Tracking Estuarine Restoration in a Tidal Freshwater Embayment, from *Nutrient Loading Reductions* to *Bloom Abatement* to *Aquatic Plant Recovery*

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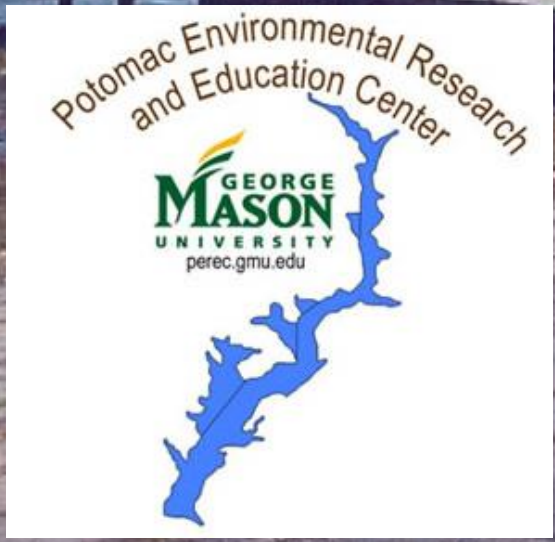


Figure 2. The tidal Potomac River and Estuary.

Tidal Potomac River: A Chesapeake Bay Subestuary

- The tidal Potomac River is the largest subestuary in the Chesapeake Bay system
- Salinity zones
  - Tidal Freshwater ("tidal river"),0.5 ppt salinity
  - Oligohaline ("transition zone" 0.5-6 ppt salinity)
  - Mesohaline ("estuary" 6-14 ppt salinity)
- Drainage area to tidal river at Chain Bridge: about 30,000 km^2
- So, large freshwater input that creates a large tidal freshwater zone of about 50 km in length

Historic Distribution of Submersed Macrophytes (SAV) in the Tidal Potomac

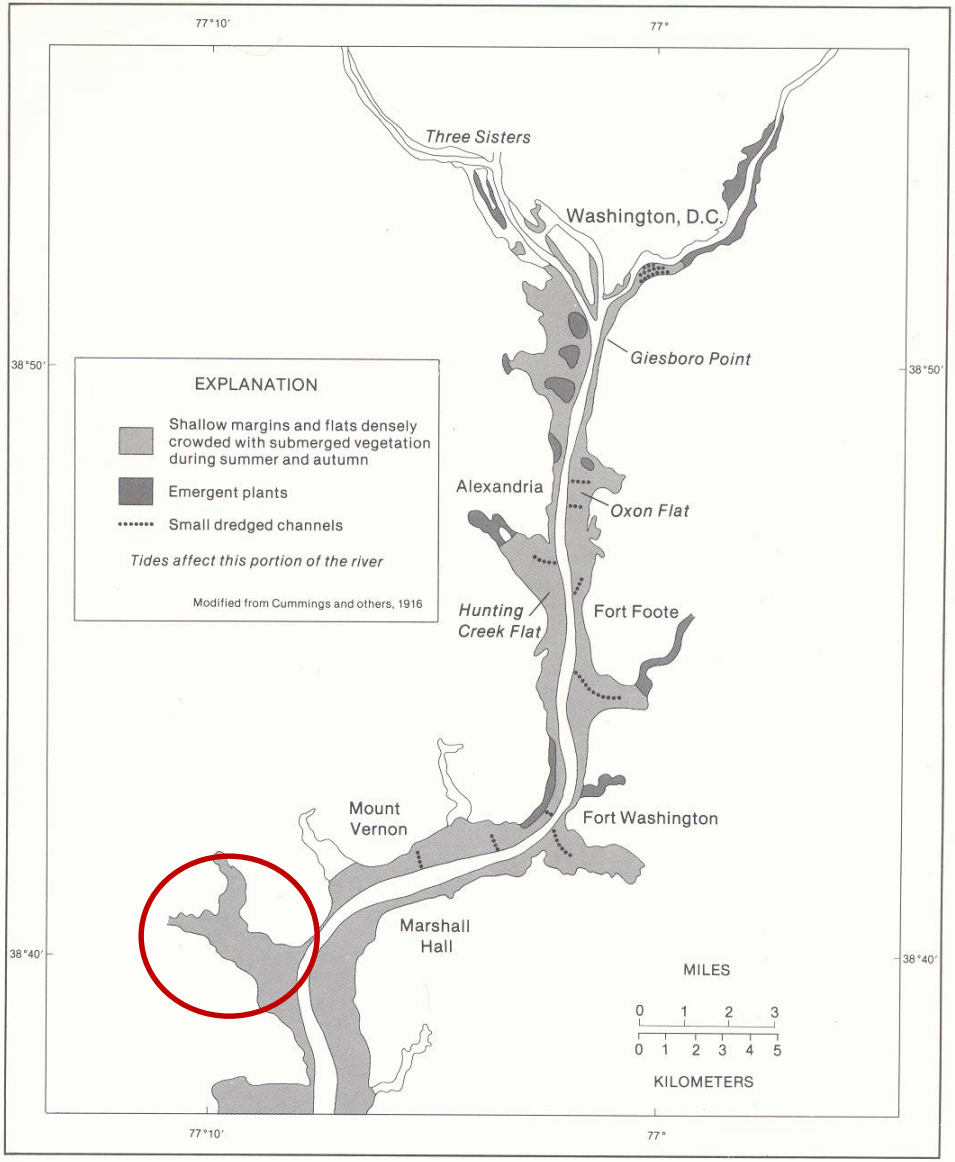


Figure 1. Upper part of tidal Potomac River at low water showing distribution of aquatic vegetation in 1916 (modified from Cumming and others, 1916).

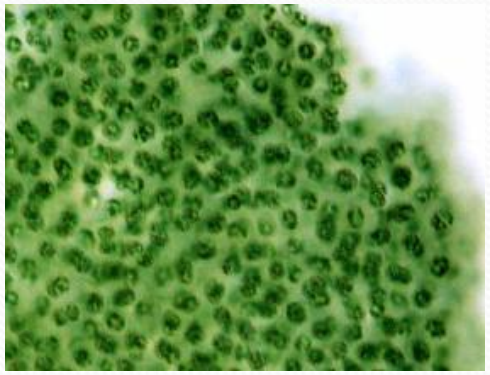
- According to maps and early papers summarized by Carter et al. (1985), submersed macrophytes occupied virtually all shallow water habitat at the turn of the 20th century
- **Gunston Cove (red circle)** was included in the survey and was occupied by SAV

P Loading and Cyanobacterial Blooms

Point Source P Loading to the Tidal Potomac (kg/day)	
1945	1,370
1960	7,400
1970	10,958

Source: Jaworski Treatise

- Fueled by nutrient inputs from a burgeoning human population and resulting increases in P inputs, phytoplankton took over as dominant primary producers by about 1930.
- While possibly not responsible for the original disappearance of SAV, phytoplankton blooms inhibited re-establishment
- By the 1960's large blooms of cyanobacteria (*Microcystis aeruginosa*) were present over most of the tidal freshwater Potomac River during late summer months



SAV Distribution in 1980

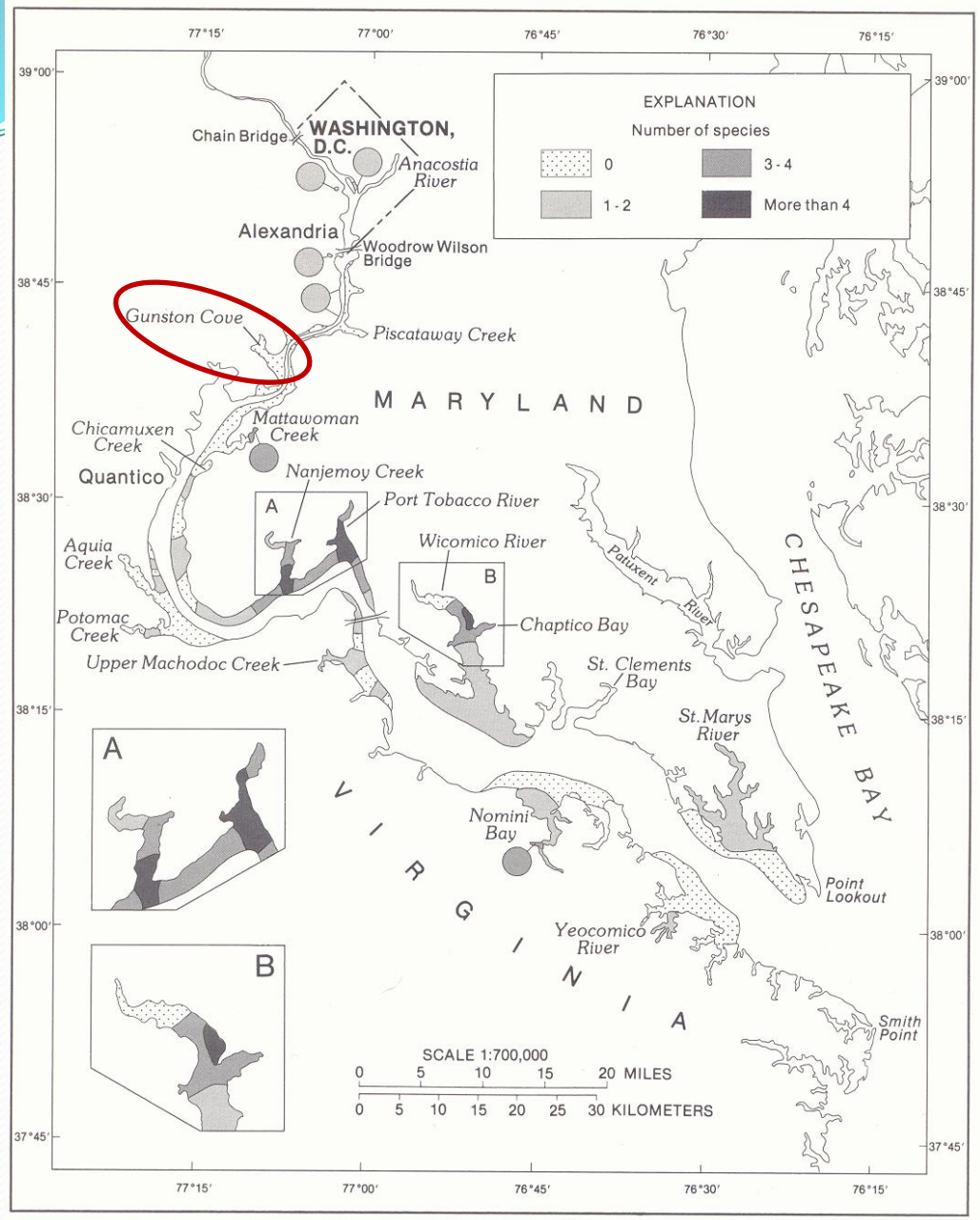


Figure 3. Distribution and number of species of submersed aquatic vegetation in the tidal Potomac River and Estuary during 1978-81. Circles represent vegetation found during informal sampling period.

- Anecdotal records indicate that by 1939, SAV had declined strongly and disappeared from much of their original habitat
- An outbreak of water chestnut (floating macrophyte) was observed in the 1940's but no SAV records (another recent, but so far limited outbreak in GC-2014)
- Surveys done in 1978-81 indicate only very sparse and widely scattered beds
- Note no submersed macrophytes were found in **Gunston Cove** in 1978-81

Source: Carter et al. (1985)

P sources to the tidal Potomac

- Loading to the tidal Potomac is concentrated in two areas:
  - Blue Plains (BP) (largest circle)
  - Noman Cole (NC): smaller circle on Gunston Cove
- We'll focus on NC which is the biggest P loader to GC
- P loading all of these plants was greatly reduced in the 1970's and early 1980's (lower graph shows time course of loading to Gunston Cove)*
- This was done in spite of significant increases in treated waste discharge volume

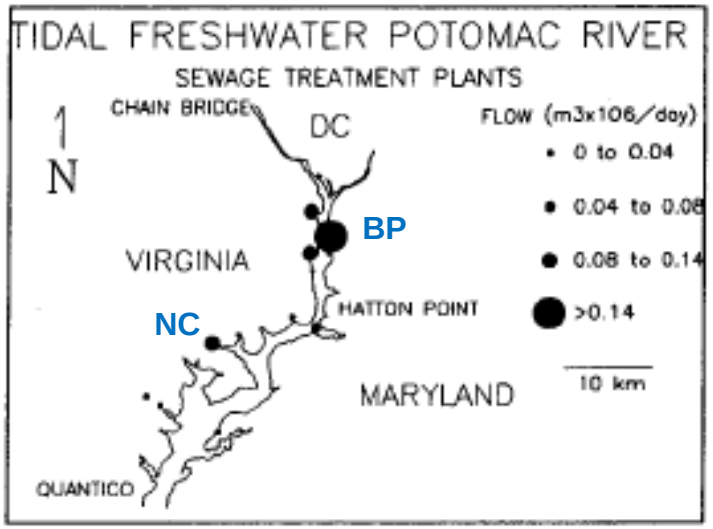
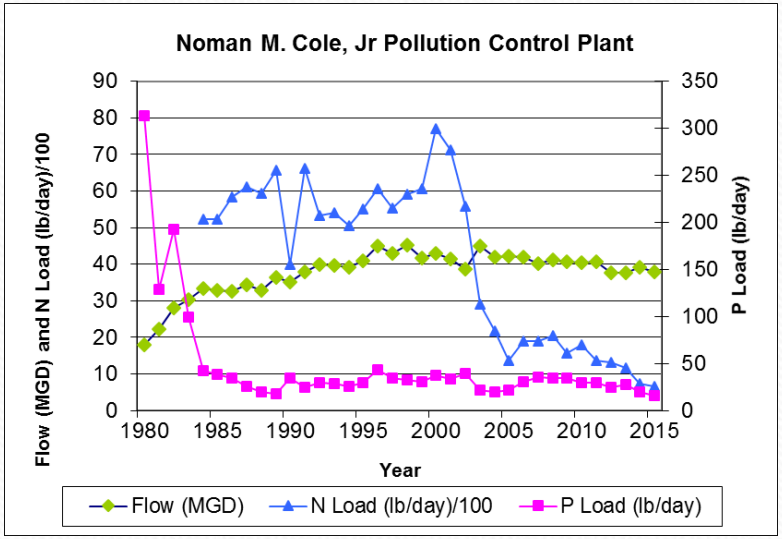
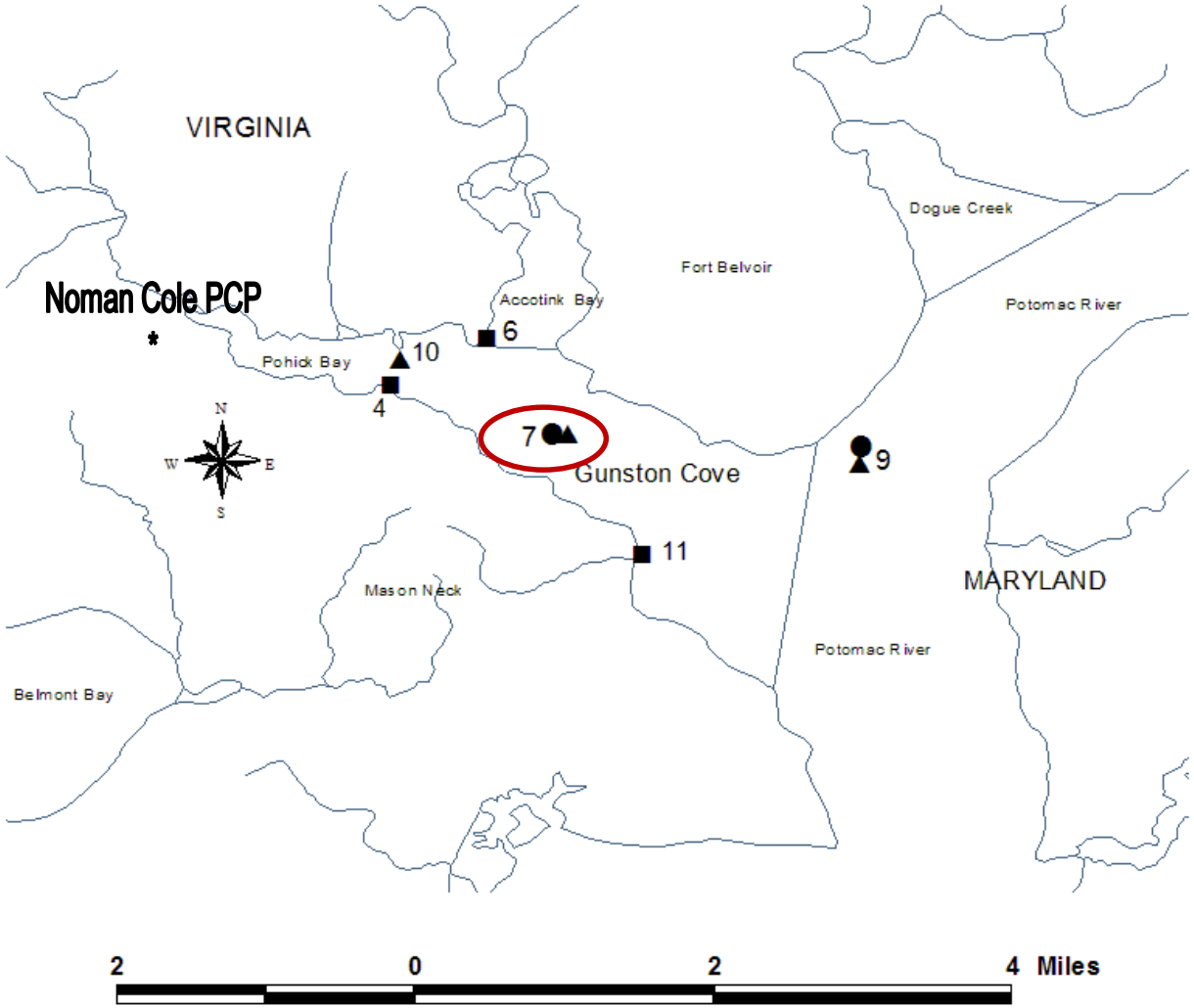


Fig. 1. Tidal freshwater Potomac River showing the location of sewage treatment plants and their relative output.



Gunston Cove Study



Since 1983/84, water quality, plankton, fish and benthos have been monitored on a semimonthly basis at a number of sites in the Gunston Cove area. This paper utilizes mid-cove Station 7

Monitoring Site Key:

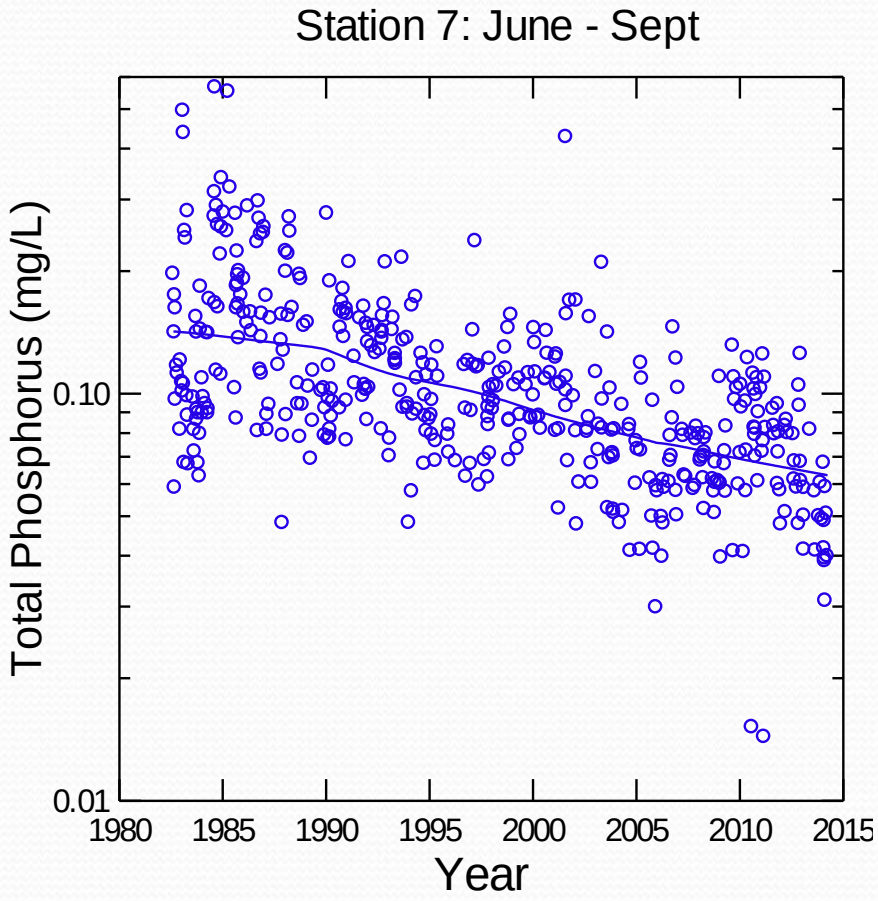
- ● water quality and plankton
- ▲ fish trawl
- ■ fish seine

Note: Early in the study, there were many more sample sites, but after analyzing the data it was found that this smaller number of sites largely represented the important spatial variation, but we continued semimonthly regime to catch more variable temporal patterns.

Water Quality Data Analysis

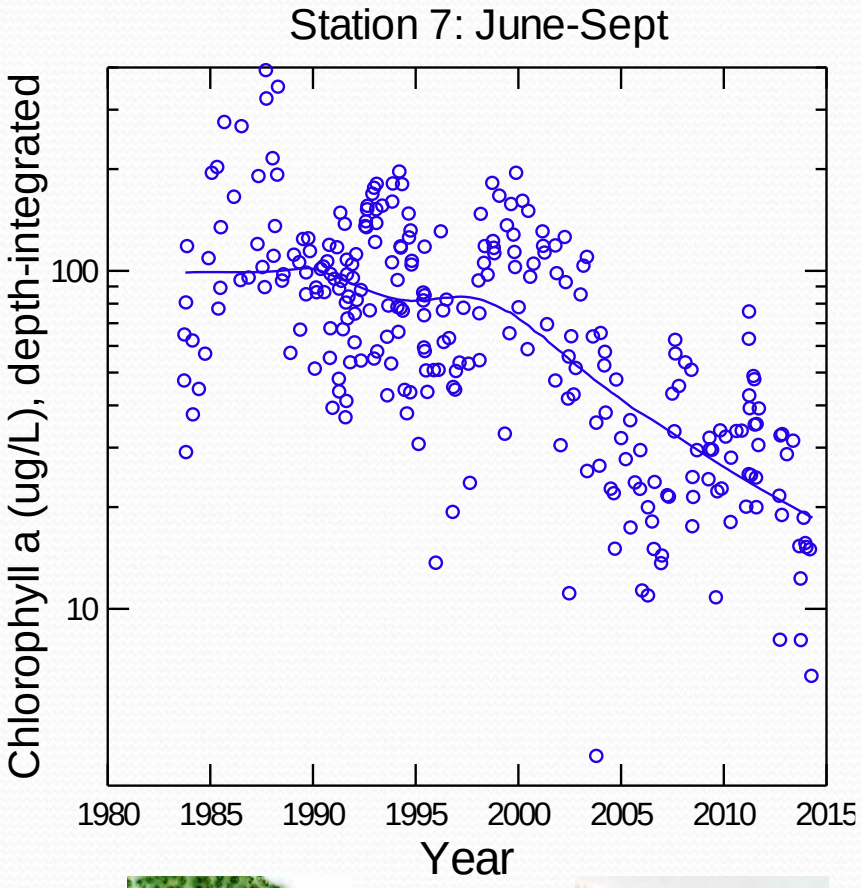
- Summer data (June-September) utilized
- Utilized one cove station (Station 7) that has been sampled continuously over the period 1983-2010
- Scatterplot by year over the study period
- LOWESS smoothing function applied
- Linear regression of each parameter vs. year was conducted for more rigorous statistical analysis and determination of rate of change

Gunston Cove Station
Total Phosphorus



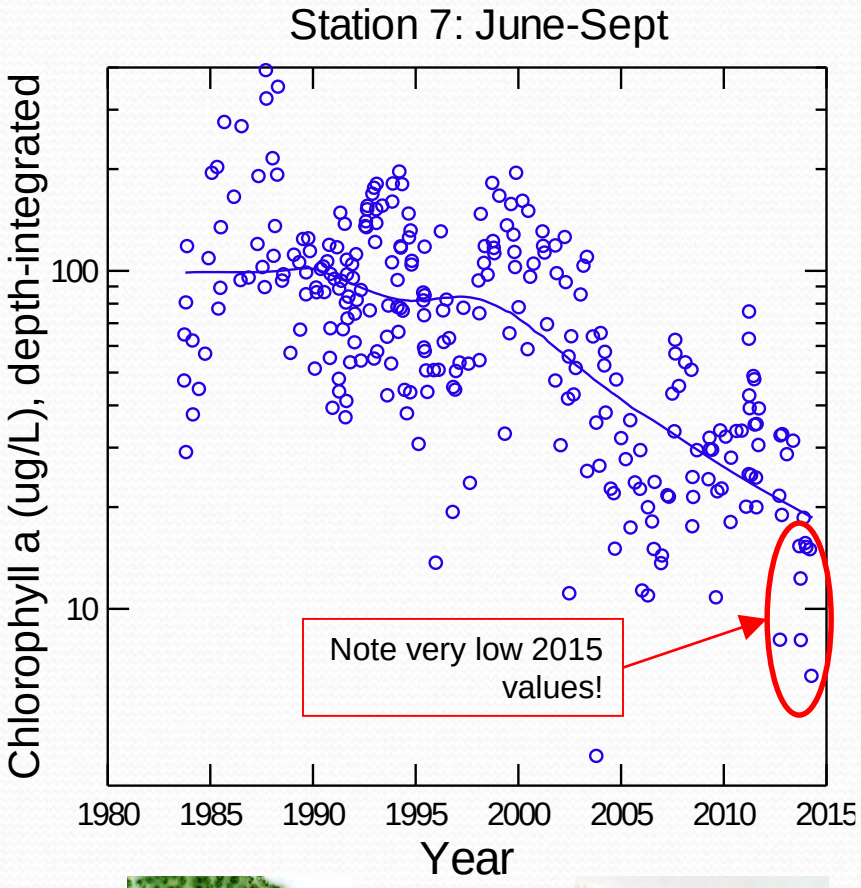
- P is limiting nutrient in this system
- Summer total phosphorus showed little change from 1983 through 1989
- Summer total phosphorus has decreased consistently from 1989 through 2014
- Linear trend highly significant with a slope of -0.004 mg/L per yr or 0.13 mg/L over the period of record (n=400).

Gunston Cove Station Chlorophyll *a*



- Chlorophyll *a* levels have decreased substantially over the period.
- In the mid to late 1980's chlorophyll *a* often exceeded 200 µg/L with a median of about 100 µg/L.
- Decline started in 1990 and quickened after 2000
- By 2006 values were generally less than 50 µg/L with a median of about 30.
- Linear regression yielded a significant linear decline at a rate of -3.9 µg/L per year or 121 µg/L over the entire study
- And during that time, the dominant taxa shifted from cyanobacteria (*Microcystis*) to diatoms (*Melosira*), a vast improvement for water quality and food webs

Gunston Cove Station Chlorophyll *a*



- Chlorophyll *a* levels have decreased substantially over the period.
- In the mid to late 1980's chlorophyll *a* often exceeded 200 µg/L with a median of about 100 µg/L.
- Decline started in 1990 and quickened after 2000
- By 2006 values were generally less than 50 µg/L with a median of about 30.
- Linear regression yielded a significant linear decline at a rate of -3.9 µg/L per year or 125 µg/L over the entire study
- And during that time, the dominant taxa shifted from cyanobacteria (*Microcystis*) to diatoms (*Melosira*), a vast improvement for water quality and food webs

With Reduced Phytoplankton, Will SAV Return?

- Full restoration of Gunston Cove requires re-establishment of submersed macrophyte beds
- The primary requirement for this is light availability throughout the water column
- Light attenuation is due to algae, inorganic particles, and dissolved substances

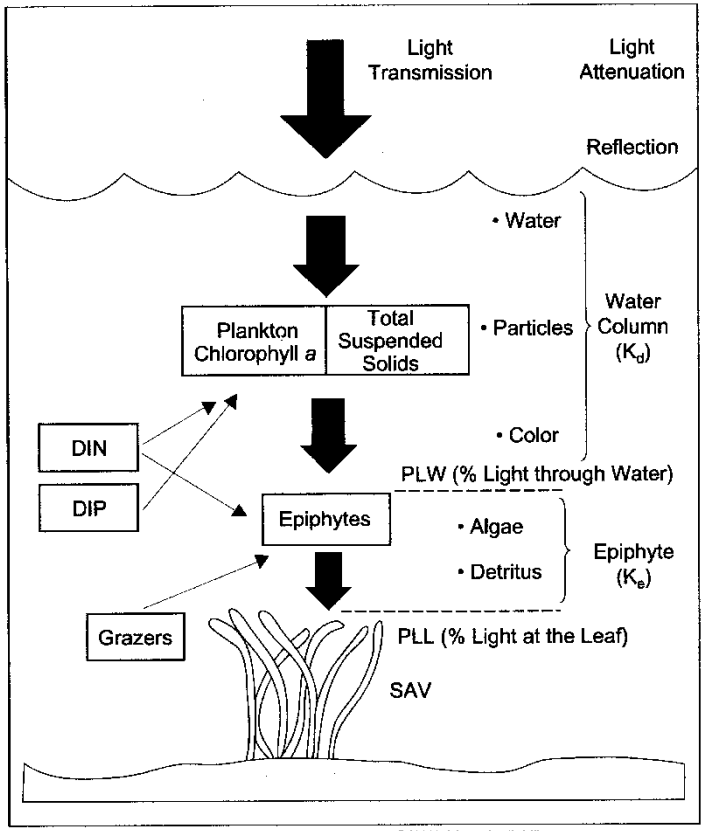
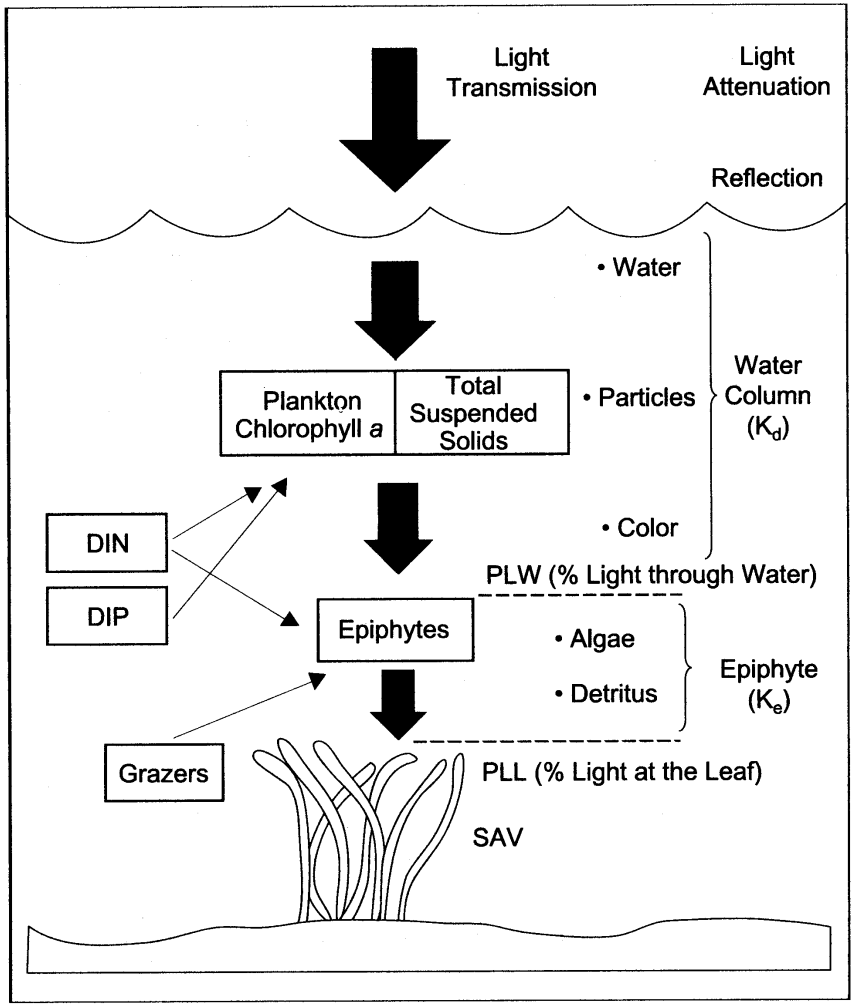


FIGURE 1. Conceptual Model of Light/Nutrient Effects on SAV Habitat. Availability of light for SAV is influenced by water column and at the leaf surface light attenuation processes. DIN = dissolved inorganic nitrogen and DIP = dissolved inorganic nitrogen.

Light Conditions Required for Submersed Macrophyte Growth

- Batiuk et al. established minimum light requirements for SAV growth in Chesapeake Bay
- In tidal fresh region, 9-13% of incident light during SAV growing season was needed
- We'll use 10% in this paper



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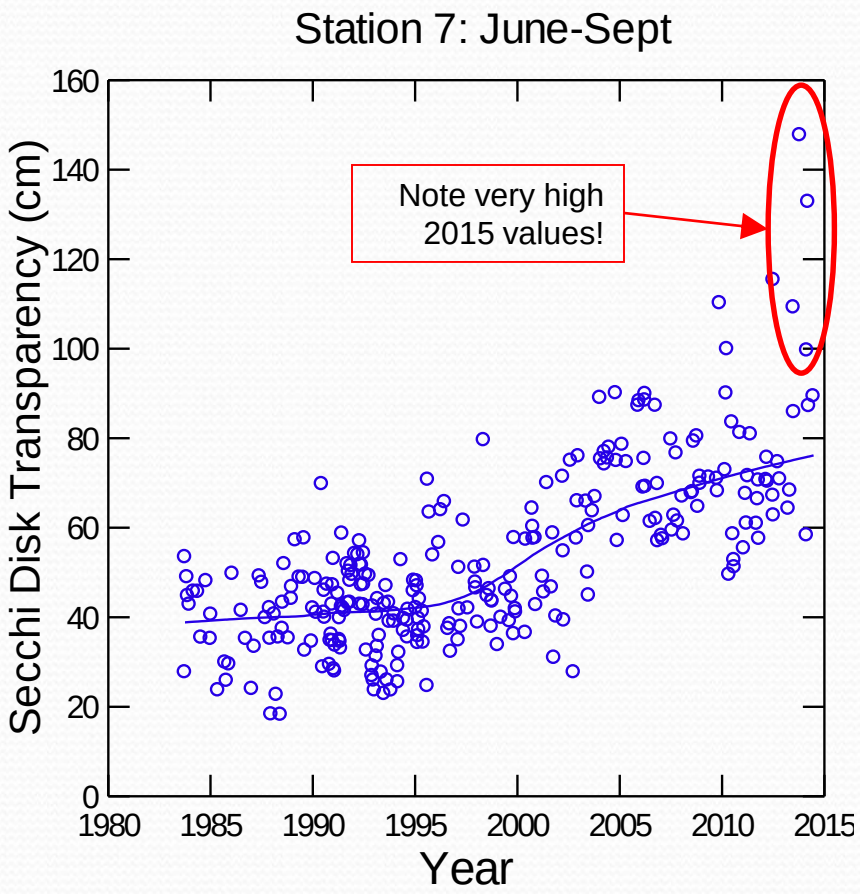
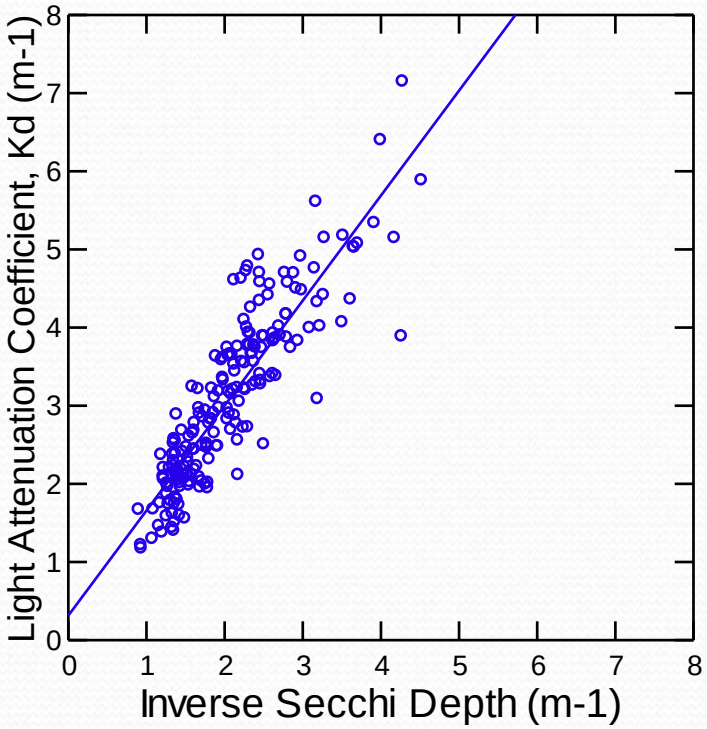
Light Availability: Gunston Cove Station



- Secchi disk was fairly constant from 1984 through 1995 with the trend line at about 40 cm.
- Since 1995 there has been a steady increase in the trend line from 40 cm to nearly 75 cm in 2014.
- Linear regression was highly significant with a predicted increase of 1.7 cm per year or a total of 54 cm over the long term study period
- Note record high water clarity in the cove in 2015
- Goes hand in hand with decreased phytoplankton and increased SAV

Light Conditions Required for Submersed Macrophyte Growth

Gunston Cove Station 7 (June-Sept): 1991-2013

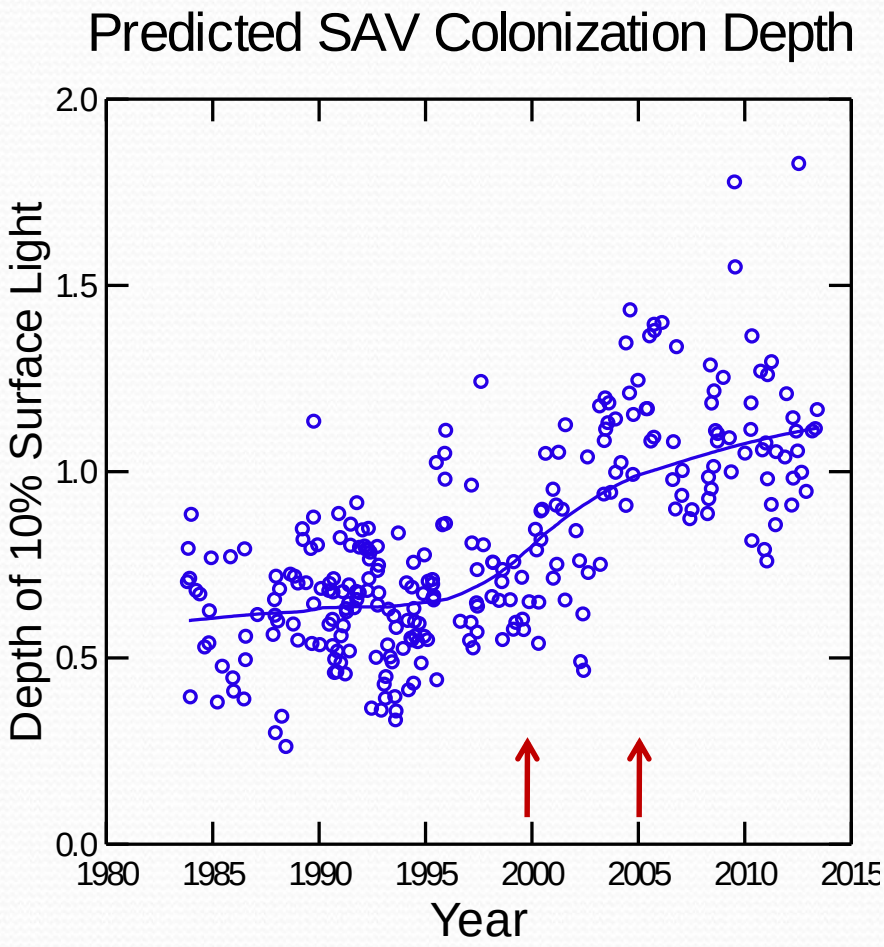


$K_d = 1.48 \times (1/z_{SD})$

$P<0.00001$, $n=198$

- As mentioned above, direct measurements of k_d were available beginning in 1991
- But Secchi depth was available for a longer period
- A relationship was developed to allow k_d to be derived from Secchi depth

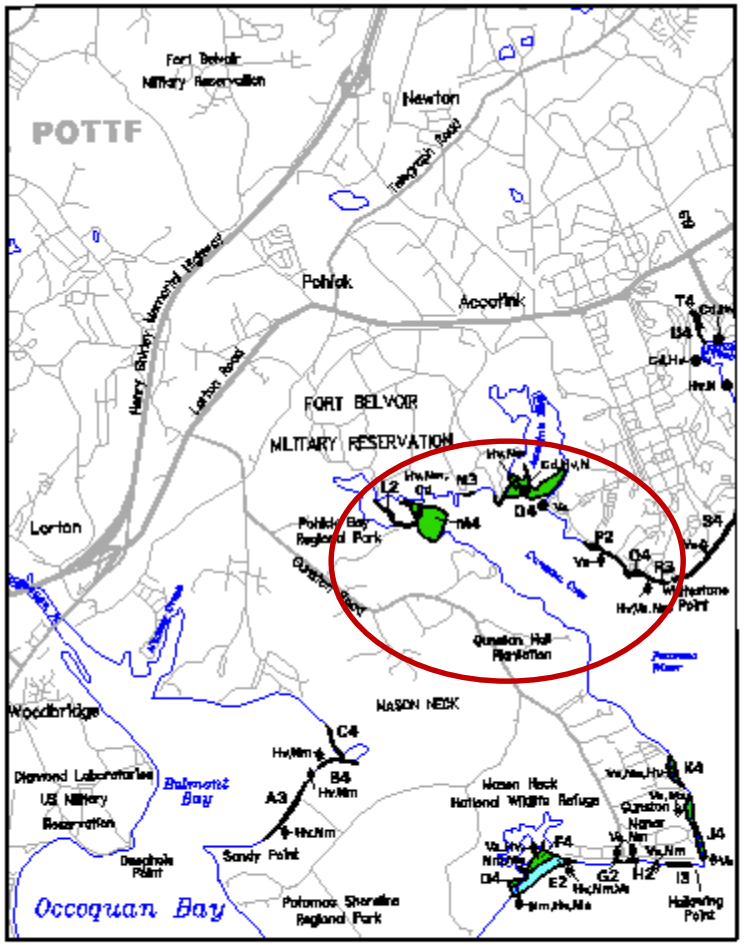
Gunston Cove Light Environment over time



- Using the time series of K_d derived from Secchi, maximum depth of macrophyte colonization was predicted using the 10% surface light criterion
- Predicted maximum macrophyte depth was well below 1 m during the 1980's and 1990's
- But beginning in about 2000 it started to rise consistently and by 2005 was consistently above 1 m.
- Let's look at SAV distributions from these two years: 2000 and 2005

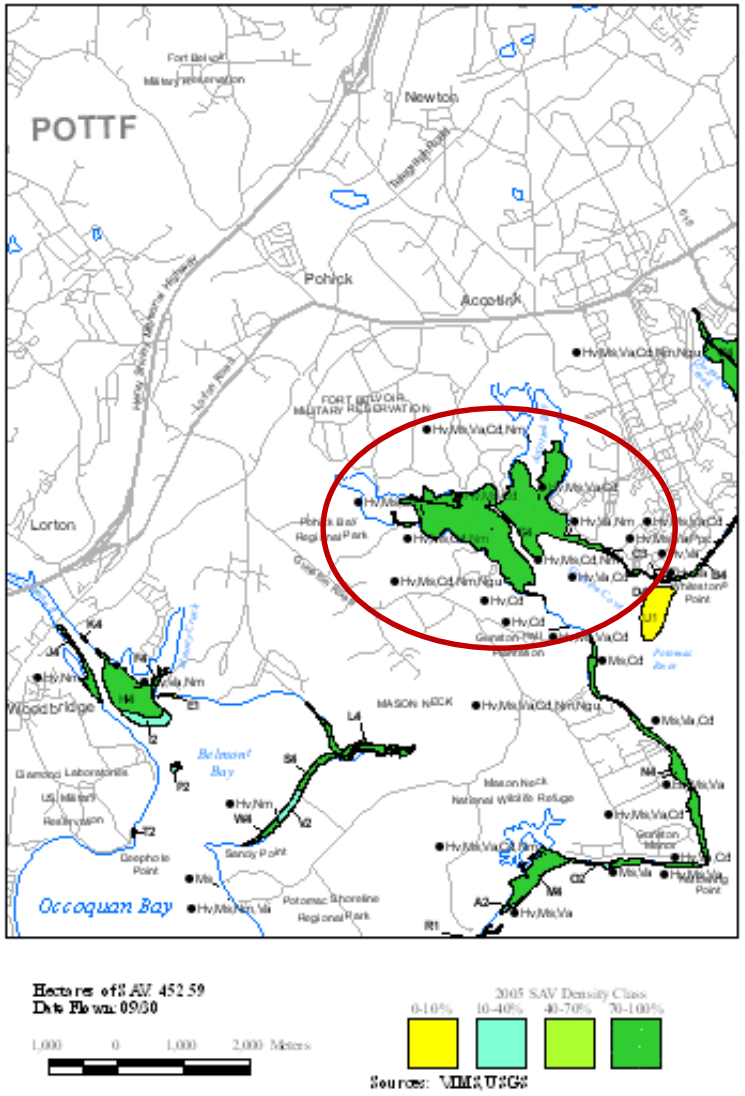
Reemergence of Submersed Macrophytes in Gunston Cove

- 2000 Distribution
  - SAV restricted to very shallow upper reaches of Gunston Cove (Pohick and Accotink Bays)



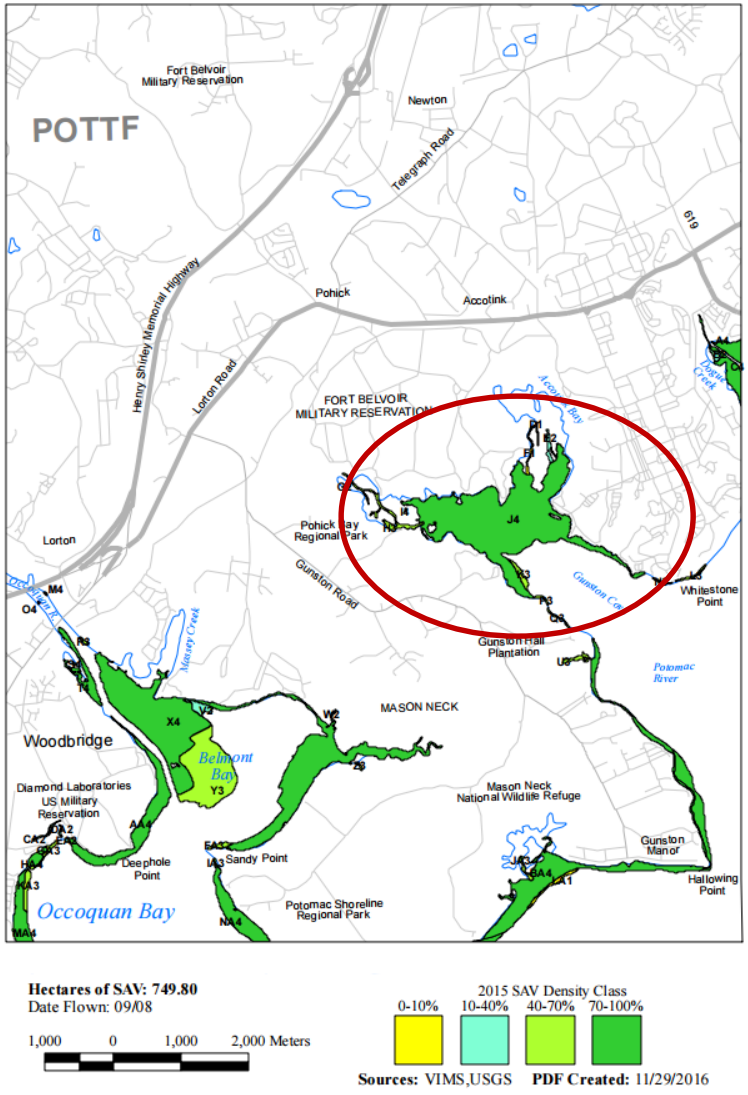
Reemergence of Submersed Macrophytes in Gunston Cove

- 2005 Distribution
  - SAV coverage made a strong push into Gunston Cove proper which has a mean depth of about 2 m
  - This pattern of greater coverage has continued through 2014



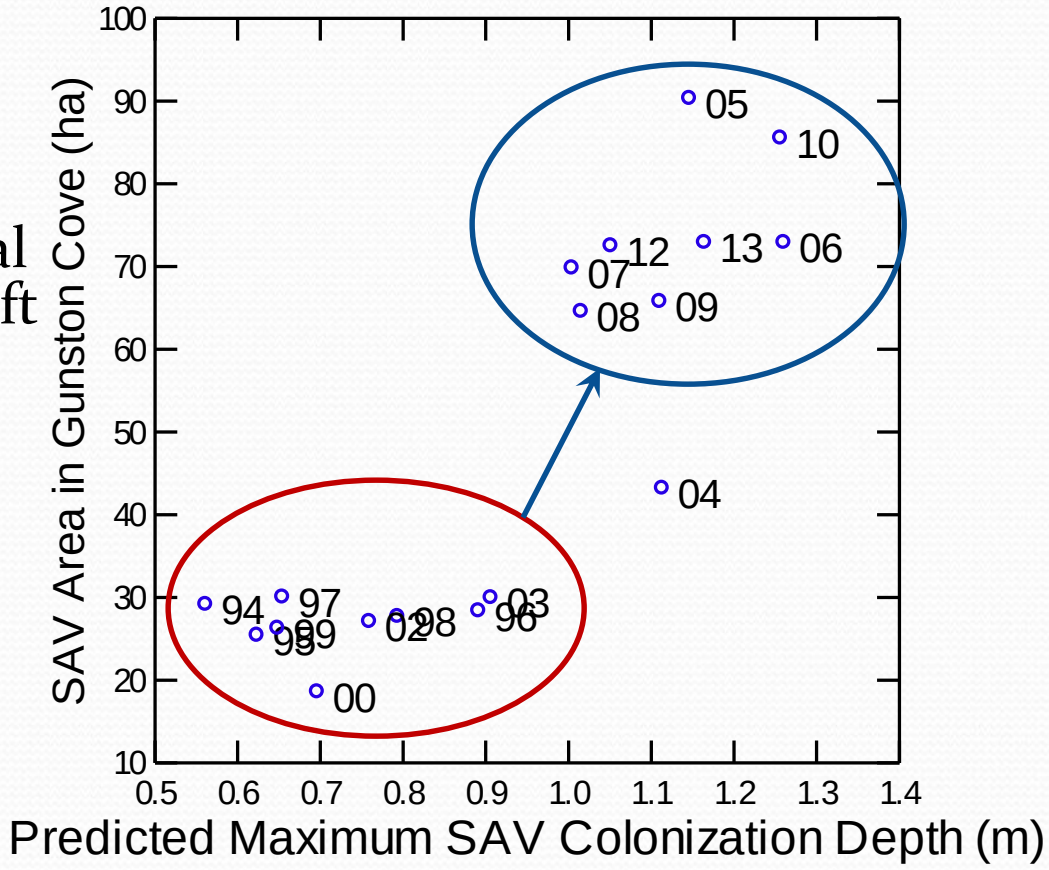
Reemergence of Submersed Macrophytes in Gunston Cove

- 2015 Distribution
  - SAV has maintained the beachhead in the upper part of Gunston Cove
  - Still waiting for it to spread further out
  - Increased water clarity in the past two years suggest that it should



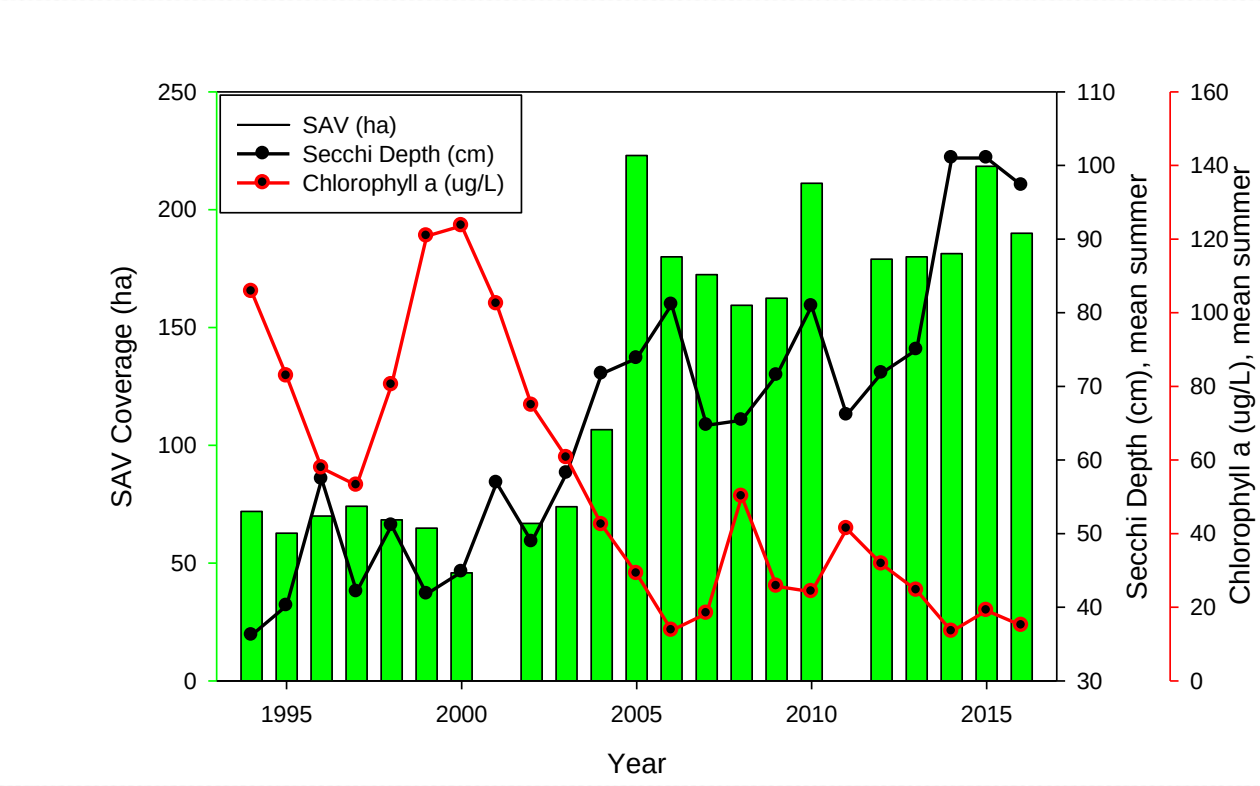
Reemergence of Submersed Macrophytes in Gunston Cove: a New Stable State?

- Predictions of maximum SAV colonization depth vs. SAV area in Gunston Cove
- Both predictions and actual SAV area show a strong shift in the strength of the SAV community between the 1992-2003 period and the 2005-2013 period with an apparent transition year in 2004
- This graph suggests a state change in Gunston Cove which appears relatively stable



Summary of Phytoplankton, Light, and SAV Response

- Improvements in water clarity related to P-limitation and decline of phytoplankton were correlated with an increase in submersed macrophyte coverage in Gunston Cove
- Since 1 m colonization depth was achieved (2004/5), macrophyte coverage has increased strongly
- The recent increase in water clarity (Secchi Depth), if continued could lead to further increases in SAV coverage indicative of continued restoration.



Overall Conclusions

- We have documented the partial restoration of Gunston Cove to its pre-eutrophication conditions including:
  - Decrease in P loading
  - Decrease in TP and phytoplankton chlorophyll
  - Increase in water clarity
  - Reestablishment of submersed macrophyte beds to a substantial portion of the cove
  - Apparent regime shift from phytoplankton dominance to “partial” SAV dominance.

Acknowledgements

- This study has been supported since inception in 1984 by Fairfax County through it's Department of Public Works and Environmental Services and the County's Environmental Quality Advisory Committee
- Individuals at Fairfax County deserving acknowledgement for their support of the study include:
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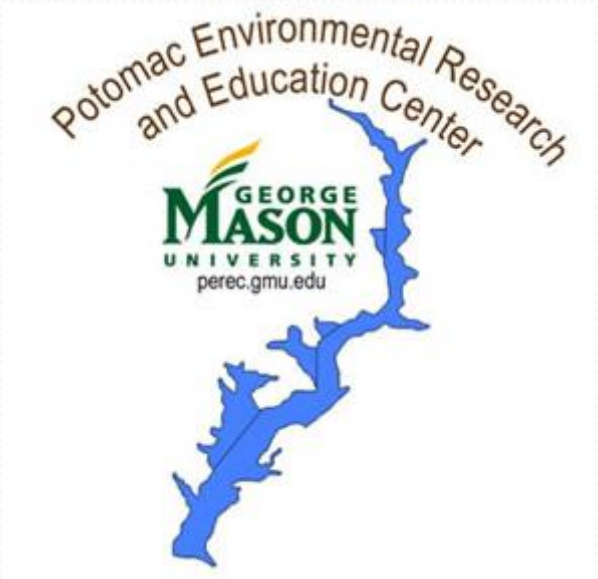
  - Jimmie Jenkins, Former Director of Public Works and Environmental Services
  - Shahram Mohsenin, Director, Wastewater Planning and Monitoring Division



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