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# York River Water Budget

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# York River Water Budget Report

By the Center for Coastal Resources Management
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## Introduction

Virginia has been slow to begin development of water supply planning. At this time there are still no watershed level accountings of all existing and (pending) withdrawals for any of Virginia's rivers. This makes it impossible to determine what potential water remains to support additional future usage without affecting ecological services such as habitat and recreation. Recently it has become clear, that under severe drought conditions, the available flows in some rivers, such as the York and Rappahannock, are fully subscribed. There is little or no surplus beyond current uses and the minimum flows necessary to support aquatic life. Planning for new withdrawals requires very careful consideration of ecological consequences and affects on existing uses.

Ideally, the state planning process will involve an estimation of minimum instream flows necessary to maintain water quality, and avoid permanent damage to aquatic life in streams, bays, and estuaries. The velocity and volume of water in a river affect food, physical habitat, temperature, water quality, flow regime and biotic interactions, all important factors for structuring the river ecosystem (Orth 1987). Minimum instream flow requirements are used to protect aquatic resources in a river when a conflict exists for water demand and/or to insure good water quality when certain flows are required for wastewater dilution (Allain and El-Jabi 2002).

An instream flow policy requires clear and measurable goals to be successful. A good policy should identify the resources targeted for protection, define the desired level of protection for those resources, and establish the criteria for evaluating achievement (Beecher 1990). A precautionary approach to goal setting generally seeks to maintain the diversity of both species and habitats in a river system. A basic strategy would target preservation of habitats having potential to benefit the widest array of species.

Goals must be translated into practical operating guidelines using flow assessment methods to determine instream flow requirements. Prioritization of the resources to be protected is important since not all uses or species can be simultaneously targeted. Protection of all existing resources is only possible if there is no change in the flow regime. Most policies target highly valuable or sensitive resources.

One of the challenges confronting water management in Virginia is the fact that most of its surface waters discharge into highly valued estuaries. These complex systems are significantly influenced by the volume, contents, and timing of river discharges. As a result, Virginia's management of river flows must consider withdraw impacts on conditions and uses both above and below the fall line. There are currently no widely accepted methods for estimating discharge requirements for conditions in the tidal freshwaters at the head of estuaries. In this report we briefly review methods typically used in waters above the fall line, and management considerations that arise in the coastal plain below the fall line. We identify information needed to establish discharge requirements, and we recommend a precautionary approach for managers until that information can be developed.

## Methods of determining instream flow requirement

There are three main methods used for determining instream flow requirements: hydrologic (or historic), hydraulic, and biological. All three methods are based on the same set of principles (Jowett 1997), although each method approaches the question differently. The over-reaching goal is to maintain the stream flow ecosystem. There is an implicit assumption that the characteristic being maximized (proportion of low, wetted perimeter or physical habitat) to reach the required level of protection will reflect the condition of the stream or river. They also assume that there is a linear relationship between the amount of flow in a river and the state of the ecosystem, or there is a threshold minimum flow beyond which aquatic life cannot survive.

### *Hydrological methods*

Hydrological methods rely solely on an analysis of historic flow measures, making them the fastest and cheapest of the three method types (Allain and El-Jabi 2002). This type assumes that lower than natural flows are harmful to stream ecosystems and that keeping the minimum flow within natural, historic bounds will sustain aquatic life. Historic minimum food, water quality, and temperature are considered the essential parameters sufficient to support any species which has survived in the stream ecosystem in the past (Jowett 1997). This assumption may be problematic when other conditions (such as nutrient enrichment) change over time. The advantage of hydrological methods is that they tend to maintain hydraulic conditions of a river; so a fast moving river will remain a fast moving river, while a slow river will still have a slow flow (Jowett 1997). This helps to maintain the character of the river, and may (theoretically) help maintain the river's diversity. A disadvantage of these methods is they do not specifically consider the aquatic biota or recreational water uses.

There are five types of hydrological methods commonly used (Allain and El-Jabi 2002). The Tennant method (Tennant 1976) is one of the best know hydrologic methods. It is based on a percentage of mean annual flow, which varies seasonally, and is intended to be optimized for faunal and recreational usages. Tennant (1976) found that stream width, water velocity and depth all increase rapidly with increasing flow during the first 10% of mean flow. However the rate of increase declines with increasing flow after that. At less than 10% of mean flow, the flow is not sufficient to provide for long-term survival of aquatic species. The Tennant method should be used to determine flow recommendations for areas where competition for water is minimal (Estes and Orsborn 2007). This method never produces a zero flow recommendation, so it is not appropriate for streams which are seasonally dry. In addition, it is based on the assumption that a proportion of the average flow will maintain suitable depths and velocities for trout, and this assumption may not hold true for streams which are of different sizes or gradients to the ones that he studied (Jowett 1997), or for species with different habitat requirements. Other common hydrological methods include:

- 25% of mean annual flow;
- ABF, Q50 (Aquatic Base Flow calculated from the median flow in August);
- Q90 (monthly flow equaled or exceeded 90% of the time); and

- 7Q10 (the statistical 7-day low flow that occurs on average every 10 years).

Each method specifically targets some aspect of the stream flow regime, but they are all based on the same general theory.

### Hydraulic methods

Hydraulic methods use physical information (such as depth, width, velocity and wetted perimeter) and relate that information to rates of stream flow. One frequently used hydraulic method considers the variation in wetted perimeter with changes in flow. This method is the third most common modeling method used in the United States (Reiser et al. 1989). Wetted perimeter usually increases with flow and sometimes has a threshold level which indicates bankfull flow levels. Minimum flow requirements are set to retain a certain percentage of the mean flow (Jowett 1997). The rationale behind the wetted perimeter method is that the wetted perimeter is the "food producing" area of the stream and a full channel supports the highest food production (Jowett 1997). This rationale may be problematic in tidal areas because some tidal producers (such as marsh plants and algae) require both wet and dry periods to be functional. The wetted perimeter may also be related to biological indicators (i.e. a specific fish species) when the river width is related to useable fish habitat. As with hydrological methods, hydraulic methods never result in a zero flow recommendation, which may restrict their use under certain conditions. An advantage of this type method is that it retains the width of the river, which helps it maintain some of the flow characteristics (Jowett 1997). However, the resulting water depth depends on the channel morphology. A wide, flat channel may get too shallow to support aquatic life while still maintaining the same width. A disadvantage of this method type is a dependence on stream size. Hydraulic methods tend to give higher minimum flow requirements for smaller streams than larger ones (Jowett 1997).

### Biological methods

Biological methods are the most flexible of the three method types and can be used to consider the needs of multiple species or life history stages. These are the most commonly used methods in the United States (Reiser et al. 1989). However, it is important to carefully define the goals of this type method, since some species may have competing habitat requirements. Biological methods are really an extension of hydraulic methods, but use hydraulic requirements based on conditions that meet specific biological requirements (Jowett 1997). The goal is to provide or retain a suitable physical habitat for aquatic organisms that live in the river (Jowett 1997). The methods generally compare water depth and velocity with habitat suitability requirements for a species of interest. This is done over a variety of flows to determine how suitable habitat area varies with flow. Habitat area information is used to determine flow regime capacity to support spawning, feeding and passage of fish. Unlike other methods, biological methods preserve (or improve) habitat in terms of depth and velocity, but do not necessarily preserve river character. The relationship between habitat area and flow is generally non-linear, so flow recommendations are set at the threshold above which diminishing returns are realized. In situations where the relationship between habitat area and flow is linear, the resulting flow recommendations are similar to the hydrologic and hydraulic flow methods. Disadvantages of biological methods are that their focus on target species may fail to consider other, important aspects of river ecology, and the resulting minimum flow recommendations are dependent on stream size, with higher minimum flow requirements in smaller streams (Annear and Conder 1984).

Biological methods are based on use of habitat suitability curves (Jowett 1997), which can be labor intensive and expensive to develop. Habitat suitability curves can be specified for particular organisms, particular life stages, or recreational uses. The most widely used method is the Physical Habitat Stimulation Component (PHABSIM; Milhous et al. 1984) of the instream flow incremental method (Jowett 1997). This method should be used to determine flow recommendations when there is keen competition for water resources and/or when detailed evaluations of species responses to flow variations are required (Estes and Orsborn 2007). Other examples of biological methods include the Washington method for salmon (Collings 1972; 1974), the California method for trout (Kelley et al. 1960) and the Habitat Quality Index (Binns and Eiserman 1979).

**Summary of the differences between the main methods of setting minimum flow standards (adapted from Jowett 1997)**

| | Hydrological | Hydraulic | Biological |
|---|---|---|---|
| Data requirement | Flow record | Cross-section survey | Cross-section survey; habitat suitability criteria; % habitat retention |
| Intensity of data collection | Low | Moderate | High |
| Method of assessing flow requirement | % of average annual or monthly flow; % exceedance | Inflection point | Inflection point; optimization; minimum habitat |
| Stream hydraulics | Effect on width, depth and velocity depends on morphology; maintains character | Effect on width, depth and velocity depends on morphology; maintains character of variable of interest | Potential loss of character |
| Ecological assumptions | Close relationship between natural flows and existing ecology | Biological productivity related to wetted area | Close relationship between habitat and ecology |
| Conceptual basis | Assumes reduced flows result in degraded systems | Assumes reduced flows result in degraded systems | No a priori assumptions, some aspects of the environment may be enhanced through altered flows |
| Advantages and disadvantages | Straight forward, no interpretation required; trade-off considerations not possible; flow always less than but related to natural flows; precludes enhancement | Some interpretation required; trade-off considerations not possible; flow dependent on channel shape; levels of protection difficult to relate to ecological goals | Approach, application and interpretation critical; models can consider ecological requirements; allows for trade-offs; flow assessment independent of natural flow; enhancement potential |

### *Comparing methods in rivers and estuaries*

All of the methods discussed above are well-established techniques for the development of instream flow requirements in streams and rivers. Unfortunately, none of them are particularly well-suited for use in estuaries. Estuaries are unique environments. They have flow both up and down the estuary as tides influence the system. Connecting flow in estuaries to ecological conditions is further complicated by the gradient of saline water which increase from headwaters to mouth, and which varies at any point along the way as tides rise and fall. Salt content affects both the types of species that thrive in a given area and the physical properties of the water (such as the sediment holding capacity) which can influence habitat suitability. Estuarine species tend to be either freshwater species which are tolerant of saline conditions or marine species which are tolerant of brackish conditions and frequently have complicated life histories. This makes the establishment of thresholds difficult and increases the likelihood that improving the habitat for one species or life stage will come at the expense of another species or life stage.

| Characteristic | Rivers | Estuaries |
|---|---|---|
| *Flow direction* | Uni-directional | Reversing |
| *Depth determined by* | Flow | Primarily tides |
| *Bathymetry determined by* | Sediment regime | Sediment regime, flocculation, littoral drift |
| *Water characteristics* | Fresh | Fresh and salt |
| *Pollutant flushing by* | Rainfall runoff | Rainfall runoff and tidal flows |
| *Water quality changes* | Downstream of source | Up and downstream of source |
| *Biota* | Limited to freshwater species | Includes fresh, salt and estuarine species |
| *Ecological interactions* | Less complex | Very complex |
| *Size of pertinent body of literature* | Large | Small |
| *Understanding of environmental flow effects* | Limited | Very limited |

There are many key differences between rivers and estuaries which argue that different methods may be necessary for determining minimum instream flow in each system. Some of the differences are summarized in the table above (modified from Pierson et al. 2002)

Rather than targeting specific species, in estuaries it may be better to target habitats which are known to be beneficial to a wide diversity of species and life stages. Examples of these habitats include marshes and submerged aquatic vegetation (SAV). Requirements should be related to a variety of different estuarine factors, to include the widest possible definition of estuarine condition. Flow requirements in estuaries must also take into account the changing conditions prevalent in estuaries. These include short term events such as tidally influenced water depth and currents, longer term events such increased eutrophication and sediment inputs associated with watershed development, and very long term events such as sea-level rise. All of these factors make defining the "typical" estuarine condition a moving target, and make goal development problematic.

## Virginia's instream flow management policies

In Virginia, the riparian doctrine (common law) and permit systems are used for the allocation of water. Riparian rights are considered common law property rights, which can be purchased or inherited. These laws give riparian landowners exclusive rights to remove water from streams for reasonable uses. Usage is subject to the "reasonable use rule," which holds that a person objecting to the use of water by someone upstream has to show actual damage for action to be taken.

The Virginia Water Protection Act (1992) (VR 680-15-02) established the Virginia Water Protection Permit which is regulated under DEQ. Under this Act a permit is required for any project that requires federal permits for discharge of dredge material or fill in a waterway or wetland (Clean Water Act, Section 404), work or construction in a navigable waterway (Rivers and Harbors Act, Section 10), or a water withdrawal will be reviewed by DEQ for issuance of a VWP permit. Without the VWP permit (formerly called the 401 Certification) the federal permits will not be issued. Exceptions include water withdrawals occurring before July 1, 1989, and withdrawals receiving a Section 401 water quality certification before January 1, 1989, withdrawals for irrigation.

The 1989 Surface Water Management Act (VA Code 62.1-242) gives the State Water Control Board the right to regulate use of water in the state, up to a point. Water withdrawals of 300,000 or more gallons per month in designated surface water management areas are required to have a surface water withdrawal permit if new, or to have a surface water withdrawal certificate to continue withdrawing surface water. Permits and certificates will include a conservation plan that is activated during low-flow conditions in the surface water source. Due to exemptions from both permitting processes, such as irrigation withdrawals, a full accounting of water use and establishment of accurate minimum instream flows are compromised. However, voluntary reporting of irrigation use by farmers from 1982-1990 and mandatory reporting since 1992 may enhance estimations of water use (Vadas and Weigmann 1993; VA Code 62.1-44.38). Mandatory reporting applies to every user whose average daily withdrawal of groundwater or surface water exceeds 10,000 gallons per day during any single month in Virginia including the Potomac River abutting Virginia. Reportable withdrawals include, but are not limited to, those for public water supply, manufacturing, mining, commercial, institutional, livestock watering, artificial fish culture, and steam-electric power generation uses. This also applies to every user withdrawing ground or surface water for the purpose of irrigating crops whose withdrawal exceeds 1 million gallons in any single month (9VAC25-200-20).

Under this Act the State Water Control Board has the authority to designate surface water management areas throughout the state. Each area will be declared by a separate regulation that will establish a low water flow level for streams, below which permit limits for withdrawals from the streams become effective. An area may be designated a surface water management area if there is evidence to indicate that: 1) A stream has substantial instream values as indicated by evidence of fishery, recreation, habitat, cultural or aesthetic properties; 2) Historical records or current conditions indicate that a low flow condition could occur which would threaten important instream uses; and 3) Current or potential offstream uses contribute to or are likely to exacerbate natural low flow conditions to the detriment of instream values.

Under the Virginia Ground Water Management Act of 1992 (VA Code 62.1-44.93), any person or entity wishing to withdraw 300,000 or more gallons per month in designated ground water management areas is required to obtain a permit. At present, two ground water management areas have been declared: the Eastern Shore Ground Water Management Area includes Accomack and Northampton counties; the Eastern Virginia Ground Water Management Area includes the area east of I-95 and south of the Mattaponi and York rivers.

Furthermore, The Surface Water Management Act of 1989 and associated regulations apply a principle similar to ground water management to areas where surface water resources have a history of low flow conditions that threaten important instream and off-stream uses. The Commonwealth has the responsibility to ensure that adequate surface flow of water in streams is maintained at levels that allow for the variety of potential uses, including minimum flows during periods of drought, assimilation of treated wastewater, and support of aquatic and other water-dependent wildlife.

## York River System

The York River system has important recreational, cultural, natural and aesthetic resources as well. Due to the relatively pristine and isolated nature of the watershed, particularly in the upper reaches, it is used extensively by recreational hunters, fishermen, photographers, cyclists and artists each year. The Mattaponi River was named one of the 20 most endangered rivers in 1998 in the U.S. by *American Rivers*, a prominent river conservation group, primarily due to the proposal to withdraw and pump as much as 75 million gallons per day of the Mattaponi's flow to serve domestic, commercial, and industrial interests in Virginia's lower peninsula region. The York River system is dominated by forested and agricultural land use, and the river is an important source of irrigation for local farmers.

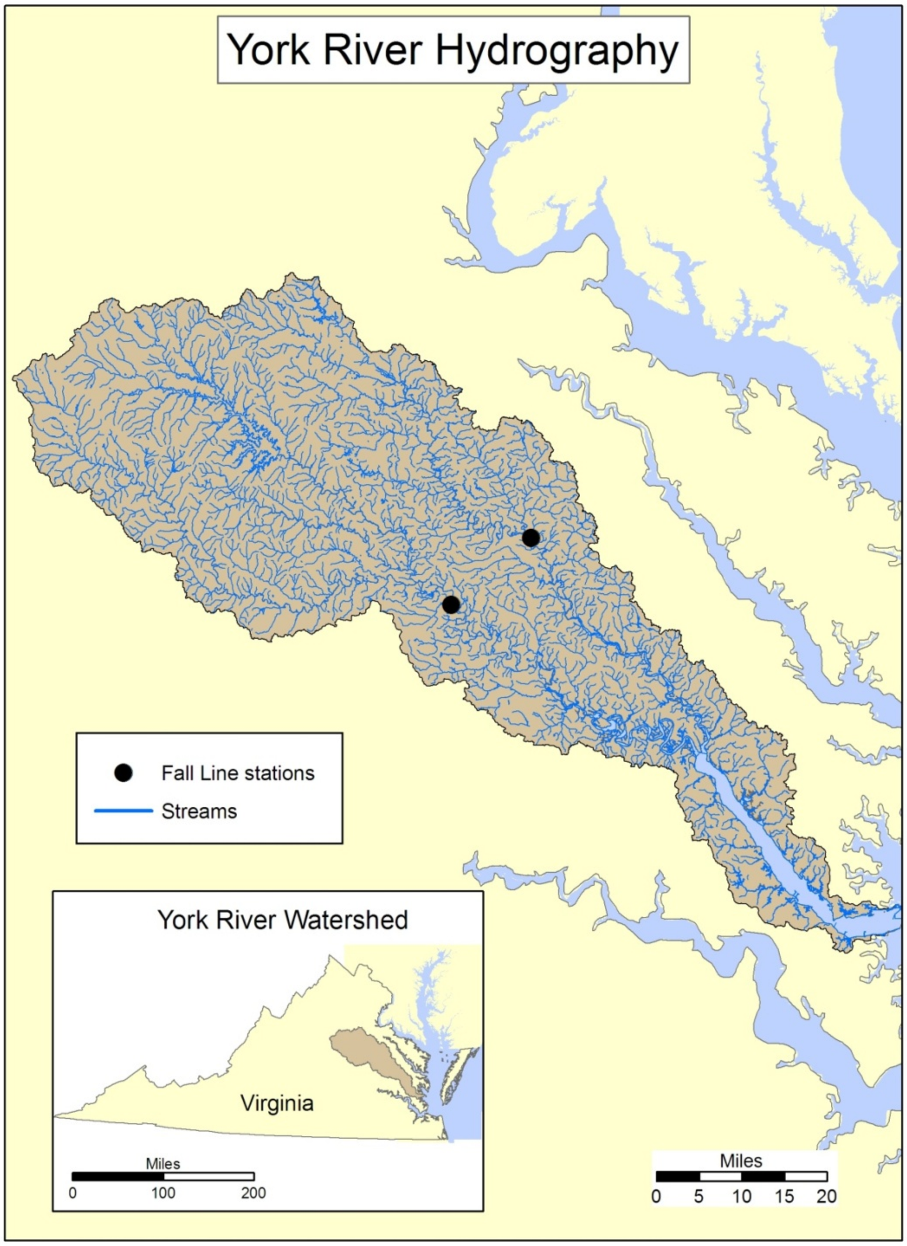
Two Native American tribes, the Mattaponi and Pamunkey, use the rivers and have the oldest reservations in the country along the riverbanks**.** These two tribes have treaties with the Commonwealth of Virginia that predate the United States and trace their history back to Chief Powhatan who ruled most of Tidewater Virginia when Europeans arrived in 1607. Because of the lengthy history of human occupation in the York River system, historically and culturally significant areas are found along the rivers. For instance, the Pamunkey Indian Reservation, which is located on the Pamunkey River, has been designated A Virginia Historic Landmark, it contains approximately 1,200 acres of land, 500 acres of which is wetlands.

The York River system is a tidal sub-estuary of the Chesapeake Bay in eastern Virginia in the United States. It is approximately 40 mi (64 km) long and is formed at West Point by the confluence of the Mattaponi and Pamunkey rivers. It drains into the Chesapeake Bay approximately 5 mi (8 km) east of Yorktown. Salinity in the York River varies from approximately 20 parts per thousand (ppt) at the mouth of the river, to 0 ppt several miles above West Point. Salinity distribution is correlated with freshwater river discharge (Hyer et al. 1971; Sisson et al. 1997). The river supports a wide range of habitats, from freshwater swamps to tidal freshwater marshes to salt marshes.

The York River system freshwater flow is primarily fed from two tributaries, the Pamunkey and Mattaponi Rivers. Pamunkey River is approximately 90 miles long from its start at the convergence of North and South Anna rivers, to its end at the town of West Point. The river is primarily non-tidal north of the Rt. 360 bridge, transitioning to a tidal freshwater system at the bridge and then to a more estuarine setting south of Putney's Mill (DGIF 2008). Mattaponi River is 84 miles long, originating further up in the York River watershed at the confluence of four smaller rivers. The river is primarily non-tidal north of Aylett, transitioning to a tidal freshwater system at Aylett and then to a more estuarine setting (DGIF 2008). Flow into the York River is measured at USGS gauging stations on the two tributary rivers, located near Beulahville on Mattaponi River and Hanover on Pamunkey River.

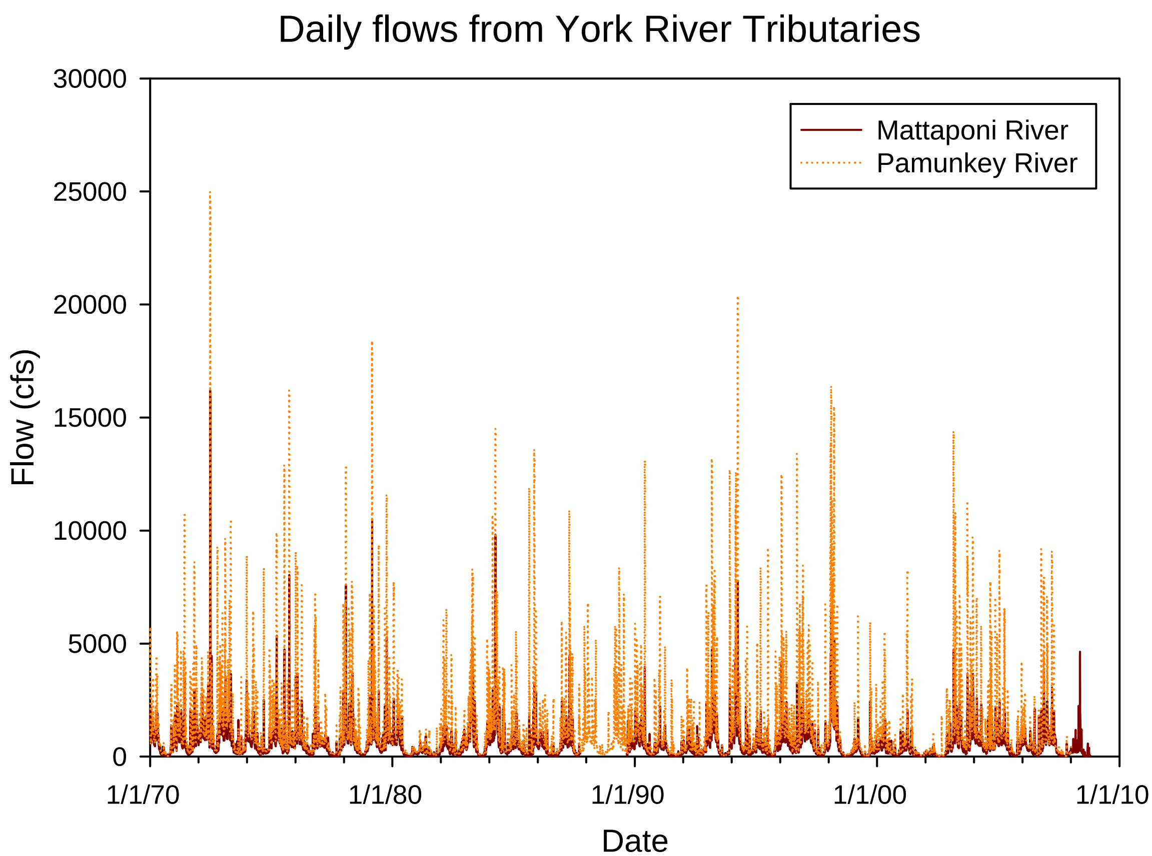
Pamunkey River is partially fed from Lake Anna Reservoir, which has a regulated discharge that effectively establishes a base flow for the river. Lake Anna Reservoir has been in operation since 1978. Its owner, Dominion Virginia Power is required to maintain flows from the reservoir at a minimum of 40 cubic feet per second (cfs), the approximate historic low flows at the dam site, except during extreme droughts. The minimum required discharge under drought conditions (lake elevation <248.0 ft) is 20 cfs. The reservoir is not thought to have a major impact on the Pamunkey's hydroperiod. There is no comparable reservoir on the Mattaponi.

Consumptive uses have increased on both rivers in recent history and now have an indeterminate impact on flows during extreme drought periods. Consumptive use for 1990 was estimated to average 34.2 million gallons per day (mgd) on the Pamunkey River and 3.1 mgd in the Mattaponi River. While consumptive use may slightly alter natural flow, the impact is most likely minimal during non-drought conditions due to low average consumptive use, and the systems may be considered natural flow rivers. Land uses in the Mattaponi and Pamunkey watersheds are dominated by forest (66.7% and 63.2%, respectively) and agricultural (15.2% and 15.3%, respectively).

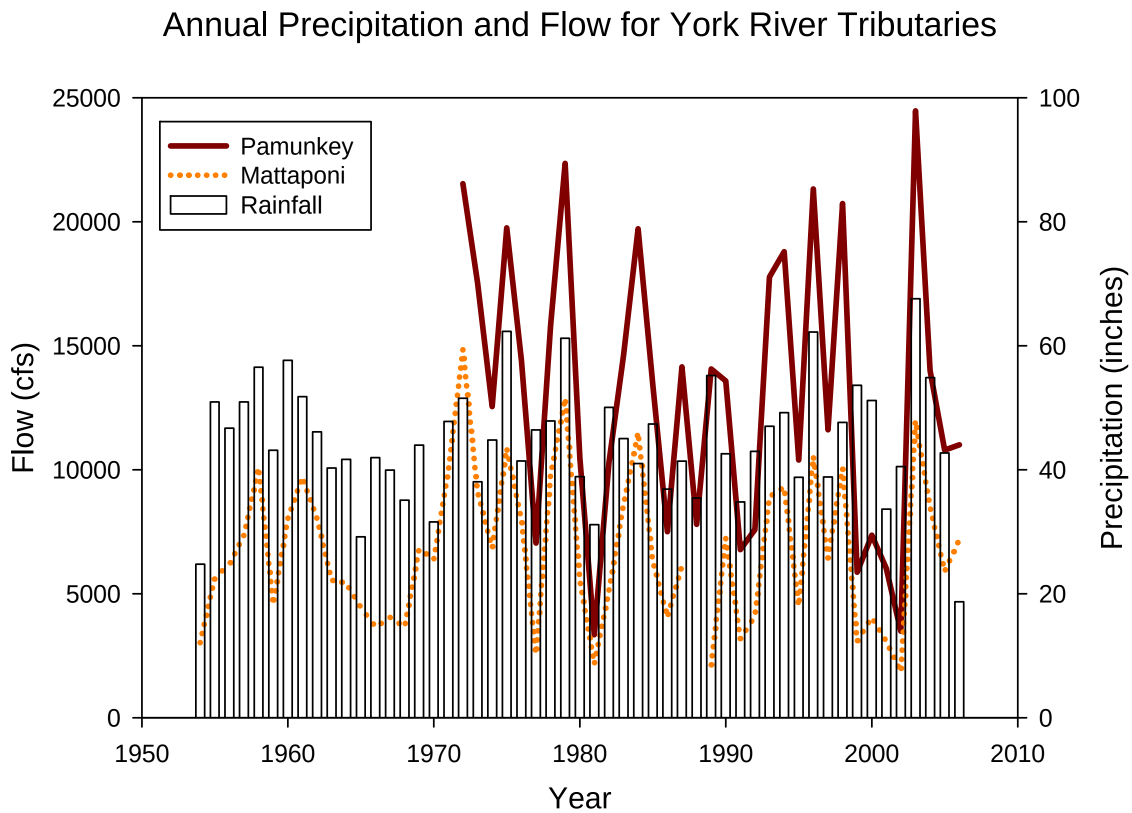

York River Hydrography
Fall Line stations
Streams
York River Watershed
Virginia
Miles
0
100
200
Miles
0 5 10 15 20

### ***Historic flows in the York River System***

Historic York River flows were obtained from the USGS monitoring data. Flow rates vary daily and seasonally in both the Mattaponi and Pamunkey rivers with peak flows tending to occur in the early spring and lower flows occurring in the late summer. Flows are overall higher in the Pamunkey River, but the pattern of flow rates tends to be correlated between the two rivers. Average daily flow in the Mattaponi River between 1970-2007 was 593 cfs, with a minimum flow of 0.25 cfs and a maximum flow of 16,200 cfs. Average daily flow in the Pamunkey River between 1970-2007 was 1075 cfs, with a minimum flow of 22 cfs and a maximum flow of 25,000 cfs. Average annual flow during that same time period was 6,907 cfs in the Mattaponi River and 13,069 cfs in the Pamunkey River.



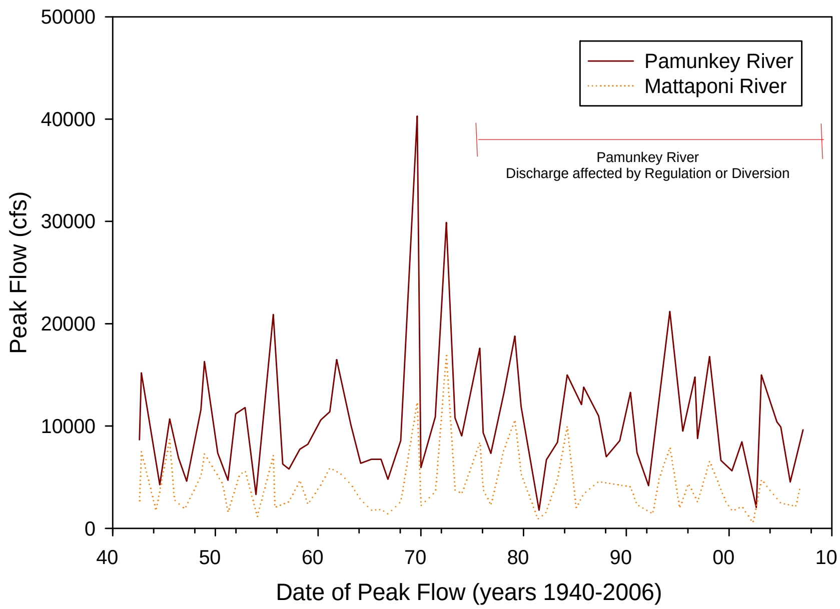

Although flow rates are highly variable by year, records for the Mattaponi River dating back to the 1950's do not indicate any clear pattern of either increased or decreased flow rates. The range of flow rates peaked during the 1970's and appears slightly higher today than during the 1950's. In the Pamunkey River, the range of flow rates appears to have also decreased slightly since the 1970's, but there are no previous data to indicate if this decrease represents a return to previous flow regimes as suggested by the Mattaponi data.




Flow rates in both rivers are moderately correlated with annual precipitation in the York watershed. Years with higher rainfall tended to also have higher annual flow rates, while years with lower rainfall tended to have lower annual flow rates. Therefore, it is likely that changes in the weather system resulting in increases in the frequency of drought or wet years will impact the river flows. However, the quantity of rainfall was not closely correlated with the volume of flow. This suggests that the precipitation data alone may not explain all the variation in flow and groundwater may significantly contribute to the system.

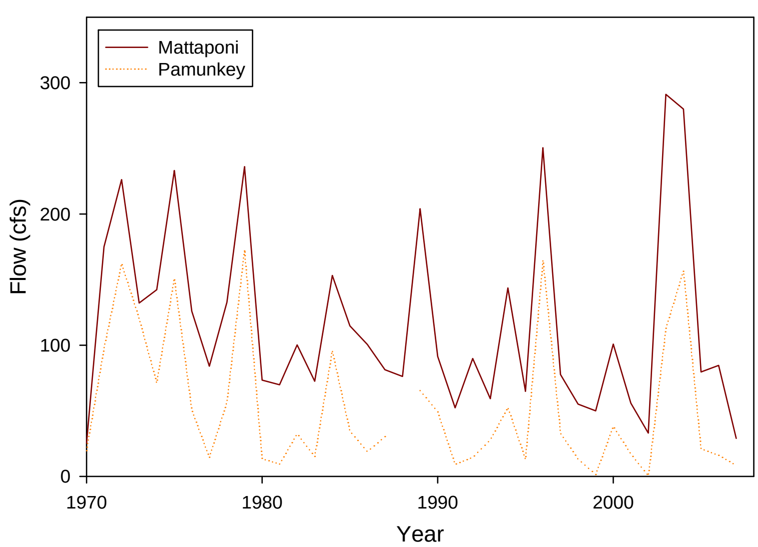
Peak flow is defined as an instantaneous local maximum value in the flow data that is preceded by a period of increasing values and followed by a period of decreasing values. On average, peak flow events occur in the Mattaponi and Pamunkey Rivers once every 370 days. However, there are years in which no peak flow events occur and years in which multiple peak flow events occur. In the time period from the 1940s-2006, the average peak flow in the Mattaponi was 4,248 cfs (about 7 times the average daily flow) and in the Pamunkey was 10,539 cfs (about 9 times the average daily flow). During the period of record, peak flow events were highest during the 1970s (about 4 times the average peak flow levels in the Pamunkey River), but otherwise show no pattern of historical change, despite the regulation of portions of the Pamunkey River flow starting in the early 1970s. However, the regulation of the Pamunkey River flow coincides with a reduction in flow levels to levels seen during the 1940-60s. This may indicate that there was an overall increase in flow levels, possibly due to increased upland development, that was regulated back to historic levels.

Peak Flow Events in York Rivers Tributaries




Low flow events, for this purpose, are defined as the lowest 7-day average flow in a given year. Low flow events tended to be somewhat lower in the Mattaponi River, due to lower overall flow, but are highly correlated between the two rivers. The lowest low flow events in both rivers occurred between 1990 and the present time which may indicate a pattern of increasing frequency of extremely low flow events. However, a longer period of record would be needed to determine if the pattern was new, or indicated a return to pre-1970s conditions. The years in which these extreme low flow events occurred do not coincide with particularly low annual precipitation or flow, but they may be due to periods of seasonal drought.

Annual 7-day Low Flow Events



## *Considerations for York River System Instream Flow Requirements*

Our review of river flow management in Virginia indicates that instream flow requirements have typically been developed using one or more of the common methods for assessing impacts to hydrology or habitat suitability. As we have reviewed uses and issues relevant to the York River system, three considerations have suggested themselves as additional factors in establishing flow requirements. These include: impacts to recreational boating above the fall line; implications for sediment budgets above and below the fall line; and impacts to biological resources below the fall line. In the following sections we review each of these subjects and discuss options for considering them in future instream flow management. In each case there are some significant information needs before each issue can be fully addressed in regulatory decision making.

### Recreational Boating Use Considerations

Minimum instream flow for recreational paddling (canoeing, kayaking, or rafting) is generally determined by the amount of instream water present that will allow a paddler to travel the waterway without having to continually exit the boat. In the York River watershed, the minimal instream recreational flow values have been established by stakeholders in the area. The minimum flow level can be determined by either visually inspecting Randy Carter (RC) gauges or viewing USGS stream gauge data.

The Randy Carter (RC) gauges were established by Randy Carter, a whitewater canoeist and author of river guide books, and are a system of bridge abutments/piers/footings markings that indicate the amount of water available for paddling. Carter paddled various rivers and streams and noted the depth of water in both the widest and shallowest parts of the waterway. As a general rule, the minimum level for paddling ('0' in his system of marking) was determined if there was barely enough water to get through without stepping out of the boat. It is important to note that the RC zero indicates a minimum for paddling not that there is no water in the river. In some instances (Table X) the RC gauge has been tied to the USGS gauge. Surveying the RC gauges and benchmarking them to USGS gauges would provide a complete budget for recreational minimum instream flow needs.

**Gauge locations and recreational minimum instream flow values.**
**VaW = Virginia Whitewater, AW = American Whitewater.**

| River [Segment] | RC Gauge Location | USGS Gauge equivalent | Reference |
|---|---|---|---|
| North Anna River [Hanover: Rt 301 to Rt 360] | Route 1 Bridge | 1.2 ft | VaW |
| North Anna River [Rt 601 to Rt. 1] | | 300 cfs | AW |
| Little River [Rt 601 to Doswell Rt 1] | Rt 685 Bridge | 1.8 ft | VaW |
| Little River [Rt 685 to Rt 1] | | 300 cfs | AW |

| | | | |
|---|---|---|---|
| South Anna River | abutment at the pumping station near Rt 54 | | VaW |
| Mattaponi River [confluence of Poni/Matta Rivers - 2 miles above Rt 626 - to Milford - Rt 207] | | 1.5 ft | VaW |
| Matta River [Rt 738 to Rt 1] | | 2.0 ft | VaW |
| Po River [Rt 208 to Rt 1] | | 2.0 ft | VaW |

## Sediment Budgets

*Geological/Sedimentary Context*

The Mid-Atlantic states (e.g. Maryland, Virginia, North Carolina) consist of 5 physiographic provinces, from west to east being the Appalachian Plateau, Valley and Ridge, Blue Ridge, Piedmont, and Coastal Plain. The Coastal Plain has gentle slopes, and low relief and meandering river systems with large sections of the rivers having tidal influence. The underlying geology consists of thick deposits of well-consolidated marine sediments that thin from east to west and lap onto the crystalline rocks that underlie the Piedmont. The boundary between the Piedmont and Coastal Plain provinces is called the fall line and corresponds roughly with the Interstate 95 corridor in Virginia.

The geology and hydrology of rivers are linked, because most of the sediment is carried by water. Sources and sinks of sediment (sediment budget) may provide insights into a water budget. Sources include upland erosion (land use), bank erosion, and input through the estuary mouth. Sinks include accumulation in the channel and wetlands, and loss through the estuary mouth. For rivers on the western shore of Chesapeake Bay, watershed inputs are the primary source of sediment delivered to tidal fresh regions of tributaries (USGS 2003). Sediment is critical for maintaining tidal wetlands and beaches.

A modeling study was conducted to quantify transport and mixing processes in the York River estuary. The mean age and residence time of water in the estuary are functions of freshwater discharge. Under high flow and mean flow conditions, it takes about 2 months and 3 months, respectively for a substance (e.g. a pollutant) discharged into the headwaters to be transported to the mouth of the estuary (Shen and Haas 2004). Although the residence times do not strictly apply to sediments, the results highlight the relationship between water flow and travel time in the river. Salinity intrusions due to reduced freshwater flow or sea level rise cause changes in the geochemistry and organic matter mineralization in tidal freshwater sediments (Weston et al. 2006). These types of changes may affect aquatic organisms and habitat.

Stream flows are affected by many factors—precipitation, gradient, vegetation, soil type. Alteration to any of the factors will affect the stream hydrograph and the water's ability to transport sediment. Storms may flush and trap sediments further downstream, and hurricanes may flush sediments completely out of the system (Geyer et al 2001; Gao and Collins, 1997).

Over time, however, stream gradient is among the most important and pervasive influences on channel form and associated vegetation (Hupp and Osterkamp 1996). Any changes in upstream flows may reduce peak flows and lessen the ability of the river to redistribute sand bars and move larger sediment particles (e.g. pebbles and cobbles).

Sediment is deposited below the fall line when river water enters the tidal portion and the velocity decreases. Sediments range from clayey sand to sand in the lower Pamunkey (Nichols et al., 1991), but no systematic data have been catalogued farther upstream. Sediment trapping and deposition also occurs in the estuarine turbidity maximum (ETM) zones of Chesapeake Bay tidal tributaries. These are river reaches in which the mixing of salt water and freshwater creates chemical and physical conditions that enhance settling of suspended sediments. In the York River system the ETM is typically found around the confluence of the Pamunkey and Mattaponi rivers. In the area upstream of the ETM zone, in the tidal freshwater zone, the contribution of sediment from watershed sources will be significant.

There are no sediment cores in the tidal freshwater zone of the river to help understand sediment accumulation and distribution, and the amount of sediment accumulation in this zone is unknown. Bathymetric data for the upper York River and lower Mattaponi and Pamunkey Rivers were collected by NOAA's National Ocean Service in 1911 only in the main channel. Bathymetric data can be used to visualize channel configuration and estimate sediment accumulation. New, more widely distributed (i.e. along channel and cross channel) bathymetric data and bottom typing are needed. There has been some work done on bank erosion in the estuary (Herman, 2001; Hardaway et al., 1992; Ibison et al., 1990), but additional data are needed to better understand the contribution of bank erosion to sediment accumulation in the in the tidal freshwater zone.

### *Sediment Budget Considerations for Flow Alteration*

Noe and Hupp (2005) documented rates of nutrient accumulation in the floodplains of Atlantic Coastal Plain Rivers with different watershed land use and anthropogenic alterations in hydrology. Patterns of nitrogen accumulation were strongly correlated with organic matter deposition, whereas phosphorus accumulation was strongly correlated with mineral sediment deposition. Floodplains downstream from an urbanizing watershed had the highest rates of sediment and nutrient deposition. The floodplain immediately downstream from intensive agriculture was the location of the highest rate of phosphorus accumulation in the watershed, mostly due to greater sediment phosphorus concentrations. Consequently, diminishing flows in a river system can reduce hydraulic connectivity between floodplains and rivers, and thus limit sediment and nutrient accumulation rates in floodplains.

Tidal freshwater forested wetlands have received considerable ecological study, but distinctly less hydrogeomorphological study; quantitative assessments of the linkages among hydrology, geomorphology and ecology remain largely undocumented. Although heavily impacted by land use, these unique systems remain a critical landscape element for the maintenance of water quality by trapping and storing large amounts of sediment and associated contaminants (Hupp, 2000).

More is known about tidal freshwater marshes. Sediment is trapped in wetlands during high tides when water covers the marsh surface. This sediment input is critical for wetland health and survival. Neubauer et al. (2002) found that short-term sediment deposition rates in tidal freshwater marshes on the Pamunkey River are spatially and temporally variable. An analysis of historical vegetation patterns at Sweet Hall marsh has suggested that the marsh has grown vertically at a rate similar to relative sea level rise. They suggest that part of the difference between sediment deposition and accretion rates is due to periodic storm-induced erosion and historical variability in sedimentation rates. Little is known about the factors that control sediment deposition rates in tidal freshwater wetlands (Darke and Megonigal, 2003). A study on the Mattaponi River found that sediment dynamics can vary dramatically and that part of this variability may depend on location along the fluvial–estuarine continuum. The flows needed to maintain adequate sediment inputs to marsh surfaces are unknown.

## Tidal Freshwater Biological Resource Considerations

### *Biological Resources in the York River system*

The York River is a coastal plain estuary that drains into the Chesapeake Bay and the salinity gradient gradually decreases from the Chesapeake Bay to the upland headwaters. The effect of tides is observed as far upriver as approximately 60 miles on the Mattaponi and 37 miles on the Pamunkey River, with annual and interannual variation. Because of the diversity of habitats within this estuary system, the biota is diverse as well. Wetlands, of the upper York, typically dominated by *Spartina patens*, serve as nursery grounds for drum (Sciaenidae spp.) and Atlantic menhaden (*Brevoortia tyrannus*). Toward the mouth of the river, blue crabs (*Callinectes sapidus*) and hard clams (*Mercenaria mercenaria)* are commercially harvested. There was a historic oyster (*Crassostrea virginica*) fishery in the York River that was decimated due to severe population depletions by disease, although some privately leased oyster grounds do still exist.

The York River also supports commercially harvested finfish, including bluefish (*Pomatomus saltatrix*), speckled trout (*Cynoscion nebulosus*), Atlantic croaker (*Micropogonias undulates*), spot (*Leiostomus xanthurus*) and summer flounder (*Paralichthys dentatus*). Anadromous fish, such as striped bass (*Morone saxatilis*), American shad (*Alosa sapidissima*), hickory shad (*A. mediocris*), and river herring (*A. pseudoharengus, A. aestivilis*) utilize tidal freshwater habitat for spawning and nursery grounds and are an important commercial and recreational fishery resource. Within freshwater reaches, yellow and white perch (*Perca flavescens, M. Americana*), channel, white and blue catfish (*Ictalurus punctatus, Ameiurus catus, I. furcatus*), largemouth bass (*Micropterus salmoides*), redbreast sunfish (*Lepomis auritus*), crappie (*Pomoxis nigromaculatus*), walleye (*Stizostedion vitreum*), carp (*Cyprinus carpio*), and gar (*Lepisosteus osseus*) are important recreational fishery species. Numerous wildlife species are evident within the watershed, including beaver, muskrat, otter and waterfowl.

Several endangered or threatened plants, wildflowers, and birds exist within the York River Watershed, such as the bald eagle (*Haliaeetus leucocephalus*), peregrine falcon (*Falco peregrinus*), Bachman's sparrow (*Aimophila aestivalis*) tiger's salamander (*Ambystoma tirinum*), Mabee's Salamander (*Ambystoma mabeei*), sensitive joint-vetch (*Aeschynomene virginica*), tropical water-hyssop (*Bacopa innominata*) and small whorled pagonia (*Isotria medeoloides*).

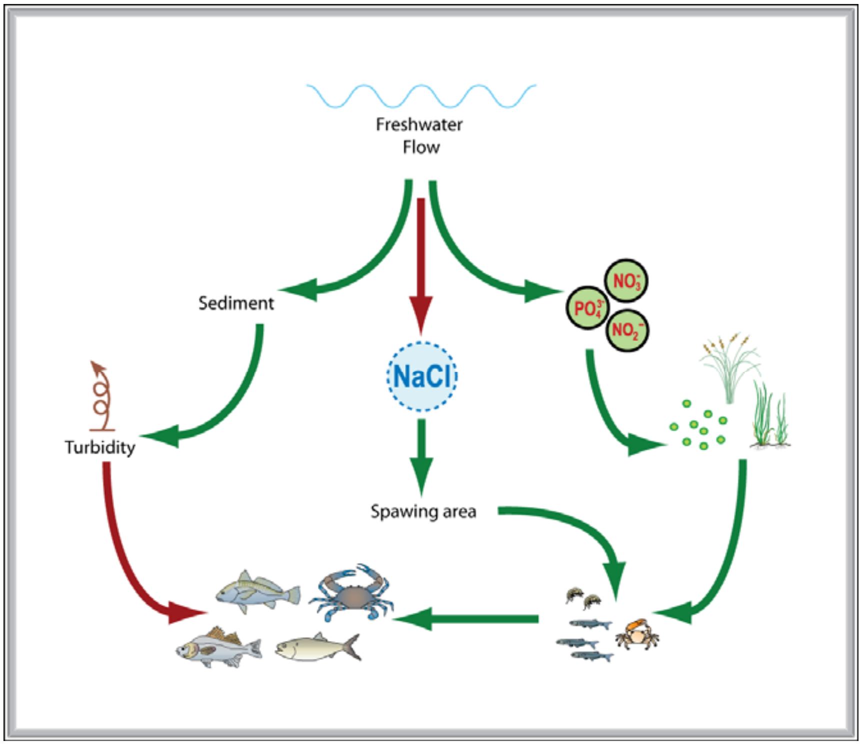
Other marsh plants, including American three square, wild rice, spatterdock, giant cordgrass, narrow-leafed cattails and pickerel weed provide food for migrating wildfowl and year-round residents such as herons, bald eagles and egrets.

### *Impacts of Changing Flow*

Variation in freshwater flow is the dominant source of seasonal and interannual variability in estuaries, influencing the physics, geology and biology of the estuary (Skreslet 1986). Changes in freshwater flow can affect the inundation of intertidal areas, the loadings and advection of materials and organisms, the dilution and mobilization of contaminants, estuarine salinity distribution, estuarine stratification and residence time for water and biota (Kimmerer 2002). Changes in historic flow rates may be due to human use, diversion and impoundment of river water or changing climatic conditions resulting in altered rates and timing of precipitation.

The complex effects of freshwater inflow and salinity on estuarine productivity and aquatic ecosystems have been researched for decades (for reviews see Copeland 1966, Cross and Williams 1981, Turek et al 1987, Pierson et al 2001, Estevez 2002, Kimmerer 2002). Freshwater inflow supports estuarine circulation patterns, salinity gradients, sediment and nutrient transport and primary and secondary productivity in the estuary. To accurately estimate the optimal flow required to sustain estuarine ecosystem functions, interacting biological, geological, chemical and physical parameters must be considered.

Ecological effects from changing flows in estuaries are most obviously related to salinity alterations. Salinity tolerances dictate species distributions and subsequent trophic interactions. Shifts in salinity will result in loss/gain of habitat and associated secondary productivity with complex effects on food webs. The estuarine turbidity maximum (ETM), a mixing zone with elevated levels of suspended particulate material, is a crucial retention zone that may influence the survival and recruitment of economically important river spawning species, striped bass and white perch (North and Houde 2001). Flow alteration may result in the mismatch of predator and prey availability as the turbidity maximum strength and location is changed. Long-term salinity alterations will lead to shifts in plant and animal assemblages including loss/stress of flora and fauna with low salinity tolerance, reduced water quality as plants (riparian and intertidal/subtidal) have diminished capacity to trap nutrients and sediments, and introduction of predatory marine animals.




A conceptual summary of selected impacts associated with increased freshwater flow. Green arrows indicate a positive interaction; red arrows indicate a negative interaction. (Modified from information in Kimmerer 2002)

To establish optimal flows in estuaries for water planning, biological resources anticipated to be affected by altered flow and representative of the ecosystem most likely will be considered as potential indicators of estuarine condition, including tidal wetlands, submerged aquatic vegetation, shellfish and finfish. An understanding of biological responses to altered flows will enhance the accuracy of optimal flow estimation. Prior to setting standards based on hypothesized biological-inflow connections, a comprehensive review of the state of the knowledge, estimation of limitations of the approach, and description of research needs should be completed.

### *Tidal Marshes Considerations*

The distribution and health of freshwater tidal marshes is the most viable potential indicator of estuarine condition because they are extensive throughout the Mattaponi and Pamunkey rivers, their past and current distribution is well documented and their ecology has been thoroughly researched. Tidal freshwater wetlands are riverine areas characterized by measurable tidal fluctuation and salinities (generally) less than 0.5 ppt. They are located downstream of the fall line and upstream of salt wedge intrusion. There are a wide variety of plant species found in the tidal freshwater regions of the York River Estuary, characterized by varying sensitivity to salt and inundation.

Freshwater tidal marshes are ecologically important communities which have high plant diversity and support extensive avian and aquatic plant communities (Mitsch and Gosselink 1993). Tidal freshwater marsh plants provide a variety of ecological values to the estuary. In the Chesapeake Bay, they have been found to serve a habitat to a wide variety of aquatic species

(McIvor and Odum 1988, Rozas and Odum 1987, Yozzo and Smith 1998). Tidal freshwater marshes tend to have pronounced seasonal variation in community composition (Odum et al. 1984) which provides diverse habitat for benthic communities (Yozzo and Diaz 1999). They also provide habitat and food for many nekton species. Decomposition of plant material occurs rapidly in tidal freshwater marshes (Odum and Haywood 1978) resulting in high quality, nutritional detritus for the basis of the aquatic food chain (Odum et al. 1984). They support a diverse fish community, including a mixture of warm freshwater species, estuarine species with wide ranges and anadromous marine species that use the tidal freshwater for spawning and nursery habitat (Yozzo and Diaz 1999).

As sea level rise continues, it is critical that marshes elevate themselves to prevent conversion to open water through drowning and a loss of ecological services. Marsh vegetative species composition and arrangement affects sedimentation rates and organic content production and through these, marsh elevation (Pasternack et al. 2000). A disruption of one of these processes can cause a cascade of changes to the others. Therefore, a change in vegetative type (such as a change from freshwater to brackish water species) could have significant impacts on the long-term survival of marsh functions. Changes in plant composition and marsh elevation are linked to changes in local topography, which affects flooding duration (Rozas and Reed 1993), benthic invertebrate community composition (Yozzo and Diaz 1999) and nekton use of the marsh (Yozzo and Smith 1998).

There are a number of potential impacts to tidal freshwater marshes associated with changing environmental conditions (both anthropogenically influenced and natural). Predicted increases in sea-level rise will increase flooding and salinity levels in estuaries, impacting plant species productivity and survival, potentially leading to changes in plant community composition (Spalding and Hester 2007). Decreased production is predicted to lead to decreased soil organic matter, while changes in porewater chemistry may result in alterations in nutrient cycling (Spalding and Hester 2007). Due to their position in the landscape, tidal freshwater marshes are particularly susceptible to alterations that result in salinity changes. Natural fluctuations in salinity are known to significantly impact wetland vegetation patterns (Pearcy et al. 1982, Perry and Hershner 1999). Changes in salinity can impact marsh plant productivity (McKee and Mendelssohn 1989) and photosynthetic response (Kemp and Cunningham 1980). Salinity regime also affects the nekton community (Yozzo and Smith 1998) and specifically the clutch size, life span, growth and sex ratio of grass shrimp (Alon and Stancyk 1982). Submerged aquatic vegetation distribution, an ecologically related community, is related to local salinity levels, and can affect the age-class distribution of nekton using the marsh surface and edge (Yozzo and Smith 1998).

Tidal freshwater wetlands are the best ecological candidate for evaluating the impact of changes in freshwater flow on the York River system because they are extensive, easy to observe, have a relatively long historical record and they affect numerous other parts of the biotic ecosystem.

The historical record of tidal freshwater marsh location and species composition has been extensively studied in both Mattaponi and Pamunkey rivers. A study on long-term changes in community composition was conducted along several transects on the Mattaponi River (Hershner et al. 1991). Analysis of historical data from 1941-1987 looking at marsh plant community composition, freshwater flow and modeled salinity distribution found little change in the community composition or river salinities over the 35-year period. Mean salinities increased only 0.02-0.24 ppt over the historic period, with the higher change occurring at the downstream end of the river. In Sweethall Marsh, Pamunkey River a comparative study of plant composition from 1974-1987 found a shift towards more salt-tolerant species (Perry and Hershner 1999). The change in plant community was attributed to eustatic sea level rise, isostatic effects or groundwater withdrawal. Since both rivers should have similar rates of eustatic sea level rise and isostatic effects, but changes were only apparent in the Pamunkey, it seems likely that groundwater withdrawal is a key component of the changing community on the Pamunkey River. This may be due to large industrial water withdrawals which are found on the Pamunkey, but not the Mattaponi River. Groundwater withdrawals can deplete the freshwater and draw the salt wedge upriver.

There have been two estuary models that specifically looked at the impacts of changing freshwater flow on tidal freshwater wetlands. A model of the Yellow River Estuary, China (Sun et al. 2008) used the water surface area and water depth necessary to provide a stable habitat for animals including, food, water and nesting materials as the parameter of interest. This is similar to the wetted perimeter approach. Their variables were the ratio of water surface area to total wetland surface area, water exchange period (this was estimated due to lack of data), total wetland area, and average water depth. Other than the water exchange period, these variables are relatively easy to estimate. They also modeled salinity equilibrium with its relation to wetland distribution.

A model of the Suwannee Estuary (Mattson 2002) examined the impact of changing salinity on tidal freshwater swamps and marshes. The parameter of interest was the maintenance of current habitat distributions and the method used was a habitat method. Previous work in the area indicated that two of the main tree species in the area have distinct responses to changing salinity regimes. Cypress seedlings exhibit reduced net photosynthesis and stomatal conductance (Pezeshki et al 1987) and some maple species have reduced seedling survival (Williams et al. 1998) at salinities of 2 ppt or higher. In addition, two marsh grass species showed distinct boundaries based on salinity regimes. The breakpoint between sawgrass and black rush communities appears to be at 7 ppt-11 ppt (Clewell et al. 1999). This information allowed them to model the minimum freshwater flow necessary to maintain the tidal freshwater swamp and sawgrass communities at their present extents. The plant data necessary for this approach are likely to be available for the York River system; however, the issue of groundwater withdrawals (addressed above) would need to be explicitly addressed.

### *Submerged Aquatic Vegetation Considerations*

Submerged Aquatic Vegetation (SAV) has been considered as an ecological indicator for estuarine health due to its contributions to estuarine productivity, through the support of dense faunal communities (Orth and Moore 1984) and its role as an ecosystem engineer, affecting changes in habitat that impact the entire community, from bacteria to animals (Koch 2001). In the Chesapeake Bay, there are several different species of SAV which cover different ranges of salinity. *Zostera marina*, a saltwater species, is dominant in the lower reaches of the Bay, a variety of freshwater species are found in the middle and upper reaches of the Bay and *Ruppia* *maritima* is found throughout the marine and brackish water regions (http://web.vims.edu/bio/sav/aboutsav). Upper regions of the Pamunkey and Mattaponi are dominated by *Hydrilla* sp., with pockets of *Vallisneria americana.* The following species have also been found over the years: *Ceratophyllum* sp, *Najas* sp., *R. maritima* and *Elodea* sp. (VIMS, SAV ground survey 1998-2008, http://web.vims.edu/bio/sav).

Given the important ecological status of SAV, the basic management concepts tend to either follow the "more is better" philosophy of maximizing potential SAV habitat or a philosophy of determining and maintaining current or historic boundaries. SAV is only useful as an indicator with species for which the salinity-SAV relationship has been well-established (Estevez 2000) and where freshwater SAV species are present in the estuary (since marine species would generally thrive under low flow conditions). Although vague salinity-SAV relationships have been developed for several species, determining threshold salinities can be problematic due to the lack of non-linearity in the relationship. In San Francisco Bay, the relationship between the 2 ppt isohaline and estuarine fauna showed smooth rather than sigmoidal relationships, and therefore had no thresholds (Kimmerer and Schubel 1994).

The other difficulty with developing salinity-SAV relationships is the number of other factors that control plant growth, including: temperature, light, depth, sediment type and nutrient supply (Koch 2001, French and Moore 2003). Many of these factors vary with freshwater flow and may interact with the effects of salinity. For example, the interaction of light and salinity was examined for *V. americana* in the Chesapeake Bay and it was determined that although salinity is the primary limiting factor, low light levels also limit growth, particularly at high salinities (French and Moore 2003). Other factors known to impact SAV growth are current velocity, wave energy, tidal range, and sediment grain size and sediment geochemistry (as reviewed in Koch 2001).

In Florida, SAV species distribution has been used to establish both minimum and maximum freshwater flow requirements. The management goal was to maintain the current populations of the (salt tolerant) freshwater species, *V. americana* and the marine species *Halodule wrightii* (Doering et al. 2002). The freshwater species requires salinities below a certain level, so its habitat requirements were used to develop the minimum flows, while the marine species cannot handle reduced salinity, so its habitat requirements were used to develop the maximum flows. Salinity thresholds were determined experimentally for each of the species and salinity gradients throughout the estuary were modeled. This information resulted in the ability to map potential SAV habitat for each species and to determine the flow regime necessary to maintain the habitat areas.

Seasonal changes in the plant community are an important consideration for flow regulation. Seasonal patterns of growth in *V. americana* in the Chesapeake Bay indicates that late spring and early summer may be the most important time for population establishment and resource procurement. The plants are the most sensitive to stress during this time period (French and Moore 2003). This suggests that the late spring timeframe may be the most important management window and that maintaining the historic hydrograph during that time frame is critical to maintaining the historic SAV distribution.

### *Faunal Considerations*

Measures of fauna, typically single species catch-per-unit-effort, landings, or abundance, have been used as an indication of the required minimum river flow to sustain habitat quality (e.g. striped bass in San Francisco Bay, Jassby et al. 1995; oyster landings in Apalachicola bay, Wilber 1992). These efforts focus on the requirements of individual species or species guilds, which may be counter to other species requirements. The relationship between discharge and finfish/shellfish is often not straightforward and at times not demonstrable, further minimizing its effectiveness as a sole determinant in optimum flow. Natural long-period shifting climate regimes, fishing pressures and other anthropogenic stressors (lag responses or nonlinear) may veil links between discharge and the species of interest.

Chesapeake Bay fish recruitment success is tempered by decade-scale climate regimes as defined by temperature, river flows and the North Atlantic Oscillation (Austin 2002). Bay finfish species demonstrably affected by climatic fluctuations can be placed into three reproductive strategy categories: 1) spring-spawning freshwater and anadromous species (e.g. catfishes, American shad, river herring, striped bass); 2) spring/summer spawning year-round residents (bay anchovy, silversides), and 3) fall-winter shelf-spawning species that are transported into the bay as larvae (spot, croaker, menhaden)(Austin 2002). All strategies are affected by temperature, with the additional influences of discharge on river spawners, and wind patterns on shelf-spawners. Patterns in temperature, discharge and wind conditions can be depicted as warm-wet or cold-dry regimes that result in varying success for reproductive strategies. Climate conditions favoring bay spawners (warm/dry) are the antithesis of those supporting river spawners (cool/wet springs), thus successful recruitment in one guild could mean recruitment failure for the opposite guild (Wood 2000).

Water budget plans should consider underlying climate trends when specifying optimum flows and management goals. For example, during climate regimes that support river spawners, flows should mimic the natural hydrograph closely to achieve successful recruitment during these years which may contribute disproportionately to long-term stock sustainability. While evidence of consistent relationships between river spawning fish and instream flows has been elusive with differing responses occurring in different watersheds, flow affects the transport of larvae to nursery grounds. Larval dispersal determines feeding experiences and predator exposure, and may affect mortality of larvae (Bilkovic 2000). In general, egg dispersal in low flow conditions is more limited than in high discharge conditions, and extreme high flows act to advect eggs and larvae from tidal freshwater nursery environments (Bilkovic 2000). The magnitude and variability of flow will fluctuate based on watershed size which may account for disparate relationships. For example, in the Hudson River, American shad year-class was established mainly by cohorts spawned late in the season (June) with declines in flow, and increases in temperature and zooplankton levels (Limburg 1996); whereas, in the smaller Mattaponi River a positive relationship existed between an index of juvenile American shad abundance and flow during May-June, with the largest cohorts associated with high discharge years (Bilkovic 2000; Hoffman et al 2007). Decreased extreme events (including extreme low flows) were also correlated with high juvenile abundance (Bilkovic 2000). Additional non-linear analyses of previously examined or newly acquired river-spawner data may reveal hidden trends and lead to a more consistent understanding of the effects of flow on fish recruitment.

## Management Considerations

Evaluation of instream flow requirements is not a new issue for Virginia water resource managers. Traditional methods have been used for many years to regulate local impacts associated with water withdraw and impoundment projects. What we seek to address in this report is the need to consider more than local impacts, and specifically impacts that can arise in parts of the river system not traditionally considered particularly susceptible to flow alterations. Once flows cross the fall line in coastal systems, deficits in freshwater input are seemingly made up by a limitless supply of salt water.

We have come to understand that this is not an exchange without consequences. As researchers have investigated the ecology of the highly productive tidal freshwater reaches of our major river systems, they have learned that the biological communities there are tightly linked to the physical and chemical conditions created by freshwater inflows. It has been known for quite some time that relatively small difference in salinity in the nearly freshwater reaches can result in large differences in both plant and animal community composition. More recent and emerging understanding suggests that salinity is not the only factor that can affect these organisms.

Extrapolating from research in free flowing systems, researchers have begun to investigate the link between the hydrograph of a coastal river and the physical character of the habitats found just below the fall line. The frequency, duration, and magnitude of high flow events are understood to affect the type and distribution of sediments in benthic, intertidal, and riparian habitats in tidal freshwater systems. As noted in preceding sections of this report, it also can control the residence time of early life stages of motile species that rely on these systems as nursery grounds.

Estuarine ecologists have known for years that runoff from watersheds brings nutrients, and other compounds along with the sediments eroded from the landscape. They are now coming to understand the significance of the composition and timing of those inputs in coastal systems. The chemical composition of a river's discharge and the resultant impacts in the receiving waters can vary significantly over the course of a year. This makes a river's hydrograph a key factor in determining the character of tidal freshwater systems. It influences the quality of the habitat for submerged aquatic vegetation, phytoplankton, zooplankton, and anadromous fish, among many others.

For all of these reasons, instream flows above the fall line matter greatly below the fall line. The challenge managers currently confront is the incomplete understanding scientists have generated to date. There is still a significant amount of work to be done to document relationships between river flows and impacts on tidal freshwater communities. There is enough information to identify potential impacts and to raise concerns for inattention. There is not enough information to develop explicit, quantitative guidance for flow management.

At the present time, and in view of what we know, what we are able to hypothesize, and what we simply do not know, we conclude the following:

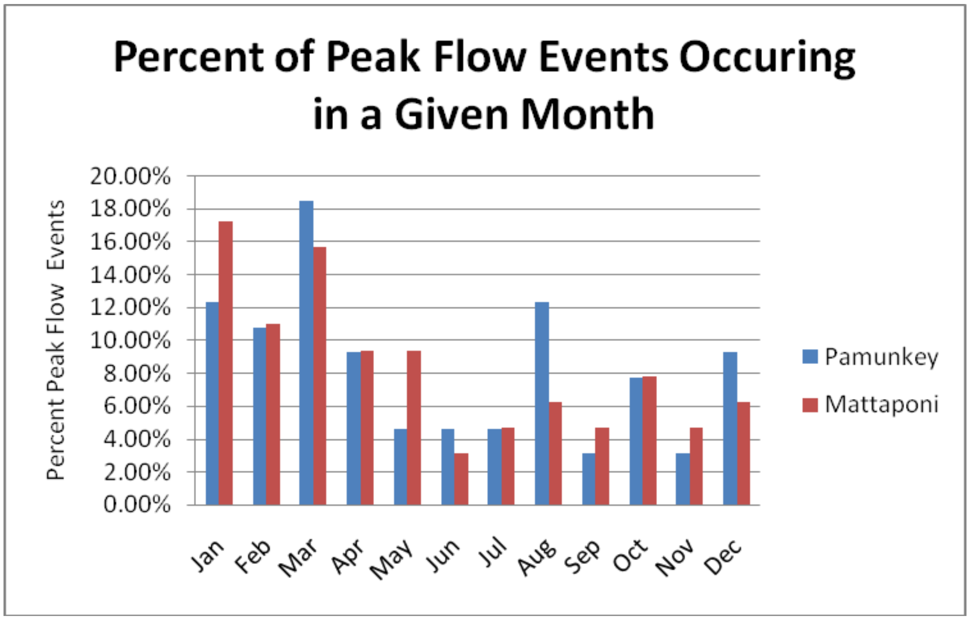
1. Modification of coastal river hydrographs will impact tidal freshwater systems.
2. Natural flow variations may be a critical factor in the capacity of tidal freshwater systems to perform many highly valued functions.
3. Absent more certain knowledge of flow modification impacts, a precautionary management strategy that seeks to preserve the general shape of a river's hydrograph is preferred.

## Management Recommendations

Estuaries function through a suite of complex interactions, all of which are important for maintaining natural ecological processes. Therefore, we suggest that simply maintaining the average hydrograph (the general approach to water withdrawal management in rivers) is insufficient for estuarine systems. A combined biological and geological approach to water withdrawal management would be more appropriate for maintaining ecological function in the York River Estuary. At this time, we are lacking much of the data needed for development of a comprehensive management based on biological and geological functions. Therefore, we propose the following management recommendations:

1. Maintain the timing and flow of peak flow events when permitting ground and surface water withdrawals. Lacking biological and geological information, maintaining a natural hydrograph is crucial. Long-term hydrograph data from the USGS monitoring sites makes it possible to model many characteristics of the York River hydrograph. When analyzing the current hydrograph, it is important to keep in mind that the natural hydrograph has possibly already been somewhat altered by past permitted withdrawals. The maintenance of the timing (seasonally) of peak flow events may be particularly important because certain biological functions in the estuary (such as diatom blooms or larval fish movement) may be dependent on those peak flow events occurring within a particular window.

   Over the time of record, peak flows in the Mattaponi occurred on average every 373 days, but could be as little as 55 days apart and as many as 981 days apart. Peaks flows in the Pamunkey occurred on average every 368 days, but could be as little as 68 days apart and as many as 675 days apart.




Historically, in both the Pamunkey and the Mattoponi Rivers, peak flow events occur primarily in the early spring (Jan-Mar, 42% and 44%, respectively), but do occur in every month. In the Pamunkey River, the highest monthly percentage of peak flow events is in March, but the second highest events are evenly split between January and August (12% in both months). This is not true in the Mattaponi River, where the 3 months with the highest percentage of peak flow events are all in the early spring. Therefore, in the Pamunkey it may be important to maintain peak flow events in August as well as in the early spring.

2. Begin baseline monitoring of biological and geological characteristics before more withdrawals are permitted. Each additional withdrawal has the potential to move the system further from natural function; therefore it is critical to establish a baseline now against which future functions can be compared. At a minimum, we recommend monitoring the following characteristics of the York River estuary: marsh vegetation extent and distribution of species (some baseline already established); submerged aquatic vegetation extent and distribution of species (some baseline already established); anadromous fish species distribution and movement; sediment erosion and deposition in marshes; and sediment erosion and deposition on beaches.

3. Require biological monitoring as part of any surface or groundwater withdrawal permits. This will help establish a baseline and provide early evidence of changes in ecological systems.

## Developing Minimum Instream Flow Requirements for the York River System

**Step 1. Evaluate freshwater inflow to estuary**

*Basic information needs include*

- ✓ Calibrated hydrodynamic model of the system (2D and 3D models exist)
- ✓ Detailed and spatially-explicit long-term salinity data (calibrated model output for over 40 years exists)
- o Inflow (surface and groundwater) estimates that encapsulate monthly/seasonal trends (need groundwater information)
- o Region specific precipitation data (need improved spatial resolution)
- o Water withdrawals (need full accounting of current and proposed)

**Step 2. Establish representative species and/or habitat affected by flow changes**

*Likely habitats and/or species groups targeted include*

- ✓ Tidal freshwater wetlands (inventory exists, needs updating)
- ✓ Submerged aquatic vegetation (inventory exists, spatial resolution could be improved)
- ✓ Anadromous fish (species lists exist, monitoring is very modest)
- ✓ Recreational fisheries or activities (qualitative information exists)

**Step 3. Determine species and/or habitat specific information needs to establish inflow requirements, for example**

Tidal freshwater wetlands

- ✓ Current distribution and species information of freshwater tidal vegetation
- ✓ Impacts of ground and surface water withdrawals
- ✓ Salinity and inundation tolerances of primary freshwater tidal vegetation

Submerged aquatic vegetation (SAV)

- ✓ Salinity tolerances of all marine and freshwater SAV species
- o Historic and current extent of each type of SAV
- o Interaction effects between flow, sediment type, salinity

Anadromous fish

- ✓ Salinity tolerances of each life stage in the estuary (i.e. egg, larvae, juvenile) (select species information exists)
- o Known distributions of each life stage
- o Long-term recruitment patterns

Recreational activities (e.g. canoeing, kayaking, fishing)

- ✓ Types of activities currently supported in the estuary
- ✓ Depth of water required to sustain activity (e.g. boat access)

**Step 4. Determine optimal/minimum flow requirements**

- o Balance needs and impacts throughout system
- o Appropriately consider non-linear relationships
- o Considers long-term climate trends

**modified from Estevez 2002*

Surface Water Withdrawal Permit Holders within the York River Watershed with Annual Average withdrawal (mgd) from 1990-1999

| **Permit Holder** | **System** | **Source** | **Annual average withdrawal in mgd (1990-1999)** |
|---|---|---|---|
| 1. Amoco Petroleum Products | Yorktown Refinery | York River | 59.02 |
| 2. Bear Island Paper Co. | Ashland Plant | Meadows Pond | 0.92 |
| 3. Bear Island Paper Co. | Ashland Plant | North Anna River | 0.60 |
| 4. Colesville Nursery | Colesville Nursery | Farm Pond | 0.04 |
| 5. Gordonsville, Town Of | Gordonsville (Route 15) | Gordonsville Quarry | 0.01 |
| 6. Hanover County | Ashland | South Anna River | 0.91 |
| 7. Hanover County | Doswell | North Anna River | 3.10 |
| 8. Hollows Corporation Inc | Hollows Golf Course | 14-Acre Lake | 0.03 |
| 9. Hollows Corporation Inc | Hollows Golf Course | South Anna River | 0.02 * |
| 10. Klockner-Pentaplast Of America | Gordonsville Plant | Gordonsville Quarry | 0.00 |
| 11. Lake Caroline Water Company | Lake Caroline | Lake Caroline | 0.20 |
| 12. Louisa County Water Authority | Louisa-Mineral | Northeast Creek Reservoir | 0.20 |
| 13. Luck Stone Sand And Gravel | Ruther Glen Plant | Reservoir | 0.22 |
| 14. Martin Marietta Aggregates | Doswell Quarry | Little River | 0.03 |
| 15. Martin Marietta Aggregates | Doswell Quarry | Quarry | 0.33 |
| 16. Spotsylvania County | Ni River | Ni River Reservoir | 3.08 |
| 17. St Laurent Paper Products Corp | West Point Plant | Pamunkey River | 3.82 |
| 18. Tanyard Country Club | Tanyard Cntry Club Golf Course | Richardson Pond | 0.05 |
| 19. U.S. Silica | Montpelier Plant | Settling Ponds | 14.40 |
| 20. United States Government | Cheatham Annex Navy Supply Ctr | Jones' Pond | 0.10 |
| 21. Virginia Power | North Anna Nuclear Power Plant | Lake Anna Unit #1 | 1022.91 |
| 22. Virginia Power | North Anna Nuclear Power Plant | Lake Anna Unit #2 | 967.03 |
| 23. Virginia Power | Yorktown Fossil Power Plant | York River | 657.65 |
| 24. West Point Country Club, Inc. | West Point Country Club | 14 Acre Pond | 0.001 * |
| 25. West Sand & Gravel Co Inc | Gloucester Plant | Poplar Spring Branch | 0.06 |
| 26. Williamsburg, City Of | Williamsburg | Waller Mill Reservoir | 3.50 |
| Total Withdrawals | | | **2729.23** |
| Total Withdrawals without Lake Anna | | | **739.29** |

* 1999 Only

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