Water Quality Conditions and Restoration of Submerged Aquatic Vegetation (SAV) in the Tidal Freshwater James River 2007

Kenneth Moore  
*Virginia Institute of Marine Science*

Betty Neikirk  
*Virginia Institute of Marine Science*

Erin Shields  
*Virginia Institute of Marine Science*

Jessie Jarvis  
*Virginia Institute of Marine Science*

David Parrish  
*Virginia Institute of Marine Science*

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WATER QUALITY CONDITIONS AND RESTORATION OF SUBMERGED AQUATIC VEGETATION (SAV) IN THE TIDAL FRESHWATER JAMES RIVER 2007

Dr. Kenneth Moore, Betty Neikirk, Erin Shields, Jessie Jarvis and David Parrish

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HOPEWELL REGIONAL WASTEWATER TREATMENT FACILITY
231 HUMMEL ROSS ROAD
HOPEWELL, VA 23860

CITY OF RICHMOND DEPARTMENT OF PUBLIC UTILITIES
1400 BRANDER STREET
RICHMOND, VA 23224

COUNTY OF HENRICO DEPARTMENT OF PUBLIC UTILITIES
P.O. Box 2032
RICHMOND, VA 23273

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EXECUTIVE SUMMARY

In 2007, wild celery (Vallisneria americana) and water stargrass (Heteranthera dubia) were planted at sites in the Hopewell region of the tidal James River. The SAV transplants from 2007 and previous years were monitored by the Virginia Institute of Marine Science (VIMS) for survivorship and growth throughout the growing season. Nursery ponds were constructed at the VIMS campus for development of SAV transplant propagules. 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 water quality sampling was also conducted along the James River from the mouth of the Chickahominy River to the upstream limits of tidal water at Richmond.

Objectives of this restoration and water quality study were to: 1) expand the SAV transplanted plots within the study sites previously transplanted; 2) conduct water quality sampling to determine the state of water quality in the tidal freshwater James relative to current water quality standards and SAV habitat requirements; 3) evaluate SAV transplant performance and compare to water quality conditions; 4) monitor SAV re-growth in the upper tidal James River.

SAV transplant growth and survival occurred at all James River field sites at depths of approximately 0.4 m below low water. Seeds obtained from wild stock and planted within the exclosures germinated and produced adult plants in 2006 and these demonstrated re-growth in 2007. Water stargrass stocks originally collected from non-tidal areas of the James and planted into grow out nursery ponds at VIMS in 2006, along with nursery grown wild celery were re-planted into tidal sites in 2007. Both species transplanted in 2007 also were successful and grew throughout 2007. SAV growth throughout the tidal freshwater James continued to expand in 2007 reaching over 300 acres. Powell's Creek plantings continued to expand with coontail (Ceratophyllum demersum) plantings mixed with recruited Hydrilla (Hydrilla verticilata) reaching over 60 acres.

Water quality monitoring in the tidal James River in 2007 indicated that turbidity levels were again suitable for SAV growth to depths of 0.5 m in most areas. Seasonal light levels were at or near water clarity criteria for most transplant sites. Turbidity levels were highest in the upper section of the JMSTF1 segment and lower section of the JMSTF2 segment. When integrated along each of the freshwater segments (JMSTF1 and JMSTF2) using continuous underway spatial sampling, turbidity goals were met for all eight SAV growing season cruises. Summertime levels of chlorophyll were the highest recorded over the past five years. When integrated across the entire segments, average concentrations were found to be well above spring and summer limits of 15-23 μg l⁻¹ and 10-15 μg l⁻¹ for JMSTF1 and JMSTF2 respectively. Similarly, average seasonal concentrations at the transplant sites were above SAV growing season goals of 15 μg l⁻¹. Nutrient levels generally were comparable with earlier years’ monitoring results, although dissolved ammonium concentrations were at or below detection for most of the year and a decreasing trend has been evident since 2002. Similarly dissolved inorganic phosphate (DIP) levels were very low throughout much of the year and all transplant sites met SAV growing season habitat requirements for DIP.

Overall, the success of the SAV restoration in the tidal freshwater James River is encouraging, but the high levels of chlorophyll are of concern and warrant continued monitoring.
1.0 Background and Objectives

The James River tidal freshwater estuary continues to be listed on the 303(d) list as an impaired waterbody for aquatic life use attainment. While low dissolved oxygen levels have been recorded, the James does not exhibit the acute or chronic low oxygen conditions reported in other estuaries. SAV abundance in the river has been low relative to historical levels but in recent years the abundance of SAV has been increasing due to both transplantation activities from this project and natural recruitment.

Excessive phytoplankton growth, measured as chlorophyll, can have adverse effects on the estuarine system in a variety of ways. High phytoplankton levels can contribute to reduced light availability for SAV. 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 contribute to low oxygen levels. 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. Water quality monitoring by the Virginia Institute of Marine Science (VIMS) and the Hopewell Regional Wastewater Treatment Facility (HRWTF) have determined that chlorophyll levels have varied both throughout the SAV growing season as well as during the spring and summer criteria periods (Moore et al 2007). Over the past several years these levels have increased during the summer, although their effects on water clarity and water quality at the transplant sites and visible blooms throughout this section of the river have not been observed (Moore et al 2007).
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 several 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. Since that time, SAV plantings in conjunction with water quality monitoring have been used to better demonstrate the cause/effect relationships between James River habitat conditions and SAV transplant success. Results of the preceding work have been very encouraging. SAV transplants have been established at four shallow water sites in the Hopewell region of the James River and have expanded in Powell’s Creek and other creeks in this region of the James (Orth et al 2007). SAV acreage in the tidal freshwater James (JMSTF1) exceeded 303 acres in 2007 (R.J. Orth unpublished). No SAV were observed in the area prior to 1999.

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.” 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-1940s (Moore et al. 1999). Until 1999 SAV was found only in scattered patches in a few small tributary creeks in this region of the James River (Moore et al. 1999).

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 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 suggest 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 Objectives

During 2007 objectives of the SAV restoration and water quality monitoring efforts, funded by HRWTF, the City of Richmond, and the County of Henrico were to:

1) Plant SAV at sites in the freshwater, tidal James River in the vicinity of Hopewell, VA, to serve as habitat as well as a source of propagules for enhanced recovery of SAV in these areas.
2) Conduct twice monthly fixed station water quality sampling at 4 shallow water sites (1m depth) in the James River from April through October and monthly from November to March.

3) Evaluate data collected during monthly continuous water quality monitoring cruises during the SAV growing season (April-October), along the axis of the James River including the Tidal Fresh 1 (JMSTF1) and Tidal Fresh 2 (JMSTF2), Chesapeake Bay Program Segments that extend from the mouth of the Chickahominy River to the fall line at Richmond.

4) Monitor the SAV 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 to evaluate the cause/effect relationships between water quality and SAV habitat recovery.

2.0 Methods

2.1 Study Sites

Four 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 2007. One previous site, in the Shirley Cove area was discontinued in 2007 due to periodic disturbance by ongoing dredge disposal from maintenance of the navigation channel in that area.

<table>
<thead>
<tr>
<th>Site</th>
<th>Lat.</th>
<th>Long.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turkey Island</td>
<td>37.3826 N</td>
<td>77.2527 W</td>
</tr>
<tr>
<td>Tar Bay</td>
<td>37.3075 N</td>
<td>77.1902 W</td>
</tr>
<tr>
<td>Powell's Creek</td>
<td>37.2929 N</td>
<td>77.1622 W</td>
</tr>
</tbody>
</table>
Westover Plantation  Lat. 37.3105 N  Long. 77.1558 W

2.2 SAV Transplanting and Monitoring

Transplanting activities at all of the James River sites were undertaken in spring and summer 2007 using bare-rooted water stargrass plants and 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 and water stargrass plants were obtained from nursery grown stock established in grow out ponds at the campus of VIMS in Gloucester Point, VA, in 2005 and 2006 (Moore et al. 2007). At each of the transplant sites (Westover, Powell’s Creek, Tar Bay and Turkey Island) 5m x 10m areas both inside and outside of fenced exclosure areas were planted in May 2007 with treatments consisting of whole bare rooted plants, intact seeds pods, and seeds that had been removed from the pods. The whole plants were planted directly into the sediments at approximately 0.2 m intervals. Plants were checked by divers for growth and bottom cover at approximately monthly intervals.

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 four James River restoration sites from January to December 2007. 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 (Kd), 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, and 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 498 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.

Eight continuous Dataflow sampling cruises were conducted from May to October 2007 as part of the Chesapeake Bay shallow water monitoring program. 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 temperature, 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 (Kd) was determined.

Data obtained from the Dataflow cruises as well as several fixed stations recording
continuous water quality measurements at 15-minute intervals have been made available for
visualization and review at the Virginia Estuarine and Coastal Observing System (VECOS) web
site (www.vecos.org). This monitoring program is a partnership between VIMS, Virginia
Department of Environmental Quality and the Virginia Commonwealth University Rice Center.

3.0 RESULTS

3.1 Transplant Survival

Water stargrass (*Heteranthera dubia*) was originally collected during the fall of 2005 from
the non-tidal James River where it co-occurs with wild celery. It was then transplanted into
exclosures in the spring of 2006 after overwintering in nursery ponds at VIMS and again in 2007
using the nursery stock that had expanded in the ponds. Re-growth of the 2006 transplants was
observed in the spring of 2007. Similarly wild celery shoots first established in the field from
seeds and seed pods in 2006 (Moore et al. 2007) re-grew in 2007 and became established within
the planting exclosures during 2007.
Growth of the wild celery and water stargrass transplanted in the spring of 2007 are presented in Figure 3-1. SAV transplants at the Tar Bay site showed rapid growth and spreading from May through July followed by seasonal dieback. The transplanted wild celery shoots outperformed the water stargrass for much of the season, but the water stargrass eventually reached similar cover. Both species reached the greatest size at Tar Bay, with shoots nearly one meter in length. Previous studies (Moore et al. 2000) have shown that sediment at this site have the greatest organic content and therefore provide abundant sediment nutrients for growth. Growth of both species was comparable at Powell’s Creek and in comparison to the other sites there was continued growth into September. Part of this may have been due to moderate herbivory observed within the exclosures during the summer. This likely reduced the overall growth rates. Reduction in grazing in the late summer allowed the plants to rebound and expand. The Westover site had the poorest growth and survival of all the sites showing moderate growth from May to August followed by dieback in the fall. Much of the loss was due to grazing inside the exclosures as well as the sandy substrate at that site (Moore et al. 2000). Both the Westover and Powell’s Creek exclosures were affected by floating logs and other tree material that ripped parts of the fencing. Repair of the fencing was accomplished, and in the case of Powell’s Creek the plants were able to recover.

Aerial photography taken in the summer of 2007 by VIMS revealed the continued expansion of SAV beds within Powell’s Creek (Figure 2-1). In 2001, SAV consisting of native SAV stock obtained from the Chickahominy River including *Hydrilla verticillata*, *Ceratophyllum demersum*, and *Elodea canadensis* were transplanted into 10 sites within upper Powell’s Creek with the assistance of Mr. Wilson Enochs, a local landowner (Moore et al. 2002). Although little growth was observed that first year the transplants within the creek have
expanded significantly, by 2007 over 60 acres of SAV were growing within the Powell’s Creek system. In 2007, SAV in the Creek system consisted principally of *Hydrilla verticillata* and *Ceratophyllum demersum*. Nearly 20% of the over 300 acres SAV mapped in the tidal freshwater James River are now growing in Powell’s Creek (R.J. Orth unpublished).

3.2 Water Quality Monitoring

3.2.1 Fixed Station Monitoring

Water temperatures (Fig. 3-2) demonstrated similar annual patterns over the 1999-2007 sampling period at all the stations with daytime minimums ranging from approximately 5 °C to maximums of 30-32 °C. During July and August the water temperatures were about 5 °C cooler than the air temperatures which commonly exceeded 40 °C during the cruises.

Conductivity (Fig. 3-3) demonstrated marked differences among the years reflecting variations in river discharge rates and low freshwater inputs in 1999, 2001 and 2002. Conductivities again showed a moderate increase in the fall of 2007. There was a significant dieback of the SAV at the Westover, Powell’s Creek and Tar Bay sites in 2003 which we attributed to the high salinities in the fall of 2002. This suggests that the limit for SAV growth in this region may be about 2000 µmhos. Figure 3-4 illustrates the mean monthly James River flow at the Cartersville, Virginia gauging station in comparison to the long term average flow. Flows during the late summer and fall of 2007 were well below the long-term average and were similar to low flows in 2001 and 2002. These low flows corresponded to the high conductivities during that same period. Flows during the spring and early summer were above average.

Daytime dissolved oxygen (DO) concentrations (Fig. 3-5) at the transplant sites continued to be high and typically above 6 mg/l even during the summer with no differences among the stations. Water column pH levels (Fig. 3-6) 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 in the fall of 2007 and was slightly above that of the fall of 2006 when conductivities were lower.

Suspended particle loads (TSS) have continued to be consistent among years regardless of river flow and salinity with no long term trends evident (Fig. 3-7). This suggests that much of the suspended material is reworked or retained within this region of the river and concentrations are controlled by physical factors including tidal circulation and wave re-suspension. Seasonally, turbidity levels are lowest during the fall. Table 1 presents median TSS concentrations and other SAV habitat criteria for the SAV growing season (April 1- October 31) at each transplant site. Sites which meet the individual criteria are shaded in grey. Generally, suspended sediment concentrations in 2007 during the SAV growing exceeded the habitat criteria of 15mg/l for SAV growth to 1m at all sites suggesting that under existing conditions re-colonization to 1m depth will be difficult. These high levels of suspended sediments are not unusual for this region of the James River which is within the turbidity maximum zone of the river. However, the goal for SAV growth in this region is only to a depth of 0.5 m. Although TSS levels associated with SAV growth to 0.5m have not been determined, suspended sediments are the largest component of turbidity in the Hopewell region of the James and therefore water clarity requirements to growth to shallower depths can be accomplished with higher suspended sediment concentrations. In fact, estimates of light requirement for SAV at 0.5m depths suggest that these requirements are met (Table 1). In addition, once established SAV beds can be restored, their capacity to decrease suspended sediment levels may permit gradual expansion to deeper depths.
Water transparencies measured as secchi depth (Fig. 3-8) and light attenuation (Fig. 3-9) also demonstrated little year-to-year variability over the past several years, regardless of river flow. Turbidity in this region of the river is largely affected by suspended sediment and the patterns of light availability parallel that of TSS. SAV growing season secchi depths for SAV growth to 0.5m met the goal of 0.4m secchi depth at all the sites in 2007 (Table 1). Growing season light attenuation (Kd) another measure of light availability, was also met at all sites. For several hours at low tidal levels each day the SAV shoots are generally floating close to the water surface and the light availability for them is high. Extremely low tides may, however, expose the shoots to desiccation. This highlights the dilemma of SAV growth at such shallow depths. Growth of SAV under high turbidity conditions in tidal areas is squeezed into a narrow depth zone. The growth in the shallowest areas is limited by exposure during extreme low tidal levels and the physical effects of waves during storms. Growth at deep areas is limited by light availability.

Chlorophyll levels in 2007 demonstrated increases over 2006 and earlier years and were the highest observed since 1999 (Fig. 3-10). Although there was considerable variability, mean concentrations ranged from 66-103 \( \mu g \) l\(^{-1}\) during the April-October SAV growing season. Low river flows throughout the summer of 2007 have contributed to this increase; however the pattern of increasing chlorophyll levels since 2003-2004 may be problematic if they continue into the future.

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 1999-2007. Numeric
chlorophyll standards for the spring and summer seasons were again exceeded at all of the transplant sites with mean concentrations increasing 40-100% over 2006.

Total organic carbon (TOC) concentrations were relatively consistent with less variability compared to earlier years. (Fig 3-11). Overall levels were less than the 2002-2003 period which was the highest over the study period. Total kjeldahl nitrogen (TKN) and total phosphorus (TP) levels (Fig. 3-12, and Fig. 3-13) were also relatively consistent among the years with few changes in 2007. As with previous years, TP followed TSS patterns since much of the total phosphorus load is bound to suspended sediments. Concentrations are quite variable and as with earlier years this suggests local sediment re-suspension in this broad, shallow region of the James may be affecting TP levels.

Throughout the long term study period nitrate + nitrite levels (Fig. 3-14) have been low during the summers as nitrate and nitrite generally represent "new" nitrogen entering the system and river flows are low during that period. No increasing trend has been evident over time. Concentrations of ammonium were at or below detection throughout much of 2007 (Fig. 3-15). It may be that the ammonium is being converted to algal biomass however there is no inverse relationship observed between yearly dissolved inorganic nitrogen (DIN) levels and phytoplankton biomass. Typically DIN levels in freshwater regions of the Chesapeake Bay are high, but other than during 2002, ammonium levels have been very low in the Hopewell region of the James.

Dissolved inorganic phosphorus (DIP) concentrations (Fig. 3-16) met the SAV growing season habitat criteria threshold of 0.02 mg/l at all sites in 2007 (Table 1). DIP concentrations continue a decreasing trend with near detection limit concentrations observed throughout the summer of 2007. In freshwater regions phosphorus can be limiting to phytoplankton, therefore
the decreases observed may be related to the increasing phytoplankton blooms during the warmer months.

3.2.2 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 again conducted at approximately monthly intervals from April through October 2007. 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. 3-17a-g) are presented in chronological order. Open areas in the data plots are due to losses of data as a result of equipment malfunction. DO concentrations were uniformly high in April (Fig. 3-17a) throughout the entire tidal freshwater James. A DO sag was evident beginning in May in the lower JMSTF1 segment (cruise miles 0-15) although DO levels throughout the James were highest during this month. This DO sag continued throughout the remainder of the year but DO levels never dropped below 4 mg/l. Overall DO concentration decreased in the summer slightly before increasing again in September and October (Figs. 3-17f-g) as water temperatures decreased.

Continuous surface measurements of chlorophyll for every cruise are presented in Figures 3-18a-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 in vivo fluorescence chlorophyll using all the paired (extracted to in vivo) 2007 verification station data. This regression (Extracted Chl=2.509 * (in vivo Chl) + 0.1484) was then used to convert the in vivo Dataflow chlorophyll data to extracted 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 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). The spatial distribution was also observed in 2006 (Moore et al. 2007). Cruise-wide concentrations were highest during the June 20-21 cruises but never exceeded 40 μg L⁻¹. Chlorophyll concentrations integrated spatially along the entire tidal freshwater James River segments showed little attainment during the March-May and July-September criteria dates (Table 3).

The distribution of turbidity was relatively consistent throughout most of the tidal freshwater segments (Figs. 3-19a-g). Lowest turbidities typically 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 more turbid water (elevated 10-20 NTU) were found all along the river. These generally varied from <1 to 5 miles 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 for this report 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 0.5m (3.6 $K_d$ or 0.4m secchi), a turbidity of 36 NTU or less should be the goal.
Integrated turbidity levels for the JMSTF1 and JMSTF2 (Table 3) 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 level for all dates. This supports our SAV transplant results that water clarity conditions during the growing season in 2007 were generally suitable for SAV growth to depths of ~0.5m in the Hopewell region. Water clarity conditions in the James River above the I-295 bridge were particularly good for SAV growth, however, shallow protected areas for SAV bed development are limited likely precluding SAV establishment. No historical records of SAV have been found so far for this upriver area.

4.0 CONCLUSIONS

Transplants of both wild celery and water stargrass were successful in the Hopewell region of the James and re-growth of previous SAV transplants was observed. Expansion of SAV into Powell’s Creek continued from 2006. Here the sheltered habitat allows for the initial development of several species of canopy forming SAV. Recent studies in the Potomac River (Rybicki and Landwehr 2007) indicate that these species can be important colonizers for the latter recruitment of wild celery and other SAV species in Powell’s Creek many years ago.

The preliminary success of water stargrass (*Heteranthera dubia*) transplants in 2006 and again in 2007 suggests another potential native SAV for restoration in this area. Grow-out ponds at VIMS were successfully planted with this species along with wild celery to provide another potential SAV species for restoration use in this tidal freshwater James River region in 2008.

Water quality monitoring in the tidal James River in 2007 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 or shallower. Summer phytoplankton concentration continued to increase from previous year however these high levels did not preclude SAV growth and survival. Overall SAV abundance in the upper James River has increased from a low of 12 acres in 2004 to a high of over 300 acres in 2007. Large areas of historically vegetated shallow water bottom, with appropriate depths and conditions for SAV growth still remain unvegetated. However, the rapid spread of SAV over the past several years suggests that there is high potential for continued re-colonization.

5.0 LITERATURE CITED


APPENDIX A

TABLES
Table 1. SAV Growing Season (April – October) median water quality. Shaded cell indicates SAV criteria met for SAV growth to 0.5 m.

<table>
<thead>
<tr>
<th>Water Quality Parameter</th>
<th>SAV Habitat Criteria</th>
<th>Turkey Island</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Atten. (Kd; m⁻¹)</td>
<td>&lt; 3.6</td>
<td>-</td>
<td>-</td>
<td>3.87</td>
<td>3.35</td>
<td>3.66</td>
<td>3.58</td>
<td>3.40</td>
<td>3.39</td>
</tr>
<tr>
<td>Secchi Depth (m)</td>
<td>&gt; 0.40</td>
<td>0.30</td>
<td>0.45</td>
<td>0.39</td>
<td>0.40</td>
<td>0.40</td>
<td>0.30</td>
<td>0.35</td>
<td>0.40</td>
</tr>
<tr>
<td>TSS (mg l⁻¹)</td>
<td>&lt;15</td>
<td>33.5</td>
<td>26.0</td>
<td>31.5</td>
<td>30.0</td>
<td>26.0</td>
<td>35.0</td>
<td>32.0</td>
<td>27.5</td>
</tr>
<tr>
<td>Chl a (μg l⁻¹)</td>
<td>&lt;15</td>
<td>11.1</td>
<td>30.8</td>
<td>30.4</td>
<td>44.8</td>
<td>6.6</td>
<td>9.2</td>
<td>12.5</td>
<td>39.1</td>
</tr>
<tr>
<td>DIP (mg l⁻¹)</td>
<td>&lt;0.02</td>
<td>0.01</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.03</td>
<td>0.03</td>
<td>0.02</td>
<td>0.01</td>
</tr>
</tbody>
</table>

| Water Quality Parameter | SAV Habitat Criteria | Shirley Cove |  |  |  |  |  |  |  |  |
|-------------------------|----------------------|--------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
| Light Atten. (Kd; m⁻¹)  | ≤ 3.6                | -             | -             | 2.80          | 2.61          | 2.87          | 3.12          | 2.77          | -             |
| Secchi Depth (m)        | ≥ 0.40               | 0.40          | 0.55          | 0.40          | 0.40          | 0.50          | 0.45          | 0.45          | 0.50          |
| TSS (mg l⁻¹)            | ≤15                  | 21.0          | 19.0          | 22.0          | 24.0          | 16.0          | 21.0          | 24.0          | 21.0          |
| Chl a (μg l⁻¹)          | ≤15                  | 13.7          | 27.5          | 37.0          | 56.0          | 8.80          | 5.65          | 9.3           | 32.9          |
| DIP (mg l⁻¹)            | ≤0.02                | 0.01          | 0.01          | 0.01          | 0.02          | 0.03          | 0.02          | 0.01          | 0.01          |

| Water Quality Parameter | SAV Habitat Criteria | Tar Bay |  |  |  |  |  |  |  |  |
|-------------------------|----------------------|---------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
| Light Atten. (Kd; m⁻¹)  | ≤ 3.6                | -       | -             | 3.94          | 3.72          | 3.54          | 3.65          | 3.33          | 3.47          |
| Secchi Depth (m)        | ≥ 0.40               | 0.35    | 0.40          | 0.35          | 0.40          | 0.40          | 0.40          | 0.40          | 0.40          |
| TSS (mg l⁻¹)            | ≤15                  | 31.00   | 28.00         | 29.5          | 34.50         | 24.0          | 32.0          | 28.0          | 34.5          |
| Chl a (μg l⁻¹)          | ≤15                  | 12.00   | 26.7          | 39.1          | 41.90         | 4.90          | 5.30          | 15.3          | 32.8          |
| DIP (mg l⁻¹)            | ≤0.02                | 0.02    | 0.02          | 0.02          | 0.02          | 0.03          | 0.03          | 0.02          | 0.01          |

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Table 1 (continued). SAV Growing Season (April – October) median water quality. Shaded cell indicates SAV criteria met for SAV growth to 0.5 m.

<table>
<thead>
<tr>
<th>Water Quality Parameter</th>
<th>SAV Habitat Criteria</th>
<th>Powell’s Creek</th>
<th>Westover</th>
</tr>
</thead>
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<tr>
<td>Light Atten.(Kd; m^{-1})</td>
<td>≤ 3.6</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Secchi Depth (m)</td>
<td>≥ 0.40</td>
<td>0.30</td>
<td>0.50</td>
</tr>
<tr>
<td>TSS (mg l^{-1})</td>
<td>≤15</td>
<td>37.5</td>
<td>29.0</td>
</tr>
<tr>
<td>Chl a (µg l^{-1})</td>
<td>≤15</td>
<td>12.6</td>
<td>43.2</td>
</tr>
<tr>
<td>DIP (mg l^{-1})</td>
<td>≤0.02</td>
<td>0.01</td>
<td>0.02</td>
</tr>
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Table 2. Mean (March-May and July-September) chlorophyll concentrations at SAV transplant sites for 1999 through 2007. Shaded cell indicates criteria met.

<table>
<thead>
<tr>
<th>Season by Year</th>
<th>JMSTF2¹</th>
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<th>JMSTF1¹</th>
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<td>Shirley Cove</td>
<td>Tar Bay</td>
<td>Powell’s Creek</td>
</tr>
<tr>
<td></td>
<td>(µg l⁻¹)</td>
<td>(µg l⁻¹)</td>
<td>(µg l⁻¹)</td>
<td>(µg l⁻¹)</td>
</tr>
<tr>
<td>Mar-May 1999</td>
<td>4.0</td>
<td>5.2</td>
<td>2.8</td>
<td>3.8</td>
</tr>
<tr>
<td>Mar-May 2000</td>
<td>36.8</td>
<td>30.3</td>
<td>28.4</td>
<td>33.3</td>
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<tr>
<td>Mar-May 2001</td>
<td>32.6</td>
<td>28.4</td>
<td>23.0</td>
<td>19.9</td>
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<td>Mar-May 2002</td>
<td>23.5</td>
<td>24.0</td>
<td>18.8</td>
<td>20.8</td>
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<tr>
<td>Mar-May 2003</td>
<td>10.8</td>
<td>12.0</td>
<td>8.9</td>
<td>10.5</td>
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<tr>
<td>Mar-May 2004</td>
<td>6.0</td>
<td>6.7</td>
<td>5.4</td>
<td>6.7</td>
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<td>Mar-May 2005</td>
<td>4.3</td>
<td>4.0</td>
<td>5.8</td>
<td>6.5</td>
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<tr>
<td>Mar-May 2006</td>
<td>19.0</td>
<td>19.7</td>
<td>18.6</td>
<td>17.0</td>
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<tr>
<td>Mar-May 2007</td>
<td>51.6</td>
<td>-</td>
<td>48.4</td>
<td>65.0</td>
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<td>Jul-Sep 1999</td>
<td>41.7</td>
<td>42.1</td>
<td>39.1</td>
<td>38.9</td>
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<td>Jul-Sep 2000</td>
<td>26.9</td>
<td>37.6</td>
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<td>26.7</td>
<td>38.9</td>
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<td>26.4</td>
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<td>50.5</td>
<td>62.9</td>
<td>49.9</td>
<td>48.4</td>
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<td>16.0</td>
<td>10.3</td>
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<td>21.3</td>
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<td>54.1</td>
<td>55.3</td>
<td>61.7</td>
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<td>Jul-Sep 2007</td>
<td>88.5</td>
<td>-</td>
<td>105.0</td>
<td>90.1</td>
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¹ JMSTF 1 - Chlorophyll Limits: March 1-May 31 (15 µg/l); July 1-Sept 30 (23 µg/l)  
JMSTF 2 - Chlorophyll Limits: March 1-May 31 (10 µg/l); July 1-Sept 30 (15 µg/l)

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td></td>
<td>Chlorophyll</td>
<td>Turbidity</td>
<td>Chlorophyll</td>
</tr>
<tr>
<td></td>
<td>Mean (µg/l)</td>
<td>S.E.</td>
<td>Mean (NTU)</td>
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<tr>
<td>JMSTF1</td>
<td>10.91</td>
<td>0.06</td>
<td>22.07</td>
</tr>
<tr>
<td>JMSTF2</td>
<td>10.12</td>
<td>0.15</td>
<td>11.61</td>
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<td>Turbidity</td>
</tr>
<tr>
<td></td>
<td>Mean (µg/l)</td>
<td>S.E.</td>
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<tr>
<td>JMSTF1</td>
<td>28.69</td>
<td>0.44</td>
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<td>JMSTF2</td>
<td>23.63</td>
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<th>October 17 &amp; 18, 2007</th>
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<td>Chlorophyll</td>
<td>Turbidity</td>
</tr>
<tr>
<td></td>
<td>Mean (µg/l)</td>
<td>S.E.</td>
</tr>
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<td>0.53</td>
</tr>
<tr>
<td>JMSTF2</td>
<td>25.41</td>
<td>0.39</td>
</tr>
</tbody>
</table>

1 Measured directly through DATAFLOW in vivo fluorescence and corrected by extracted chlorophyll
   JMSTF1 – Seasonal Chlorophyll Standards: March 1 – May 31 (15 µg l⁻¹ l); July 1 – Sept 30 (23 µg l⁻¹ l)
   JMSTF2 – Seasonal Chlorophyll Standards: March 1 – May 31 (10 µg l⁻¹ l); July 1 – Sept 30 (15 µg l⁻¹ l)
2 Secchi goal of 0.4m for SAV growth to 0.5 m estimated as <36 NTU. See conversion in text
APPENDIX B

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

- SAV Transplant Sites
- Chesapeake Bay Segments
- Current SAV
- Historic SAV

Legend:

- JMSTF2
- JMSTF1
- Turkey Island
- Shirley Plantation
- Westover
- James River
- Powell's Creek
- Tar Bay

Scale: 10 km
Figure 2-2. 2007 SAV Beds in Powell’s Creek (shown in red)
Figure 3-1. 2007 SAV Transplant Growth

Tar Bay

Powell's Creek

Westover

27
Figure 3-4: James River Streamflow (at Cartersville, Virginia)

- Measured
- 1899-2006 Mean

Cubic feet/second

January 1999 to December 2007

Streamflow data measured and calculated for the period 1899-2006.
Figure 3.5: Dissolved Oxygen

Dissolved Oxygen (mg/l)

June 3, 1999
Aug 3, 1999
Oct 6, 1999
Jan 4, 2000
Apr 12, 2000
Aug 15, 2000
Apr 10, 2001
June 5, 2001
Aug 14, 2001
Oct 23, 2001
Feb 12, 2002
May 7, 2002
July 2, 2002
Sept 10, 2002
Nov 5, 2002
Mar 19, 2003
May 28, 2003
July 22, 2003
Sept 16, 2003
Nov 11, 2003
Mar 9, 2004
May 18, 2004
July 14, 2004
September 7, 2004
November 16, 2004
March 9, 2005
May 17, 2005
July 12, 2005
September 7, 2005
November 14, 2005
March 7, 2006
May 16, 2006
July 11, 2006
September 7, 2006
October 31, 2006
February 13, 2007
May 1, 2007
June 26, 2007
August 21, 2007
October 16, 2007

Dissolved Oxygen (mg/l)
Figure 3.7: Total Suspended Solids (TSS)
Figure 3.9: Light Attenuation
Figure 3-10: Chlorophyll a
Figure 3-11: Total Organic Carbon (TOC)
Figure 3-12: Total Kjeldahl Nitrogen (TKN)
Figure 3.14: Dissolved Nitrate + Nitrite

Nitrate + Nitrite (mg/l)

June 3, 1999
Aug 3, 1999
Oct 6, 1999
Jan 4, 2000
Apr 12, 2000
Aug 15, 2000
Apr 10, 2001
June 5, 2001
Aug 14, 2001
Oct 23, 2001
Feb 12, 2002
May 7, 2002
July 2, 2002
Sept 10, 2002
Nov 5, 2002
Mar 19, 2003
May 28, 2003
July 22, 2003
Sept 16, 2003
Nov 11, 2003
Mar 9, 2004
May 18, 2004
July 14, 2004
September 7, 2004
November 16, 2004
March 9, 2005
May 17, 2005
July 12, 2005
September 7, 2005
November 14, 2005
March 7, 2006
May 16, 2006
July 11, 2006
September 7, 2006
October 31, 2006
February 13, 2007
May 1, 2007
June 26, 2007
August 21, 2007
October 16, 2007
Figure 3.15: Dissolved Ammonium
Figure 3-16: Dissolved Inorganic Phosphate (DIP)
Figure 3-17a: Upper James River Dataflow
Dissolved Oxygen April 25 & 26, 2007

Cruise Mile

Dissolved Oxygen (mg/l)

Chickahominy R.

Westover
Tar Bay
Shirley Cove
Turkey Island
I-295 Bridge
I-95 Bridge

JMSTF1

JMSTF2
Figure 3-17b: Upper James River Dataflow
Dissolved Oxygen May 23 & 24, 2007

- JMSTF1
- JMSTF2

Dissolved Oxygen (mg/l)
Figure 3-17c: Upper James River Dataflow
Dissolved Oxygen June 20 & 21, 2007

Chickahominy R.
Westover
Tar Bay
Shirley Cove
Turkey Island
I-295 Bridge
I-95 Bridge

0.00 10.00 20.00 30.00 40.00 50.00 60.00 70.00
Cruise Mile

0.00 2.00 4.00 6.00 8.00 10.00 12.00
Dissolved Oxygen (mg/l)

JMSTF1
JMSTF2
Figure 3-17d: Upper James River Dataflow
Dissolved Oxygen July 25 & 26, 2007

Dissolved Oxygen (mg/l)

Chickahominy R.
Westover
Tar Bay
Shirley Cove
Turkey Island
I-295 Bridge
I-95 Bridge

Cruise Mile
Figure 3-17e: Upper James River Dataflow
Dissolved Oxygen August 22 & 23, 2007

Dissolved Oxygen (mg/l) vs. Cruise Mile

Chickahominy R. 0.00 10.00 20.00 30.00 40.00 50.00 60.00 70.00
Westover 6.00 4.00 2.00 0.00
Tar Bay 6.00 4.00 2.00 0.00
Shirley Cove 6.00 4.00 2.00 0.00
Turkey Island 6.00 4.00 2.00 0.00
I-295 Bridge 6.00 4.00 2.00 0.00
I-95 Bridge 6.00 4.00 2.00 0.00
Figure 3-17f: Upper James River Dataflow
Dissolved Oxygen September 19 & 20, 2007

Dissolved Oxygen (mg/l)

Cruise Mile

Chickahominy R.

Westover

Tar Bay

Shirley Cove

Turkey Island

I-295 Bridge

I-95 Bridge
Figure 3-17g: Upper James River Dataflow
Dissolved Oxygen October 17 & 18, 2007

JMSTF1

JMSTF2

Cruise Mile

Dissolved Oxygen (mg/l)

Chickahominy R.
Westover
Tar Bay
Shirley Cove
Turkey Island
I-295 Bridge
I-95 Bridge

0.00 10.00 20.00 30.00 40.00 50.00 60.00 70.00

60.00 70.00
Figure 3-18a: Upper James River Dataflow
Corrected Chlorophyll April 25 & 26, 2007

Correlation
Chickahominy R.
Westover
Tar Bay
Shirley Cove
Turkey Island
I-295 Bridge
I-95 Bridge

Corrected Chlorophyll (ug/l)
Figure 3-18b: Upper James River Dataflow
Corrected Chlorophyll May 23 & 24, 2007

Chickahominy R.

Corrected Chlorophyll (µg/l)

JMSTF1

Westover

Tar Bay

Shirley Cove

Turkey Island

I-295 Bridge

I-95 Bridge

Cruise Mile

0.00 10.00 20.00 30.00 40.00 50.00 60.00 70.00
Figure 3-18c: Upper James River Dataflow
Corrected Chlorophyll June 20 & 21, 2007
Figure 3-18d: Upper James River Dataflow
Corrected Chlorophyll July 25 & 26, 2007
Figure 3-18e: Upper James River Dataflow
Corrected Chlorophyll August 22 & 23, 2007
Figure 3-18f: Upper James River Dataflow
Corrected Chlorophyll September 19 & 20, 2007

Chickahominy R.

Westover
Tar Bay
Shirley Cove
Turkey Island
I-295 Bridge
I-95 Bridge

Corrected Chlorophyll (ug/l)

0.00 10.00 20.00 30.00 40.00 50.00 60.00 70.00
0.00 10.00 20.00 30.00 40.00 50.00 60.00 70.00

Cruise Mile
Figure 3-18g: Upper James River Dataflow
Corrected Chlorophyll October 17 & 18, 2007

Chickahominy R.

Cruise Mile

0.00 10.00 20.00 30.00 40.00 50.00 60.00 70.00

Corrected Chlorophyll (ug/l)

JMSTF1

Westover
Tar Bay
Shirley Cove
Turkey Island
I-295 Bridge
I-95 Bridge

JMSTF2
Figure 3-19a: Upper James River Dataflow
Turbidity April 25 & 26, 2007

Cruise Mile

Chickahominy R.

Westover
Tar Bay
Shirley Cove
Turkey Island
I-295 Bridge
I-95 Bridge

Turbidity (NTU)
Figure 3-19b: Upper James River Dataflow
Turbidity May 23 & 24, 2007

- JMSTF1
- JMSTF2

Chickahominy R.
- Westover
- Tar Bay
- Shirley Cove
- Turkey Island
- I-295 Bridge
- I-95 Bridge

Cruise Mile
Figure 3-19c: Upper James River Dataflow
Turbidity June 20 & 21, 2007

Chickahominy R.

Westover
Tar Bay
Shirley Cove
Turkey Island
I-295 Bridge
I-95 Bridge

Turbidity (NTU)
0.00 10.00 20.00 30.00 40.00 50.00 60.00 70.00 80.00

Cruise Mile
0.00 10.00 20.00 30.00 40.00 50.00 60.00 70.00

JMSTF1
JMSTF2
Figure 3-19d: Upper James River Dataflow
Turbidity July 25 & 26, 2007

Turbidity (NTU)

Chickahominy R.

Westover
Tar Bay
Shirley Cove
Turkey Island
I-295 Bridge
I-95 Bridge

Cruise Mile

0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
Figure 3-19e: Upper James River Dataflow
Turbidity August 22 & 23, 2007

Cruise Mile

Turbidity (NTU)

Chickahominy R.
Westover
Tar Bay
Shirley Cove
Turkey Island
I-295 Bridge
I-95 Bridge

0.00 10.00 20.00 30.00 40.00 50.00 60.00 70.00
Figure 3-19f: Upper James River Dataflow
Turbidity September 19 & 20, 2007
Figure 3-19g: Upper James River Dataflow
Turbidity October 17 & 18, 2007