Potomac River Response to Biological Nitrogen Reduction at Blue Plains WWTP

How much did ambient nitrate concentrations change in the upper, tidal fresh estuary with Full BNR?

How far downstream were changes observed?

Did changes benefit living resources?

Claire Buchanan
Interstate Commission on the Potomac River Basin
October 2003

Abstract BNR-related reductions in the Blue Plains WWTP nitrogen loads have significantly reduced nitrogen concentrations in the upper and middle Potomac estuary, and appear to be reducing nitrogen concentrations in the lower estuary. Nitrogen concentrations in the lower estuary, however, are still not low enough to control excess algal growth and improve bottom water dissolved oxygen.

Nitrogen loads to the tidal Potomac River have long been recognized as too high. The Chesapeake Bay Program established a Potomac Nitrogen Goal of 50.0 million lbs/year in 1999, and this goal is being further refined as CBP develops nutrient reduction strategies and water quality standards for the Bay and its tributaries.

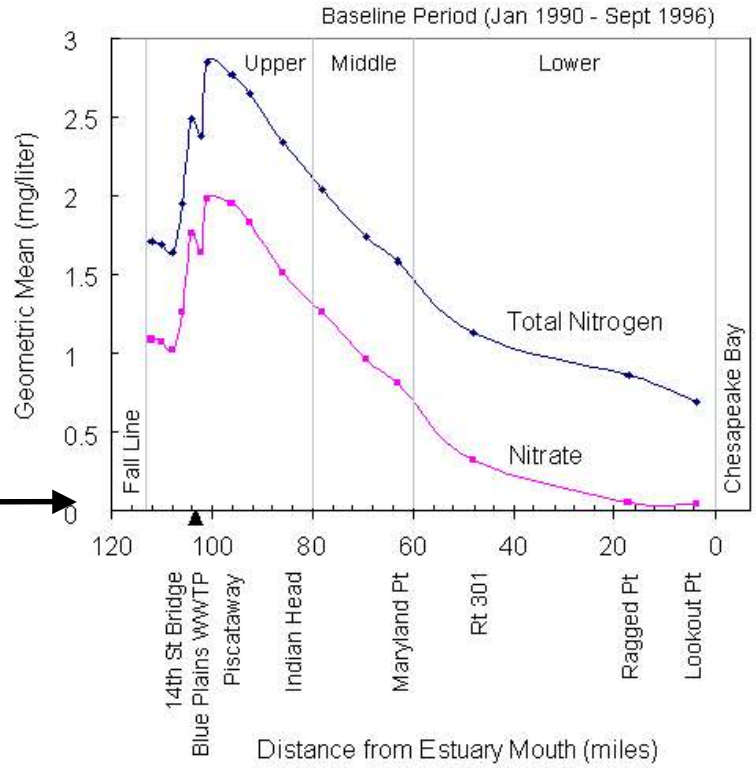
Biological Nitrogen Reduction (BNR) is a relatively new technology that effectively reduces nitrogen in waste water effluents. BNR removes nitrogen from waste water by adjusting the treatment plant's biological processes to convert nitrate in the water to gaseous N_2. Today, 73 of the 305 significant municipal wastewater treatment plants in the Chesapeake Bay watershed, operate using nutrient removal technology. By 2010, that number is likely to increase to 153 facilities, or almost 80 percent of the collective flow. (U. S. Environmental Protection Agency, Chesapeake Bay Program. 2002. State of the Chesapeake Bay Report. EPA 903-R-02-002, CBP/TRS 260/02). Five of the 14 WWTPs servicing the Washington metropolitan area are currently operating BNR. By far the largest is the Blue Plains Waste Water Treatment Plant which processes about 65% of the combined WWTP flows from the 14 Washington metropolitan area plants. Blue Plains implemented partial BNR in Oct 1996 and went to full BNR in Feb 2002. The focus of this presentation is the changes observed in the Potomac River estuary in response to this nutrient management action.

Ambient Nitrate and Total Nitrogen Concentrations in Pre BNR Baseline Period

Waste water treatment plants convert ammonia to nitrate in primary treatment.

Nitrate is a common form of Dissolved Inorganic Nitrogen (DIN). It is the preferred nitrogen source for many phytoplankton.

DIN at 0.07 mg/liter limits excess phytoplankton growth

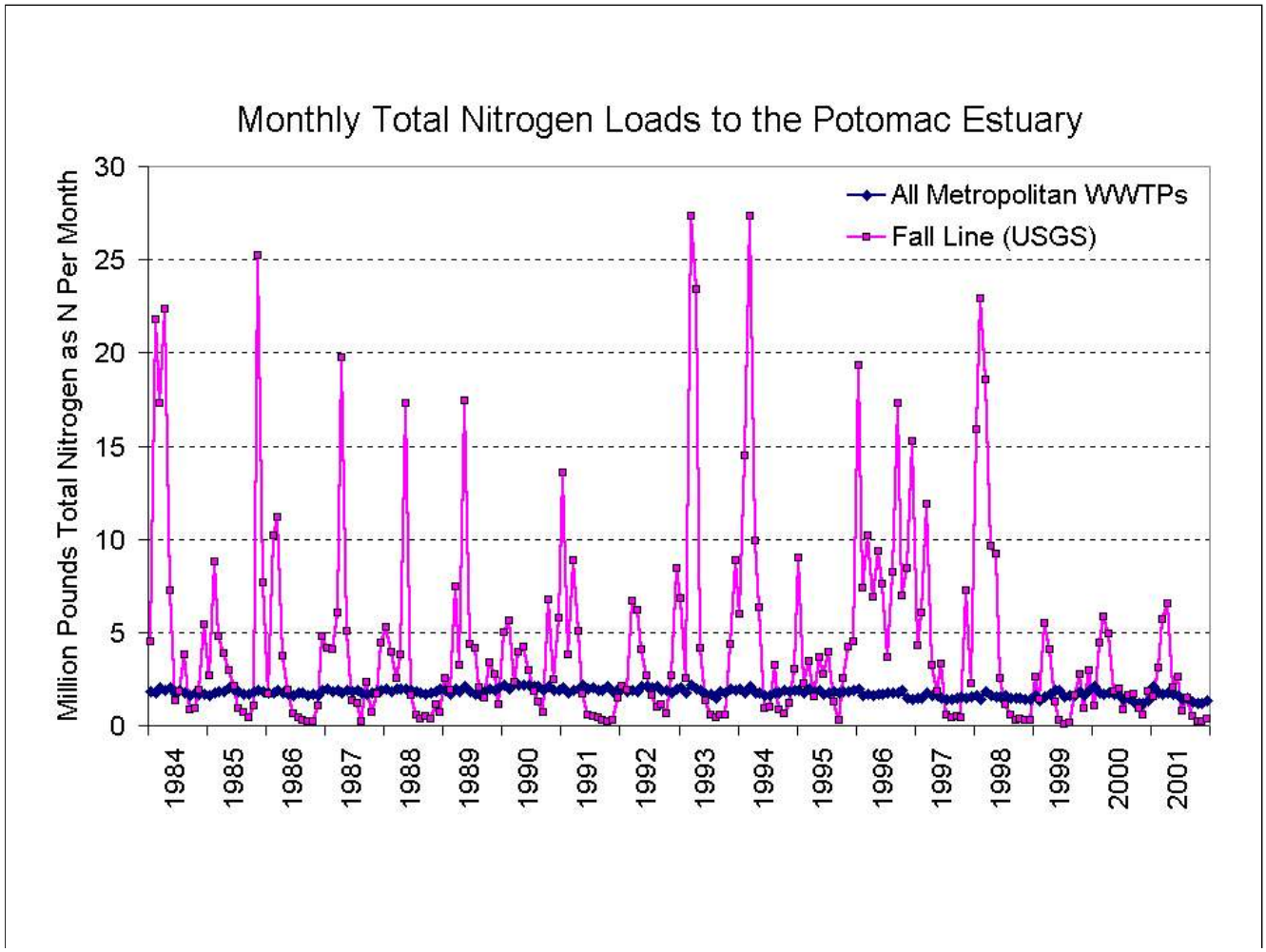


Data from Chesapeake Bay Program Data Center

Nitrogen inputs from the metropolitan Washington area point sources have a significant impact on the Potomac estuary's ambient concentrations. Longitudinal profiles of total nitrogen and nitrate (the form of nitrogen preferred by algae) reflect this impact. Average concentrations at the Fall Line, or head of tide, were ~1.1 mg/liter nitrate and ~1.7 mg/liter total nitrogen during a 1990 - 1996 Baseline Period, before BNR was implemented at Blue Plains. Concentrations fell slightly as the river traveled downstream to the 14th Street Bridge near the center of DC. Concentrations increased sharply, nearly doubling as the river passed the confluence with the Anacostia River and the Blue Plains WWTP. Concentrations peaked between Rosier Bluffs near the Woodrow Wilson Bridge and the mouth of Piscataway Creek, then decreased gradually to the mouth of the Potomac. Dilution by the relatively cleaner Bay waters moving upstream in bottom layer was primarily responsible for the decreasing concentrations in the lower estuary. Dilution by tributary flows entering below the Fall Line (equals ~28% of Fall Line flow) were probably not consequential because nitrogen concentrations were relatively high in the tributaries. Nitrogen is also removed from the water through biological processes, especially in the warmer months.

During the PreBNR baseline period, the upper, tidal fresh Potomac had nitrate concentrations 30-fold higher than levels required for healthy, controlled algae growth. Large loads of excess nitrogen were transported downstream to the more nitrogen-sensitive* lower estuary where they have been related to a severe lack of oxygen in bottom waters (anoxia). The Potomac during the baseline period had some of the highest tidal fresh nitrogen concentrations relative to other tributaries of Chesapeake Bay.

*While nitrogen and phosphorus are both critical (limiting) nutrients for algal growth, algae in higher salinity waters (mesohaline, polyhaline) tend to be more sensitive to nitrogen concentrations, and those in low salinity and fresh waters tend to be more sensitive to phosphorus concentrations.



On average:

• the estimated nitrogen loads delivered directly to the Potomac in 2000 were 61 million pounds per year or 5 million pounds per month (Chesapeake Bay 3D Water Quality Model, 2000)

• approximately one-third (31%) of the load comes from point sources, which are located primarily in the DC area. Input rates are fairly stable.

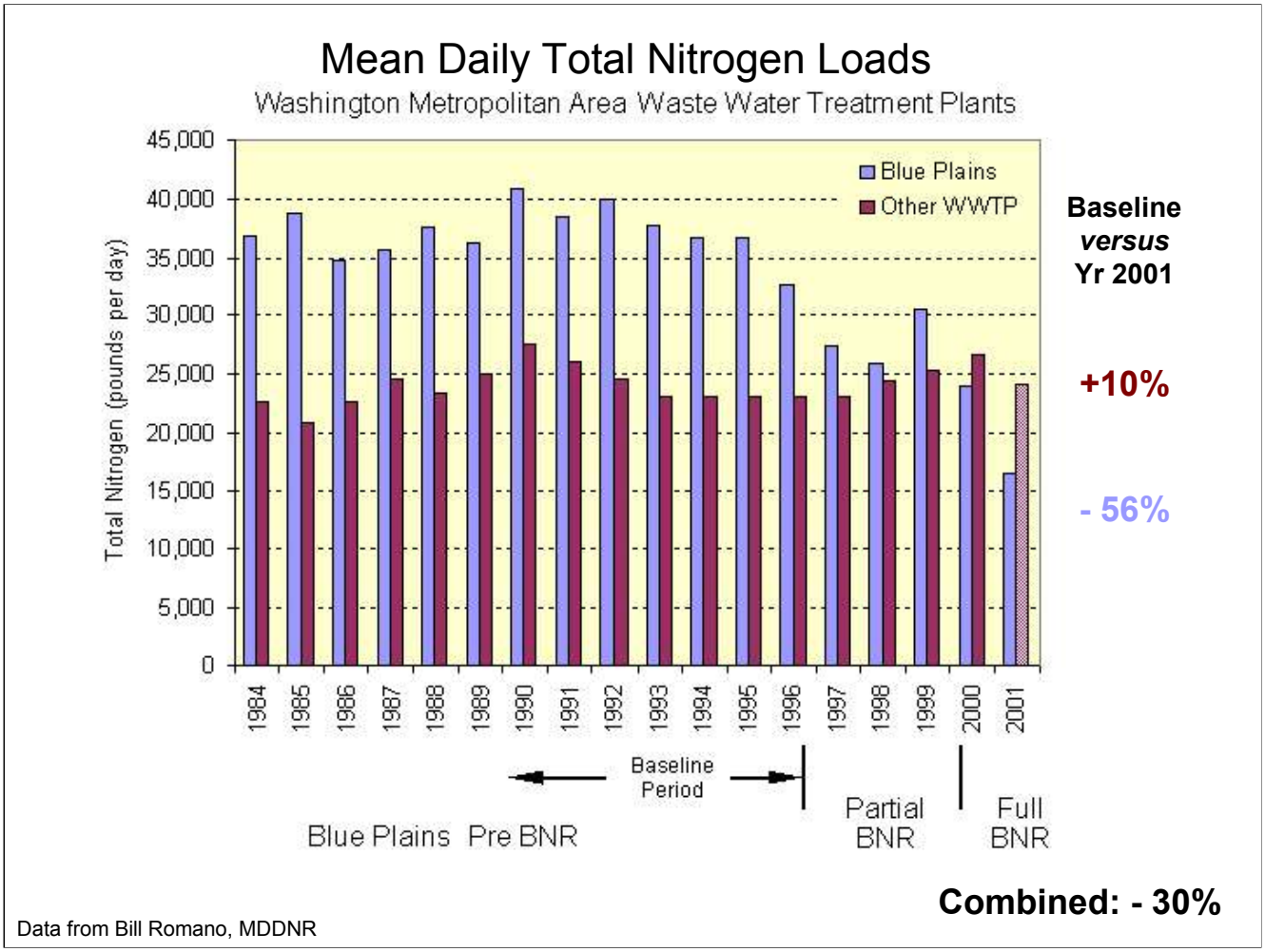
• the remaining two-thirds (69%) comes from the non-point sources above and below the fall-line. Input is highly variable due to changes in precipitation and freshwater flow. (Source: Chesapeake Bay Watershed Model, 2000)

Nitrogen loads are highly variable over time, however.

The impact of the metropolitan waste water treatment plants on the Potomac estuary depends heavily on the amount freshwater flow at the fall line. When freshwater flows are high, fall line nitrogen loads are also high and tend to overshadow the WWTP loads. When freshwater flows are low, the WWTP assume more of an impact on the estuary.

This graph illustrates the relative stability of the wastewater treatment plant nitrogen loads and the high degree of variability inherent in the Potomac fall line loads. During the normally high-flow Winter and Spring seasons, waste water treatment plant total nitrogen loads are lower than fall line loads. During the normally low-flow Summer and Autumn seasons, waste water treatment plant total nitrogen loads are frequently higher than fall line loads.

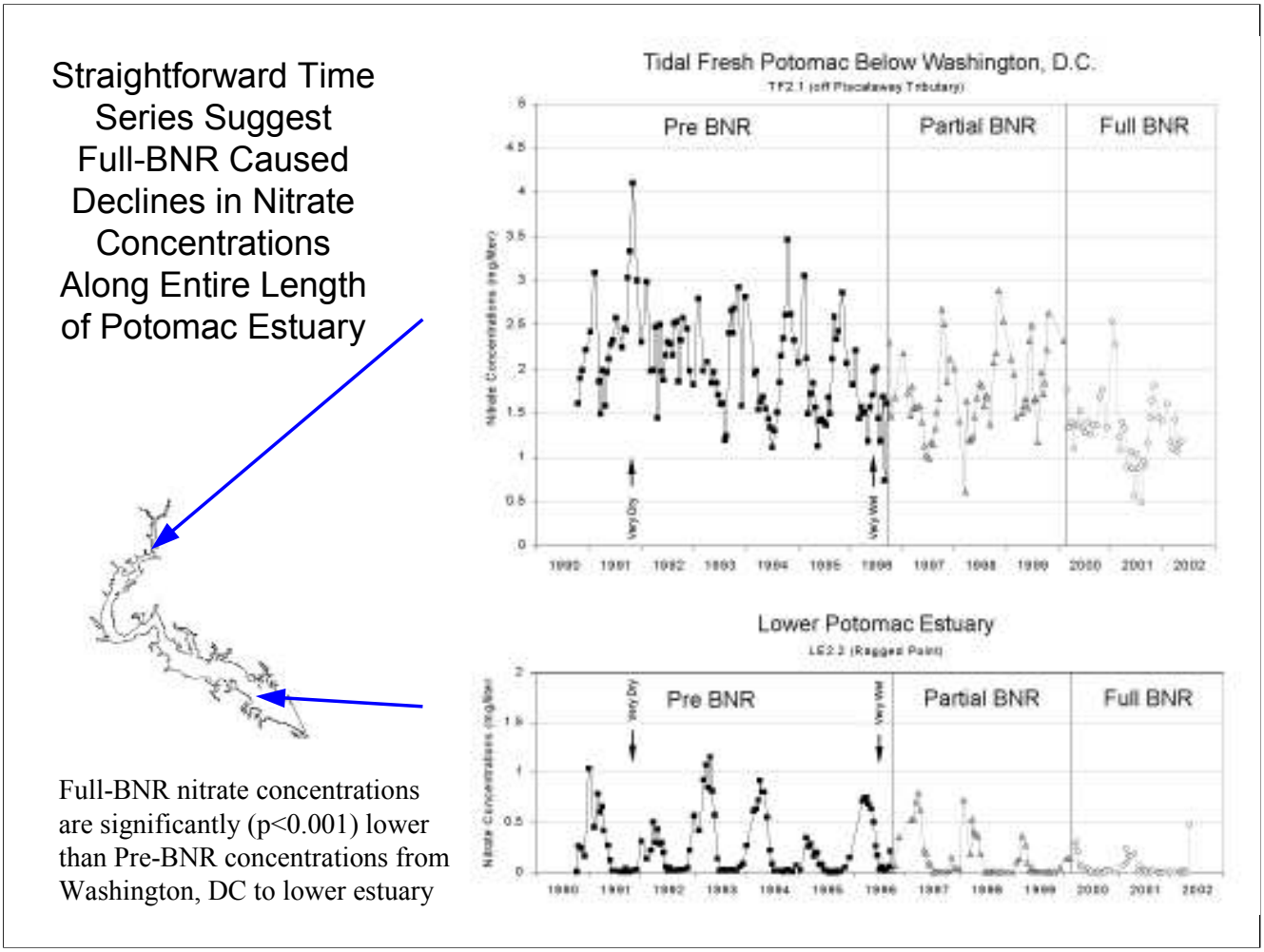
Fall line loadings data obtained from the USGS web site http://va.water.usgs.gov/chesbay/RIMP/loads.html.



Blue Plains, the largest Waste Water Treatment Plant (WWTP) servicing the Washington, D.C., metropolitan area, implemented partial Biological Nitrogen Reduction (BNR) in October of 1996 to reduce nitrogen concentrations in its effluent and nitrogen loads to the upper Potomac River estuary. The plant went to full-time BNR treatment of effluent in February 2000. The total nitrogen (TN) load in the first complete year of full-time BNR (2001) was 56% lower than the average annual loads during a 1990 – 1996 baseline period. Other metropolitan area WWTPs increased their annual TN loads approximately 10% between the baseline period and 2001, despite implementation of BNR at 4 plants. **Overall, there was a combined 30% reduction in annual TN loads delivered from WWTPs to the upper Potomac estuary.**

Data obtained from Bill Romano, Maryland Department of Natural Resources

For additional information, go to
http://maps.chesapeakebay.net/wsp/wsptable.asp?Level=2&Basno=4&Element=34
located on the Chesapeake Bay Program web site.



Changes in ambient nitrate concentrations (p<0.01) were observed along the entire length of the Potomac River estuary after the Blue Plains BNR implementation, from just downstream of the Blue Plains WWTP (TF2.1) to near the Potomac mouth (LE2.2). Differences between ambient nitrate concentrations in the Pre BNR baseline period of January 1990 - September 1996 and the Full BNR period of March 2000 - March 2002 were significant (p<0.01).

"Below Detection Limit" values: The trends in the lower Potomac estuary can be artificially affected by "below-detection-limit" nitrate values. Methods used to measure nitrate-nitrite concentrations have lower limits of reliability, or "detection limits" which were approximately 0.002 – 0.0002 mg/liter in the Potomac monitoring data after 1990 (information from Ricky Bahner, CBP Data Center).. Ambient nitrate concentrations in mesohaline and polyhaline waters of the Bay – including the lower Potomac (see graph of station LE2.2 above) – can and often do go below these limits. Below-detection-limit (BDL) concentrations hinder analysis of the data. While several analysis approaches can be taken to minimize BDL data effects, including arbitrarily setting BDL values at 1/2 of the detection limit concentration, or zero, these approaches have obvious artificial impacts on assessing change at low nitrate concentrations

Laboratory Change Effects: Analyses of samples between Piscataway (TF2.1) and Ragged Point (LE2.2) in the Potomac were done by Maryland Department of Health and Mental Hygiene (MDHMH) prior to May 1998 and by the Chesapeake Biological Laboratory (CBL) afterwards. Split sample comparisons indicate a step changes occurred in the data as a result of the change in laboratory. Specifically, CBL nitrate-nitrate measurements were ~6% lower than MDHMH measurements at high nitrate-nitrite concentrations, i.e. ~1.6 mg/liter; and measurements were ~8% lower at low concentrations, i.e., <0.5 mg/liter (information from William Romano, MDDNR). While this laboratory change effect is probably responsible for some of the changes observed in the Pre- and Full BNR comparisons, most of the change is a consequence of BNR implementation and it is still significant (p<0.01). Stations above TF2.1 and below LE2.2 are not affected.

Flow, Season, Location Affect Ambient Nitrate Concentrations

Data were partitioned into 4 seasons and 5 flow regimes for more accurate Pre- and Full-BNR comparisons

Seasons:
- Winter (Jan – Feb)
- Spring (Mar – May)
- Summer (June – Sept)
- Autumn (Oct – Dec)

Seasonal Flow Regimes*
- Record Dry/Very Dry (<10%)
- Dry (10% - 33%)
- Moderate (33% - 67%)
- Wet (67% - 90%)
- Record Wet/Very Wet (>90%)

16 of the 20 possible season-flow regimes found in Pre BNR Period

6 of 8 season-flow regimes in Full BNR Period match regimes in Pre BNR Period (monitoring data currently available for 5 regimes)

*Olson, 2002, based on USGS 1975-1994 adjusted Potomac record at Little Falls

More accurate assessments of BNR effects can be made if ambient nitrate concentrations from similar conditions in the Pre- and Full-BNR periods are compared. Season- and flow-specific Longitudinal Baselines, reaching from above the Fall Line to the Bay mainstem off the mouth of the Potomac, were derived by grouping the Pre BNR period data by 4 seasons and 5 flow regimes. Sixteen of the twenty possible longitudinal baselines were found in the Pre BNR period. Seven of these matched conditions found in the Full BNR period.

Note: The seasonal flow regimes (Olson 2002) are based on 1975 – 1994 flows for the given *season.* So, for example, a wet summer has approximately the same absolute flow in cubic feet per second (cfs) as a moderate winter or a dry spring.

Matching conditions for Pre- and Full-BNR Periods:

PreBNR	FullBNR
Spring 1990, 1995 (Very/Record Dry)	Spring 2002 (Very Dry)
Summer 1990, 1992, 1994, 1995 (Moderate)	Summer 2000, 2001 (Moderate)
Summer 1991 (Very Dry)	Summer 2002 (Record Dry)
Autumn 1994 (Dry)	Autumn 2000 (Dry)
Autumn 1991 (Very Dry)	Autumn 2001 (Record Dry)
Winter 1992 (Dry)	Winter 2001 (Dry)

Sources of Ambient Water Quality Data

Potomac River and Chesapeake Bay: District of Columbia monitoring program, Maryland Chesapeake Bay Program monitoring program

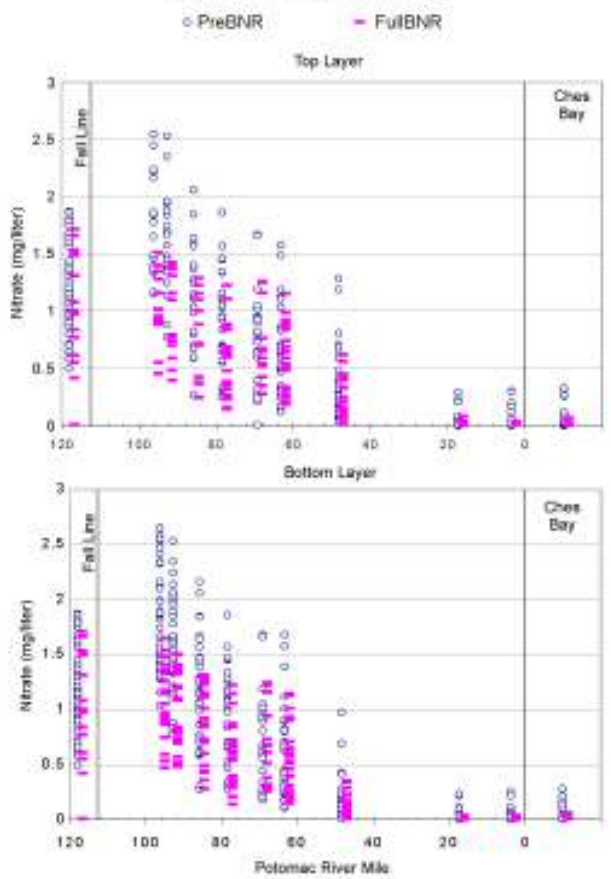
Fall Line: USGS and Washington metropolitan water suppliers (WSSC, Fairfax Co., DC); data courtesy of Norbert Jaworski, retired EPA

Moderate Summer Conditions

Pre BNR (1990, 1992, 1994, 1995)

Full BNR (2000, 2001)

- No significant differences above the Fall Line
- Significant ($p<0.05$) declines of 38%-43% in upper/middle estuary
- Too many BDLs hinder tests for significant differences in lower estuary data
- No significant differences between top and bottom layers until near the mouth

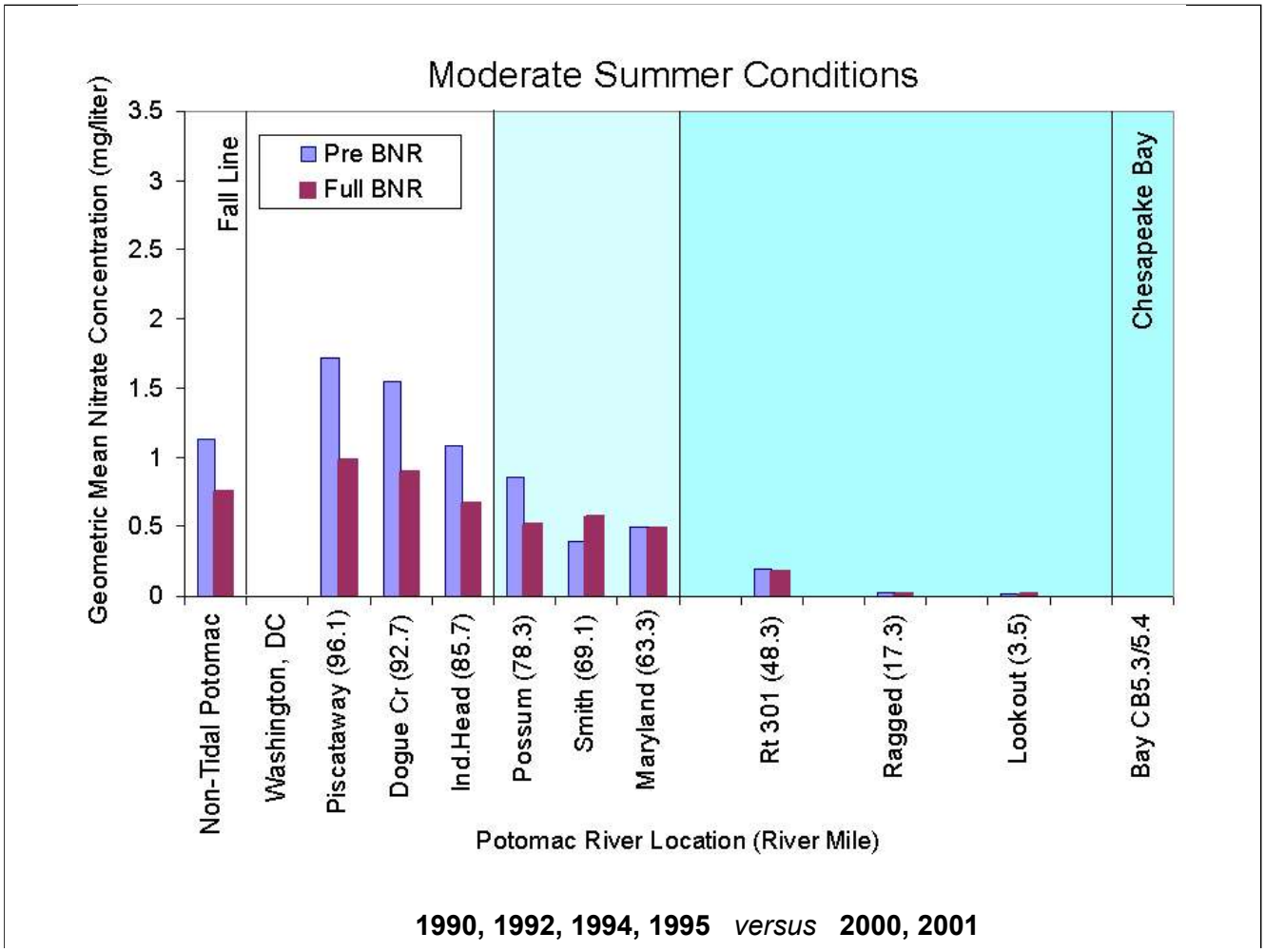


Above Fall-Line data from USGS and Metropolitan Washington water suppliers; assembled by Norbert Jaworski, retired EPA

Scatter plots of nitrate concentration versus Potomac River mile show the natural variability in the data. "Top Layer" indicates data collected from the upper water column, or above the pycnocline in the estuary; "Bottom Layer" indicates data collected from the lower water column or below the pycnocline.

Moderate Summer Conditions: No significant declines were observed in nitrate concentrations above the Fall Line in Moderate Summer conditions. (Note: The above Fall Line data are the same in the Top Layer and Bottom Layer graphs – most samples were collected from the water supply intakes.) In contrast, significant ($p<0.05$) declines of 38%-43% in the mean (geometric) nitrate concentration were found in the upper and middle estuary in these conditions.* No significant differences were found between the Top and Bottom layers until near the mouth of the Potomac, indicating the water column is well mixed. The presence of BDLs hindered test of significant difference in the lower estuary.

*These percentages *may be* 6% - 8% lower due to a "Laboratory Change Effect" (see note on on slide 5). The changes are still significant.



The Moderate Summer Conditions results are re-graphed here to show decreases in the mean nitrate concentrations. Only nitrate concentrations in the water column's top layer are shown in the graph. Bottom concentrations are approximately the same except near the mouth. The unshaded portion of the graph indicates areas that are freshwater; the light blue area indicates reaches that are typically oligohaline (the estuary's transition zone); and the blue area indicates the Potomac estuary that is mesohaline and subject to significant, bottom layer influxes from the Bay mainstem. Mean seasonal flows were for the two periods were very close: 5,551 cfs, Pre BNR period; 5,058 cfs, Full BNR period.

Comparison of the Pre- and Full-BNR periods during Moderate Summer conditions indicates that:

-Full BNR period concentrations were significantly lower than Pre BNR period concentrations in upper and part of middle estuary , but not significantly different at the fall line.

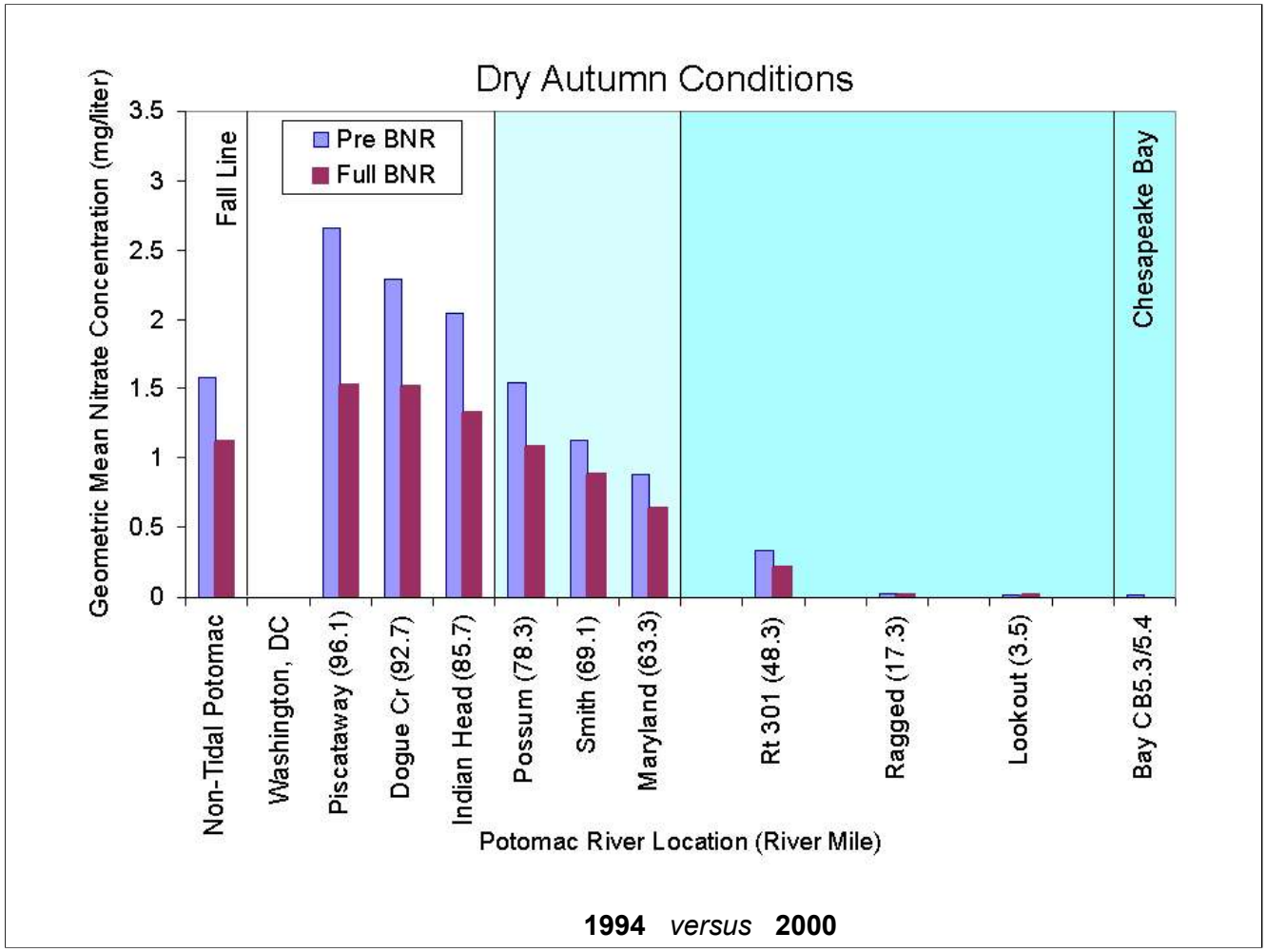
-absolute decreases in nitrate concentrations ranged from 0.75 mg/liter below Blue Plains to 0.35 mg/liter at Possum Pt, and represented an average 41% relative decrease at these stations*

-changes in nitrate concentrations above Fall Line do not explain those observed in the upper estuary

-the mean (geometric) nitrate concentration at Piscataway (1.01 mg/liter) is still higher than the mean above the Fall Line (0.75 mg/liter) in the Full BNR period, indicating continued impacts from metropolitan area nitrogen loads

-BNR-related decreases in ambient nitrate concentration may have occurred in the lower estuary but the analysis is hindered by BDLs

*This percentage *may be* 6% - 8% lower due to a "Laboratory Change Effect" (see note on on slide 5). The changes are still significant.



Dry Autumn Conditions: Only nitrate concentrations in the water column's top layer are shown in the graph. Bottom concentrations are approximately the same as top layer concentrations except near the mouth. Mean seasonal flows roughly comparable: 4,778 cfs in the Pre BNR period and 3,859 cfs in the Full BNR period. (See "Summer Moderate Conditions" for explanation of graph details.)

Comparison of the Pre- and Full-BNR periods during Dry Autumn conditions indicates that:

- Full BNR period concentrations were significantly lower than Pre BNR period concentrations in both the upper and middle estuary, and at the Rt 301 Bridge (head of the lower estuary)

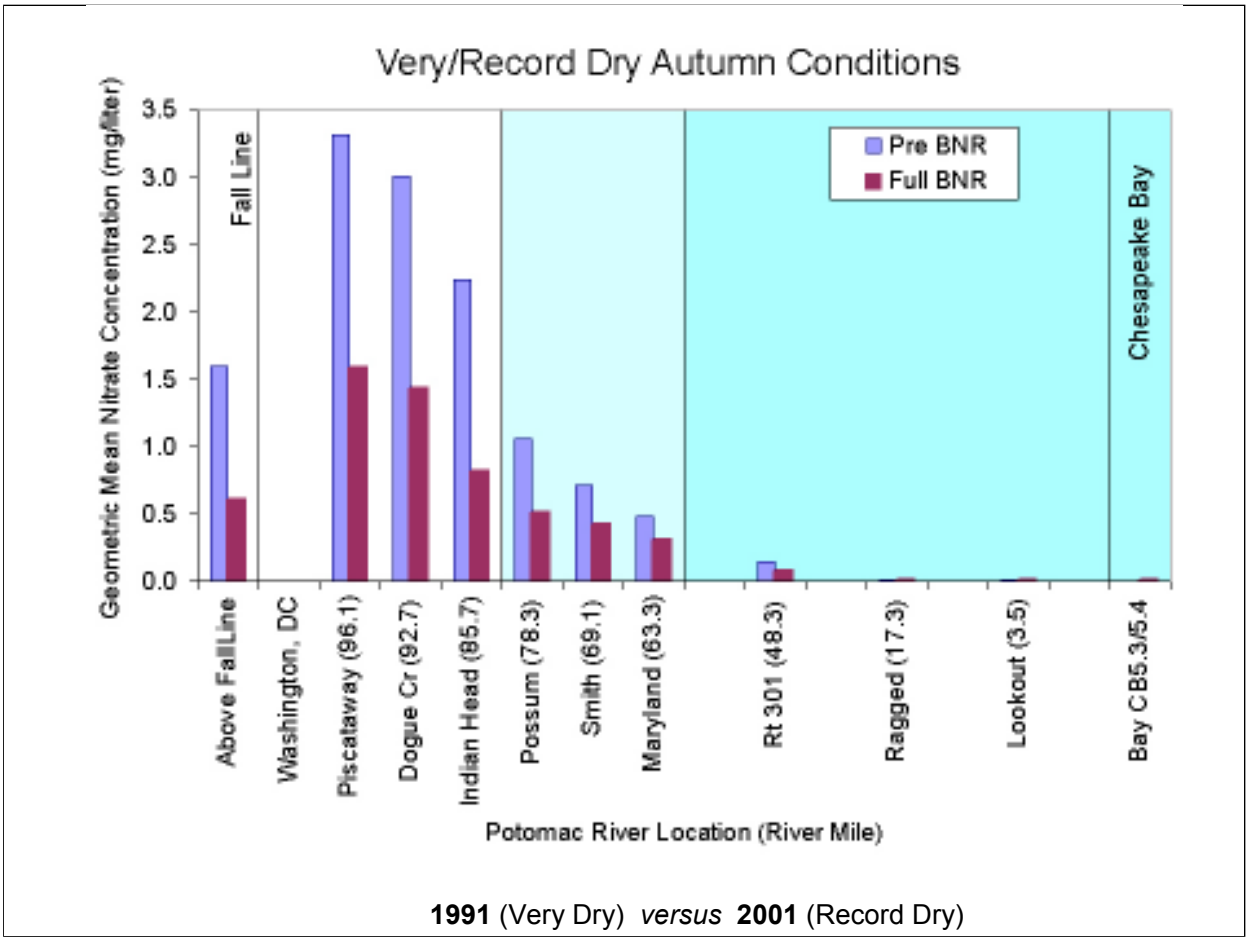
- absolute decreases in nitrate concentrations ranged from 1.12 mg/liter below Blue Plains to 0.12 mg/liter at the Rt 301 Bridge, and represented an average 36% decrease (range 21% - 44%) at these stations*

- analysis of lower estuary changes is hindered by BDLs

- changes in nitrate concentrations above Fall Line were not significant, and not large enough to explain those observed in the upper estuary

- the mean (geometric) nitrate concentration at Piscataway (1.54 mg/liter) is still higher than the mean above the Fall Line (1.12 mg/liter) in the Full BNR period, indicating continued impacts from metropolitan area nitrogen loads

*These percentages *may be* 6% - 8% lower due to a "Laboratory Change Effect" (see note on on slide 5). The changes are still significant.



Very/Record Dry Autumn Conditions: Only nitrate concentrations in the water column's top layer are shown in the graph. Bottom concentrations are approximately the same as top layer concentrations except near the mouth. Mean seasonal flows were roughly equivalent: 2,418 cfs, Pre BNR; 1,310 cfs, Full BNR. The 62% decrease in nitrate at the Fall Line could potentially be an artifact of comparing Very Dry to Record Dry conditions. (See "Summer Moderate Conditions" for explanation of graph details.)

Comparison of the Pre- and Full-BNR periods during Very/Record Dry Autumn conditions indicates that:

- Full BNR period concentrations were significantly lower than Pre BNR period concentrations in both the upper and middle estuary and at the Rt 301 Bridge (head of the lower estuary)

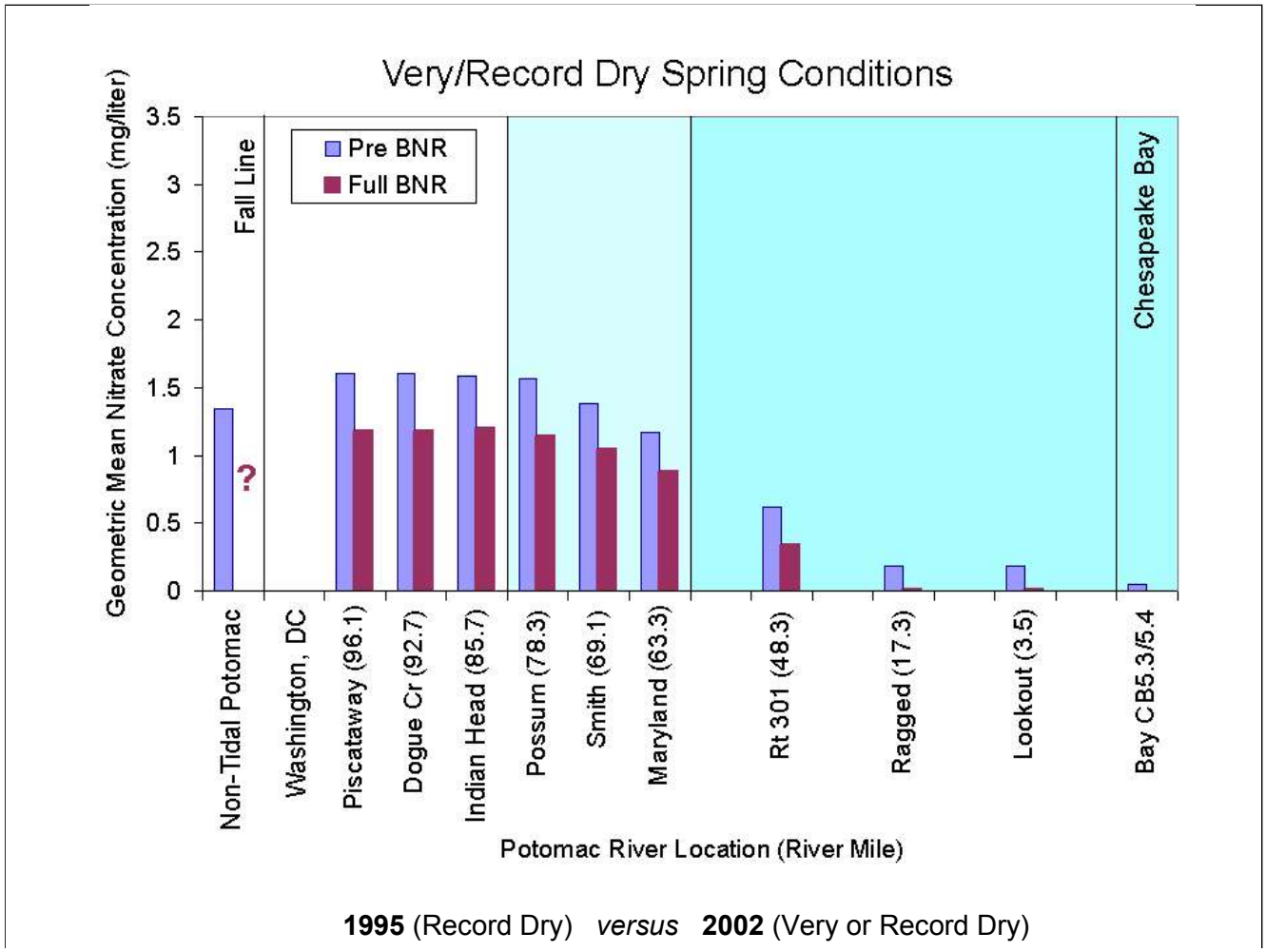
- absolute decreases in nitrate concentrations ranged from 1.75 mg/liter below Blue Plains to 0.06 mg/liter at the Rt 301 Bridge, and represented an average 52% relative decrease at these stations (range 35% - 63%)*

-analysis of lower estuary changes hindered by BDL

-changes in nitrate concentrations above Fall Line were significant and large (62%) but not large enough to explain the absolute declines observed in the upper estuary (i.e., 0.99 mg/liter decline above Fall Line *versus* 1.75 mg/liter decline in upper tidal River). Therefore, declines in above Fall Line concentrations (due to BMPs? Recent BNR at upstream WWTPs?) may be partially responsible *but not completely responsible* for declines in upper tidal River.

- the mean (geometric) nitrate concentration at Piscataway (1.58 mg/liter) is still higher than the mean above the Fall Line (0.61 mg/liter) in the Full BNR period, indicating continued impacts from metropolitan area nitrogen loads

- compare this graph to the previous graph (Dry Autumn). Note how during extremely dry conditions, the influence of the WWTPs nitrate loads is much greater in the upper and middle estuary, and hence any decline in their loads has a greater effect on the river.



Very/Record Dry Spring Conditions: Only nitrate concentrations in the water column's top layer are shown in the graph. Bottom concentrations are approximately the same as top layer concentrations except near the mouth. Mean seasonal flows were roughly equivalent: 9,346 cfs, Pre BNR; 11,046 cfs, Full BNR. (See "Summer Moderate Conditions" for explanation of graph details.)

Comparison of the Pre- and Full-BNR periods during Very/Record Dry Spring conditions indicates that:

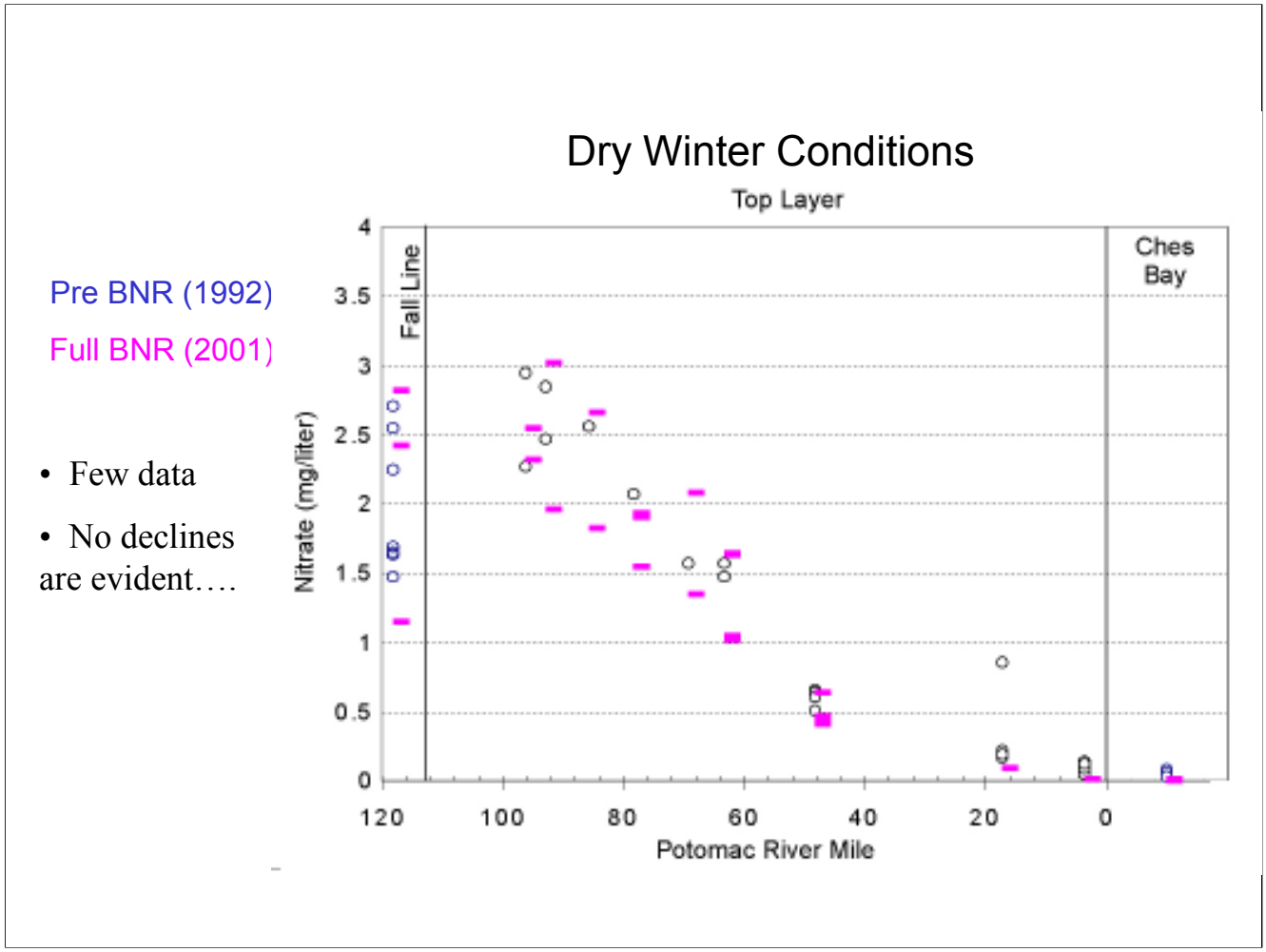
- Full BNR concentrations were significantly lower than Pre BNR concentrations along the entire length of the Potomac estuary.

- Nitrate decreased ~0.43 mg/liter in the upper estuary, ~0.34 in the middle estuary, ~0.22 mg/liter in the lower estuary, and 0.18 (top) and 0.13 (bottom) mg/liter at the mouth of the Potomac. The changes represented an average 27% decrease in the upper estuary, 25% decrease in the middle estuary, 58% decrease at the Rt 301 Bridge, and a 94%-96% decrease at Ragged Pt and Pt Lookout in both top and bottom layers. Above Fall Line nitrate concentrations are not available yet for the Full BNR period, so do not know if decreases occurred and if they were large enough to explain decreases observed in the upper estuary

-Nitrate declines in lower Potomac were larger than those observed in the Bay mainstem, indicating that the nitrate changes in the lower Potomac estuary are due at least partially due to Blue Plains BNR

- One can see in this graph the greater influence of Spring fall-line nitrate concentrations on the estuary relative to other seasons. Spring flows are usually highest compared to the other seasons, and fall line waters in Spring travel faster down the river and reach farther downstream before they are diluted by Bay water

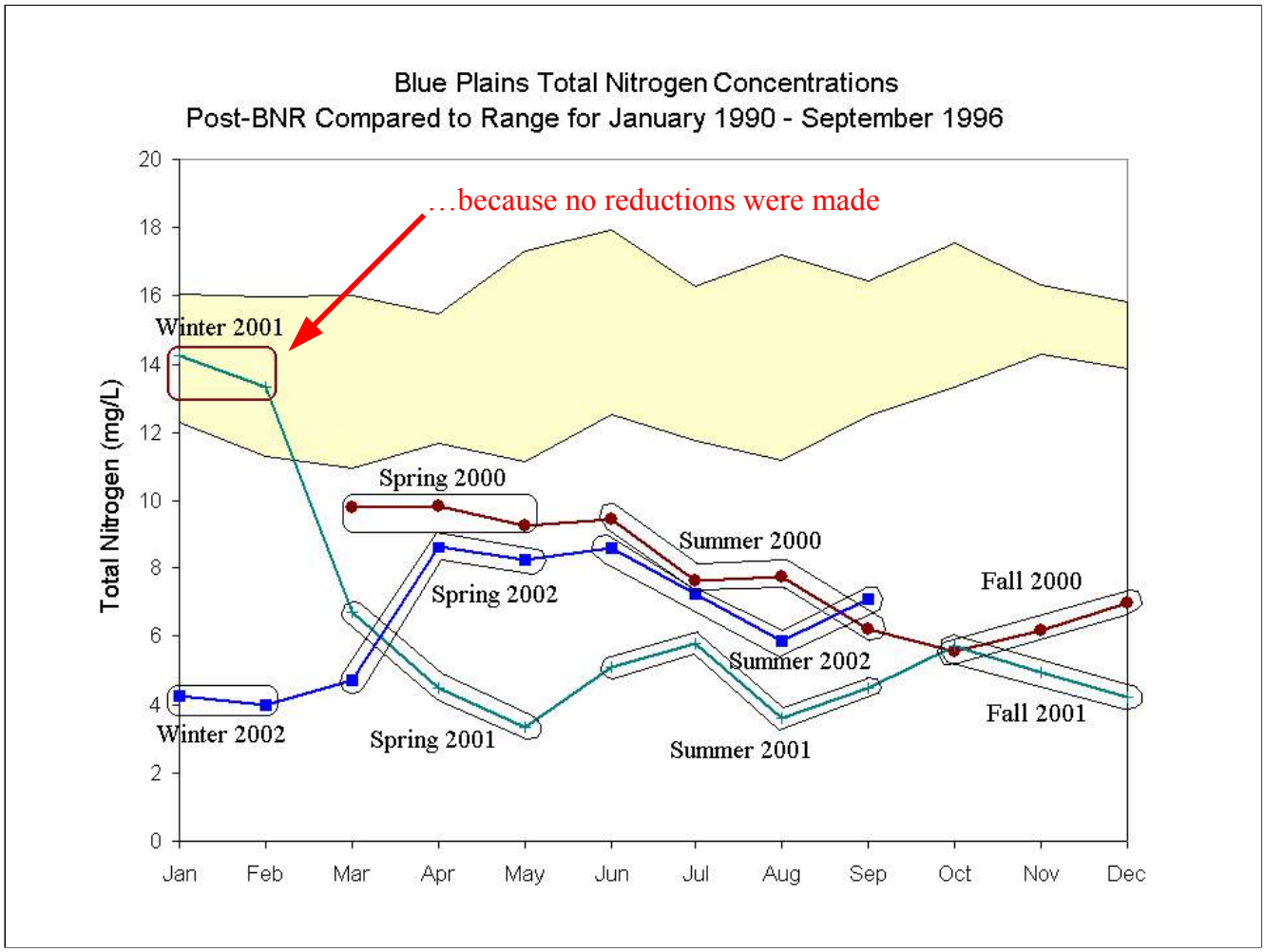
*These percentages *may be* 6% - 8% lower due to a "Laboratory Change Effect" (see note on on slide 5). The changes are still significant.



Dry Winter Conditions: Mean seasonal flows were roughly equivalent: 7,962 cfs, Pre BNR; 6,623 cfs, Full BNR.

The mean (geometric) nitrate concentration at Piscataway (2.42 mg/liter) was higher than the mean above the Fall Line (1.98 mg/liter) during the Full BNR period, indicating continued impacts from metropolitan area nitrogen loads

There appears to be no change in nitrate concentration in response to Full BNR. However….(next slide)



BNR was apparently **not** implemented in Winter 2001. Nitrate levels in the Blue Plains effluent during the Winter of 2001 were identical to those during the Pre-BNR period.

Lower Estuary Response to Blue Plains Full BNR

Nitrogen levels entering the lower Potomac estuary (~ Rt. 301 Bridge) are still too high for a significant phytoplankton response

Used "Frequency of Threshold Exceedance" to investigate BNR-related changes in lower estuary

- Analysis of nitrate data near the mouth of the Potomac is hindered by "below detection limit" values
- The Frequency of Threshold Exceedance is a more ecologically meaningful metric than average nitrate concentration

Nitrogen levels entering the lower Potomac estuary (Rt 301 Bridge) are still too high for a significant phytoplankton response.

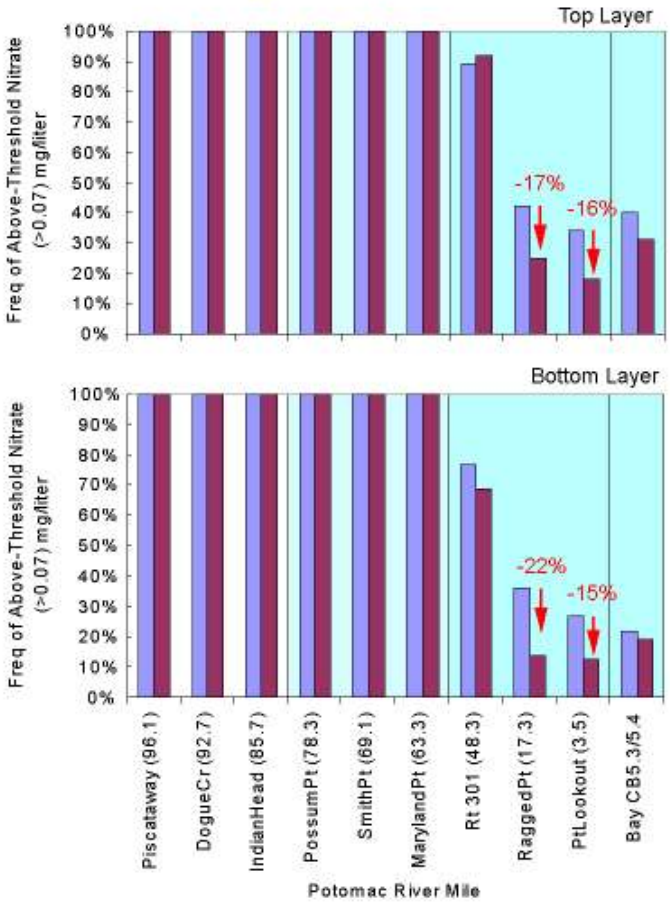
- Researchers at Horn Point Laboratory (Tom Fisher et al.) have identified 0.07 mg dissolved inorganic nitrogen (DIN) per liter as a limiting concentration for algae growth. Concentrations above this threshold promote excess, or uncontrolled algal growth when light is sufficient. Nitrate is the most common form of dissolved inorganic nitrogen in the Bay's tidal waters.
- The mean (geometric) concentrations of nitrate for the Full BNR period was 0.19 mg/liter at the Rt. 301 Bridge. This concentration is more than twice the phytoplankton nitrogen-limitation threshold of 0.07 mg/liter. Approximately 84% of the nitrate data were above the phytoplankton threshold.

BNR-related responses in the lower Potomac estuary can be examined by comparing the **frequencies of above-threshold nitrate concentrations** (>0.07 mg nitrate per liter) in Pre- and Full-BNR periods. This avoids the biases inherent in averaging BDL nitrate values. The 0.07 mg/liter limitation threshold is well above nitrate BDL concentrations, and a simple tally of nitrate values above and below the nitrogen threshold avoids the BDL problem and provides a quantitative measure of nitrogen enrichment.

The frequency of nitrate concentrations exceeding the phytoplankton "Nitrogen-Limitation Threshold" has decreased in lower estuary in Full BNR period

Difficult to determine from data alone whether the declines in frequency are due to dilution by Bay, upstream BNR, or both

Data suggest at least some of the decline is due to Full BNR



Overall, the frequency of nitrate concentrations exceeding the phytoplankton nitrogen-limitation threshold *decreased* in the lower Potomac estuary in 15% - 22% of the data records after Full BNR was implemented. Nitrate concentrations upstream of the Rt. 301 Bridge are always above the threshold, even in record dry conditions. Decreases in the frequency of above-threshold nitrate concentrations were larger in the lower Potomac Estuary compared to the Bay mainstem during the Full BNR period, indicating that upstream BNR reductions rather than dilution by Bay waters may have been primarily responsible for lowering the Potomac nitrate levels.

Note: In the dry and very/record dry autumn seasons, declines in the Bay mainstem were similar to those in the Potomac lower estuary. Therefore, it is unclear whether declines in the frequency of above-threshold nitrate concentrations were due to dilution by Bay, upstream BNR, or both in these seasons.

Note: Monitoring at LE2.3, CB5.3 and CB5.4 were done by a single laboratory (CBL) between 1990 and the present, and data from those stations are not affected by the laboratory change mentioned in slide 5.

Did BNR Nitrate Reductions Benefit Living Resources?

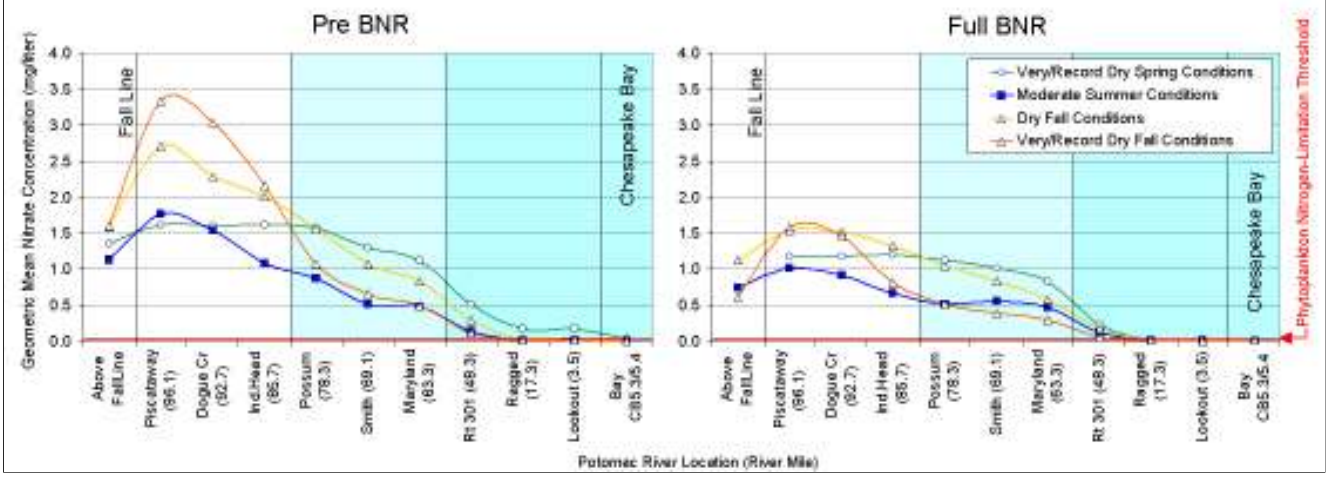
- Lower Estuary - no significant phytoplankton response yet

- Upper Estuary - appears to have significantly reduced duration and bloom intensity of *Microcystis aeruginosa* (bluegreen algae)
  - comparison of Summer 1991 (Very Dry) and Summer 2002 (Very Dry)

Summary

- Ambient nitrate concentrations have significantly declined in the upper and middle tidal Potomac River in response to Blue Plains WWTP Biological Nitrogen Reduction (BNR)

- However, nitrate concentrations in these reaches of the estuary, as well as the non-tidal Potomac River, still exceed Fisher & Gustafson's phytoplankton Nitrogen-Limitation threshold (2003)



In the four season-flow regimes where "apples-to-apples" comparisons could be made, there were significant declines in nitrate concentrations in the upper and middle Tidal Potomac River in response to the Blue Plains WWTP implementation of BNR.

Summary (Cont.)

- Nitrate has also decreased in the lower estuary, but not to concentrations low enough to significantly limit algal blooms
  - Concentrations still frequently exceed the nitrogen-limitation threshold, especially at the head of the lower estuary (Rt. 301)
- Difficult to determine from two years of monitoring data alone if current BNR (Blue Plains) is solely responsible for nitrate declines in lower estuary
  - Models could help distinguish influence of Bay mainstem from upstream BNR effects

Summary (Cont.)

- For Pre- and Full-BNR Periods with Matching Season-Flow Conditions:
  - Benefits of BNR were accentuated and concentrated in the upper and middle estuary during dry conditions (drought)
  - With return to moderate or wet flows, we hypothesize the influence of BNR on the upper and middle estuary will diminish, but the influence on the lower estuary will increase

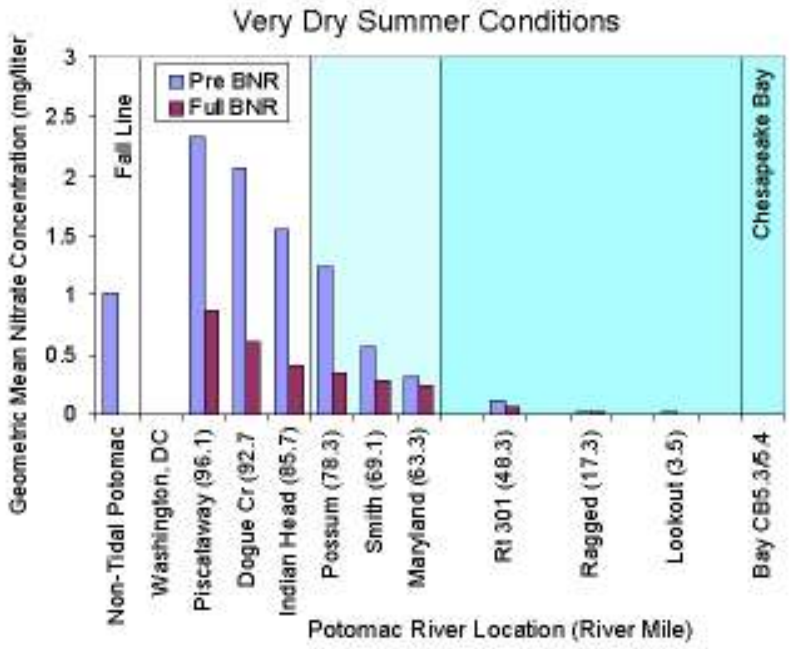
UPDATE IN PROGRESS

Data available

- Very Dry Summer (1991 vs 2002)
- Wet Spring (1994 vs 2003)

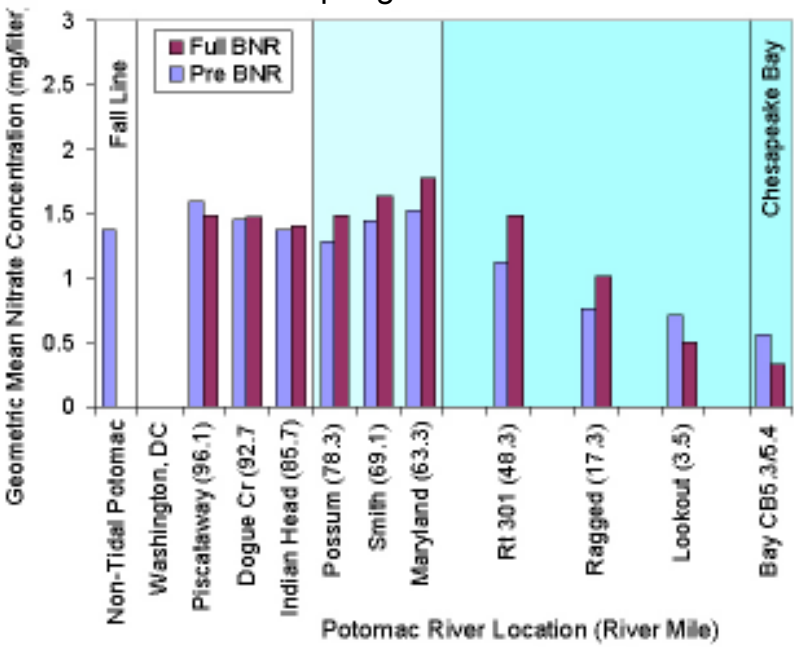
Data Pending

- Very/Record Wet Summer (1996 vs 2003)
- Wet Autumn (1990 vs 2002)

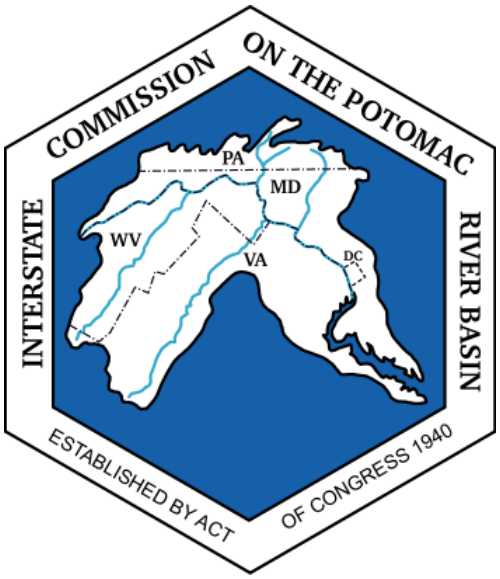


1991 *versus* **2002**

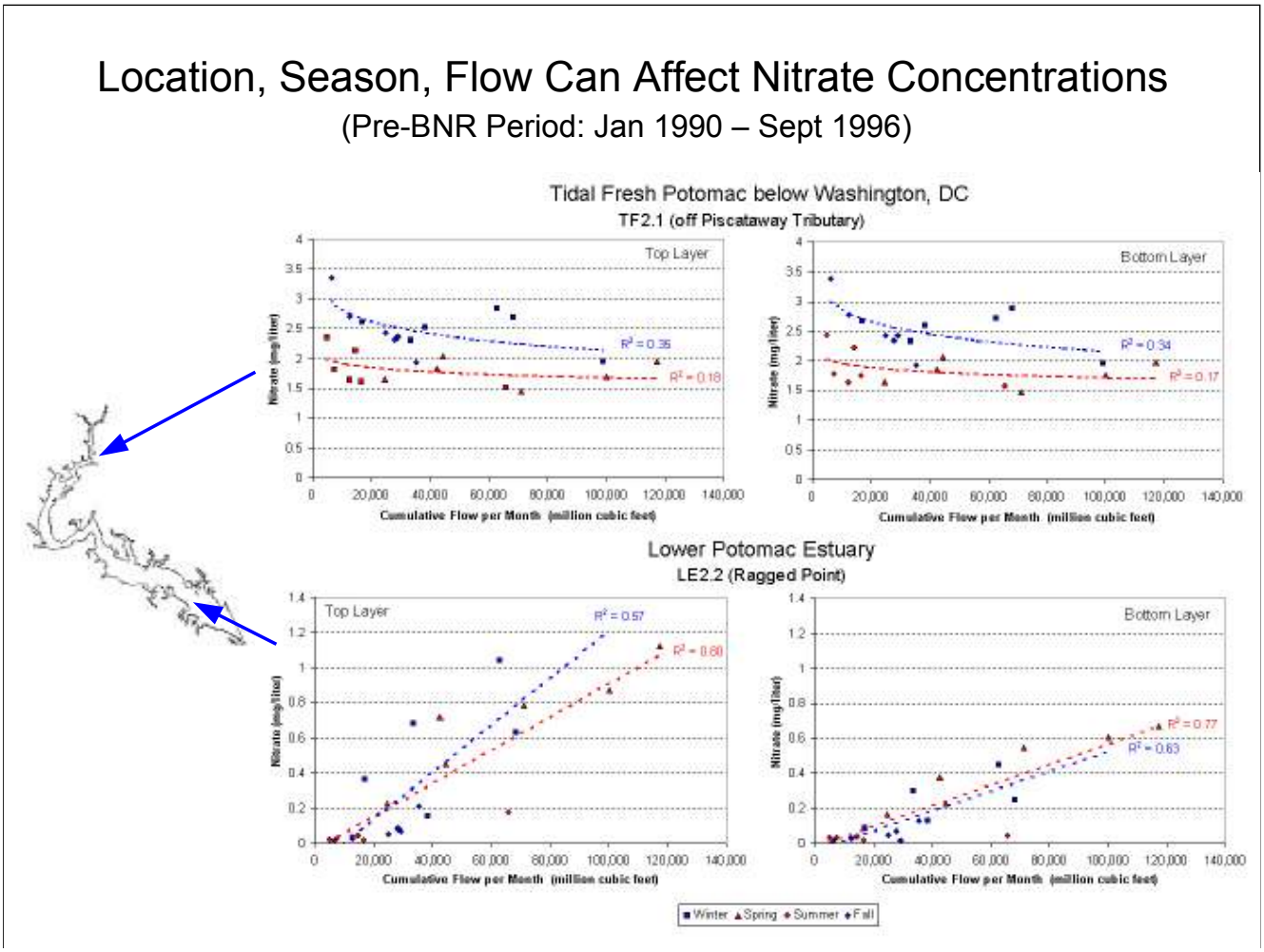
Wet Spring Conditions



1994 *versus* **2003**


COMMISSION ON THE POTOMAC
INTERSTATE
RIVER BASIN
PA
MD
WV
VA
DC
ESTABLISHED BY ACT
OF CONGRESS 1940

EXTRA SLIDES



We know that Location, Season and Flow effect nitrogen concentrations in the Potomac River, i.e.:

Upper and Middle Estuary (tidal fresh and oligohaline, <5 ppt)

- •No difference between top and bottom layers – .: waters are well mixed by tidal currents
- •As freshwater flow increases, the tidal fresh area is increasingly dominated by fall-line waters and there is a decline in nitrate concentration – reflects dilution by fall-line concentrations which are lower than WWTP effluent concentrations
- •Influence of Blue Plains WWTP on river's nitrate concentrations is strongest during drought years - i.e., ambient levels are highest during drought.
- •Spring and Summer have lower concentrations relative to Fall and Winter – phytoplankton are utilizing NO3 more rapidly due to seasonally higher temps and/or light levels
- **•NO3 concentrations are ~30-fold higher than needed for healthy phytoplankton growth**

Lower Estuary (mesohaline, 5 – 18 ppt)

- •As freshwater flow increases, nitrate concentrations increase – reflects downstream transport of unutilized nitrate
- •Large difference in top and bottom – reflects stratified nature of lower estuary
  - •upstream flow from Bay in bottom layer – Bay has lower NO3 levels
  - •downstream flow from river in upper layer – River has higher NO3 levels
- •No significant seasonal differences in bottom; slightly lower NO3 levels in Spring and Summer in top - reflects higher proportions of fall-line water in river during Winter & Spring
- **•NO3 levels are frequently limiting to phytoplankton growth (GOOD) when freshwater flows are low - nitrogen has been utilized upstream (sequestered by algae and plants).**