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Restoration of Submerged Aquatic Vegetation (SAV) in the Tidal Freshwater James River: Year 3

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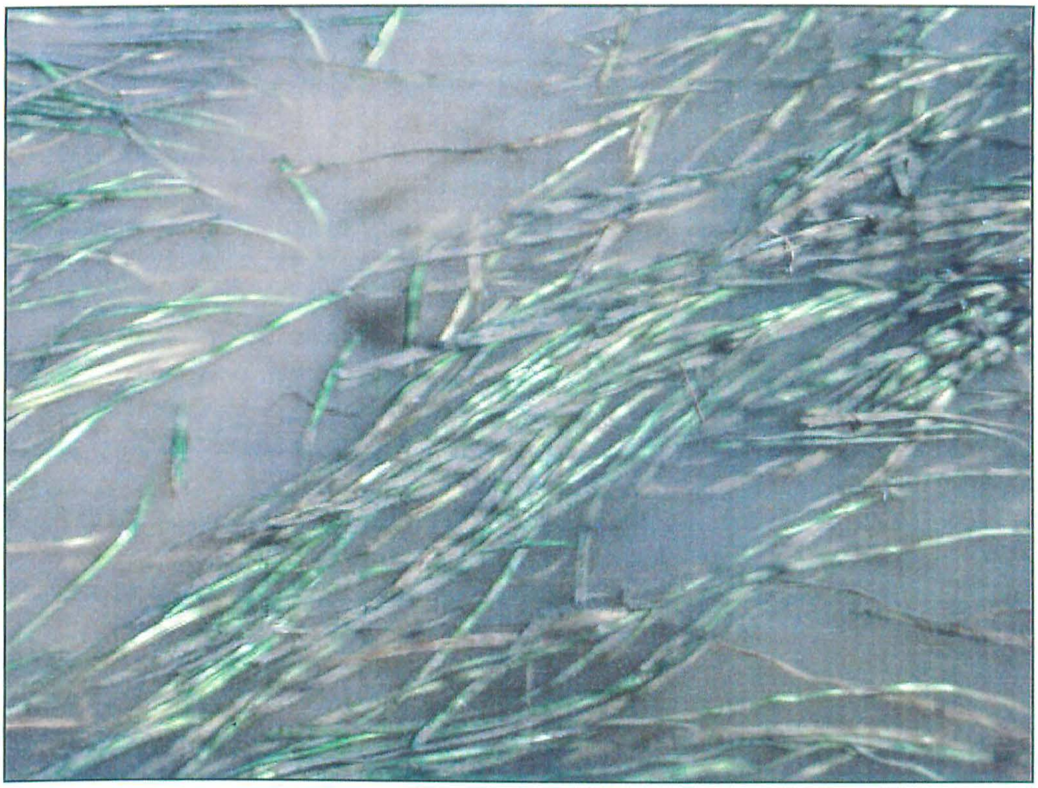
RESTORATION OF SUBMERGED AQUATIC VEGETATION (SAV) IN THE TIDAL FRESHWATER JAMES RIVER: YEAR 3



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EXECUTIVE SUMMARY

In the year 2001 four species of submerged aquatic vegetation (SAV) were transplanted into shallow water areas of the tidal, freshwater James River in the region of Hopewell, Virginia. Species included wild celery (*Vallisneria americana*) that was grown from nursery grown stock developed by the Chesapeake Bay Foundation's "Grasses in Classes" program, and coontail (*Ceratophyllum demersum*), *Hydrilla verticilata* and *Elodea canadensis*, that were transplanted from native stock in the Chickahominy 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 to monthly intervals throughout the year by the Hopewell Regional Wastewater Treatment Facility for 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 in 1999 and 2000; 2) conduct water quality sampling in one additional area for potential transplanting in 2002; 3) evaluate the success of the different SAV species for restoration in this region; and evaluate the relationships between SAV transplant performance and water quality.

Results demonstrated wild celery to be the most successful restoration species of those tested. Significant wild celery re-growth was evident at the Turkey Island site and 100% cover of the bottom was achieved after 3 years of growth. Herbivory continued to be a problem affecting SAV transplant success in some plots. Typically wild celery plots had 50-60 % initial survival and by the second year achieved 60% overall ground cover.

Of the three years of shallow water quality monitoring undertaken so far, 1999 and 2001 had much higher conductivities, reflecting lower river flows compared to 2000. Despite year-to-year differences in river flow, survival of the transplants indicated that water quality conditions were not limiting for SAV growth at depths shallower than 0.5 m. Nutrient levels were generally low and similar among the stations except for the fall of 2001 when ammonium levels were 10-fold higher than at any time previously measured. Additionally, a pattern of generally increasing chlorophyll levels from 1999 through 2001 was observed and habitat requirements for SAV growth to 1 m depths were not met in 2000 and 2001.

1.0 INTRODUCTION

1.1 Background

During 1999 an initial SAV restoration and water quality monitoring project, funded by the Hopewell Regional Wastewater Treatment Facility (HRWTF) in partnership with VIMS and assisted by CBF, was undertaken. The project was continued in 2000 and 2001 with the aid of a $10,000 grant from the Chesapeake Bay Restoration Fund. Objectives of this continuing project are to:

1) Develop and evaluate 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 shallow water sites of the Hopewell region of the James River estuary and grow into self-perpetuating grass beds.
3) Determine if the response of the transplants is related to specific water quality conditions at the sites, site characteristics, and/or physical disturbance.

In 1999, four test sites (Powell's Creek, Tar Bay, Shirley Plantation and Turkey Island) were selected for test transplanting in the Hopewell region of the estuary based upon historical photographs showing previous SAV presence and appropriate water depths (Moore et al. 2000). SAV propagules consisting of wild celery (*Vallisneria americana*) and sago pondweed *(Potamogeton pectinatus)* plants were planted at the four sites. The plants were either harvested from native stock in the Poropotank River, a tributary of the York River, or were supplied by CBF 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.

Initial plantings of wild celery at the Shirley Plantation site were rapidly lost due to apparent herbivory. The restoration plots at all four sites were then surrounded by 6-foot high wire fencing to assure initial survival and prevent natural predation and disruption of the plots which were planted in June. Maintenance of the wire fencing was required throughout the summer of 1999. Similar restoration efforts using wild celery in Maryland suggested that once established and developed the beds would become less subject to disruption.

Survival of the wild celery transplants in 1999 within the exclosures was high with approximately 40 to 60% survival through the 1999 growing season (April-October). However, the sago pondweed plants developed a dense leaf canopy at the surface, which gradually caused them to be dislodged by wave and tidal action and no plants remained by August, 1999. The wild celery transplanted in June of 1999 emerged in the spring of 2000 at Turkey Island and Tar Bay marking the first time SAV had been successfully established in this region of the James River in over 50 years. Strong tidal currents affected the Powell's Creek site particularly during Hurricane Floyd in September 1999 and no plants present at the end of 1999 sprouted in 2000.

In June 2000, the wire fencing was replaced with plastic fencing and additional fencing was installed to enlarge the plots. With the establishment of larger plots, more plants grown by CBF's "Grasses in Glasses" program during the early spring of 2000 were transplanted at each site. Since sediment type has been known to affect the growth of underwater grasses, replicate plots were transplanted into a range of sediment types to test the effect of substrate type on transplant success. In addition to wild celery grown from seeds of Chesapeake Bay stocks of SAV, wild celery plants were obtained from CBF that were grown from Florida and Wisconsin stocks.

VIMS personnel monitored each site for growth and survival at biweekly to monthly intervals during the 1999 and 2000 growing seasons, and water quality sampling was conducted throughout these periods by HRWTF personnel. As of September, 2000, the plants transplanted into all the sites had survived and spread. Fish, turtles or birds entered the individual exclosures at the Powell's Creek, Tar Bay and Turkey Island sites and cropped some of the plants. Otherwise survival was high and as of September the surviving plants had begun to flower and produce seeds. 40-80% of the transplants that survived the initial herbivory in 2000 were present at the end of the summer. Redhead grass (*Potamogeton perfoliatus*) had been planted at each of the sites in 2000. However in contrast to wild celery, little growth was evident and no plants were found by the end of August.

Water quality measurements were used to determine attainment of habitat criteria (Batiuk et al. 1992) for SAV growth to 1.0 meter depths (below mean low water). These criteria were generally only met for chlorophyll *a* although water quality sampling was limited during the summer of 2000 due to technical difficulties with the HRWTF sampling vessel (Moore et al. 2001). Light availability measured as secchi depth or light attenuation (K_d) as well as total suspended solid concentrations did not meet the criteria for 1 m depths. However, concentrations of TSS and chlorophyll *a* predicted for growth to the shallower transplant depth of 0.5 m were achieved, suggesting that water quality conditions should be suitable for growth to these shallow depths. Epiphyte fouling that was measured using artificial SAV fouling strips was found to be much less than that predicted by bay models given the levels of TSS, secchi, and nutrients monitored at the stations. Up to 8 % organic matter content of sediments had little negative effect on growth. These results suggest, therefore, that the shallow water sediments typical of this region should not be limiting to wild celery.

In general, the results of the initial two-year of transplanting in this region were quite successful. So far only wild celery plants appeared to be able to survive transplanting into this region of the river. Water quality conditions did not appear to limit survival at shallow depths of 0.5 m MLW and epiphyte fouling rates appeared to be low. Herbivory appeared to be the major factor limiting initial survival at depths of 0.5 m. Reproduction from over-wintering tubers was evident in the spring of 2000 and therefore establishing resident populations of wild celery in this area of the river appeared very possible.

1.2 Objectives

The 2001 SAV restoration and water quality monitoring project was an expansion of the SAV transplanting efforts conducted during 1999 and 2000. The specific objectives of the year 2001 study were:

1) Enlarge 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) Develop an additional site in the unvegetated shallow freshwater, tidal James River in the vicinity of Hopewell, VA. and work with the Alliance for the Chesapeake Bay, as well as the CBF to expand the restoration in this region of the river.

3) Monitor the transplant 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 of different years to evaluate the cause/effect relationships between water quality and SAV habitat recovery, and to use this information to assist in the development and implementation of tributary nutrient and sediment reduction strategies.
4) Provide a hands-on educational experience in SAV propagation and restoration for Virginia secondary school students to supplement and enhance environmental training for educators as well as to expand the educational opportunities for the students.

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 2001-2002:

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 dredge disposal operation at the Shirley Cove site, no transplants were placed there in 2001. However, water quality monitoring was continued from 2000 to assess any long-term water changes at that location. In addition, we provided technical assistance to the Alliance for the Chesapeake Bay (ACB) for the development of a restoration nursery area at that site beginning in 2002.

We also worked with CBF to evaluate for suitability the Westover Plantation site for SAV restoration and this site was monitored for water quality along with the other four sites throughout the 2001 growing season.

2.2 SAV Transplanting and Monitoring

The CBF program "Grasses in Classes" allowed students the opportunity to participate in hands-on-restoration of underwater grasses. CBF provided the seed stock as well as all materials to grow wild celery in an enclosed system in the classroom. Training workshops were held in February, 2001, in the Hopewell, Richmond, and Hampton Roads areas of Virginia. Students maintained the systems for approximately 3 months, at which time the plants were mature enough for transplanting into the James River. Each system provided the project with up to 150 individual plants. Participating students and teachers were invited to assist with actual transplant efforts in the James River in early June. Most of these plants were planted at the Westover site, located along the Charles City shoreline, under the supervision of CBF. Other Chesapeake Bay stock wild celery plants obtained from CBF were planted at the other locations.

Transplanting activities at all the sites were undertaken in early June after the wild celery propagules had grown sufficiently to withstand transplanting into the freshwater tidal environment. In addition to the nursery growth wild celery stock, harvest of wild plants growing in the upstream region of a large tributary of the James, the Chickahominy River, were collected in June of 2001. The plants were washed free of sediments, separated and placed in coolers for transport to planting sites near Hopewell.

Native stock included, *Hydrilla verticillata, Ceratophyllum dermersum* (coontail), and *Elodea Canadensis*. Prior to this time each transplant site was prepared by constructing or refurbishing the animal exclusion plastic fencing needed for that year to protect the transplants.

The three species of wild stock transplants taken from the Chickahominy River were planted in replicate arrays of 25 planting units both inside and outside of the exclosures at the Powell's Creek, Tar Bay and Turkey Island sites. Because coontail typically has little or no root material, approximately 5-10 shoots were attached together with a small mesh bag that was weighted with a few pebbles to form a planting unit. The mesh bag was then placed into the sediment to hold the plants in place. Since the lack of root material makes the plants very susceptible to wave action, the planting units were only planted at the Tar Bay site, as well as within Powell's Creek. The latter was undertaken with the assistance of Mr. Wilson Enochs, a landowner along Powell's Creek.

Transplants were surveyed by diver at biweekly to monthly intervals throughout the growing season for percent survival of planting units. Observations were also made on relative conditions of the transplants, including any evidence of herbivory. CBF scientists monitored transplant survival at the Westover site. SAV transplant survival within Powell's Creek was monitored only at the end of the 2001 growing season.

2.2 Water Quality Monitoring

HRWTF and VIMS personnel collected water quality measurements and samples at bi-weekly intervals at each of the five restoration sites. No water quality measurements were made within the interior of Powell's Creek. Water quality measurements included: air and water temperatures, turbidity (secchi depth), 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 since previous data indicates significant differences in water quality conditions can occur between shallow water areas and typical mid-channel water quality monitoring sampling.

3.0 RESULTS

3.1 Transplant Survival

At the Turkey Island site, the exclosure (TI1) that had been planted with wild celery during the spring of 1999, re-grew again in the spring of 2001 and approximately 40% of the bottom was vegetated with shoot clusters by June of 2001. Survival of the 1999 and 2001 wild celery transplants are summarized in Fig. 3-1. While listed as 100% survival throughout the year, the 1999 transplants gradually expanded throughout the 2001 growing season, reaching nearly 100% cover of the bottom by October, 2001. This suggests that approximately three growing seasons are required for normal density to be achieved by wild celery planted originally at 1 ft. centers in this region. As the density of the plants increased, their capacity to trap sediments was evident and bottom depths in the exclosure increased 5-10 cm relative to the adjacent, unvegetated bottom outside of the exclosure. This caused some of the shallowest inshore plants to become exposed during average low water and subsequently die back by the end of 2001. As with growth in 2000 the plants achieved lengths of up to 1 m in length. In contrast to the plants in exclosure TI1, those in exclosures TI2 and TI3 that showed evidence of cropping by herbivores in September and October of 2000 did not re-grow in the spring of 2001.

The Turkey Island exclosures TI2 and TI3 were planted in June of 2001 with wild celery. After some initial losses the transplants in TI3 rebounded, and survival by the end of the growing season in October 2001 was approximately 60%. Observations in the spring of 2002 (data not shown) indicated that approximately this same number re-sprouted after the 2001-2002 winter in both TI1 and TI3. The wild celery planted in exclosure TI2 declined to low levels within 6 weeks and none were present by the end of the year.

None of the wild celery transplants that were growing at the Tar Bay site at the end of the 2000 growing season, re-sprouted in the spring of 2001. Re-planting of these areas with wild celery in 2001 resulted in the same 60-70% survival by the end of the first growing season as Turkey Island (Fig. 3-1).

Although approximately 60-80% of the year 2000 wild celery planting units at Powell's Creek (PC) were still present by September, 2000, the plants themselves appeared cropped to lengths of 5-10 cm suggesting active herbivory was ongoing at that time. None of these plants re-spouted in the spring of 2001. Re-planting in the spring of 2001 resulted in 70% survival in exclosure PC 2 (similar to Tar Bay and Turkey Island), however, exclosures PC 1 and 3 that were adjacent showed limited success and eventually all transplants were gone by October, 2001 (Fig. 3-1).

The divergent patterns of survival of the replicated exclosures at the various transplant sites indicate two trajectories for wild celery transplant success during the initial growing season. The first is characterized by an initial loss of 30-50% of the planting units followed by stabilization and re-growth. By the end of the second growing season the individual planting units cannot be distinguished from new growth and overall cover of the formerly unvegetated bottom is approximately 60%. By the end of the third growing season bottom cover is approximately 100%. In the second trajectory 80-90% of the transplants are gone within one month. At this time the plants appear very short, as if cropped by fish, turtles or birds. Some new growth is evident, however, eventually this growth decreases and all the plants are gone by the end of the first year. These results confirm the significance of herbivory in limiting wild celery establishment. Losses of wild celery over the winter suggest additional herbivory may be ongoing at that time. The marked survival at Turkey Island suggests that it is probably not related to physical factors. During the winter of 2000-2001 the exclosures were left in place. Some damage to the structures was observed in the spring of 2001 so it was likely that they were not 100% successful in excluding herbivores. Additionally, all exclosures were open at the top, so waterfowl utilization may have been possible. No waterfowl have ever been seen within the exclosures and they were purposely constructed so as to limit landings and takeoff areas for ducks and geese. It may also be that limited performance of the SAV in producing over-wintering tubers at the end of the growing season at sites other than Turkey Island may be contributing to the lack of re-growth the following spring.

In contrast to the marked success of the wild celery transplants, the transplants of native species from the Chickahominy had very poor survival at all of the sites. *Hydrilla verticillata* demonstrated rapid loss regardless of whether it was planted in or out of an exclosure, although the plants in the exclosures lasted several weeks longer than those planted in adjacent areas outside (Fig. 3-2). *Elodea canadensis* plants also were rapidly lost with most rapid losses occurring outside of the exclosures (Fig. 3-3). Up to 60% of the transplants survived at the Tar Bay site for at least one month, however all were gone two months after transplanting. Similarly the coontail transplants demonstrated rapid loss (data not presented). Additionally, no coontail could be observed in October at any of the planting locations within Powell's Creek where they were planted in June.

3.2 Water Quality Monitoring

Results of water quality measurements are presented for all three years of shallow water SAV habitat monitoring. Samples were not taken for the months of June and July of 2000 therefore time, as presented on the x-axis, is not linear. Sampling was initiated at Westover Plantation on April 10, 2001.

Water temperatures (Fig. 3-4) demonstrated similar annual patterns over the 1999-2001 sampling period with daytime minimums ranging from approximately 5 °C to maximums of 30-32 °C. Lower summertime temperatures in 2000 reflect the lack of sampling in the summer. Conductivity (Fig. 3-5) demonstrated marked differences among the years reflecting difference in river discharge rates. Conductivities were generally in the range of 100-300 μmhos (0 psu salinity) throughout most of the year increasing to nearly 1000 μmhos (0.5 psu salinity) in the fall of 1999 and 2000 μmhos (1.0 psu salinity) in the fall of 2001. Rapid declines at the station in the fall of 1999 were due to the passage of Tropical Storm Floyd. The fall of 2000 demonstrated no appreciable increase in conductivity. Typically salinities of 3-5 psu are required to stress growth and reproduction of wild celery (French and Moore, in review), however other freshwater species can be more sensitive to elevated salinity levels. When conductivity levels increased in the fall of 1999 and 2001, highest levels were reached at the most downstream stations of Westover Plantation and Powell's Creek. At other times there were no differences among the stations. Daytime dissolved oxygen (DO) concentrations

(Fig. 3-6) followed somewhat similar annual patterns over all years with lowest levels in the late spring (May-June), another decrease in the late summer, and highest levels in the winter as temperatures decreased. Typically daytime DO levels at the transplant sites did not fall below 5 mg/l. Increasing DO levels throughout the 2001 SAV growing season generally paralleled the increasing salinity. Water column pH levels (Fig. 3-7) paralleled changing DO levels to some extent, however pH is affected by many factors including the buffering capacity of the water, which is related to salinity. Highest salinities typically buffered pH to between 7.5 and 8.0. Generally there were no consistent differences in pH among the stations.

Suspended particle loads (TSS) were consistently lowest at the Shirley Cove station (Fig. 3-8). Very high levels (>50 mg/l) likely reflected wind re-suspensions of bottom sediments. Levels were generally higher in the late winter and early spring (Feb-Apr) and lowest in summer. Year-to-year differences in salinity were not generally reflected in the suspended sediment concentrations. TSS levels consistently exceeded the habitat requirement of 15 mg/l established by the Chesapeake Bay Program (Batiuk et al. 2000) for SAV restoration of SAV to one-meter depths at all the sites.

The pattern in 1999 of low phytoplankton levels in the spring followed by high levels during the summer was not generally repeated during the other low flow year of 2001 (Fig. 3-9) although levels were typically high from May through October 2001. Rapid declines between the sampling dates of September 8 and 23 of 1999 coincided with the passage of tropical storm Floyd. Similarly, chlorophyll levels dropped in October 2001 as salinity dropped although levels increased again in January 2002. All stations usually followed the same temporal patterns indicating generally similar phytoplankton levels throughout this region of the river. However, the variability in ranking of the various stations from sampling date to sampling date suggests some patchiness in the bloom events. A pattern of generally increasing chlorophyll levels from initiation of the monitoring in 1999 through 2002 is evident. Overall, seasonal chlorophyll medians were below the habitat requirement of 15 μg/l for freshwater regions in 1999, in spite of the high levels during the summer, but were well above the requirement for 2001. In spite of this, wild celery survival and growth during the growing season was similar during all years.

Water transparencies measured as secchi depth (Fig. 3-10) demonstrated generally greater depths (clearer water) during the higher flow year of 2000 than the lower flow years of 1999 and 2000. This may be related to a shifting in the turbidity maximum of the river that may shift slightly downriver of the Hopewell region of the estuary during wet years and slightly upriver during dry years. Generally secchi depths were greatest 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 are generally less.

Total organic carbon (TOC), total kjeldahl nitrogen (TKN) and total phosphorus (TP) levels (Figs. 3-11, 3-12, 3-13) were relatively consistent among the years. Generally TP followed TSS patterns as much of the total phosphorus load is bound to suspended sediments. In this regard, levels were consistently lowest at Shirley Cove. TKN concentrations were below detection limits for many sampling periods but occasional increases in levels were not related to general decreases in conductivity, suggesting a source unrelated to watershed inputs. Levels were usually, but not always, higher in the summer in 1999 and 2000 and increased in the fall and winter of 2001-2002. TOC levels were lowest at Shirley Cove and highest at Turkey Island, the most upstream site. However, periodic high concentrations at Westover may reflect patterns of greater re-suspension at this relatively more exposed site.

Dissolved inorganic nitrogen constituents (nitrate, nitrite and ammonium), in contrast to dissolved inorganic phosphorus (DIP), have been found to generally not be limiting for phytoplankton and epiphyte growth in tidal freshwater regions. In low salinity regions, however, total dissolved inorganic nitrogen levels (nitrate + nitrite + ammonium) above 0.15 mg/l have been found to be associated with SAV declines and lack of recovery. Throughout the study period nitrate and nitrite levels (Fig. 3-14) have been quite variable, both over time and among stations. During the latter part of 2001 levels of these inorganic nitrogen constituents were generally highest in the most upstream, Turkey Island station, and lowest in the most downstream Powell's Creek and Westover stations. This may reflect the potential watershed sources, as watershed influences in the most downriver stations were reduced due to the high salinities, especially during the fall and winter. In contrast to the variable nitrate and nitrate concentrations over time, a marked increase in dissolved ammonium concentrations (Fig. 3-15) was observed for all stations during the fall of 2001 when salinity levels increased due to reduced river flow. Generally levels were below detection limits during 1999 (detection limits at that time were 0.2 mg/l) and low and variable during 2000. The marked increase in the fall of 2001, that was unrelated to river flow, may reflect greater inputs of point source ammonium, or less dilution of ammonium due to reduced freshwater input. Typically dissolved inorganic phosphorus (DIP) concentrations (Fig. 3-

16) remained at or below the SAV habitat requirement threshold of 0.02 mg/l for the tidal fresh SAV regime for all three years of study. These low levels suggest there is the potential that epiphyte growth on SAV may be nutrient-limited to some degree.

4.0 DISCUSSION AND CONCLUSIONS

Three years of SAV restoration and water quality measurements in the Hopewell region have revealed several points. First, wild celery appears, so far, to be the best SAV species for use in restoration here. Other native species, typically found in other tidal, freshwater bay regions, either do not survive the transplanting process, or are rapidly uprooted by the tidal currents and wave action in this region of the river. Species such as redhead grass, and sago pondweed have been successfully transplanted into other regions of the bay, so their lack of survival here should not preclude eventual success in this region. Additionally, species such as coontail, *Hydrilla* and *Elodea* that are currently growing in abundance in the Chickahominy, performed poorly here. This may be related to the process of transplanting whole plants removed from their source during the growing season. The use of tubers or other rootstock material may result in greater success.

A second factor that appears to be important in SAV survival and restoration success is herbivory. This can be successfully reduced by use of fencing material, however over-wintering losses of tubers remain problematic. Over three years of continuing success at the Turkey Island site, and now two years (2001-2002) success of CBF transplants at the Westover site, indicate that herbivory is not insurmountable. Ongoing work by investigators at Virginia Commonwealth University in 2002 may provide clues as to the probable herbivores involved (either fish, turtles or birds), and strategies for protection can then be devised. One future task will be to remove the exclosure from one of the established transplant beds at Turkey Island and follow the survival of the plants.

Water quality and sediment conditions appear not to be limiting for SAV growth at the shallow planting depths used here (0.3m MLW) in spite of year-to-year-differences in river flow, nutrient and suspended sediment levels. Epiphyte growth, measured using artificial substrates, appears to be below that predicted by bay models (Moore et al 2000). During 2002 actual epiphyte growth on the transplant leaves is being measured. Water column turbidity, due to phytoplankton and suspended sediments, likely precludes SAV growth below 0.5 m depths, however. This raises some constraints, as plants established at these shallow depths may become exposed by unusually low tides during the growing season. This may stress the plants and limit survival. Some evidence of this is evident at the Turkey Island site as natural sediment accumulation within the bed is effectively raising the bottom elevation several inches. The plants should adapt to this by growing out into slightly deeper water. This potential will be investigated in subsequent years' work.

Water quality appears generally similar among the sites. However, the relationships between river flow and water quality conditions are somewhat counterintuitive as overall turbidity appears higher during the low flow years of 1999 and 2001 compared to the higher flow year of 2000 and ammonium levels highest during 2001 when river flow the lowest. This suggests that more spatially extensive and integrated monitoring of water quality along a longer reach of the tidal freshwater James

River using new technologies (such as spatially integrative continuous monitoring) may be necessary to determine the relationships between the water quality conditions in this region and the factors regulating them.

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APPENDIX OF FIGURES

Figure 2-1: Location of SAV Transplant Sites

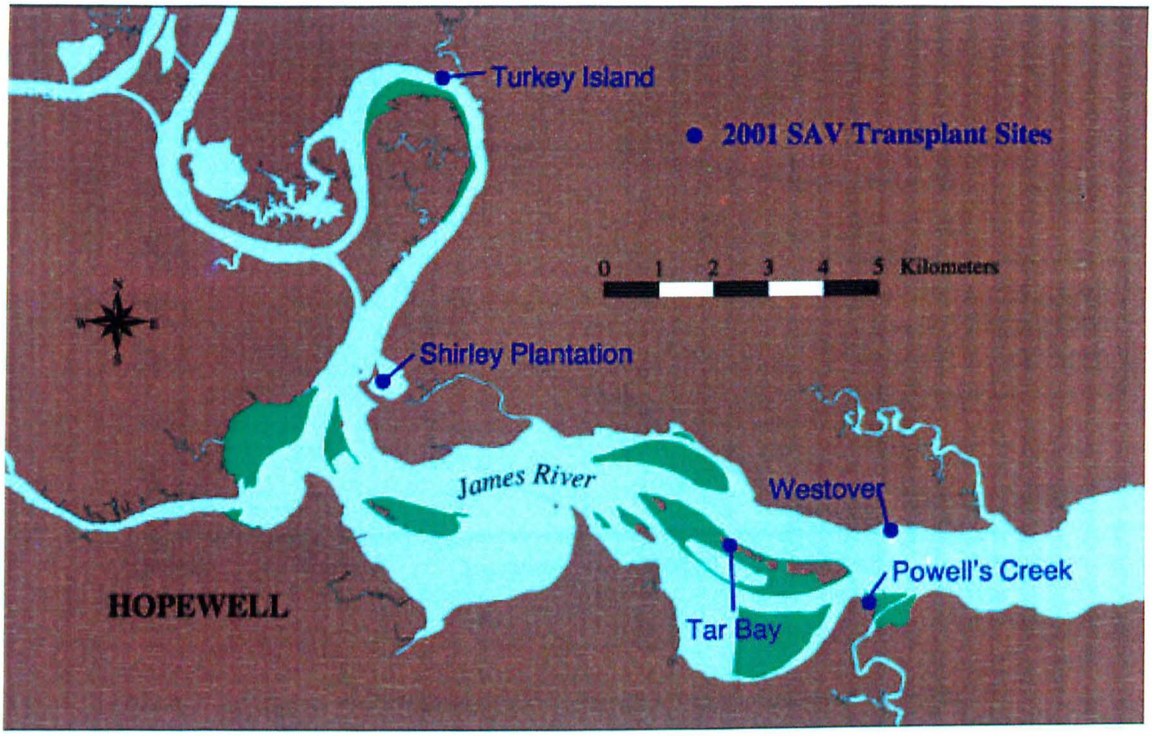
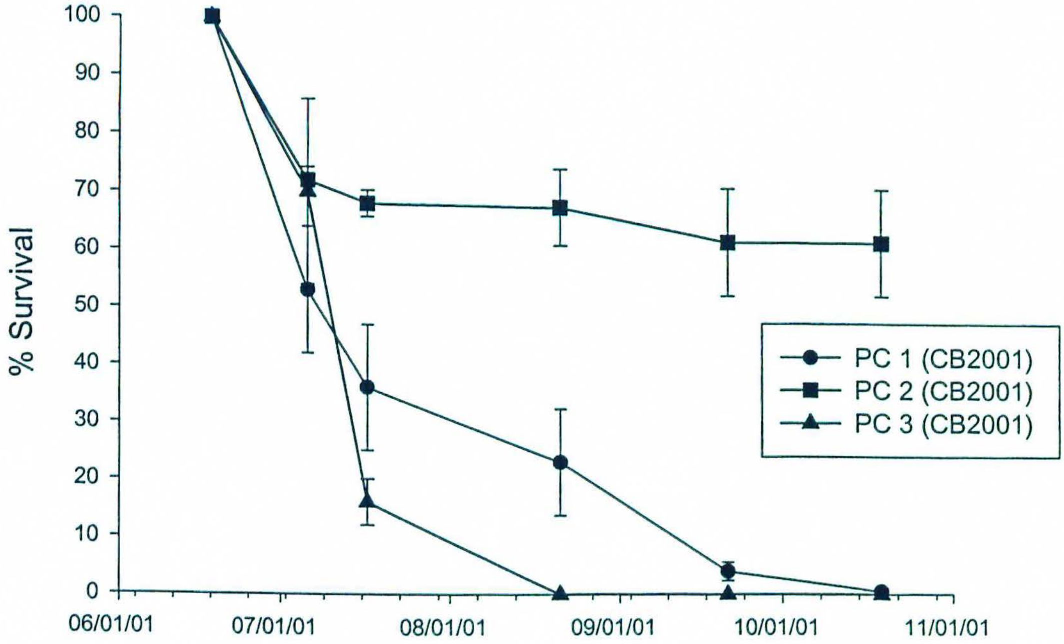


Figure 3-1. Wild Celery (*Vallisneria americana*) Transplant Survival
(CB1999 = 1999 Chesapeake Bay Stock. CB2001 = 2001 Chesapeake Bay Stock.
PC = Powell's Creek. TB = Tar Bay. TI = Turkey Island.)



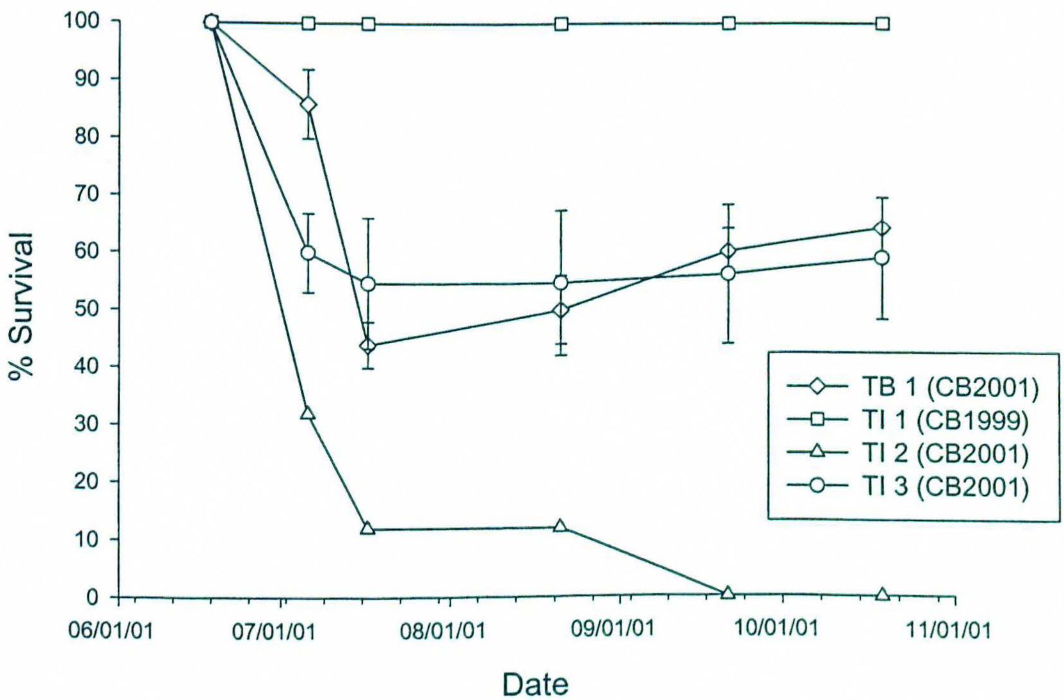
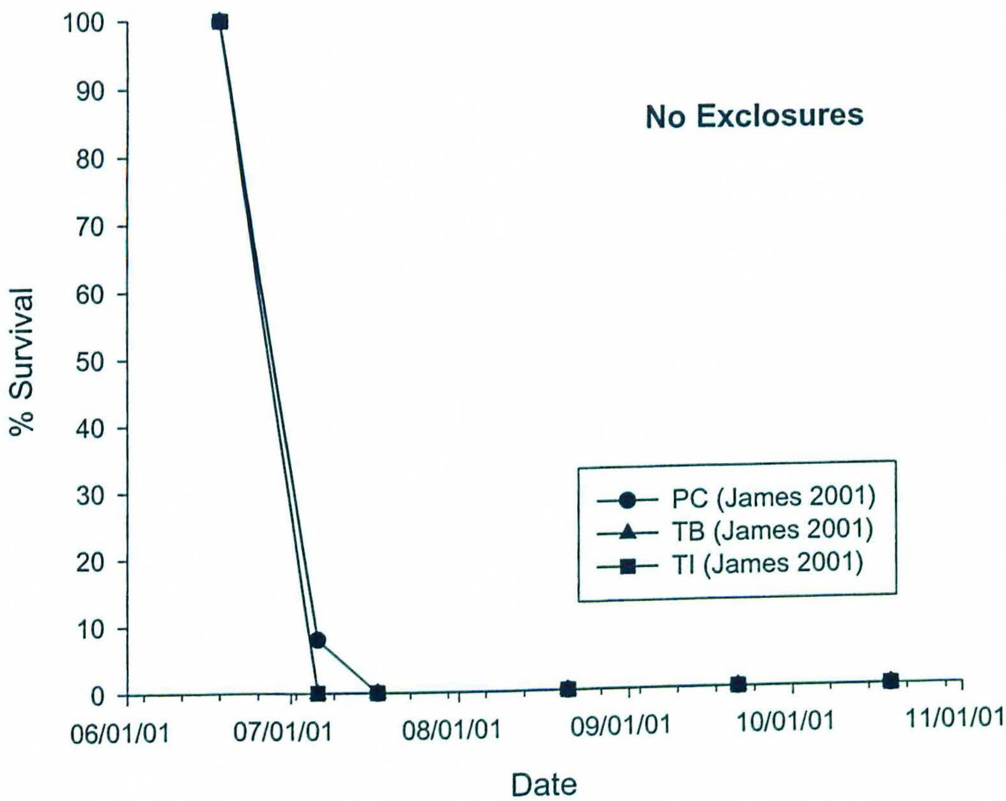


Figure 3-2. *Hydrilla verticillata* Transplant Survival
James 2001 = 2001Chickahominy River Stock
PC = Powell's Creek. TB = Tar Bay. TI = Turkey Island.



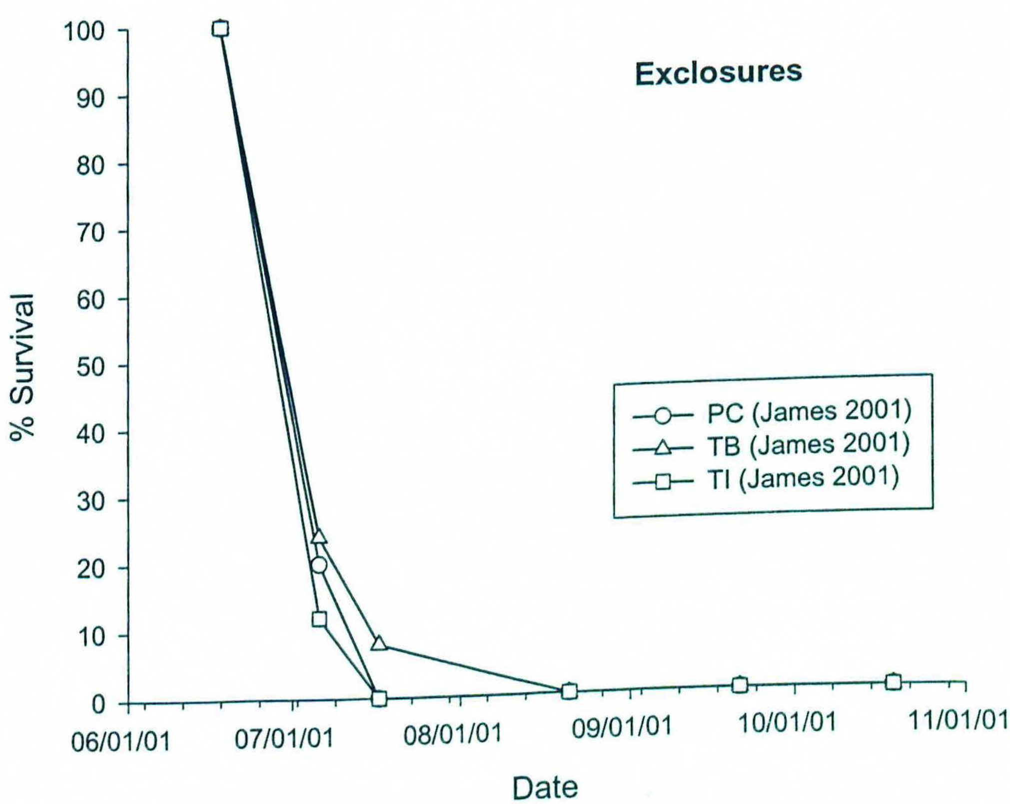
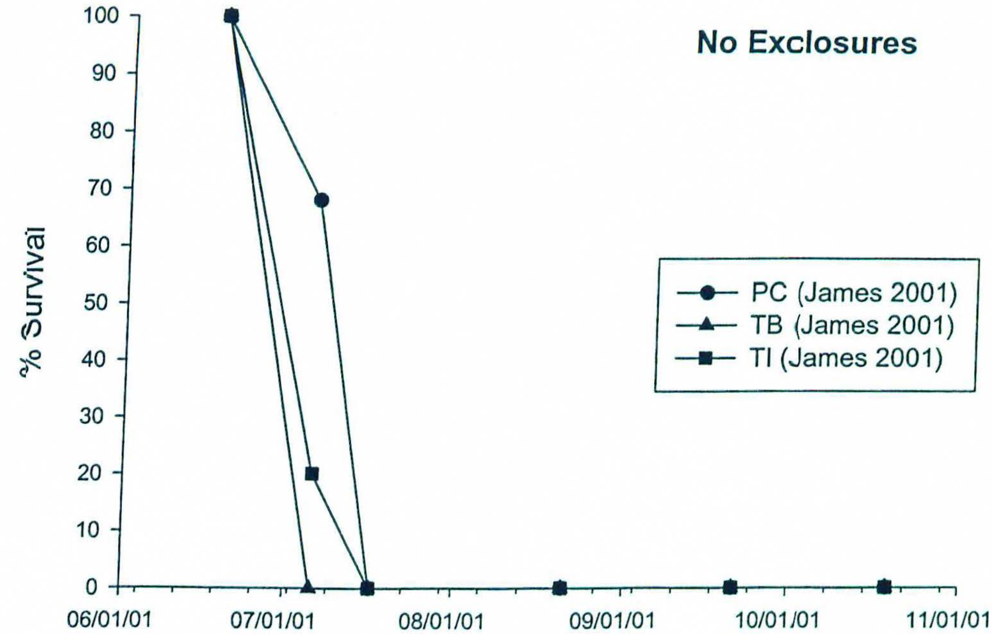


Figure 3-3. ***Elodea Canadensis*** **Transplant Survival**
James 2001 = 2001Chickahominy River Stock
PC = Powell's Creek. TB = Tar Bay. TI = Turkey Island



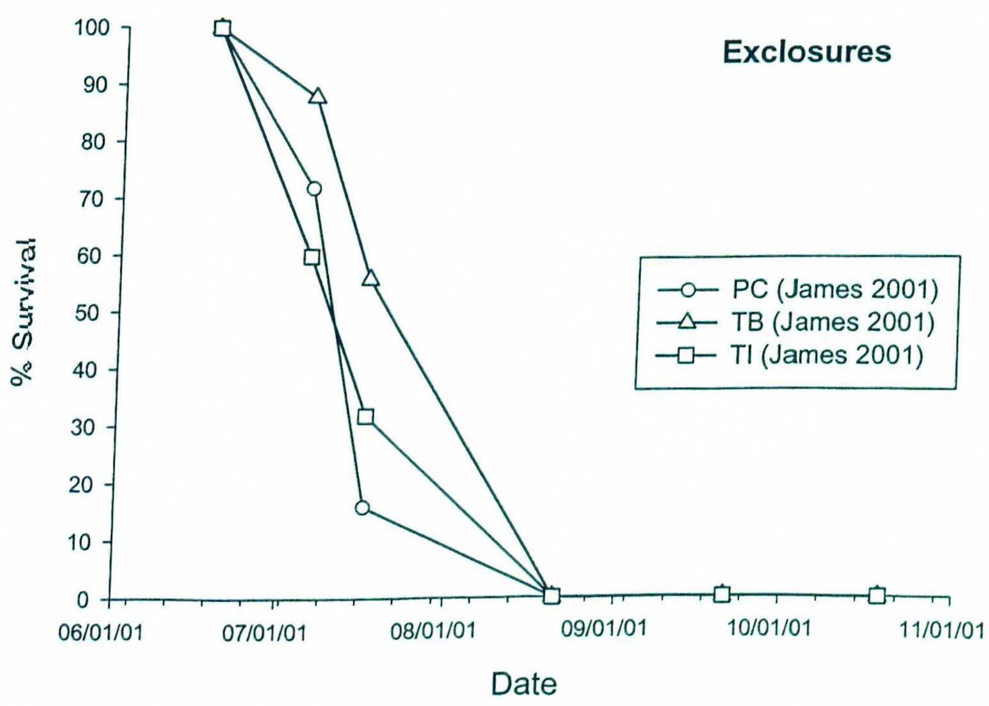


Figure 3-4: Water Temperature

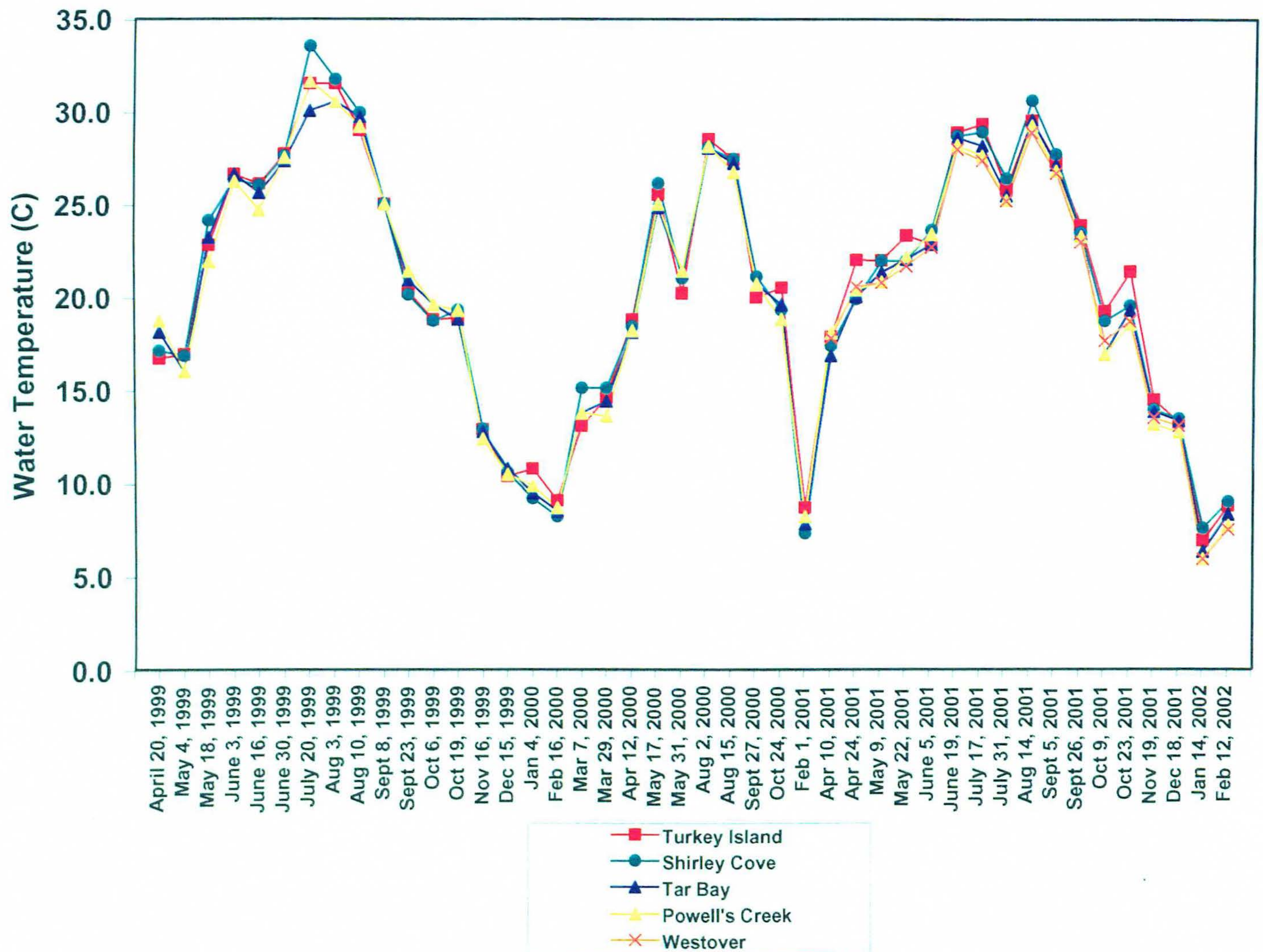


Figure 3-5: Water Column Conductivity

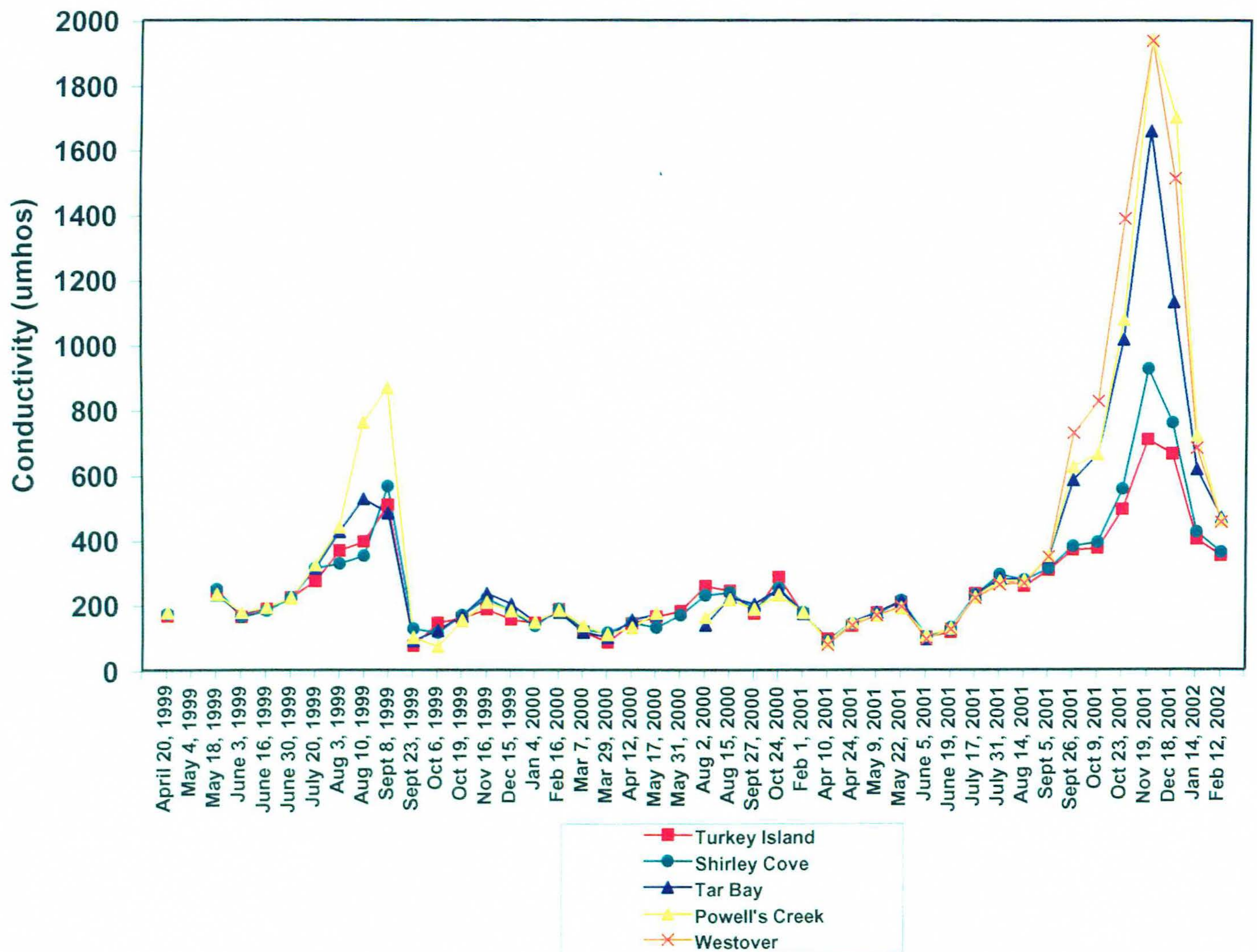


Figure 3-6: Water Column Dissolved Oxygen

Figure 3-7: Water Column pH

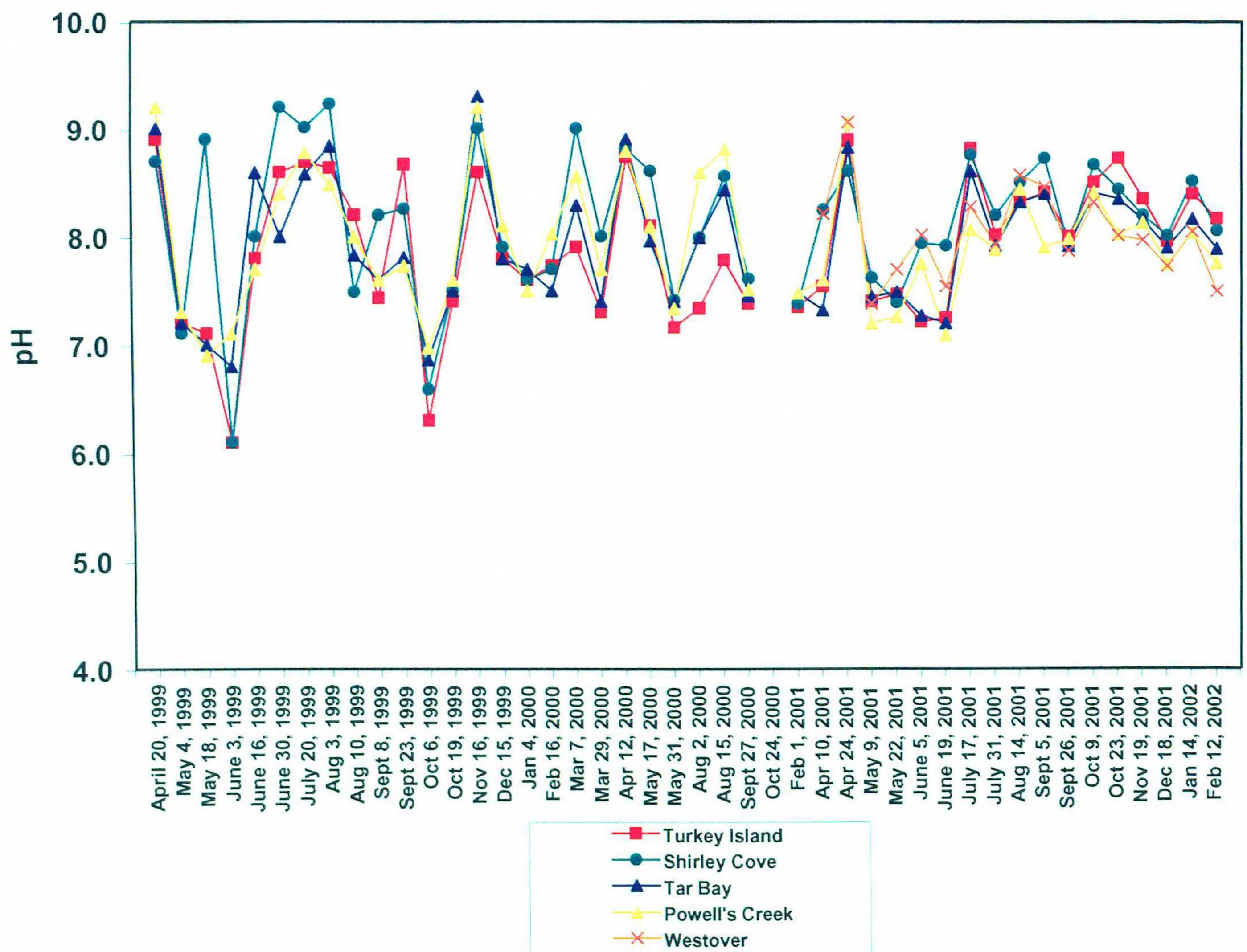


Figure 3-8: Total Suspended Solids (TSS)

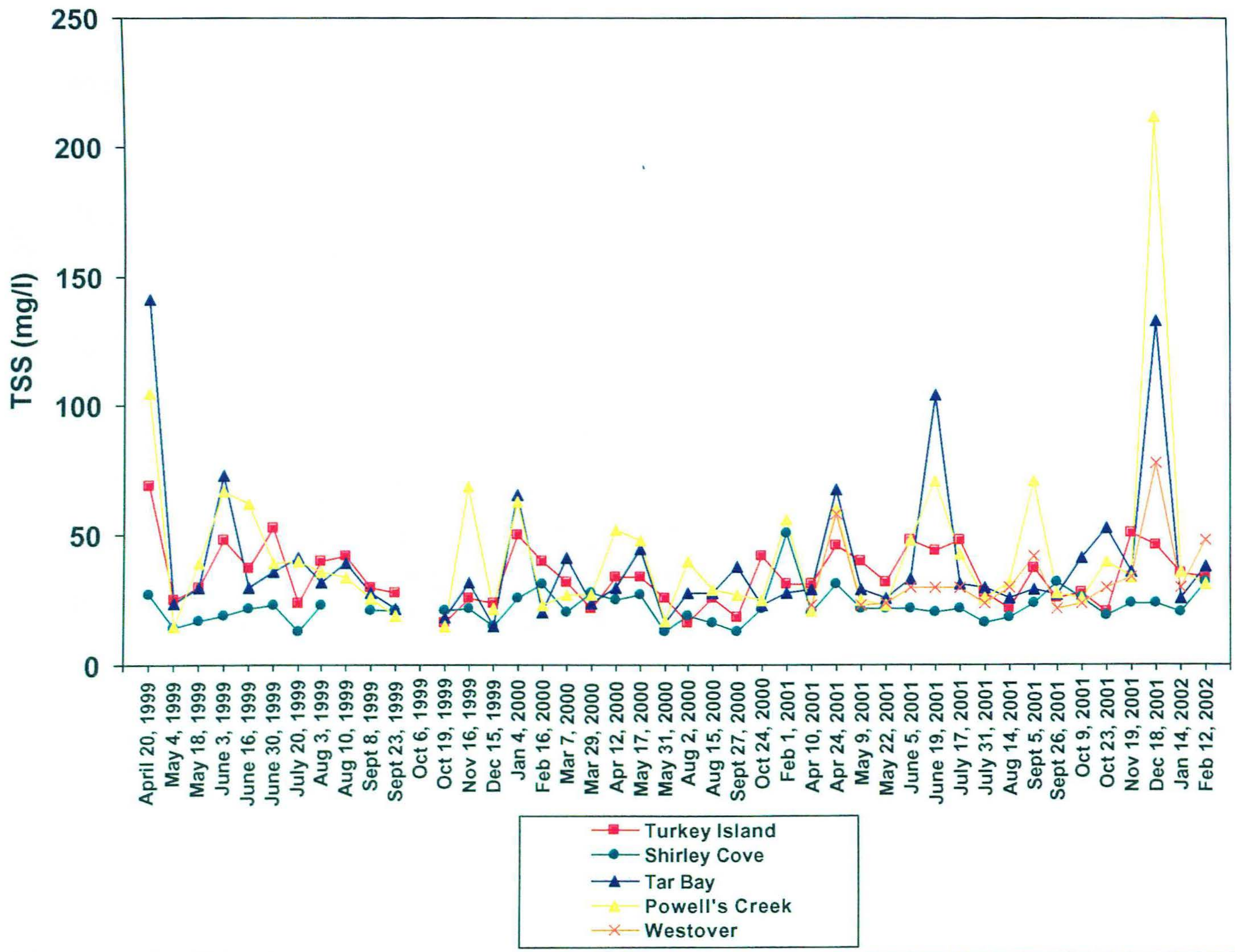


Figure 3-9: Phytoplankton as Chlorophyll a

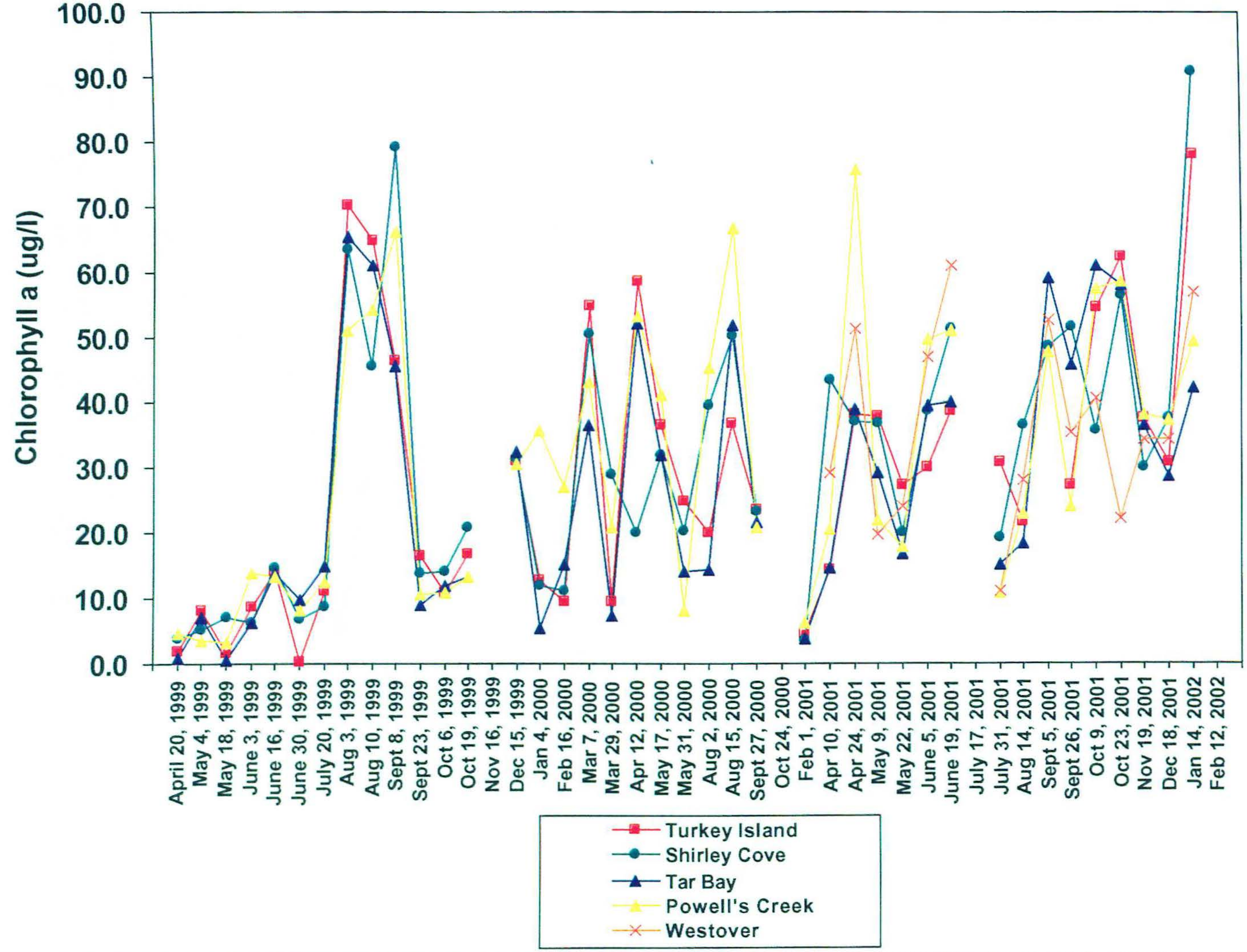


Figure 3-10: Secchi Depth

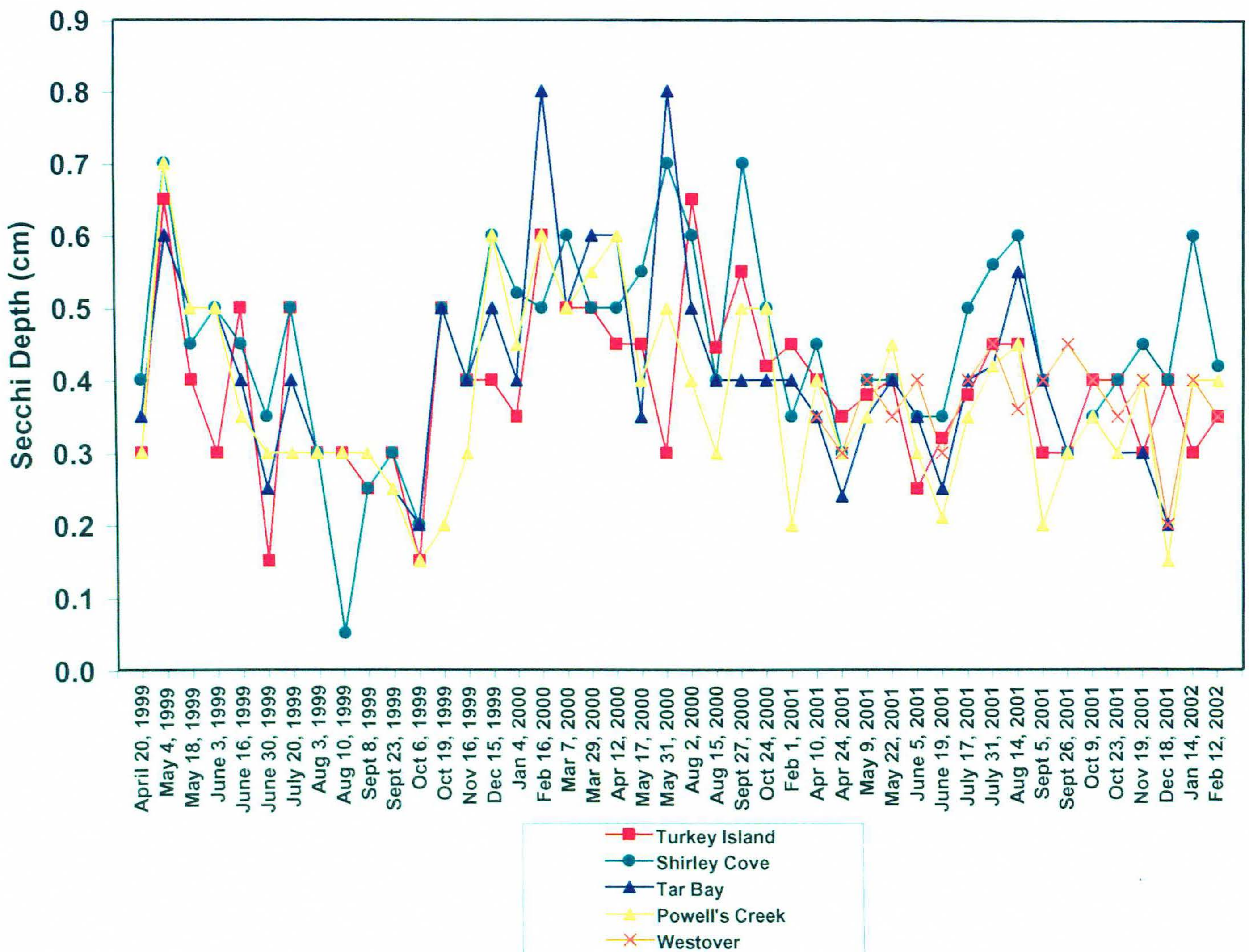


Figure 3-11: Total Organic Carbon (TOC)

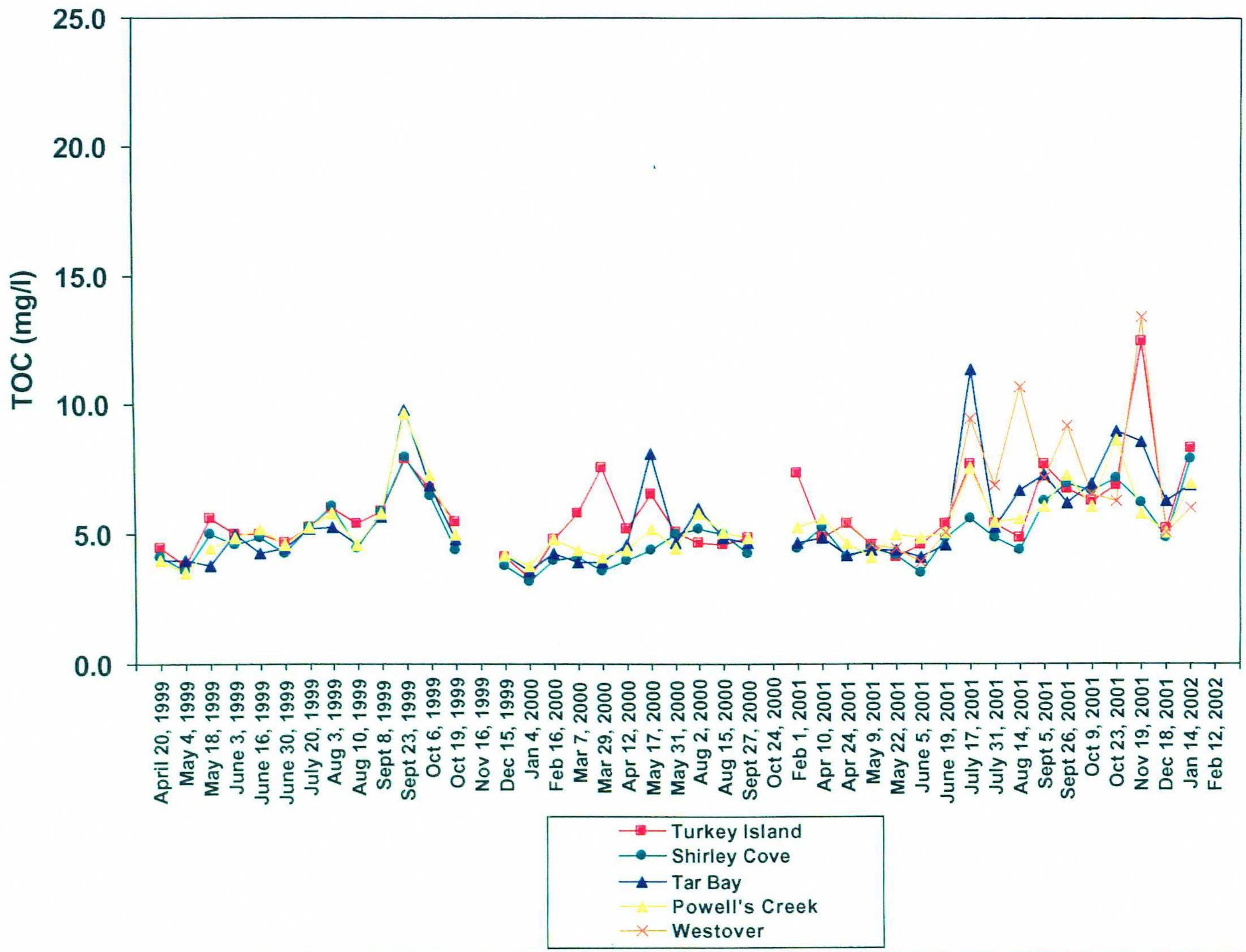


Figure 3-12: Total Kjeldahl Nitrogen (TKN)

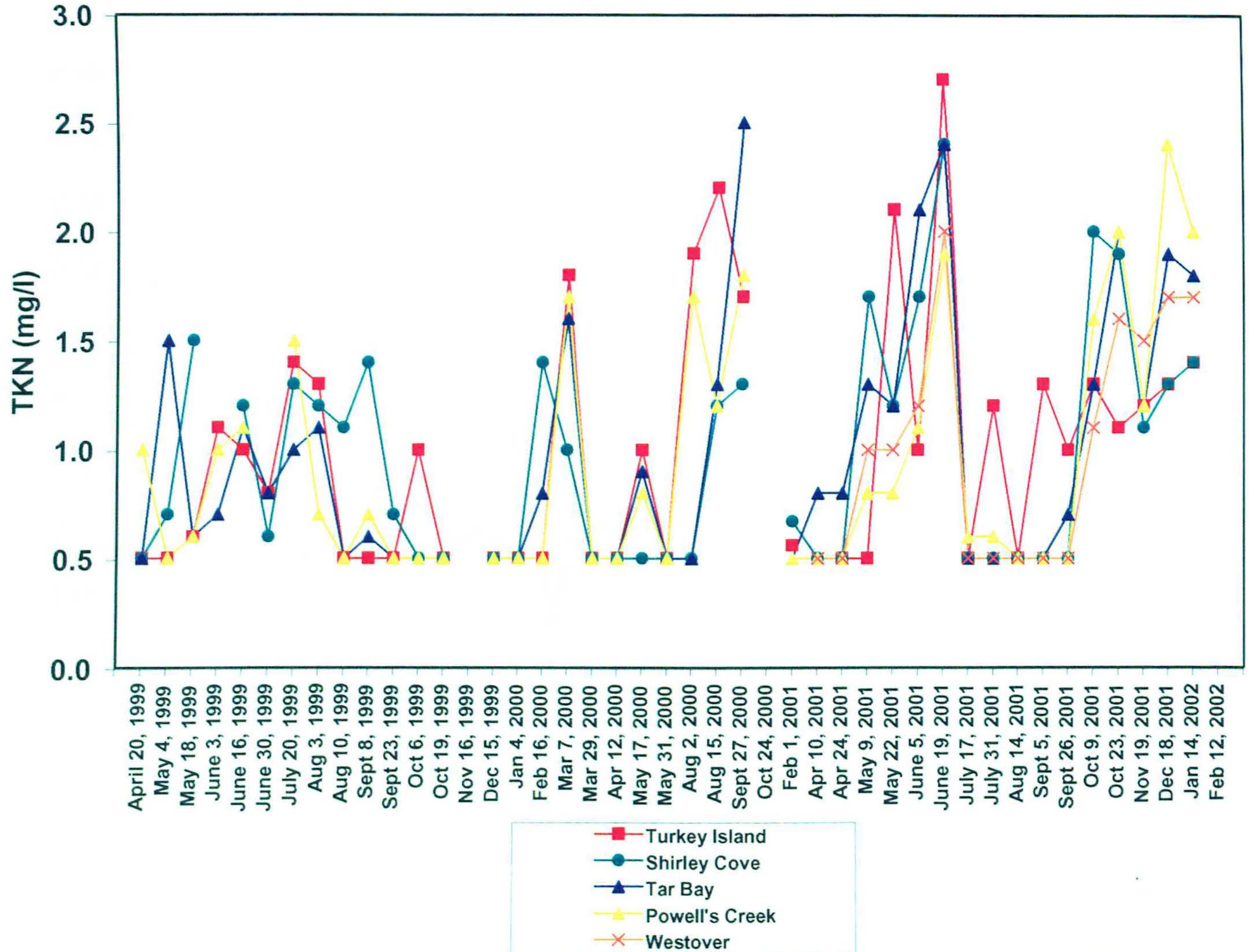


Figure 3-13: Total Phosphorus (TP)

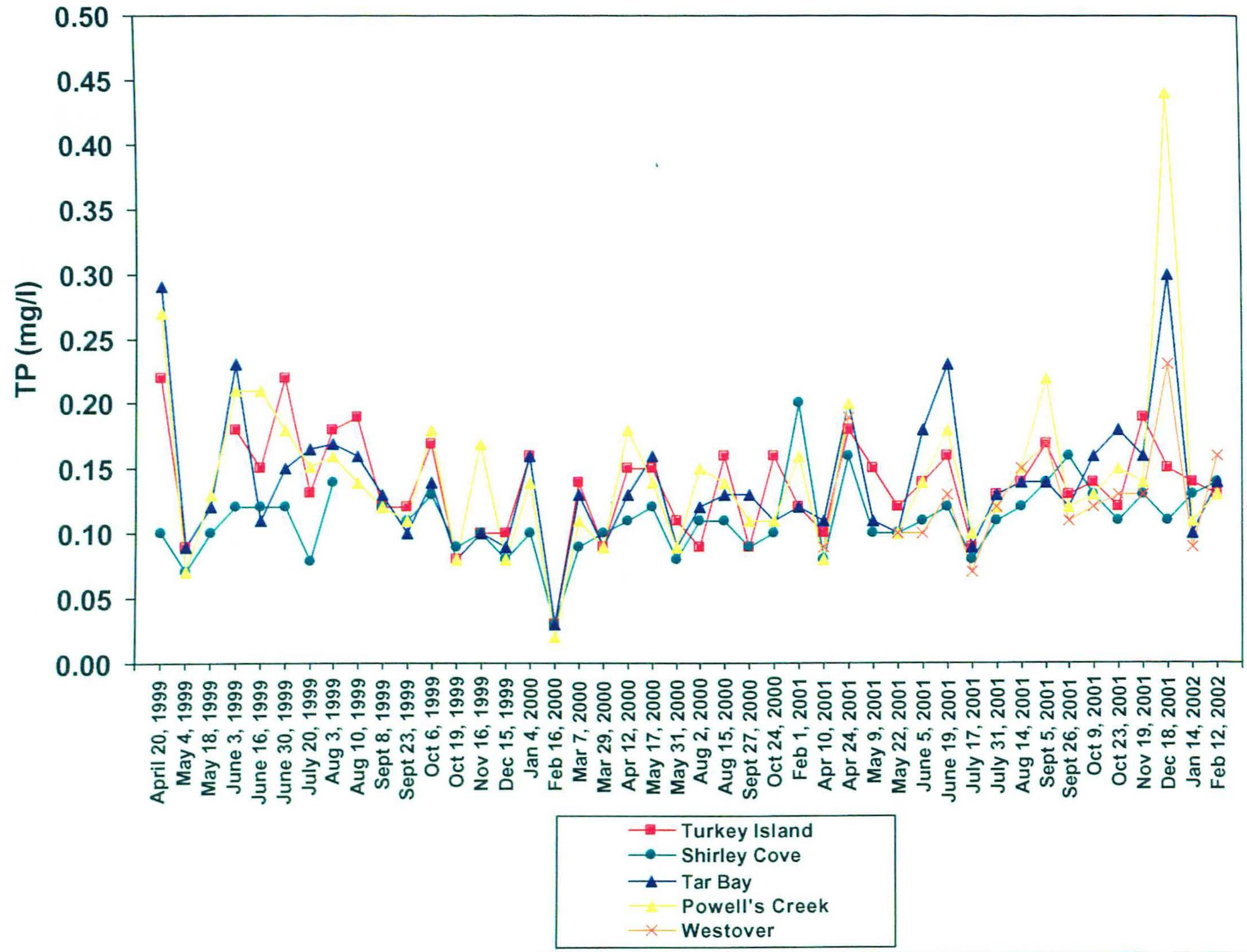


Figure 3-14: Dissolved Nitrate + Nitrite

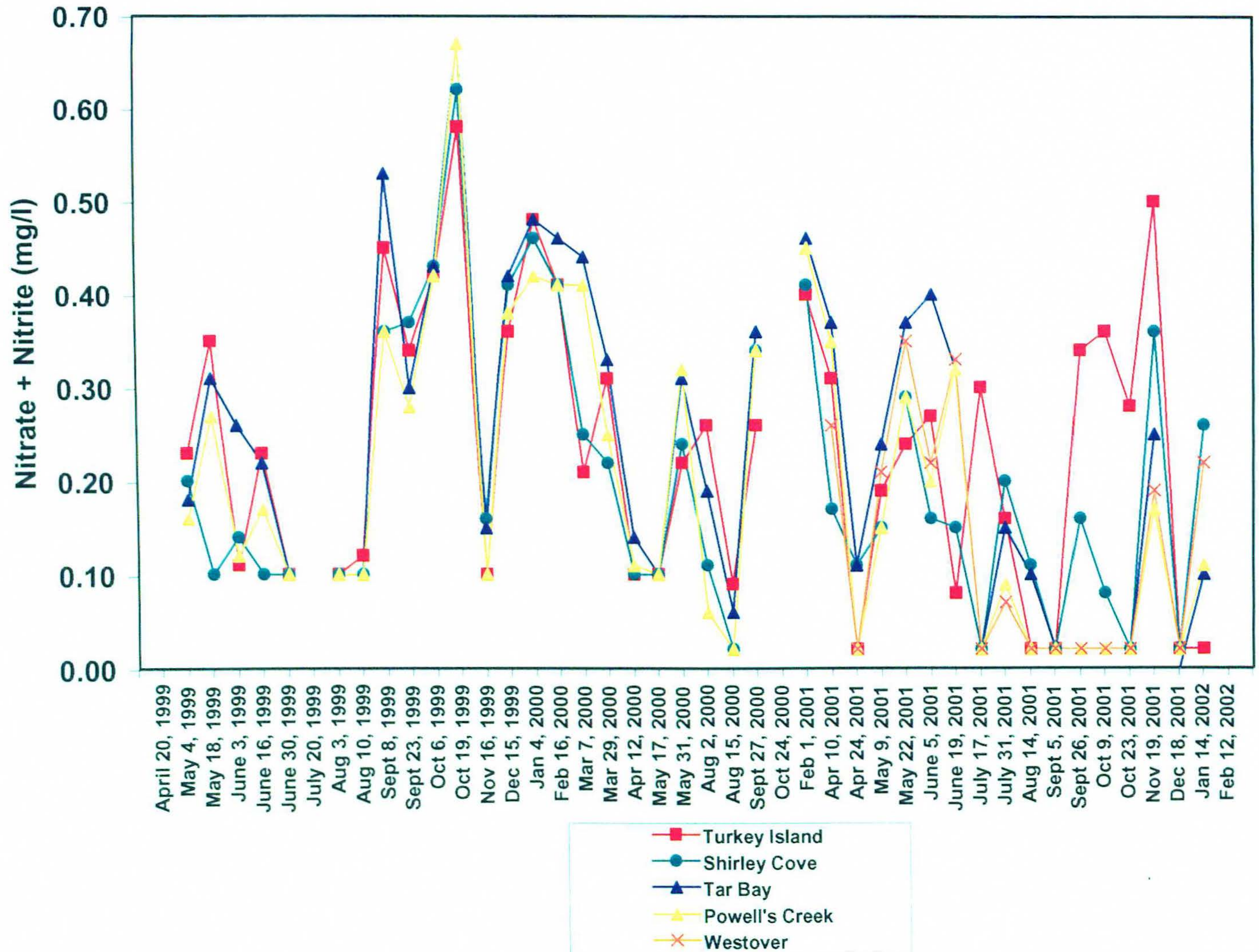


Figure 3-15: Dissolved Ammonium

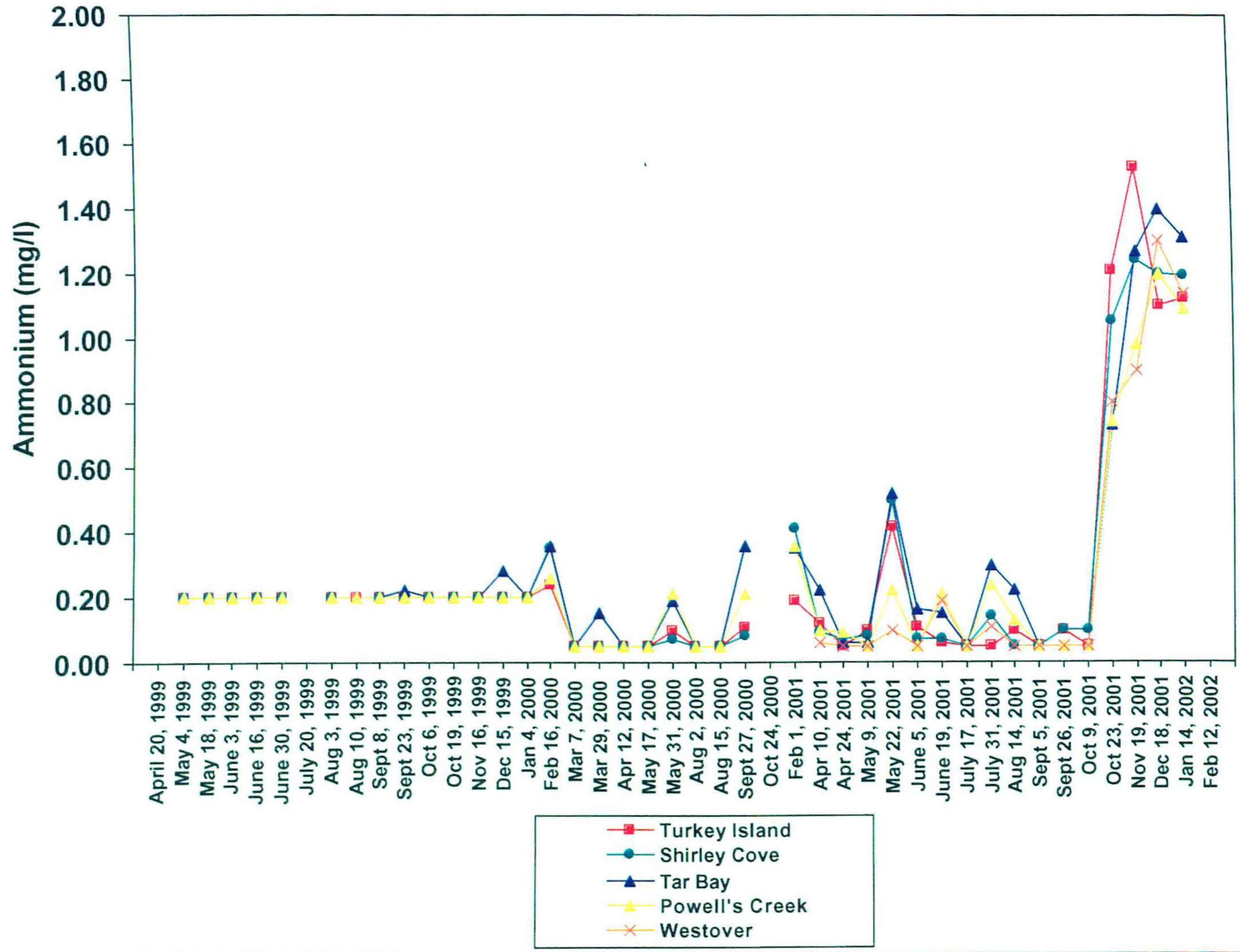


Figure 3-16: Dissolved Inorganic Phosphate (DIP)