Water quality conditions and restoration of submerged aquatic vegetation (SAV) in the tidal freshwater James River, 2008

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WATER QUALITY CONDITIONS AND RESTORATION OF
SUBMERGED AQUATIC VEGETATION (SAV) IN THE TIDAL
FRESHWATER JAMES RIVER 2008

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

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# TABLE OF CONTENTS

LIST OF TABLES .............................................................................................................................................. ii

LIST OF FIGURES .................................................................................................................................................... iii

EXECUTIVE SUMMARY ........................................................................................................................................... v

1.0 Background and Objectives ................................................................................................................................. 1

1.1 Statement of Problem .......................................................................................................................................... 1

1.2 Project Objectives ............................................................................................................................................. 2

2.0 METHODS ......................................................................................................................................................... 3

2.1 Study Sites ........................................................................................................................................................ 4

2.2 SAV Transplanting and Monitoring .................................................................................................................. 4

2.3 Water Quality Monitoring ............................................................................................................................... 4

2.3.1 Fixed Station Monitoring .......................................................................................................................... 4

2.3.2 Continuous Monitoring Using Dataflow Technology ..................................................................................... 5

3.0 RESULTS .......................................................................................................................................................... 7

3.1 Transplant Survival ........................................................................................................................................... 7

3.2 Water Quality Monitoring ............................................................................................................................... 9

3.2.1 Fixed Station Monitoring .......................................................................................................................... 9

3.2.2 Continuous Monitoring Using Dataflow Technology ..................................................................................... 13

4.0 CONCLUSIONS .................................................................................................................................................. 16

5.0 LITERATURE CITED ......................................................................................................................................... 18

APPENDIX A TABLES ............................................................................................................................................... 19

APPENDIX B FIGURES ............................................................................................................................................. 24
# LIST OF TABLES
(APPENDIX A)

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 1</td>
<td>SAV Growing Season (April-October) Median Water Quality</td>
<td>20</td>
</tr>
<tr>
<td>Table 2</td>
<td>Mean (March-May and July-September) Chlorophyll Concentrations at SAV Transplant Sites for 1999 through 2008</td>
<td>22</td>
</tr>
<tr>
<td>Table 3</td>
<td>Spatially Averaged Dataflow 2008 Turbidity and Chlorophyll Measurements for James River Tidal Freshwater Segments</td>
<td>23</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

## (APPENDIX B)

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-1</td>
<td>Location of SAV Transplant and Water Quality Monitoring Sites</td>
<td>25</td>
</tr>
<tr>
<td>2-2</td>
<td>SAV Transplant Species</td>
<td>26</td>
</tr>
<tr>
<td>3-1</td>
<td>2008 SAV Transplant Growth</td>
<td>27</td>
</tr>
<tr>
<td>3-2</td>
<td>2008 SAV Transplant Abundance</td>
<td>28</td>
</tr>
<tr>
<td>3-3</td>
<td>2008 SAV Abundance in Powell’s Creek</td>
<td>29</td>
</tr>
<tr>
<td>3-4</td>
<td>Water Temperature</td>
<td>30</td>
</tr>
<tr>
<td>3-5</td>
<td>Conductivity</td>
<td>31</td>
</tr>
<tr>
<td>3-6</td>
<td>James River Monthly Mean Streamflow at Cartersville (1899-2008)</td>
<td>32</td>
</tr>
<tr>
<td>3-7</td>
<td>Dissolved Oxygen</td>
<td>33</td>
</tr>
<tr>
<td>3-8</td>
<td>Water Column pH</td>
<td>34</td>
</tr>
<tr>
<td>3-9</td>
<td>Total Suspended Solids (TSS)</td>
<td>35</td>
</tr>
<tr>
<td>3-10</td>
<td>Secchi Depth</td>
<td>36</td>
</tr>
<tr>
<td>3-11</td>
<td>Light Attenuation</td>
<td>37</td>
</tr>
<tr>
<td>3-12</td>
<td>Chlorophyll a</td>
<td>38</td>
</tr>
<tr>
<td>3-13</td>
<td>Total Organic Carbon</td>
<td>39</td>
</tr>
<tr>
<td>3-14</td>
<td>Total Kjeldahl Nitrogen (TKN)</td>
<td>49</td>
</tr>
<tr>
<td>3-15</td>
<td>Total Phosphorus (TP)</td>
<td>41</td>
</tr>
<tr>
<td>3-16</td>
<td>Dissolved Nitrate + Nitrite</td>
<td>42</td>
</tr>
<tr>
<td>3-17</td>
<td>Dissolved Ammonium</td>
<td>43</td>
</tr>
<tr>
<td>3-17</td>
<td>Dissolved Inorganic Phosphate</td>
<td>44</td>
</tr>
<tr>
<td>3-19a</td>
<td>Upper James River Dataflow Dissolved Oxygen April 16 &amp; 17, 2008</td>
<td>45</td>
</tr>
</tbody>
</table>
Figure 3-19b  Upper James River Dataflow Dissolved Oxygen May 15 & 16, 2008.........................46
Figure 3-19c  Upper James River Dataflow Dissolved Oxygen June 4 & 5, 2008......................47
Figure 3-19d  Upper James River Dataflow Dissolved Oxygen July 1 & 2, 2008.......................48
Figure 3-19e  Upper James River Dataflow Dissolved Oxygen August 23 & 24, 2008..............49
Figure 3-19f  Upper James River Dataflow Dissolved Oxygen September 10 & 11, 2008...........50
Figure 3-19g  Upper James River Dataflow Dissolved Oxygen October 21 & 23, 2008...............51
Figure 3-20a  Upper James River Dataflow Chlorophyll April 16 & 17, 2008............................52
Figure 3-20b  Upper James River Dataflow Chlorophyll May 15 & 16, 2008.............................53
Figure 3-20c  Upper James River Dataflow Chlorophyll June 4 & 5, 2008...............................54
Figure 3-20d  Upper James River Dataflow Chlorophyll July 1 & 2, 2008.................................55
Figure 3-20e  Upper James River Dataflow Chlorophyll August 13 & 14, 2008.........................56
Figure 3-20f  Upper James River Dataflow Chlorophyll September 10 & 11, 2008...............57
Figure 3-20g  Upper James River Dataflow Chlorophyll October 21 & 22, 2008......................58
Figure 3-21a  Upper James River Dataflow Turbidity April 16 & 17, 2008....................59
Figure 3-21b  Upper James River Dataflow Turbidity May 15 & 16, 2008...............................60
Figure 3-21c  Upper James River Dataflow Turbidity June 4 & 5, 2008.................................61
Figure 3-21d  Upper James River Dataflow Turbidity July 1 & 2, 2008.................................62
Figure 3-21e  Upper James River Dataflow Turbidity August 13 & 14, 2008.........................63
Figure 3-21f  Upper James River Dataflow Turbidity September 10 & 11, 2008.......................64
Figure 3-21g  Upper James River Dataflow Turbidity October 21 & 23, 2008.........................65
EXECUTIVE SUMMARY

In 2008, wild celery (*Vallisneria americana*), water stargrass (*Heteranthera dubia*) and hydrilla (*Hydrilla verticilata*) shoots were transplanted into shallow water sites in the Hopewell region of the tidal James River and sampled for survivorship and growth throughout the SAV growing season. 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 as part of the Chesapeake Bay Monitoring Program. Objectives of this restoration and water quality study were to: 1) expand the SAV transplanted plots within the study areas previously transplanted; 2) conduct water quality sampling to determine the state of water quality for 2008 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 0.4-0.5 m below low water. Water stargrass and wild celery stocks originally collected from non-tidal areas of the James and planted into grow out nursery ponds at VIMS, were transplanted into the enclosed tidal restoration sites in 2008. Similarly, hydrilla shoots obtained from tidal areas in Powell’s Creek were grown out at the nursery ponds at VIMS and transplanted into the James River study sites in 2008. SAV growth throughout the tidal freshwater James continued to expand in 2008 reaching over 350 acres. All three species grew to form beds with canopies of 60-90 cm and maximum bottom covers of 60 to 100%. Powell’s Creek plantings continued to expand with coontail (*Ceratophyllum demersum*) plantings mixed with recruited hydrilla reaching over 68 acres in 2008.

Water quality monitoring in the tidal James River in 2008 indicated that turbidity levels were again suitable for SAV growth to depths of 0.5 m in most areas, but did not meet levels suitable for SAV growth to 1m depths. Seasonal light levels were at or near water clarity criteria for growth to 0.5m depths at most transplant sites. Turbidity levels were lowest in the upper section of the JMSTF2 near Richmond. When integrated along each of the freshwater segments (JMSTFl and JMSTF2) using continuous underway spatial sampling, turbidity levels for growth to 0.5m were met for all eight SAV growing season cruises. Summertime levels of chlorophyll were generally lower than 2007. When integrated across the entire segments, average concentrations were found to be spring and summer limits of 15-23 µg l⁻¹ and 10-15 µg l⁻¹ for JMSTF1, however they met the criteria during April and May 2008 in JMSTF2. Average seasonal concentrations at the transplant sites were above SAV growing season goals of 15µg l⁻¹ and ranged from 30 to 72 µg l⁻¹ during the spring and 72-82 µg l⁻¹ during the summer. No noxious blooms or other symptoms of excess algae were observed. Nutrient levels generally were comparable with earlier years’ monitoring results, although increases in analytical detection limits precluded trend analysis. Total kjeldahl nitrogen, dissolved ammonium and dissolved inorganic phosphorus concentrations were at or below detection for most of the year. Dissolved nitrate plus nitrite also were below detection during the summer while total phosphorus showed higher concentrations than previous years.
Overall, the continued success of the SAV restoration and growth in the tidal freshwater James River is encouraging. Most water quality parameters remain consistent from earlier years, but continued high levels of chlorophyll are still prevalent during the summer.
1.0 Background and Objectives

In 1999, the Hopewell Regional Wastewater Treatment Facility (HRWTF) along with the Virginia Institute of Marine Science (VIMS) initiated a study to transplant and re-introduce several species of underwater grasses to the tidal freshwater James River (Moore et al. 1999). Additionally, water quality has been monitored to quantify the conditions associated with the SAV growth and survival. Until this work in 1999 no transplants of SAV had been formally attempted in the tidal freshwater region of the James River. Results of these studies have been successful and have demonstrated that SAV can grow and reproduce in shallow water areas in this region of the river if protected from grazing and herbivory. 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 2009). SAV acreage in this region of tidal freshwater James (JMSTF1) has steadily increased to 352 ac. in 2008. 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.“ In addition, EPA listed the James River on the 303(d) List
as impaired for aquatic life use attainment. 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 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 had been 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 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 Objectives

During 2008 objectives of the SAV restoration and water quality monitoring efforts, funded by HRWTF, and the Counties of Henrico and Chesterfield 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 2008. 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.
2.2 SAV Transplanting and Monitoring

Transplanting activities at all of the James River sites were undertaken in summer 2008 using bare-rooted water stargrass (*Heteranthera dubia*), hydrilla (*Hydrilla verticillata*) and wild celery (*Vallisneria americana*) donor plants. 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, hydrilla and water stargrass plants were obtained from nursery grown James River stock established in grow out ponds at the campus of VIMS in Gloucester Point, VA (Moore et al. 2007). At each of the transplant sites (Westover, Powell’s Creek, Tar Bay and Turkey Island) 5m x 10 m areas inside fenced exclosure areas were planted in July 2008 with treatments consisting of whole bare rooted plants. 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 five James River restoration sites from January to December 2008. 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 HRWT personnel and stored on ice in the dark until the end of each sampling cruise. At that time the samples were returned to HRWT personnel for subsequent laboratory analyses according to Standard Methods (APHA, AWWA, & Water Environment Federation 1995). Water quality analyses resulting at concentrations at the detection limits are presented as one-half the analytical detection limit.

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 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.

Eight continuous Dataflow sampling cruises were conducted from May to October 2008 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 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 (Kₐ) 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 SAV Transplant Survival

Water stargrass 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 and 2008 using the
nursery stock that had expanded in the ponds. Re-growth of the 2006 transplants was observed in the spring of 2007 and additional plantings in 2007 from this same nursery stock were also successful. Similarly wild celery shoots first established from seeds and seed pods in 2006 and 2007 (Moore et al. 2008) re-grew in 2008 and became established within the planting exclosures during 2008. Hydrilla was originally collected from the upper section of Powell’s Creek and transplanted into the VIMS nursery ponds in 2006.

Growth and cover of the wild celery, hydrilla and water stargrass transplanted at Westover and Powell’s Creek in 2008 are presented in Figures 3-1 and 3-2. Initial growth and elongation of the water stargrass exceeded that of the wild celery and hydrilla although by the end of the growing season all three species ranged from 60 to 90 cm in length (Figure 3-1). Maximum bottom cover ranged from 60 to 100% with rapid spreading during the first month after transplanting (Figure 3-2). Slight decreases observed in September were due in part to seasonal diebacks and some herbivory within the exclosures. The rates of cover expansion were similar to that observed in 2007 for both water stargrass and wild celery. Spreading of the hydrilla was comparable to the other two species. The growth of SAV at Westover in 2008 exceeded that observed in 2007; primarily due to moderate herbivory observed within the exclosures during the summer of 2007. Overall the results indicated that all three species can be successfully transplanted into these shallow water areas when initially protected from herbivory.

Transplants at the Tar Bay site were confounded by exclosure damage and herbivory with the result that growth was sparse for much of 2008. By September 2008, however, individual plants of wild celery had grown up to 50-60 cm in length and water stargrass to 70-85 cm in overall length. This was comparable in length to those at the other sites.
Aerial photography taken in the summer of 2008 revealed the continued expansion of SAV beds within Powell’s Creek (Figure 3-3). In 2001, SAV consisting of native SAV stock obtained from the Chickahominy River including *Vallisneria americana*, *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 and by 2008 over 68 acres of SAV were found growing within the Powell’s Creek system alone. SAV in the Creek system have consisted principally of *H. verticillata*, *C. demersum* and *E. canadensis*. This is approximately a 13% increase over SAV levels observed in 2007. Nearly 20% of the over 350 acres SAV mapped in the tidal freshwater James River are growing in Powell’s Creek (Orth et al. 2009).

### 3.2 Water Quality Monitoring

#### 3.2.1 Fixed Station Monitoring

Water temperatures (Figure 3-4) demonstrated similar annual patterns over the 1999-2008 sampling period at all the stations with daytime minimums ranging from approximately 5 °C to maximums of 30-33 °C. During July and August 2008 the water temperatures were about 2-3 °C cooler that the air temperatures (data not shown) which commonly exceeded 35 °C during the cruises. While air temperatures were slightly cooler in 2008 compared to 2007, water temperatures were comparable.

Conductivity (Figure 3-5) demonstrated marked differences among the years reflecting variations in river discharge rates with lowest freshwater inputs observed in 1999, 2001 and 2002 (Figure 3-6). Conductivities showed slight increases in the late summer and fall of 2008. 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 (Moore et al. 2003). This suggests that the limit for SAV growth in this region may be about 2000 µmhos. Conductivities in 2008 were well below this threshold suggesting the effects of salinity on SAV growth in 2008 were minimal.

Daytime dissolved oxygen (D.O.) concentrations (Figure 3-7) at the transplant sites continued to be high and typically above 6 mg/l even during the summer with no consistent differences observed among the stations. Maximum concentrations in 2008 were slightly below those observed in 2007 and most previous years. Water column pH levels (Figure 3-8) paralleled changing D.O. levels but levels in 2008 were comparable to 2007 in contrast to D.O. However, pH is affected by many factors including the buffering capacity of the water, which is, in part, related to salinity which was slightly lower in 2008 than 2007.

Suspended particle concentrations (TSS) have continued to show consistent patterns among years regardless of river flow and salinity with no long term trends evident (Figure 3-9). As with previous years’ results this suggests that much of the suspended material may be reworked or retained within this region of the river and the suspended concentrations are controlled in large part by physical factors including tidal circulation and re-suspension. High peak concentrations on specific sampling days were likely due to re-suspension of bottom sediments. Seasonally, turbidity levels continued to be 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. Suspended sediment concentrations in 2008 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 of SAV 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 for 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 attenuation ($K_d$) for SAV at 0.5m depths (3.6 m$^{-1}$) suggest that these requirements are usually met (Table 1). Successful growth of SAV at the shallow transplant depths here indicates sufficient light for growth even in these turbid conditions. In addition, once established SAV beds can be restored, their capacity to decrease suspended sediment levels may permit gradual expansion to deeper depths as is evident in many of the tidal tributary creeks such as Powell’s Creek.

Water transparencies measured as secchi depth (Figure 3-10) and light attenuation (Figure 3-11) 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 at all the sites in 2008 (Table 1). Growing season median light attenuation ($K_d$), another measure of light availability, was also met for a SAV restoration depth of 0.5m at all of sites except for Turkey Island. For several hours at low tide levels each day the SAV shoots are generally floating close to the water surface and the light availability for them is high (see this report’s cover photograph). 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. 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. All three species transplanted here grew to approximately the same length, suggesting that light or physical factors may be controlling their shoot length. Given maximum plant lengths of 75-100 cm for growing in 40-50 cm water depths at low tide, it suggests that 50% of the shoots may be very near the water surface after approximately a month of growth.

Chlorophyll levels in 2008 demonstrated continuing high levels throughout the SAV growing season (Figure 3-12). Summertime levels were below that observed in 2007. Median SAV growing season chlorophyll concentrations for each of the monitoring sites (Table 1) show that chlorophyll levels continue to be considerably above the habitat criteria established for SAV growth to depths of 1m. No appreciable effect of high phytoplankton levels on SAV growth has been apparent, as the SAV transplants continue to be successful and grow. In part, this lack of observable effect may be due to the shallowness (~0.5m) of the SAV transplants and the overwhelming effects of suspended sediments on light attenuation.

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 1999-2008. Numeric chlorophyll standards for the spring and summer seasons were again exceeded at all of the transplant sites although levels were below that observed in 2007.

Total organic carbon (TOC) concentrations were relatively consistent with lower variability compared to earlier years. (Figure 3-13). Levels continued lower than the high levels observed during the 2002-2003 period. Total phosphorus (TP) and total kjeldahl nitrogen (TKN) levels (Figures3-14 and 3-15) were higher than previous years. There was an increase in the analytical detection limit for TKN in 2008 from 0.6 mg l⁻¹ to 1.0 mg l⁻¹ which affected the long
term comparison. Other measures associated with particles such as TOC and TSS showed little change from previous years however.

Throughout the long term study period nitrate + nitrite levels (Figure 3-16) 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. Maximum concentrations during the winter ranged up to 0.7 mg l\(^{-1}\). No increasing trend has been evident over time. Concentrations of ammonium were at or below detection throughout much of 2008 although the detection limit increased to 0.2 mg l\(^{-1}\) for 2008 (Figure 3-17). Other than during 2002, ammonium levels have been less that 0.2 mg l\(^{-1}\) in the Hopewell region of the James.

Dissolved inorganic phosphorus (DIP) concentrations (Figure 3-18) did not meet the SAV growing season habitat criteria threshold of 0.02 mg l\(^{-1}\) in 2008 due to the increase in detection limit up to 0.1 mg l\(^{-1}\). (Table 1). This increase unfortunately precludes any analysis of DIP or the estimates of causes for observed increases in TP. Since 2005 there had been a trend for decreasing DIP concentrations.

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 again conducted at approximately monthly intervals from April through October 2008. Continuous surface dissolved oxygen (D.O.) concentrations from the mouth of the Chickahominy River (mile 0.0) to the limits of tidal influence in Richmond (Figures 3-19a-f) are presented in chronological order. Open areas in the data plots are due to losses of data as a result of equipment malfunction. D.O. concentrations were uniformly high in April and May (Figures 3-19a and 19b) throughout the entire tidal freshwater James. A D.O. sag was evident beginning in June in the lower JMSTF1
segment (cruise miles 2-10) but D.O. levels throughout the James were high during this monthly
cruise. This surface D.O. sag continued throughout most of the remainder of the year but D.O.
levels never dropped below 4 mg/l. This persistent feature was also evident in earlier years.
Typically D.O. levels were found to be high in the upstream areas of the river near the I-95
Bridge. D.O. concentrations decreased in the summer slightly before increasing again in
September and October (Figures 3-17e and 17f) as water temperatures decreased.

Continuous surface measurements of chlorophyll for every cruise are presented in
Figures 3-20a-f. 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 each of 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) 2008 calibration station data. This
regression (Extracted Chl=2.4513 * (in vivo Chl) was then used to convert the in vivo Dataflow
chlorophyll data to extracted values comparable to those obtained at the fixed, restoration
stations. Results indicate that concentrations were highest during the July and August cruises but
never exceeded 40 ug/l. Spatially integrated concentrations in JMSTF1 segment exceeded those
in JMSTF2 from May through September. Numeric criteria attainment was met in the JMSTF2
segment in both April and May 2008 (Table 3).

Summer chlorophyll levels were generally highest in the SAV transplant region
(Westover to Turkey Island; cruise miles 20-40). Blooms of phytoplankton extending for
distances of two miles or more were recorded throughout the system. Lowest concentrations of
chlorophyll were typically 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). A similar spatial distribution was also observed in 2006 and 2007 (Moore et al. 2007, 2008). River-wide concentrations were highest during the July 1-2 cruises but never exceeded 40µg l⁻¹. During previous years the highest concentrations were also observed during this late June-early July period.

Overall, turbidity levels decreased with distance upriver (Figures 3-21a-f). Lowest turbidities typically occurred in the region above the I-295 bridge (above cruise mile 50). Individual patches of higher (elevated 10-20 NTU) turbidity water were found all along the river. These generally varied from <1 to 5 mile in length. In some cases they co-occurred with chlorophyll peaks suggesting some component of phytoplankton particles in the suspended load.

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) has been calculated previously (Moore et al. 2007) using calibration station simultaneous measurements of Dataflow NTU and light attenuation profiles to Kₜ:

\[
\text{Dataflow NTU} = \frac{(Kₜ - 1)}{0.072}
\]

This relationship indicates that for tidal freshwater SAV growth to the approximate transplant depth of 0.5 m (3.6 Kₜ or 0.4 m 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 2008 were generally suitable for SAV growth to depths of 0.5m in the Hopewell region. Using the same relationship between Dataflow turbidity measurements and light attenuation, sufficient
light for SAV growth to 1m is estimated to require turbidity levels of approximately 7 NTU or less. Most of this region would not meet these more stringent levels. Water clarity conditions in the James River above the I-295 bridge was particularly good for SAV growth, suggesting that growth to even 1m depths might be possible. However, shallow protected areas for SAV bed development are limited in this region of the tidal river, possibly precluding SAV establishment. Additionally, no historical records of SAV have been found so far for this upriver area suggesting factors other than water clarity might be inhibiting SAV establishment.

4.0 CONCLUSIONS

2008 transplants of wild celery, water stargrass and hydrilla were successful in the Hopewell region of the James and re-growth of SAV transplants from previous years transplanting was observed in 2008. Continued expansion of SAV from transplants and natural recruitment in Powell’s Creek continued from earlier years. Here, the sheltered habitat allows for the initial development of several species of canopy forming SAV. Growth of hydrilla in the protected exclosures at the transplant sites suggest that this species should also be able to grow in more exposed sections of the river. It does show the potential for grazing impacts, as did the other two species of wild celery and water stargrass, suggesting it may be subject to the same grazing bottleneck as the other SAV relative to expansion in the exposed areas of the river. It has been observed to have spread into open areas of the Potomac River (Rybicki and Landwehr 2007), and that this species can be an important colonizer for the latter recruitment of wild celery and other native SAV species.

The success of water stargrass transplants here, suggests another potential native SAV, in addition to wild celery, suitable for restoration in this area. It demonstrated the most rapid elongation of the three species planted in 2008. Re-growth of water stargrass transplanted
previously in the spring of 2007 were less abundant in 2008 than the wild celery transplants also planted in 2007. This suggests possibly poorer over-wintering capacity of the water stargrass compared to wild celery in the habitats tested here. However, the survival of this species, even though it may be less than the wild celery, is encouraging. Water Stargrass does grow in abundance just above the fall line in the James River at Richmond, so it is likely that it should be able to survive and grow from one year to another in the tidal freshwater James if it can become established.

Water quality monitoring in the tidal James River in 2008 indicated continued adequate water quality for SAV growth. Turbidity levels were usually suitable for SAV growth to depths of 0.5m. Summer phytoplankton concentrations continued high in 2008; however these high levels did not preclude the SAV transplant growth and survival. Overall SAV abundance in the upper James River has increased to over 350 acres in 2007. Large areas of historically vegetated shallow water bottom, with appropriate depths and conditions for SAV growth, still remain unvegetated. However, the 30-fold increase in SAV observed over the past several years suggests that there is a steady re-colonization of SAV occurring in this region and the results of these transplant studies indicate that species such as wild celery and water stargrass can grow in multiple currently unvegetated areas within this region.
5.0 LITERATURE CITED


Table 1. SAV Growing Season (April – October) median water quality. Shaded cell indicates SAV criteria met for SAV growth to 0.5 m. (-) No data. (*) At or below detection limit.

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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. (-) No data. (*) At or below detection limit.

<table>
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<tr>
<th>Water Quality Parameter</th>
<th>SAV Habitat Criteria</th>
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Table 2. Mean (March-May and July-September) chlorophyll concentrations at SAV transplant sites for 1999 through 2008. Shaded cell indicates criteria met.

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<tr>
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<td>4.0 (µg/l)</td>
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<td>36.8</td>
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<td>Mar-May 2002</td>
<td>23.5</td>
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<td>Mar-May 2003</td>
<td>10.8</td>
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<tr>
<td>Mar-May 2005</td>
<td>4.3</td>
<td>4.0</td>
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<tr>
<td>Mar-May 2008</td>
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<td>Jul-Sep 2008</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)

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<td>Mean (NTU)</td>
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<tr>
<td>JMSTF1</td>
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<td>15.74 ± 0.18</td>
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<tr>
<td>JMSTF2</td>
<td>7.26 ± 0.13</td>
<td>9.47 ± 0.15</td>
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<th>August 13 &amp; 14, 2008</th>
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<td>Mean (µg/l)</td>
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<td>JMSTF1</td>
<td>36.72 ± 0.50</td>
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<tr>
<td>JMSTF2</td>
<td>31.61 ± 0.55</td>
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<tbody>
<tr>
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<td>Chlorophyll¹</td>
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<td></td>
<td>Mean (µg/l)</td>
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<tr>
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<td>JMSTF2</td>
<td>20.68 ± 0.17</td>
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¹ Measured directly through DATAFLOW in vivo fluorescence and corrected by extracted chlorophyll.

JMSTF1 – Seasonal Chlorophyll Standards: March 1 – May 31 (15µg/l); July 1 – Sept 30 (23µg/l)

JMSTF2 – Seasonal Chlorophyll Standards: March 1 – May 31 (10µg/l); July 1 – Sept 30 (15µg/l)

² Secchi goal of 0.4m for SAV growth to 0.5 m estimated as <36 NTU. See conversion in text
Figure 2-1. SAV Transplant and Water Quality Monitoring Sites
Figure 2-2. SAV Transplant Species

Wild celery (*Vallisneria americana*)  Water stargrass (*Heteranthera dubia*)  Hydrilla (*Hydrilla verticillata*)
Figure 3-1. 2008 SAV Transplant Growth

Westover

![Graph showing the growth of Water Stargrass, Wild Celery, and Hydrilla over time.]

Powell's Creek

![Graph showing the growth of Water Stargrass, Wild Celery, and Hydrilla over time.]

Date

Shoot Length (cm)

7/7/08 7/21/08 8/4/08 8/18/08 9/1/08 9/15/08 9/29/08


27
Figure 3-2. 2008 SAV Transplant Abundance

Westover

![Graph showing percent cover over dates for Westover with categories: Water Stargrass, Wild Celery, Hydrilla]

Powell's Creek

![Graph showing percent cover over dates for Powell's Creek with categories: Water Stargrass, Wild Celery, Hydrilla]
Figure 3-3. 2008 SAV Abundance in Powell's Creek
(mapped SAV beds in red)
Figure 3-4. Water Temperature
Figure 3-5. Conductivity

![Graph showing conductivity levels with specific dates marked, indicating fluctuations over time.](image-url)
Figure 3-6. James River Streamflow (at Cartersville, Virginia)
Figure 3-7. Dissolved Oxygen
Figure 3-8. Water Column pH
Figure 3-9. Total Suspended Solids (TSS)
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
January 22, 2008
April 15, 2008
June 10, 2008
August 5, 2008
September 30, 2008
December 9, 2008
Figure 3-11. Light Attenuation

Kd
Figure 3-12. Chlorophyll a

Chlorophyll a (ug/l)

Turkey Island
Shirley Cove
Tar Bay
Powell's Creek
Westover
Figure 3-13. Total Organic Carbon (TOC)
Figure 3-14. Total Kjeldahl Nitrogen (TKN)
Figure 3-15. Total Phosphorus (TP)

Total Phosphorus (mg/l)

- Turkey Island
- Shirley Cove
- Tar Bay
- Powell's Creek
- Westover

Dates:
- June 3, 1999
- Aug 3, 1999
- Oct 6, 1999
- Dec 15, 2000
- Feb 9, 2001
- Apr 12, 2000
- Aug 15, 2000
- Oct 18, 2000
- Jan 4, 2000
- Apr 10, 2001
- June 5, 2001
- Aug 14, 2001
- Oct 23, 2001
- Jan 4, 2002
- Apr 10, 2002
- June 5, 2002
- Aug 14, 2002
- Oct 23, 2002
- Jan 4, 2003
- Apr 10, 2003
- June 5, 2003
- Aug 14, 2003
- Oct 23, 2003
- Jan 4, 2004
- Apr 10, 2004
- June 5, 2004
- Aug 14, 2004
- Oct 23, 2004
- Jan 4, 2005
- Apr 10, 2005
- June 5, 2005
- Aug 14, 2005
- Oct 23, 2005
- Jan 4, 2006
- Apr 10, 2006
- June 5, 2006
- Aug 14, 2006
- Oct 23, 2006
- Jan 4, 2007
- Apr 10, 2007
- June 5, 2007
- Aug 14, 2007
- Oct 23, 2007
- Jan 4, 2008
- Apr 10, 2008
- June 5, 2008
- Aug 14, 2008
- Oct 23, 2008
Figure 3-16. Dissolved Nitrate + Nitrite

Nitrate + Nitrite (mg/l)

Turkey Island
Shirley Cove
Tar Bay
Powell's Creek
Westover
Figure 3-17. Dissolved Ammonium

- Turkey Island
- Shirley Cove
- Tar Bay
- Powell's Creek
- Westover

Ammonium (mg/l)
Figure 3-18. Dissolved Inorganic Phosphate (DIP)
Figure 3-19a. Upper James River Dataflow
Dissolved Oxygen April 16 & 17, 2008

Cruise Mile

Dissolved Oxygen (mg/l)

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

JMSTF1
JMSTF2
Figure 3-19b. Upper James River Dataflow
Dissolved Oxygen May 15 & 16, 2008

Dissolved Oxygen (mg/l)

Chickahominy R.  Westover  Tar Bay  Shirley Cove  Turkey Island  I-295 Bridge  I-66 Bridge

Cruise Mile
Figure 3-19c. Upper James River Dataflow
Dissolved Oxygen June 4 & 5, 2008

Cruise Mile

Dissolved Oxygen (mg/l)

0.00 10.00

Chickahominy R.
Westover
Tar Bay
Shirley Cove
Turkey Island
I-295 Bridge
I-95 Bridge
Figure 3-19d. Upper James River Dataflow
Dissolved Oxygen July 1 & 2, 2008

Cruise Mile

Dissolved Oxygen (mg/l)

JMSTF1

JMSTF2

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 3-17e. Upper James River Dataflow
Dissolved Oxygen August 13 & 14, 2008
Figure 3-19f. Upper James River Dataflow
Dissolved Oxygen September 10 & 11, 2008

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

JMSTF1  JMSTF2
Figure 3-19g. Upper James River Dataflow
Dissolved Oxygen October 21 & 23, 2008
Figure 3-20a. Upper James River Dataflow
Corrected Chlorophyll April 16 & 17, 2008

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

Cruise Mile

Corrected Chlorophyll (ug/l)

0.00  10.00  20.00  30.00  40.00  50.00  60.00  70.00

JMSTF1  JMSTF2
Figure 3-20b. Upper James River Dataflow
Corrected Chlorophyll May 15 & 16, 2008
Figure 3-20c. Upper James River Dataflow
Corrected Chlorophyll June 4 & 5, 2008

JMSTF1

JMSTF2
Figure 3-20d: Upper James River Dataflow
Corrected Chlorophyll July 1 & 2, 2008

Chickahominy R.

Westover
TarBay
ShirleyCove
TurkeyIsland
I-95 Bridge
I-295 Bridge

Corrected Chlorophyll (ug/l)

Cruise Mile

0.00 10.00 20.00 30.00 40.00 50.00 60.00 70.00

JMSTF1
JMSTF2

0.00 10.00 20.00 30.00 40.00 50.00 60.00 70.00 80.00

55
Figure 3-20e. Upper James River Dataflow
Corrected Chlorophyll August 13 & 14, 2008

Corrected Chlorophyll (ug/l)
Figure 3-20f. Upper James River Dataflow
Corrected Chlorophyll September 10 & 11, 2008

Cruise Mile

Chickahominy R.

JMSTF1

JMSTF2

W. Va. Bridge

Shirley Cove

Turkey Island

I-295 Bridge

I-95 Bridge
Figure 3-20g. Upper James River Dataflow
Corrected Chlorophyll October 21 & 23, 2008

Cruise Mile

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

Corrected Chlorophyll (ug/l)
Figure 3-21a. Upper James River Dataflow
Turbidity April 16 & 17, 2008

JMSTF1

JMSTF2

Turbidity (NTU)

Chickahominy R.

Westover

Tar Bay

Shirley Cove

Turkey island

I-295 Bridge

I-66 Bridge

Cruise Mile
Figure 3-21b. Upper James River Dataflow
Turbidity May 15 & 16, 2008

[Graph showing turbidity levels along the James River.]
Figure 3-21c. Upper James River Dataflow
Turbidity June 4 & 5, 2008

Cruise Mile

Turbidity (NTU)

Chickahominy R.
Westover
Tar Bay
Shirley Cove
Turkey Island
I-295 Bridge
I-95 Bridge
Figure 3-21e. Upper James River Dataflow
Turbidity August 13 & 14, 2008

Cruise Mile

Chickahominy R.

Turbidity (NTU)

Westover
Tar Bay
Shirley Cove
Turkey Island
I-295 Bridge
I-95 Bridge
Figure 3-21f. Upper James River Dataflow
Turbidity September 10 & 11, 2008
Figure 3-21g. Upper James River Dataflow
Turbidity October 21 & 23, 2008

Cruise Mile

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

Turbidity (NTU)