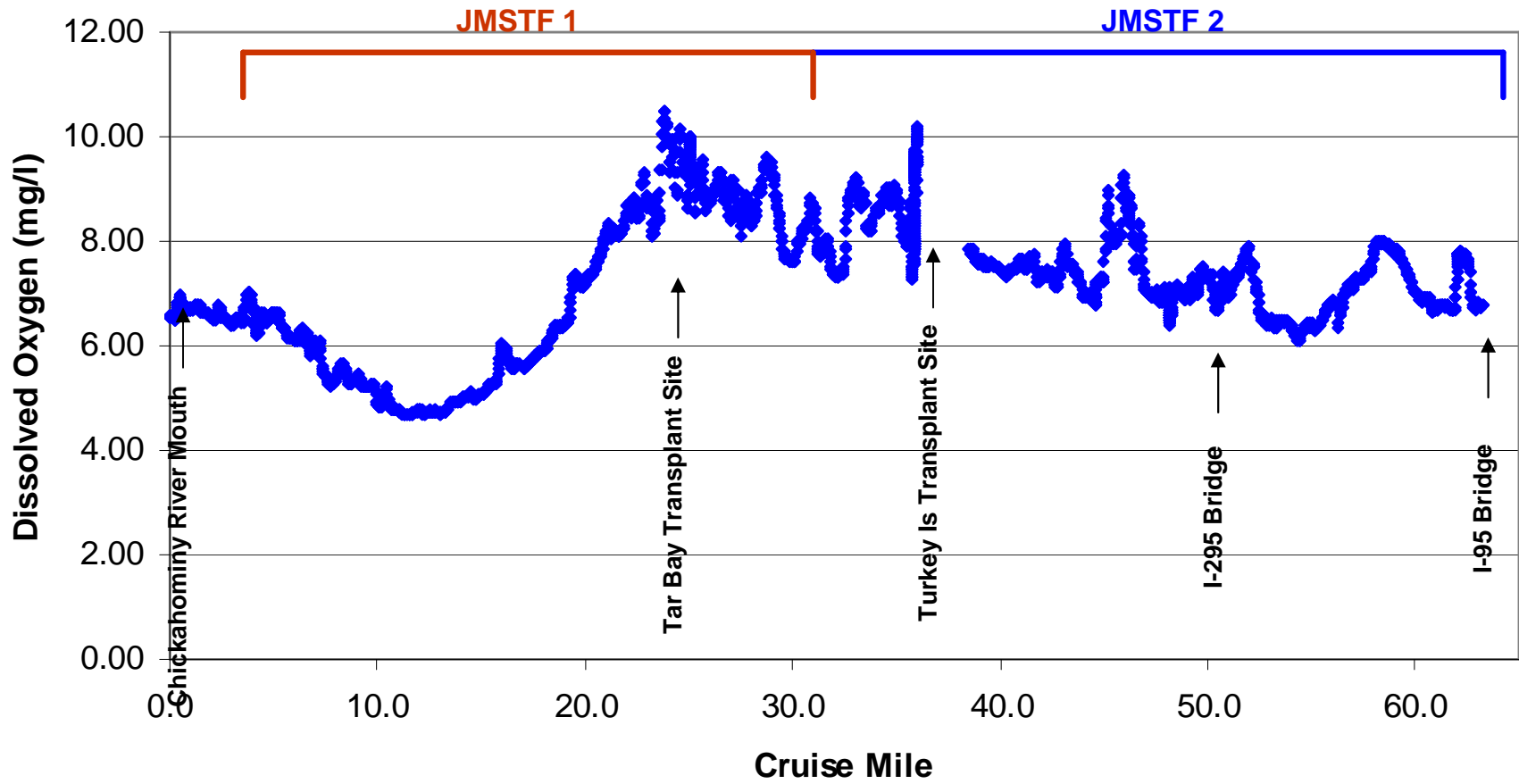


Figure 3-15e. Upper James River 08-15-05
Dataflow Dissolved Oxygen

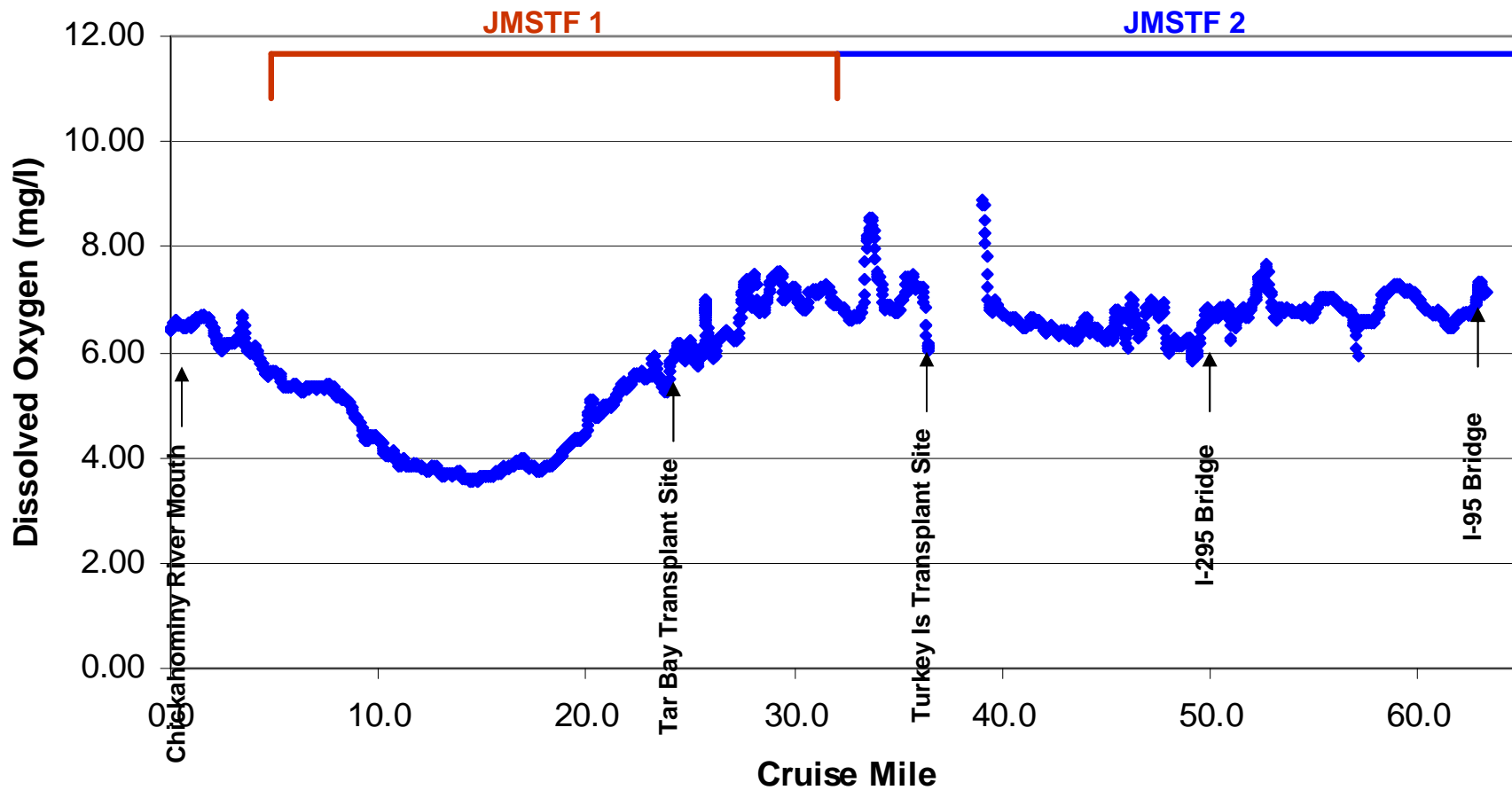


Figure 3-15f. Upper James River 09-13-05
Dataflow Dissolved Oxygen

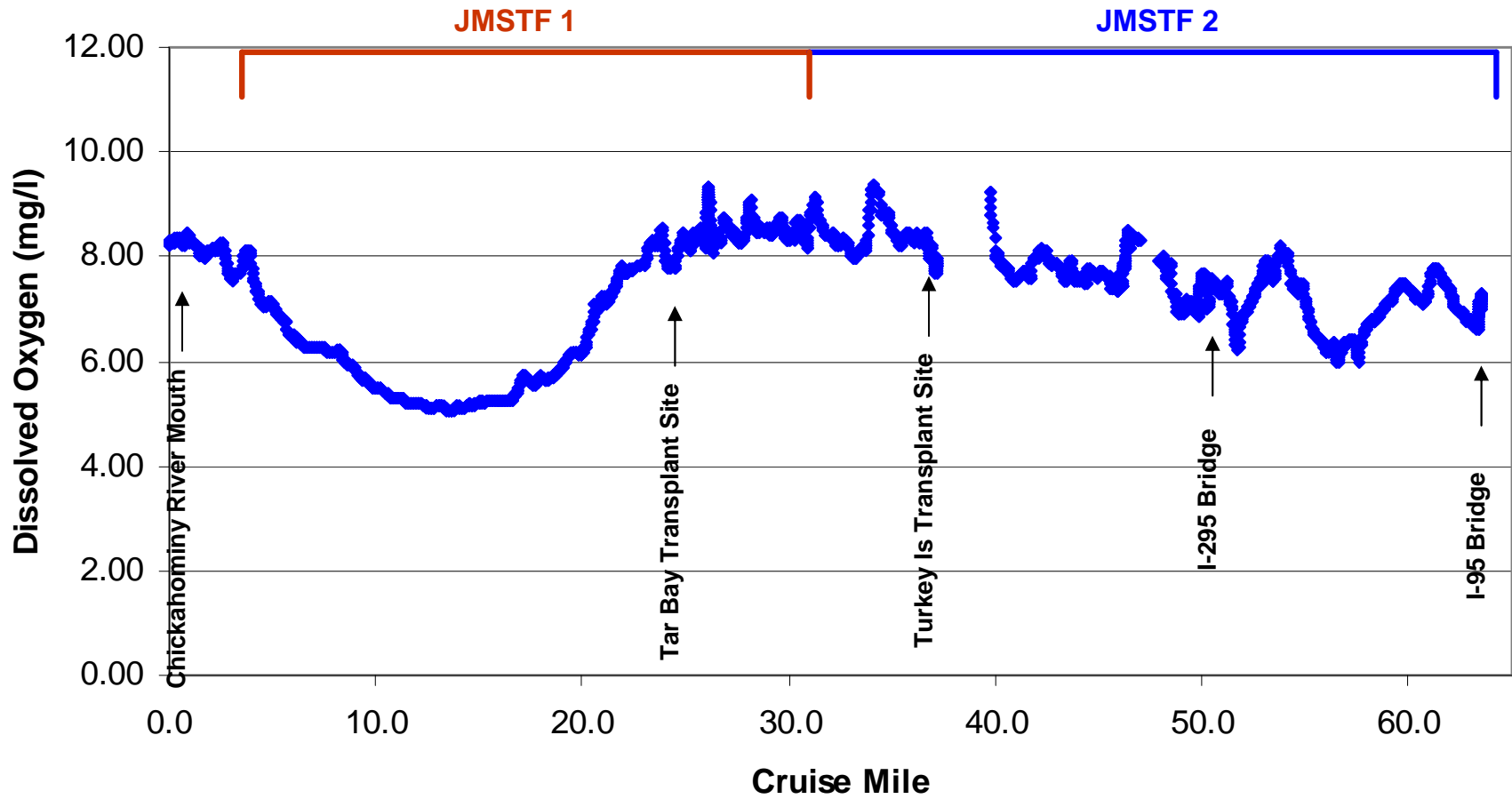


Figure 3-15g. Upper James River 10-27-05
Dataflow Dissolved Oxygen

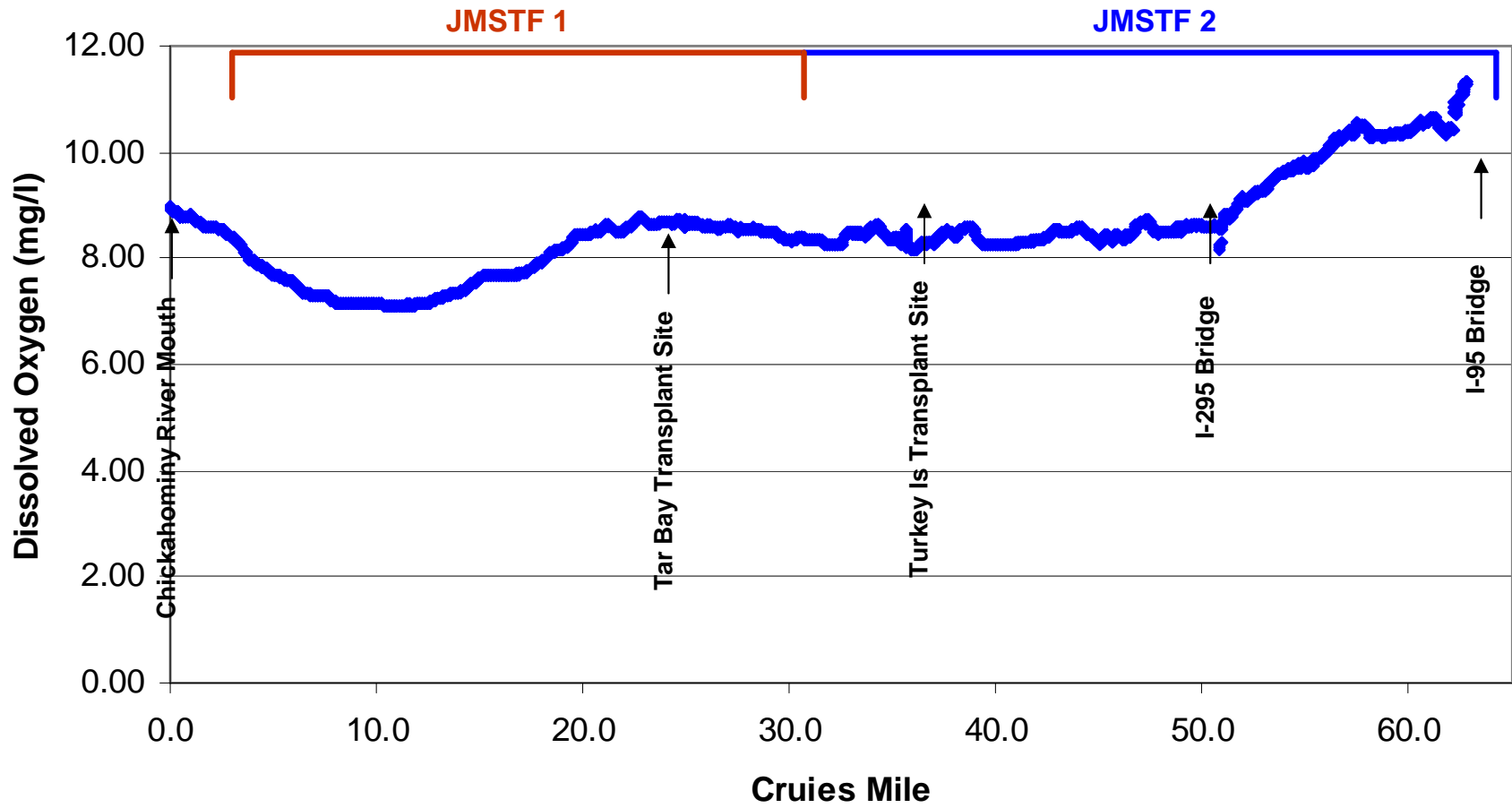


Figure 3-16a. Upper James River 04-07-05
Dataflow Corrected Chlorophyll

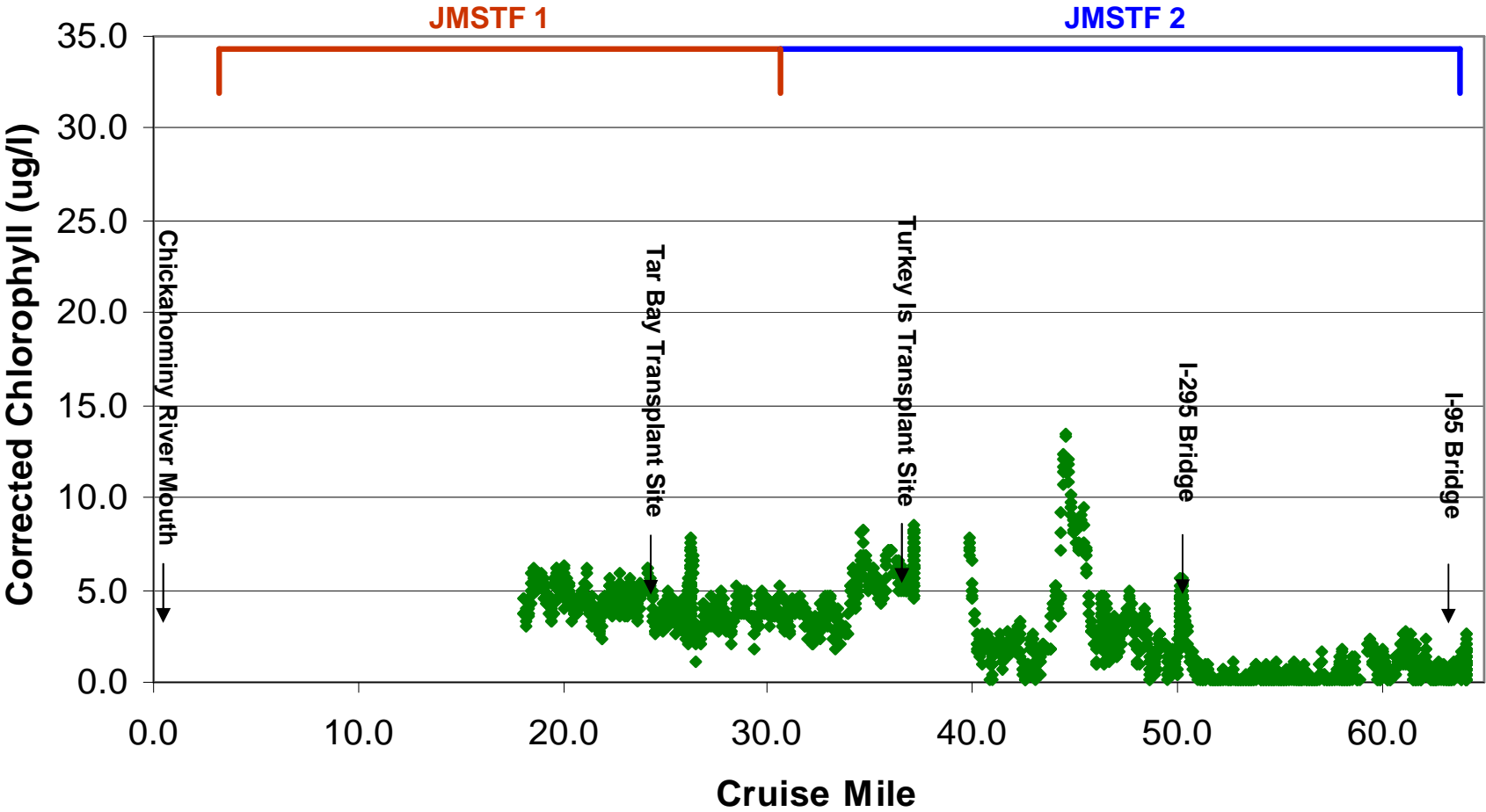


Figure 3-16b. Upper James River 05-04-05

Dataflow Corrected Chlorophyll

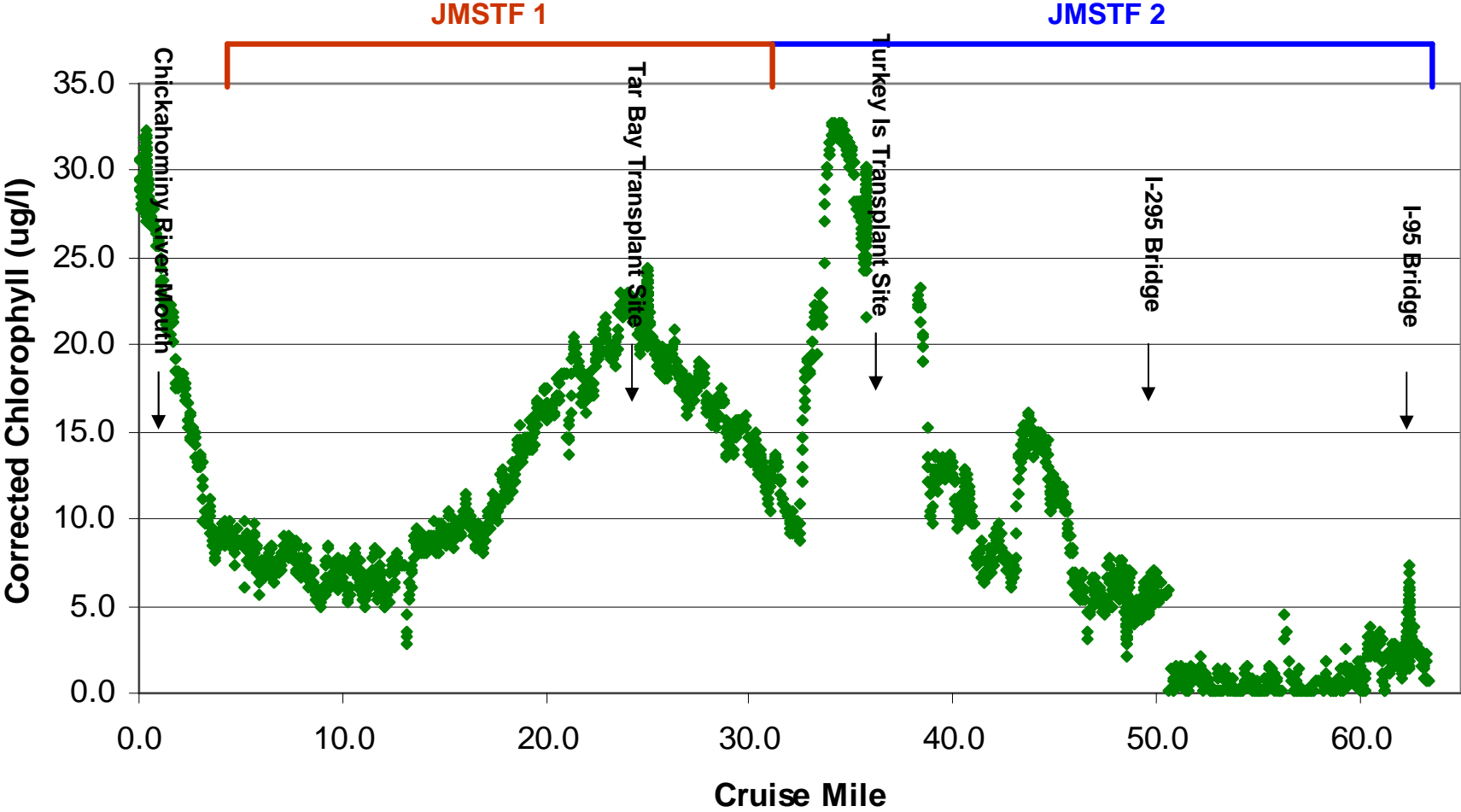


Figure 3-16c. Upper James River 06-03-05
Dataflow Corrected Chlorophyll

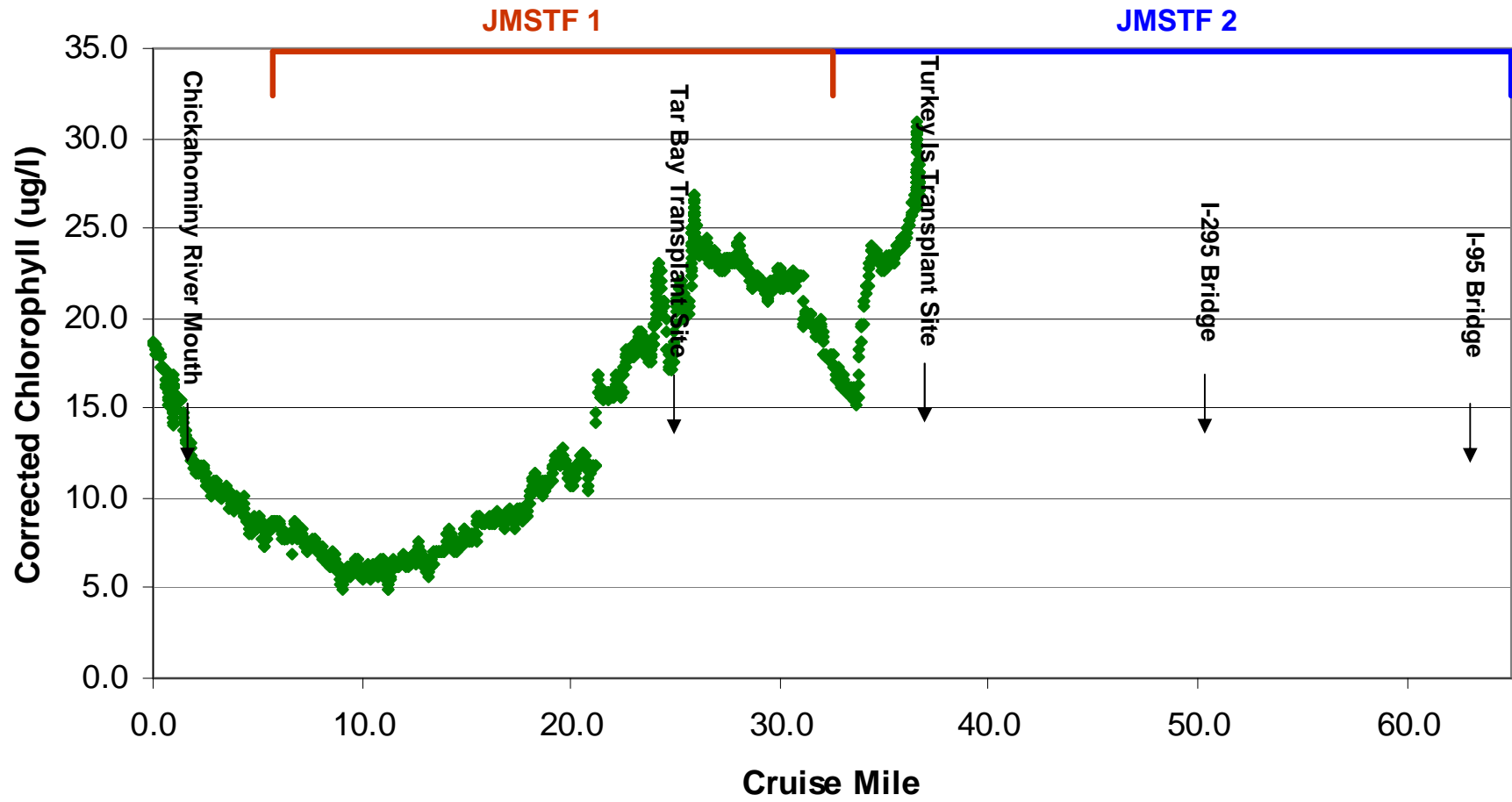


Figure 3-16d. Upper James River 07-01-05
Dataflow Corrected Chlorophyll

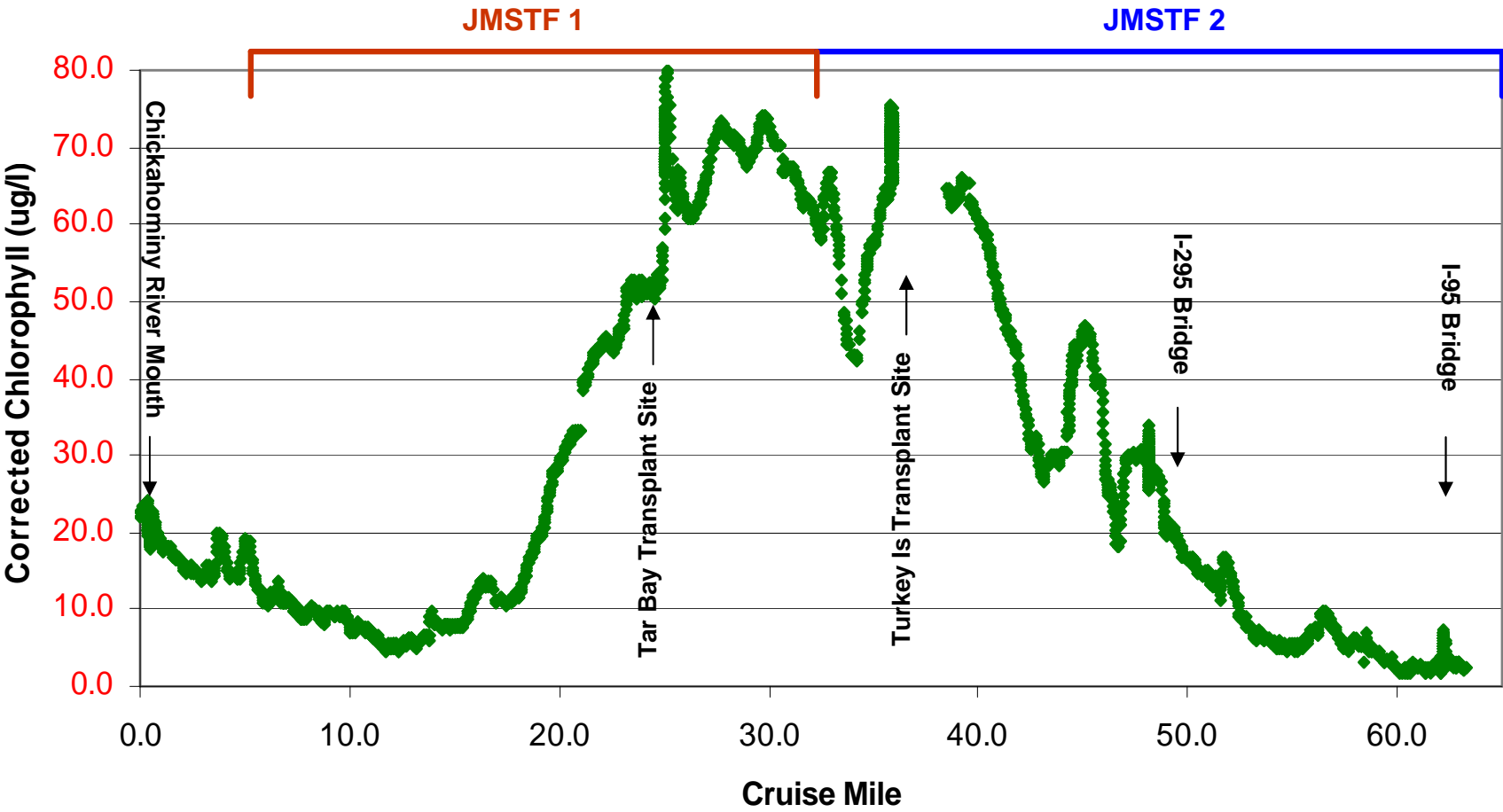


Figure 3-16e. Upper James River 08-15-05
Dataflow Corrected Chlorophyll

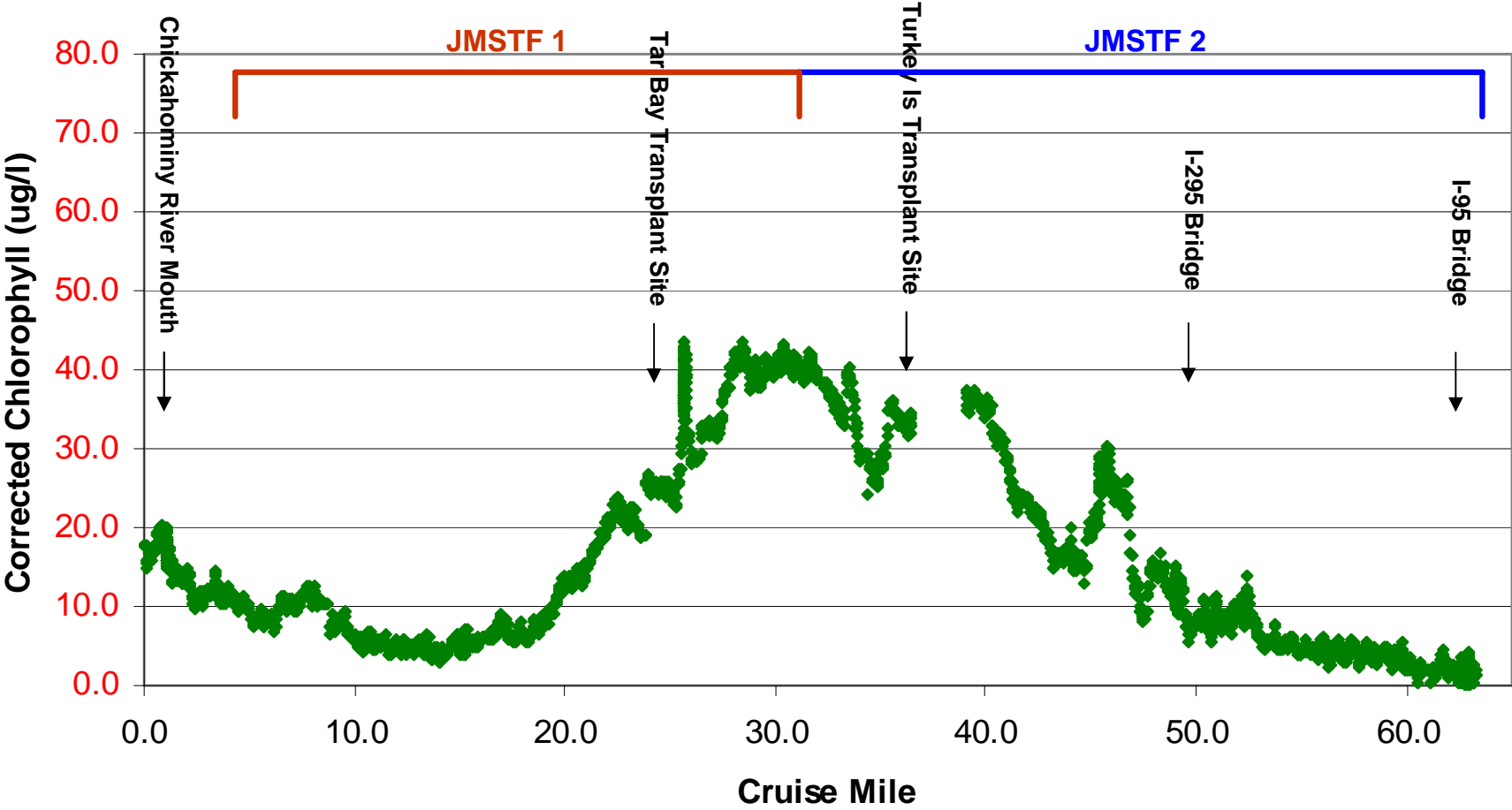


Figure 3-16f. Upper James River 09-13-05
Dataflow Corrected Chlorophyll

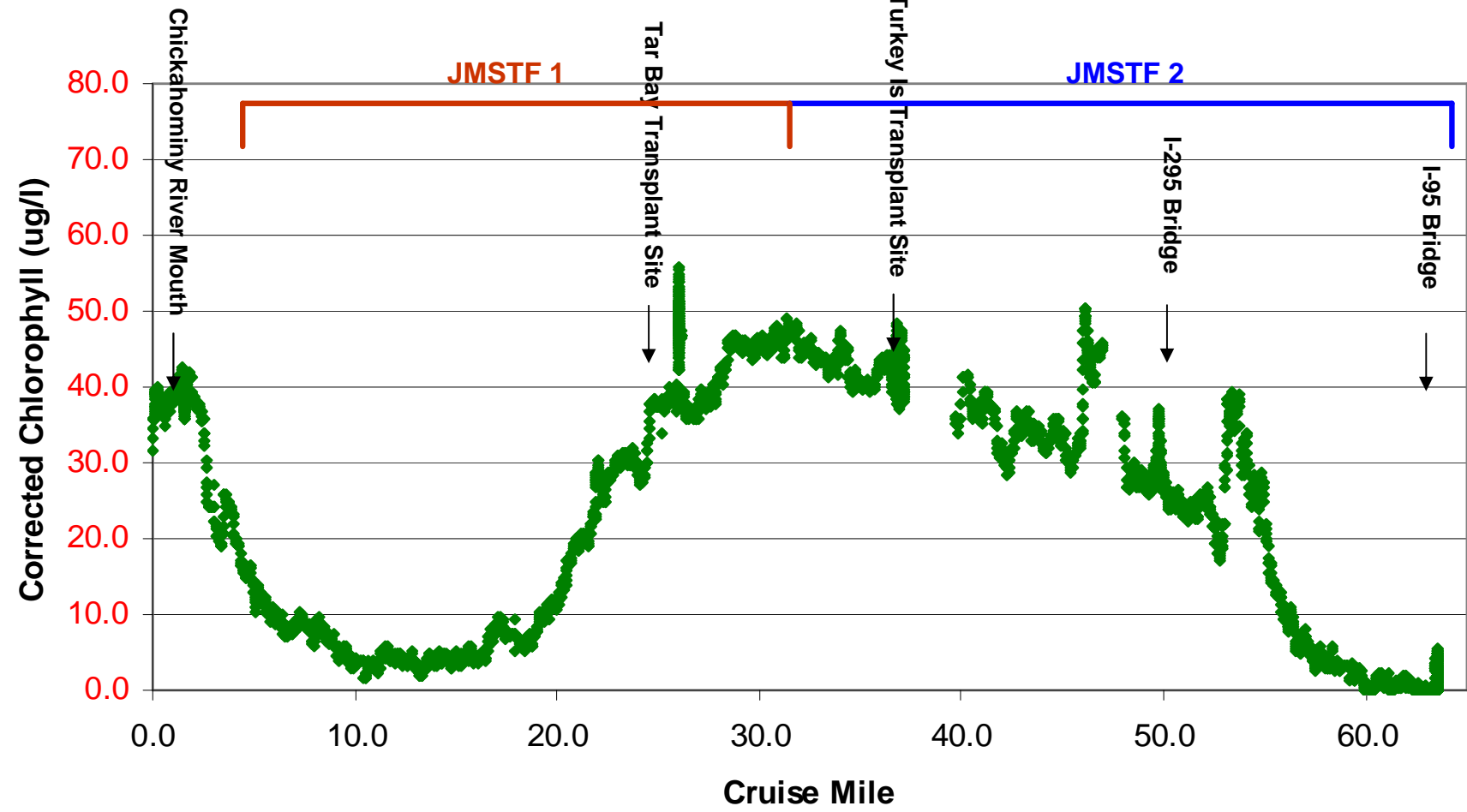


Figure 3-16g. Upper James River 10-27-05
Dataflow Corrected Chlorophyll

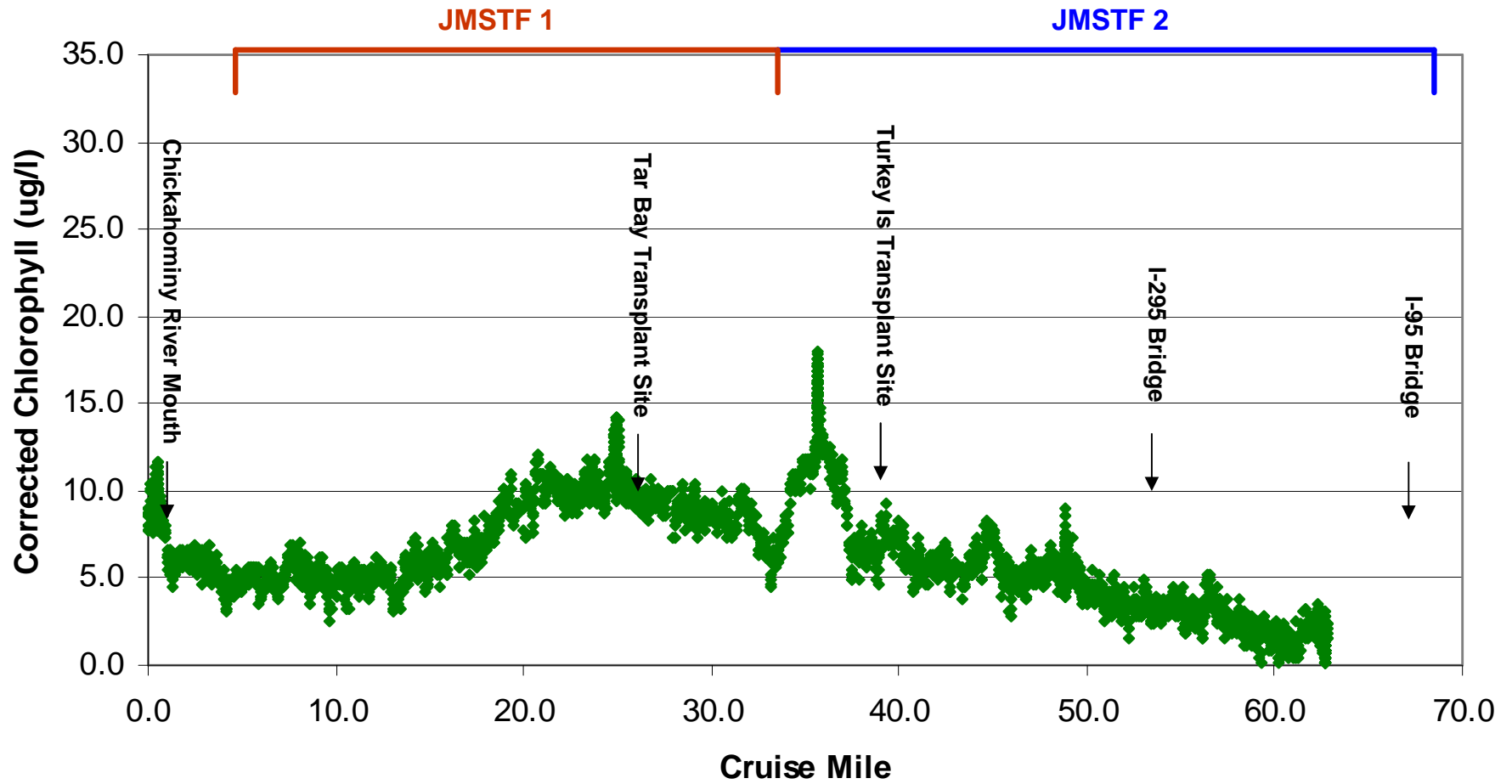


Figure 3-17a. Upper James River 04-07-05
Dataflow Turbidity

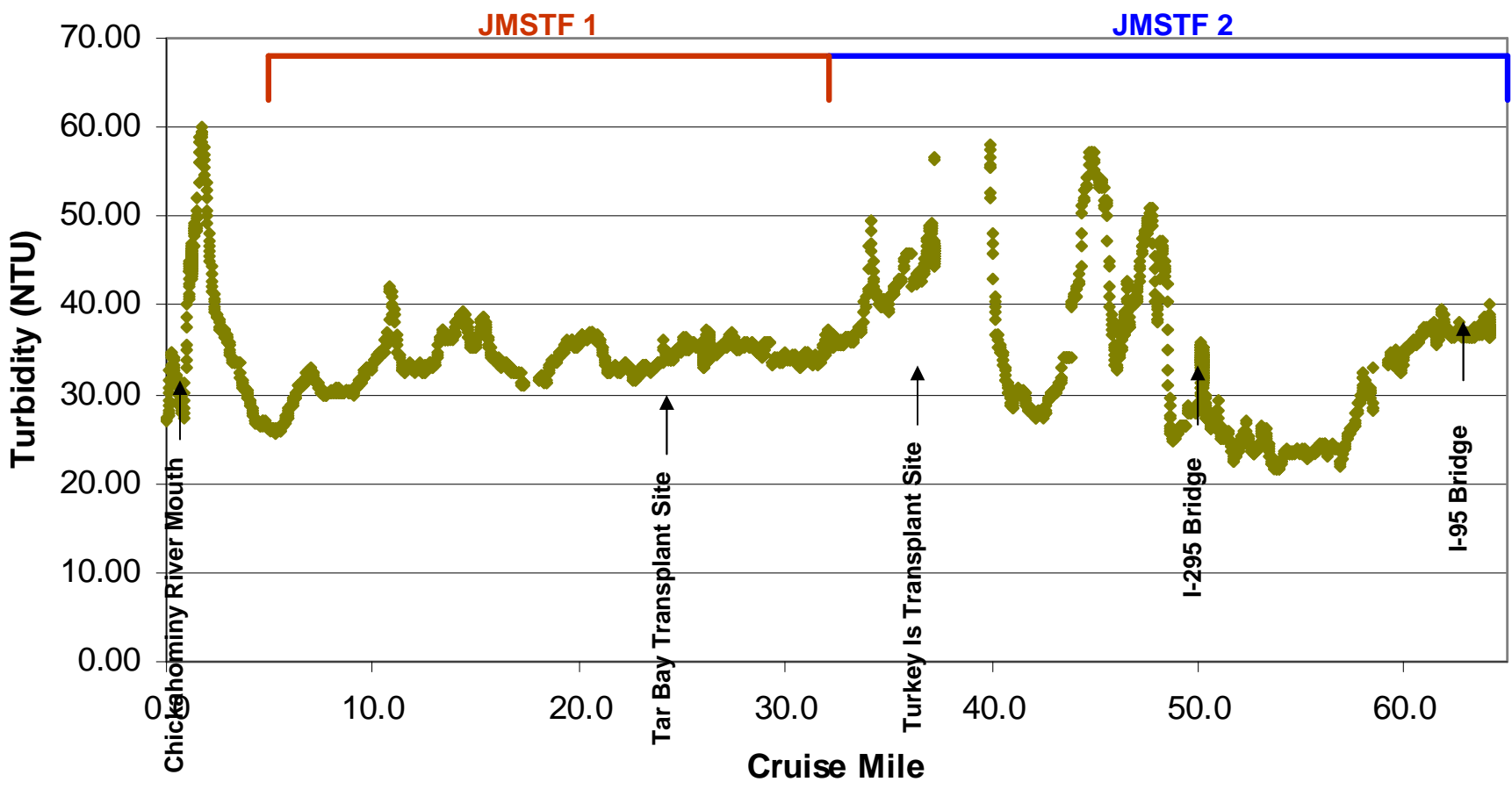


Figure 3-17b. Upper James River 05-04-05

Dataflow Turbidity

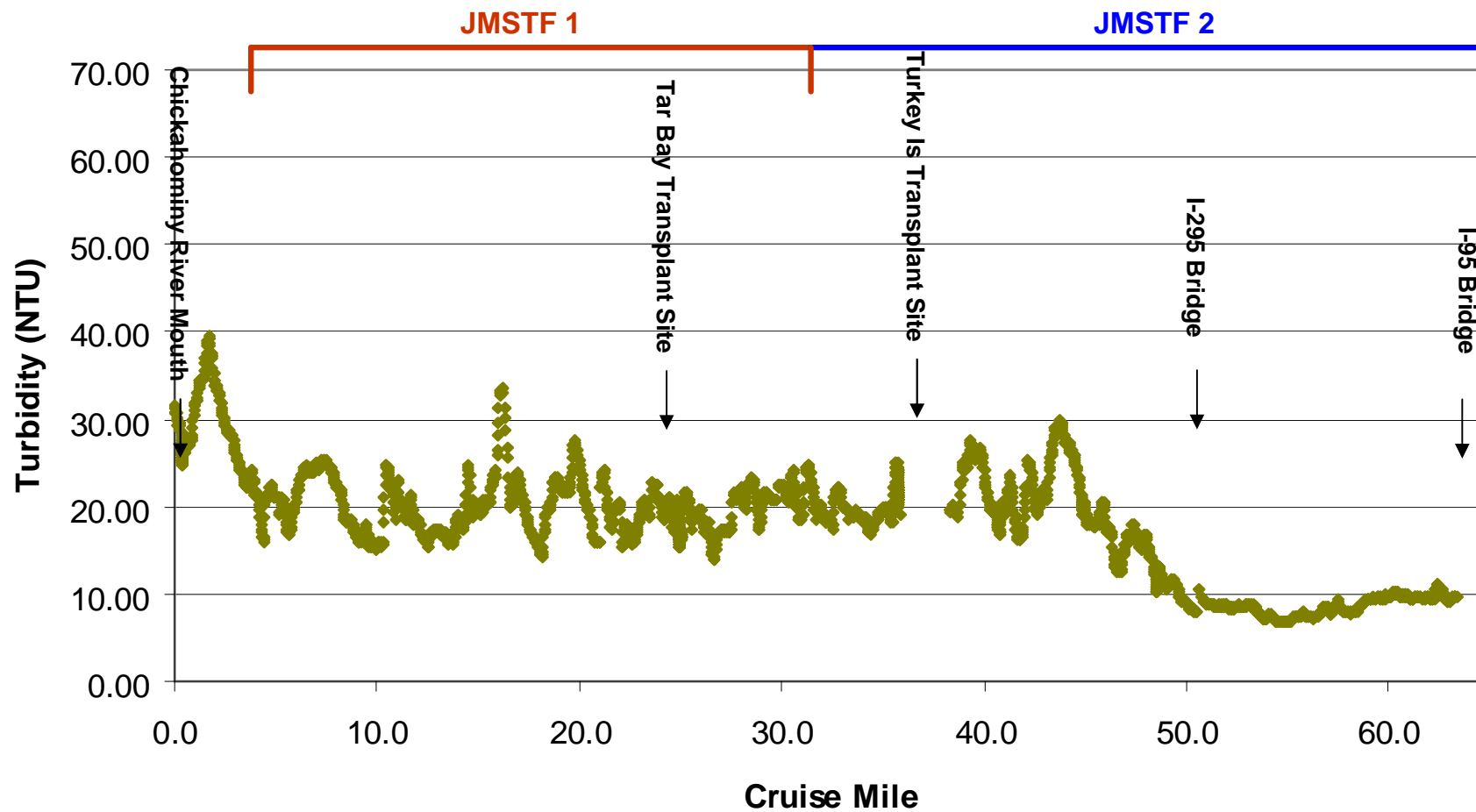


Figure 3-17c. Upper James River 06-03-05
Dataflow Turbidity

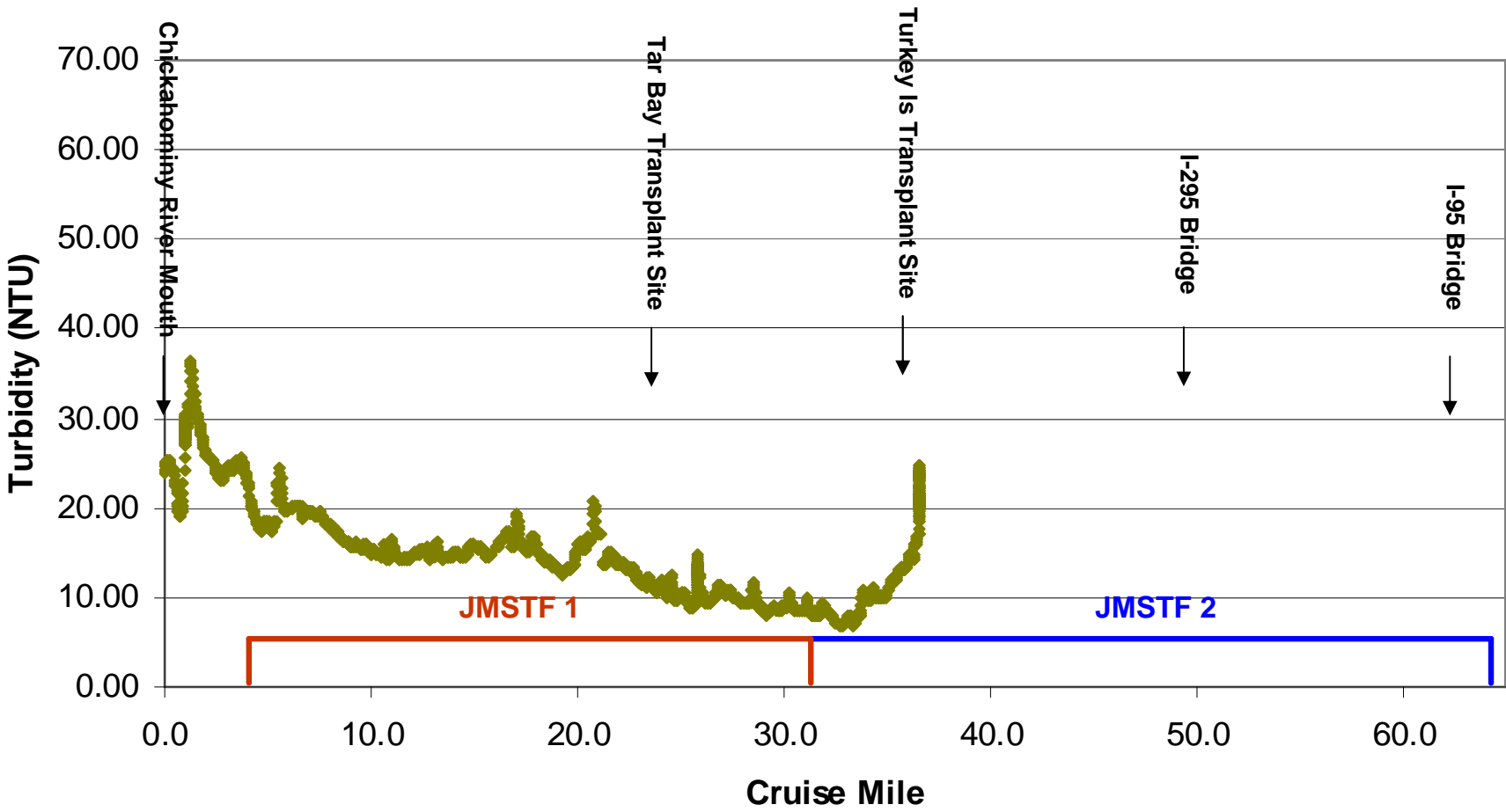
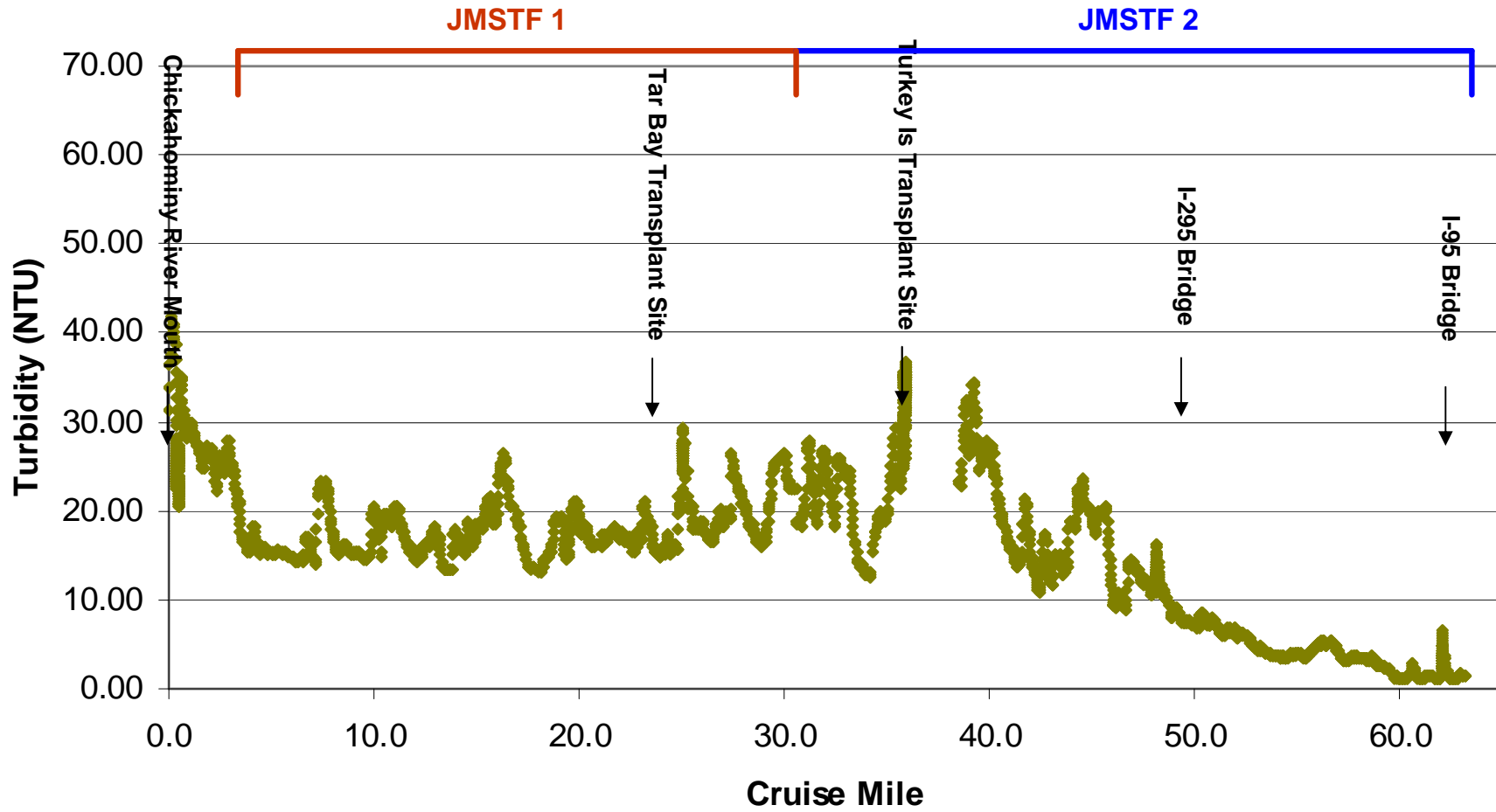


Figure 3-17d. Upper James River 07-01-05
Dataflow Turbidity



**Figure 3-17e. Upper James River 08-15-05
Dataflow Turbidity**

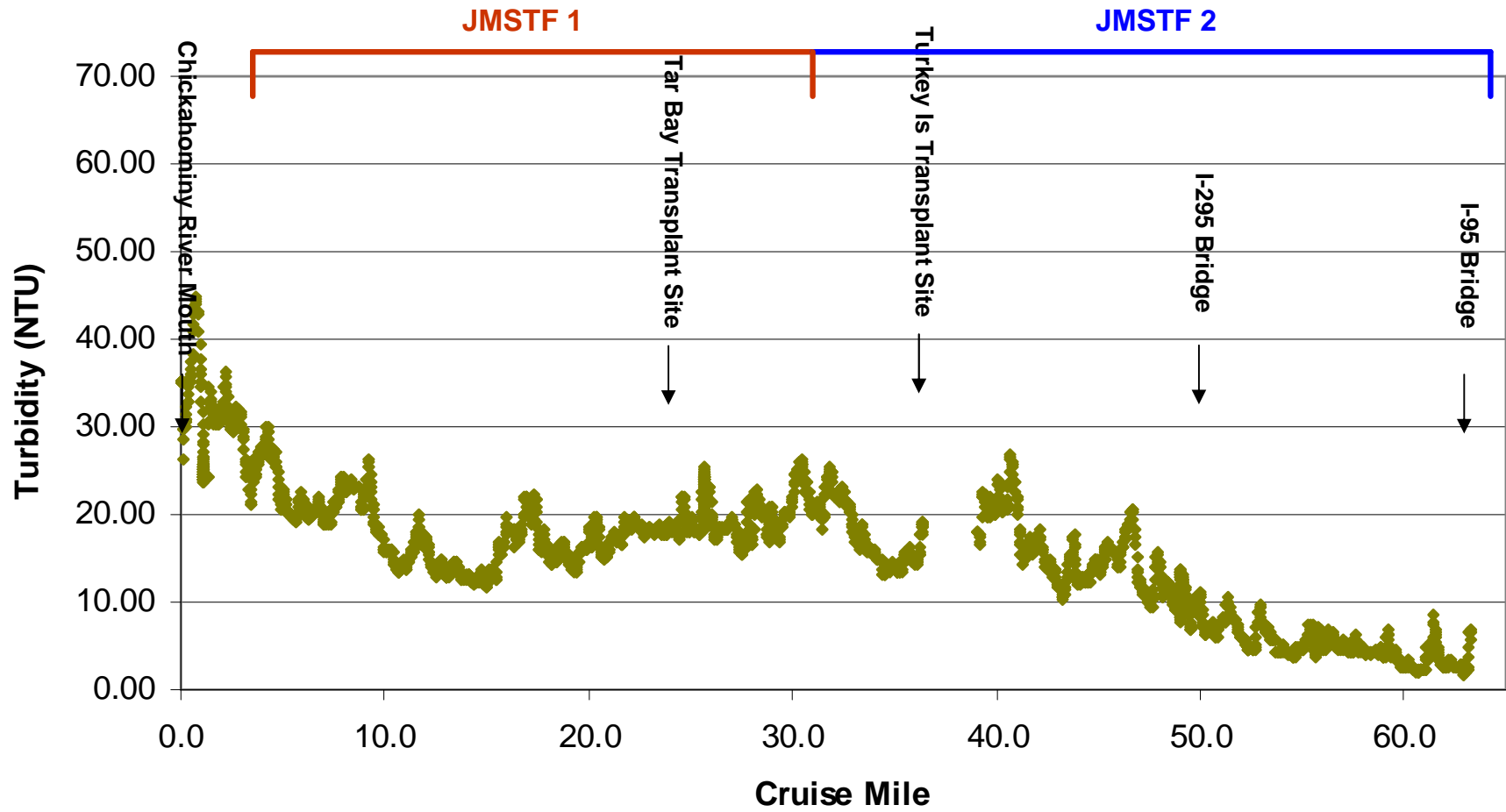


Figure 3-17f. Upper James River 09-13-05
Dataflow Turbidity

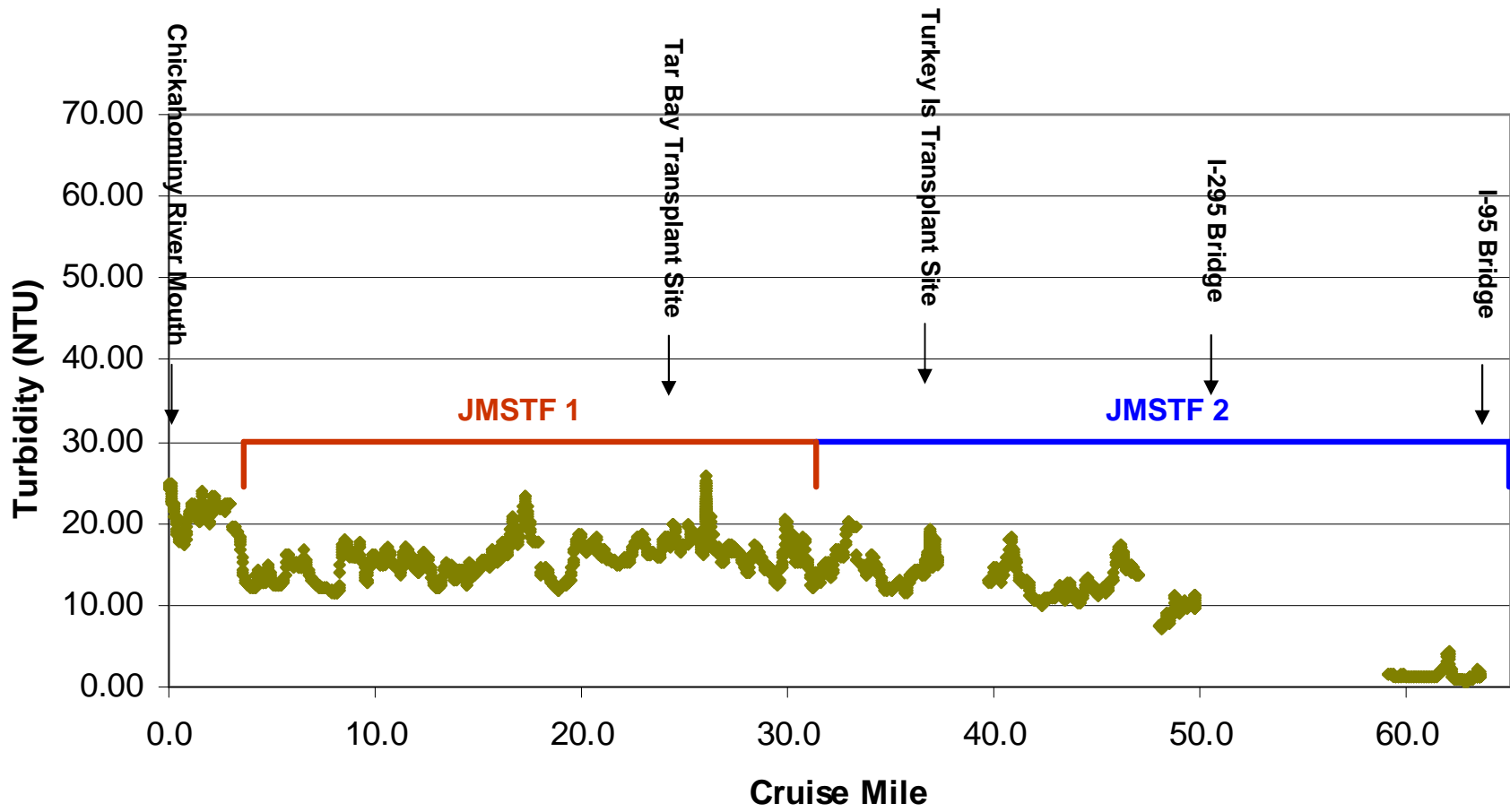


Figure 3-17g. Upper James River 10-27-05
Dataflow Turbidity

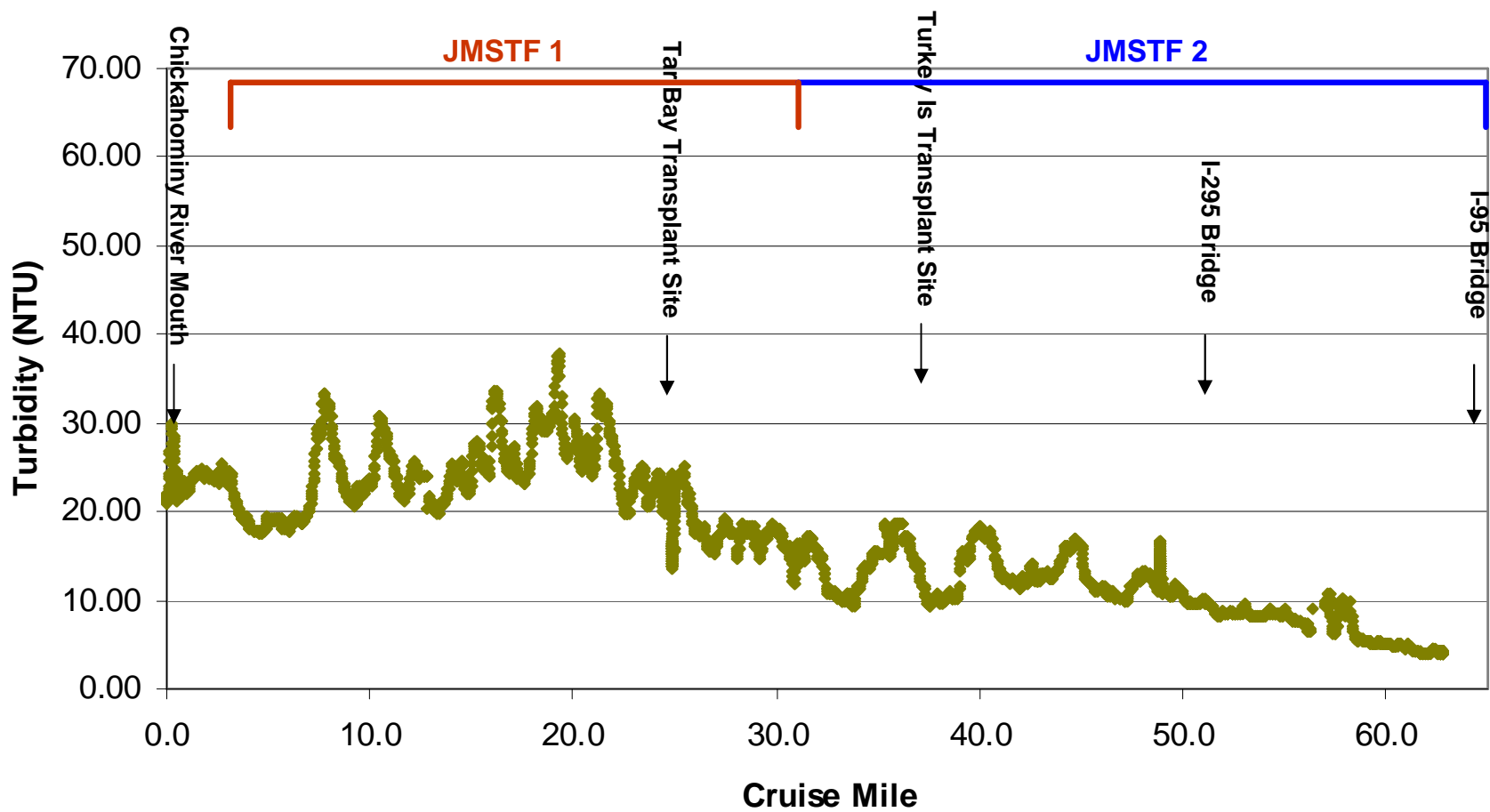
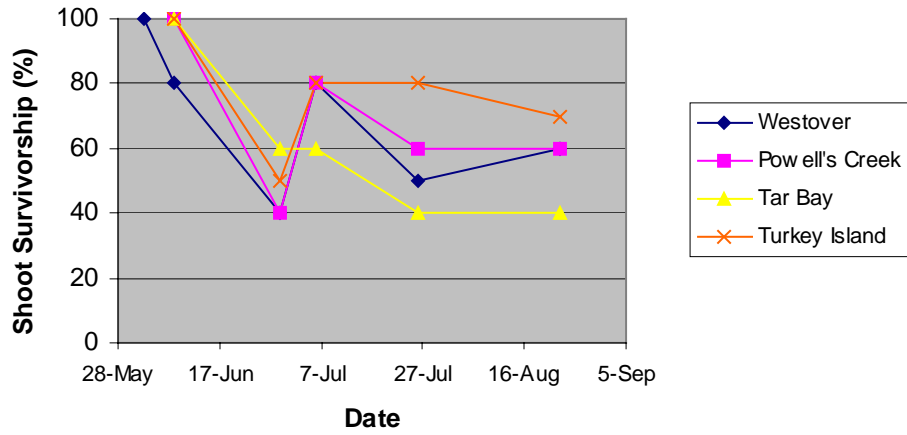
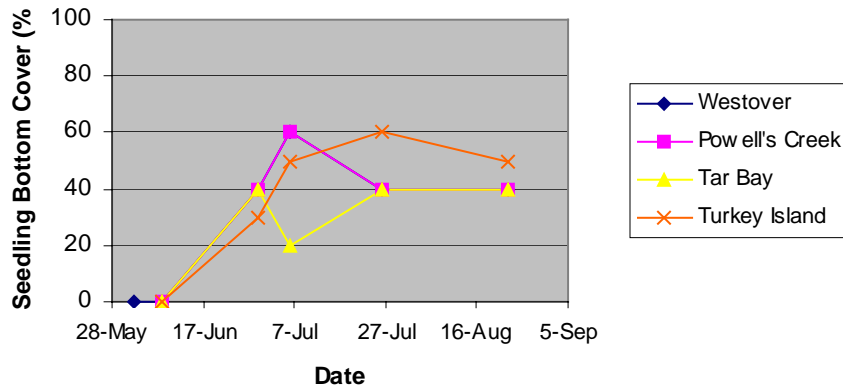


Figure 3-18. Wild Celery 2005 Transplant Success Within Enclosures

Whole Shoot Transplants (in enclosures)



Seed Transplants (in enclosures)



Seed Pod Transplants (in enclosures)

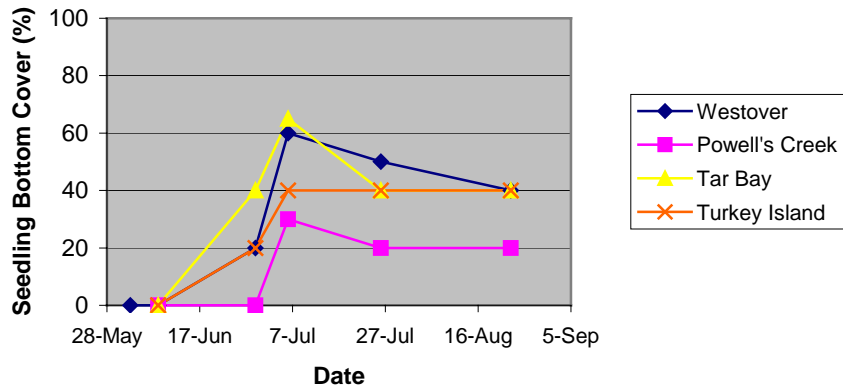


Figure 3-19. Wild Celery 2005 Transplant Success Outside Exclosures

