Status and trend analysis in the Maryland water quality monitoring program

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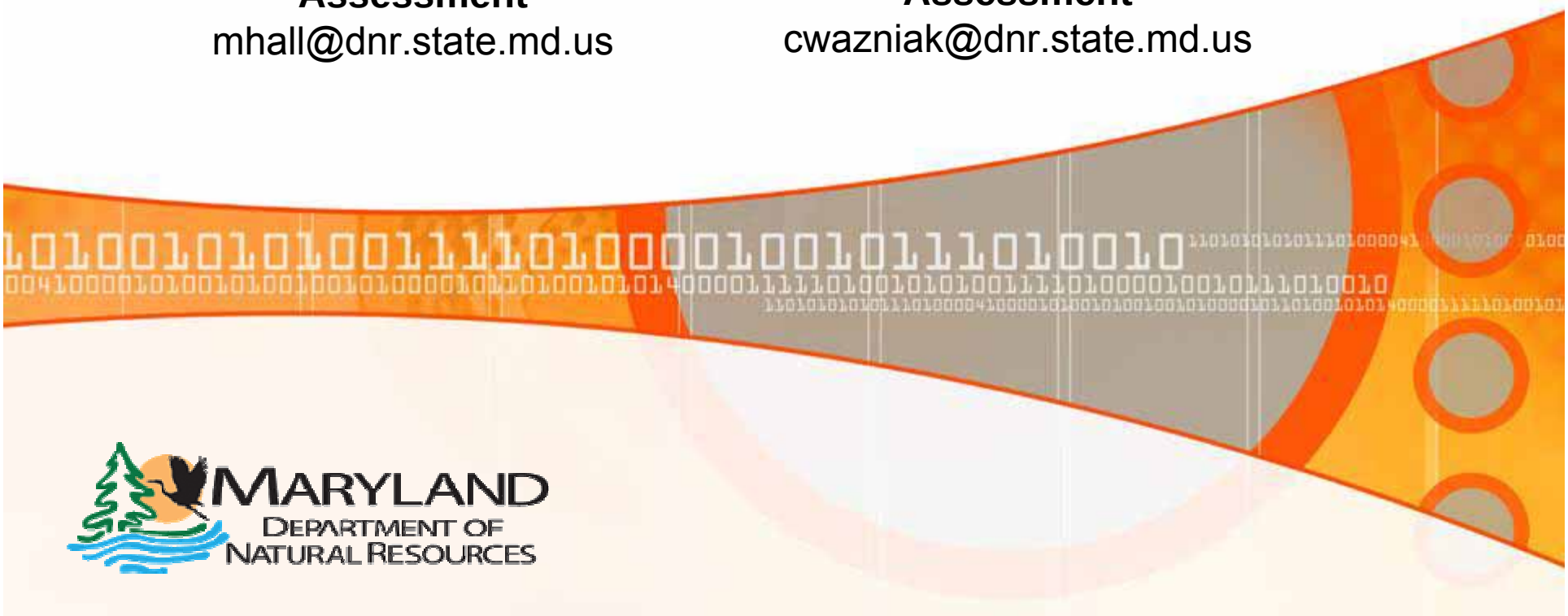


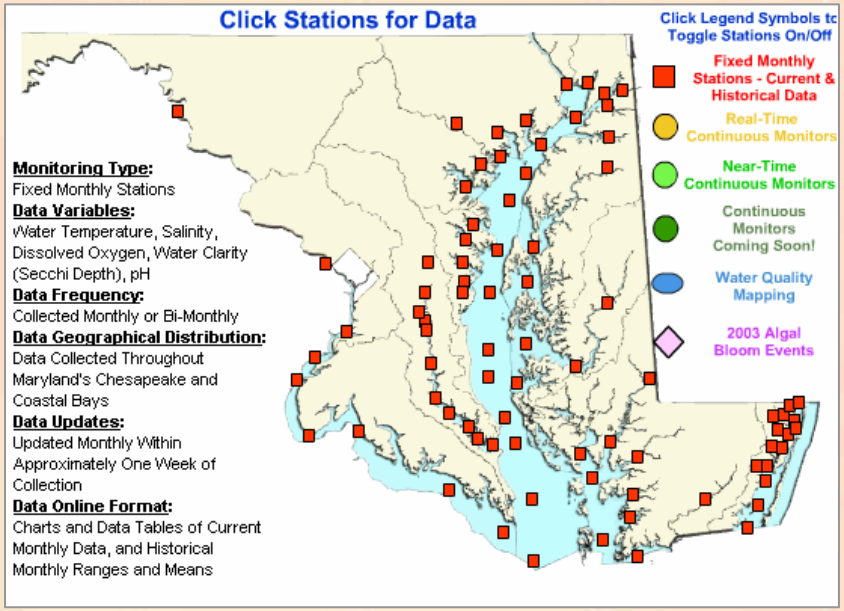
MARYLAND
DEPARTMENT OF NATURAL RESOURCES

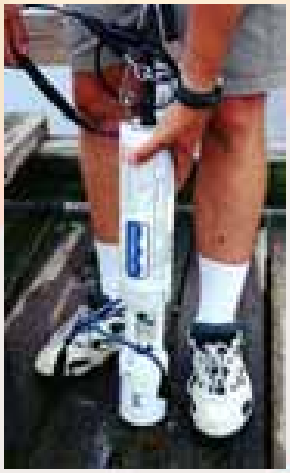
Outline of presentation

- Maryland water quality monitoring program overview
- Long-term trends
  - Seasonal Kendall's tau (linear)
  - Quadratic regression (non-linear)
- Three-year status
  - Median
  - Thresholds

Long-Term Fixed Station Monitoring

- Over 90 stations with an 18-year data record (5-8 years in Coastal Bays)
- Physically sampled by biologists 12 to 20 times per year via research vessels or bridges
- A full suite of nutrient, physical, and biological parameters are collected
- Data are used for status and trend analysis





Introduction to trends

- Trends – measure of indicator change over time
- Trend reliability depends on three factors:
  - Length of period of record
  - “Completeness” of data set during period of record
  - Level of sampling during period of record
- Other considerations
  - Flow adjustment
  - Assumptions (for parametric tests only)
- Two methods:
  - Seasonal Kendall tau test and Sen slope estimation (linear)
  - Quadratic regression (non-linear)

Period of record

- Must have long enough data record to detect trends
  - Ten years as rule of thumb, although dependent on scale of detection

Completeness

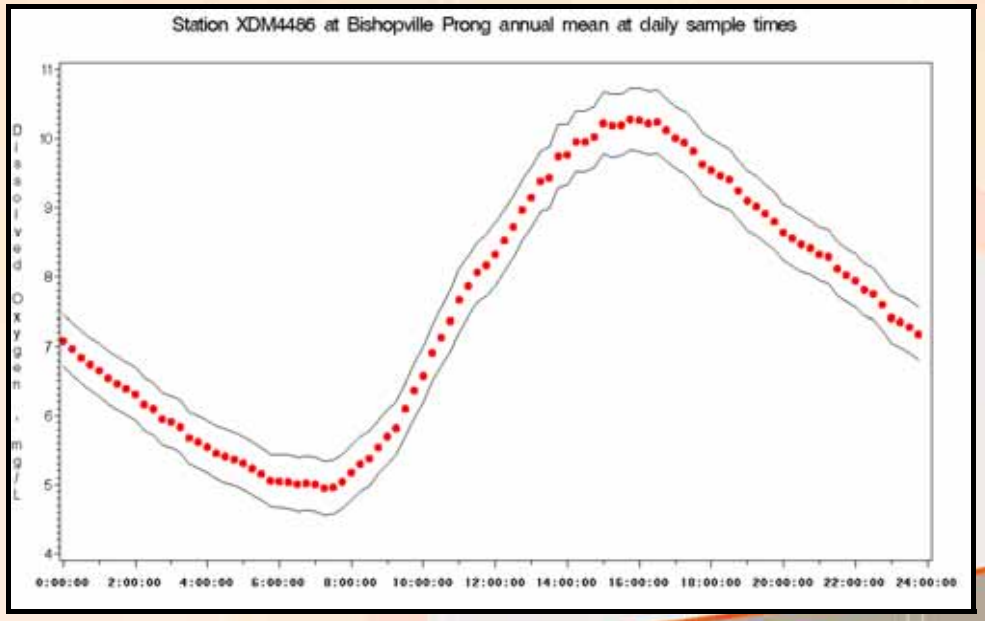
- Kendall's tau test is robust against missing data.
- However, should check data for patterns of missing data.
- For example, NPS dataset for Maryland Coastal Bays were not sampled during winter months through 1993. So, trimmed those months from all years for the trend analysis.

	CHLA												
	MONTH												All
	1	2	3	4	5	6	7	8	9	10	11	12	
1987	0	0	0	0	0	0	0	0	0	0	0	0	0
1988	0	0	0	0	8	0	8	8	9	8	0	0	41
1989	0	0	0	9	9	9	9	9	8	7	0	0	60
1990	0	0	0	0	0	9	9	9	8	9	0	0	44
1991	0	0	0	13	13	13	13	18	18	18	0	0	106
1992	0	0	0	0	6	6	6	5	6	0	0	0	29
1993	0	0	0	17	18	**18**	**18**	**18**	**18**	0	0	0	107
1994	0	0	17	18	18	**18**	**18**	**18**	**18**	18	0	17	160
1995	18	16	18	18	18	**18**	**18**	**18**	**18**	18	0	14	192
1996	17	18	18	18	17	**18**	**18**	**17**	**18**	18	18	18	213
1997	17	18	18	18	18	**18**	**18**	**18**	**18**	17	18	18	214
1998	16	18	18	18	18	**18**	**16**	**18**	**18**	14	18	16	206
1999	18	18	18	18	18	**18**	**18**	**18**	**18**	18	18	18	216
2000	18	18	15	17	18	**18**	**18**	**18**	**18**	18	18	18	212
2001	18	18	14	11	18	**15**	**18**	**18**	**18**	18	5	18	189
2002	13	11	11	18	17	**18**	**18**	**18**	**15**	8	9	7	163
2003	10	15	14	11	11	**15**	**16**	**18**	**18**	18	18	18	182
2004	13	18	18	18	18	**18**	**18**	**18**	**18**	0	0	0	157
All	158	168	179	222	243	247	257	264	262	207	122	162	2491

Level of sampling

Level of sampling effort can be important, depending on management or political needs, or on behavior of the water quality parameter.

For example, DO is not evaluated for trend in the Coastal Bays because of variation at a level smaller (daily) than the sampling period (monthly).
NOTE: This is not a problem in stratified systems such as the Chesapeake, where bottom DO is measured for trend.



Some data issues

- Data points that are below detection limits of lab instrumentation.
  - Normally censored in water quality data sets.
  - Maryland DNR (CBP) QA procedure censors all data BDL to detection limit.
  - After censoring, all censored data set to half detection limit.
- Changes in laboratories or laboratory techniques over time.
  - Lower values of BDL later in data record may be falsely detected as a downward trend.
  - DNR (CBP) censors data to highest detection limit of analysis period.

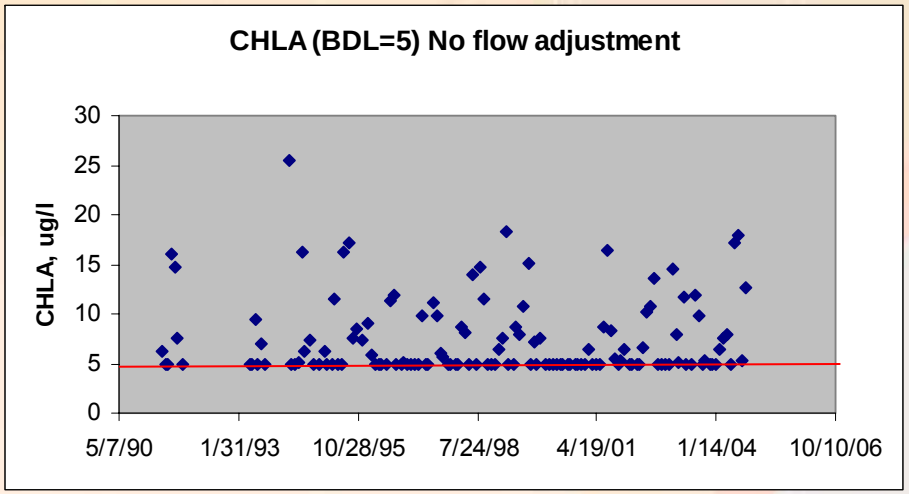
More on censoring

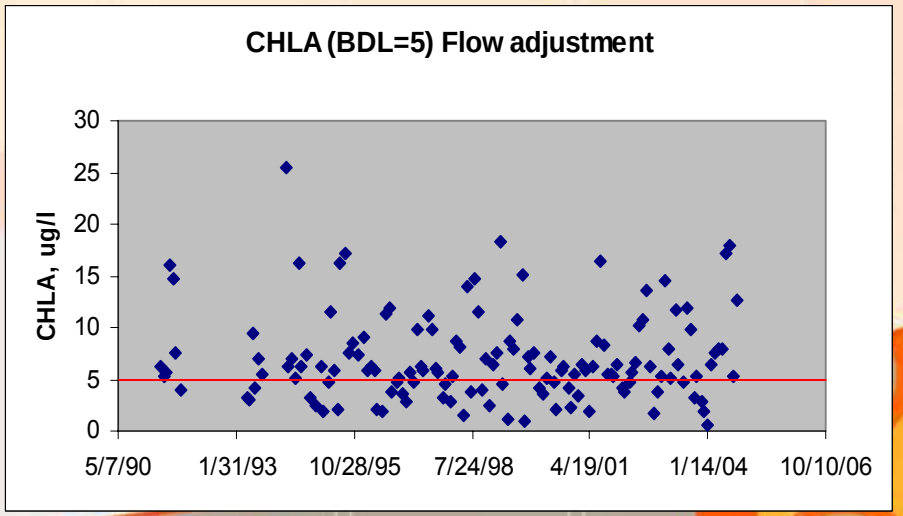
- Data sets having large numbers of values BDL may create statistical problems for trend analyses.
  - Seasonal Kendall's tau test adjusts variance estimates upward for ties in magnitude.
  - Since BDL values produce such ties, trend analyses of data sets with high percentages of BDLs will be based upon greater variances than those without (reduction in power).
  - DNR (CBP) has drawn up a set of guidelines for handling data sets with large numbers of BDL values. Base rule: When BDLs less than 15%, report trend, p-value, and slope direction. Greater than 50%, do not report trend.
  - Judgment call as to what level of BDLs are acceptable.

Censoring and flow adjustment

The seasonal Kendall's tau test is a non-parametric rank test. Therefore, censored data (i.e., below detection level) points will be ranked the same and averaged.

Chesapeake Bay Program had used an algorithm to adjust for varying levels of flow during the period of record. This led to the censored data not maintaining its average rank (i.e., these values contributed more to the trend than censored values should).





Seasonal Kendall's tau (linear trend)

- Actually a combination of statistics:
- Mann-Kendall statistic for trend over years for each "season"
- Seasonal Kendall procedure provides two statistics per station
  - Combined test for trend based on individual monthly Mann-Kendall statistics
  - Test for homogeneity of trends among months (determines if reasonable to use combined statistics)
- Sen's slope estimator and confidence interval (quantify magnitude of trend)
- Alpha level: 0.01 for all trend tests
- If seasonal heterogeneity significant, report as best available assessment (judgment call)

Sample output

Report#2 - Seasonal Kendall Test results by month (TN)

Segment=Chinco Station=A10 Layer=S Season=SAV1

Month	n	S	Std Err	Z	p_val	slope
4	8	10	8.0829	1.1135	0.276000	2.57
5	8	8	8.0829	0.8660	0.398000	1.85
6	8	12	8.0829	1.3609	0.178000	3.67
7	8	8	8.0829	0.8660	0.796000	2.13
8	8	10	8.0829	1.1135	0.552000	1.67
9	8	6	8.0829	0.6186	0.548000	1.18
10	8	20	8.0829	2.3506	0.014200	2.00

End Report#2

Report#3 - Seasonal Kendall Test results by season (TN)

Segment=Chinco Station=A10 Layer=S Season=SAV1

season	S	Std Err	Z	trend p_val	homogeneity p-val	slope	95% CI
SAV1	74	21.3854	3.4136 a	0.0006 a	0.9265 c	1.9333	(1.0254, 3.1383)
			3.4603 b	0.0005 b			

a - computed using continuity correction

b - computed without continuity correction

c - p-value of chi-square test for homogeniety among monthly slopes within season

use statistics w/o continuity correction when n > 10 for each month

Quadratic analysis (non-linear trend)

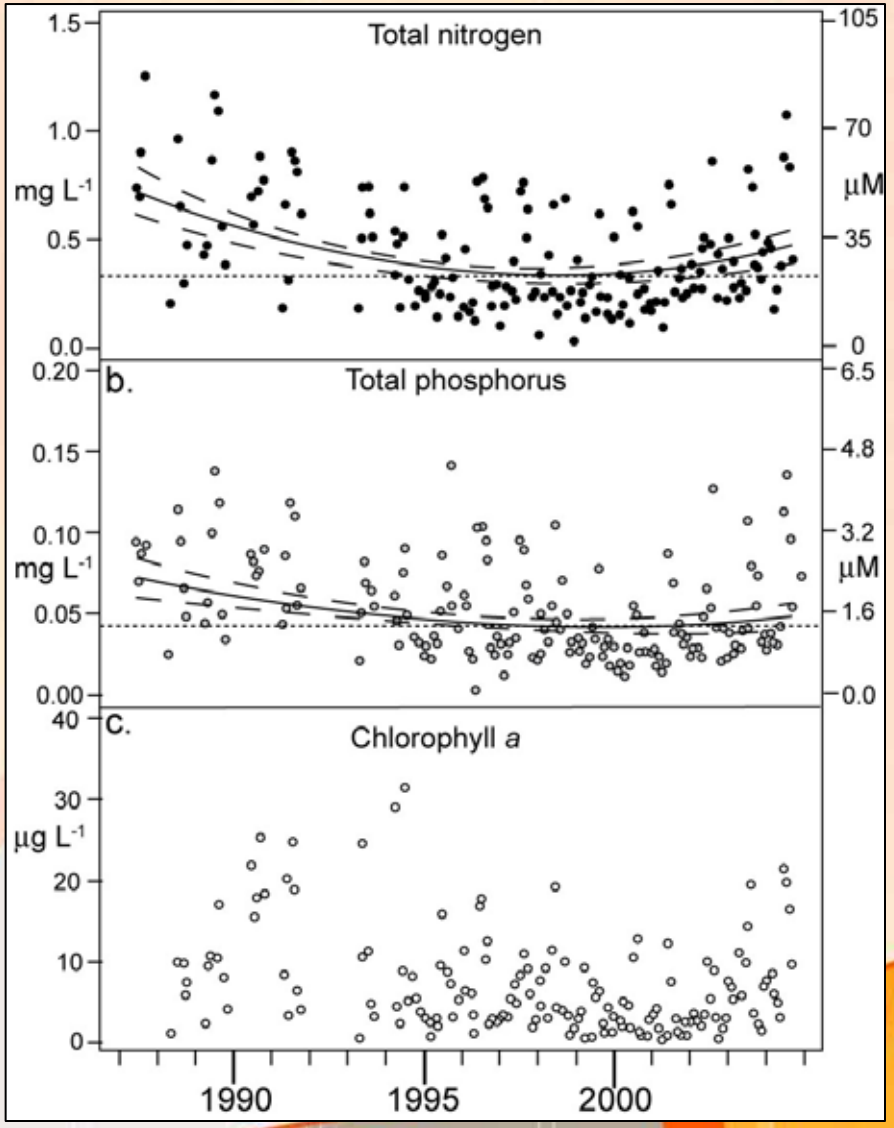
- Regression model includes “season” terms
- Standardize data to centralized date (forces β_1 and β_2 terms to be orthogonal)
- Regression equation:

  $\text{Log [indicator]} = \beta_0 + \beta_1(\text{time}) + \beta_2(\text{time}^2) + (\beta_3 \ldots \beta_m)(\text{seasons}) + \varepsilon$

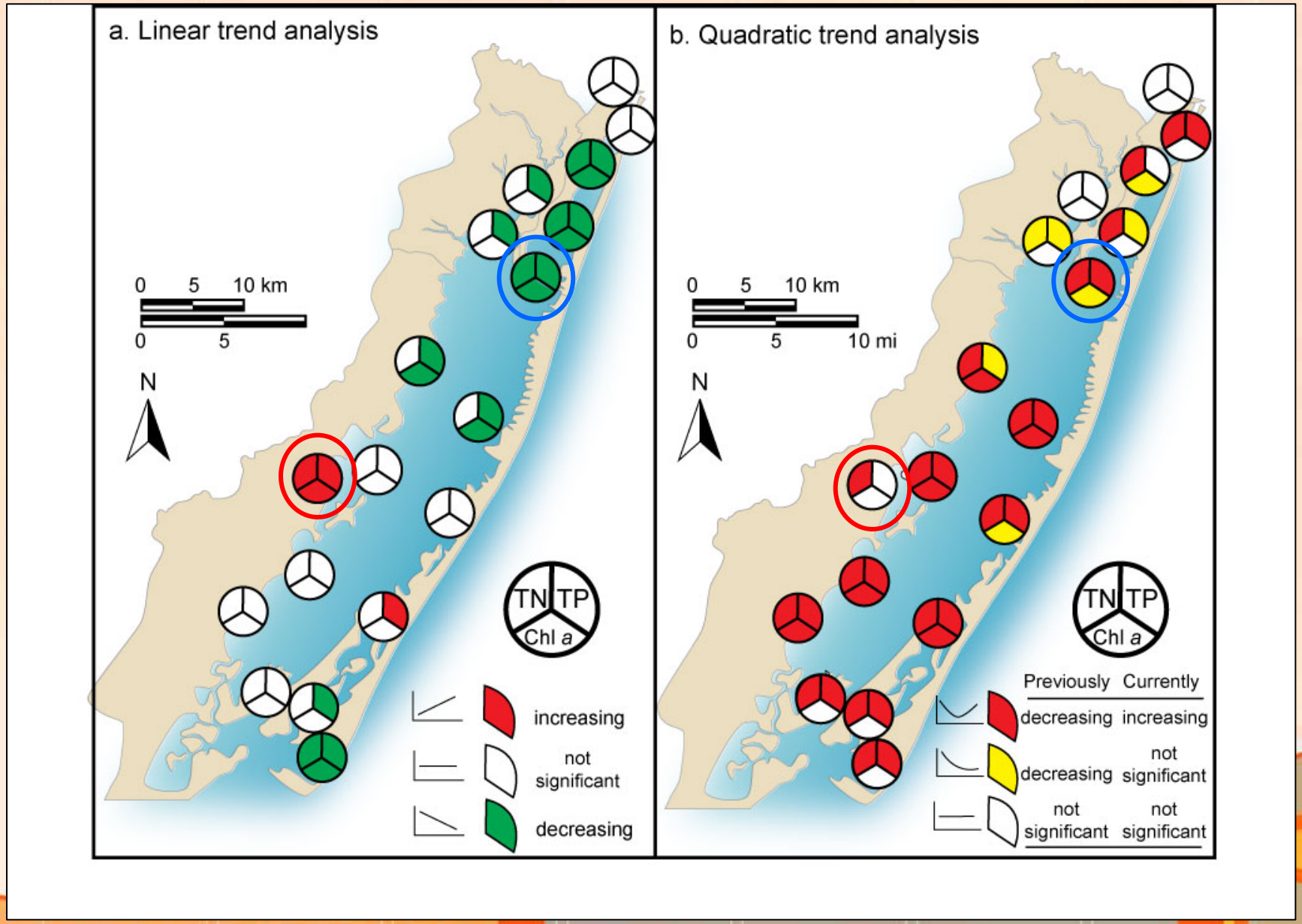
- Post-test residuals for normality and heteroscedasticity (log transform should handle this)

Post-inflection analysis

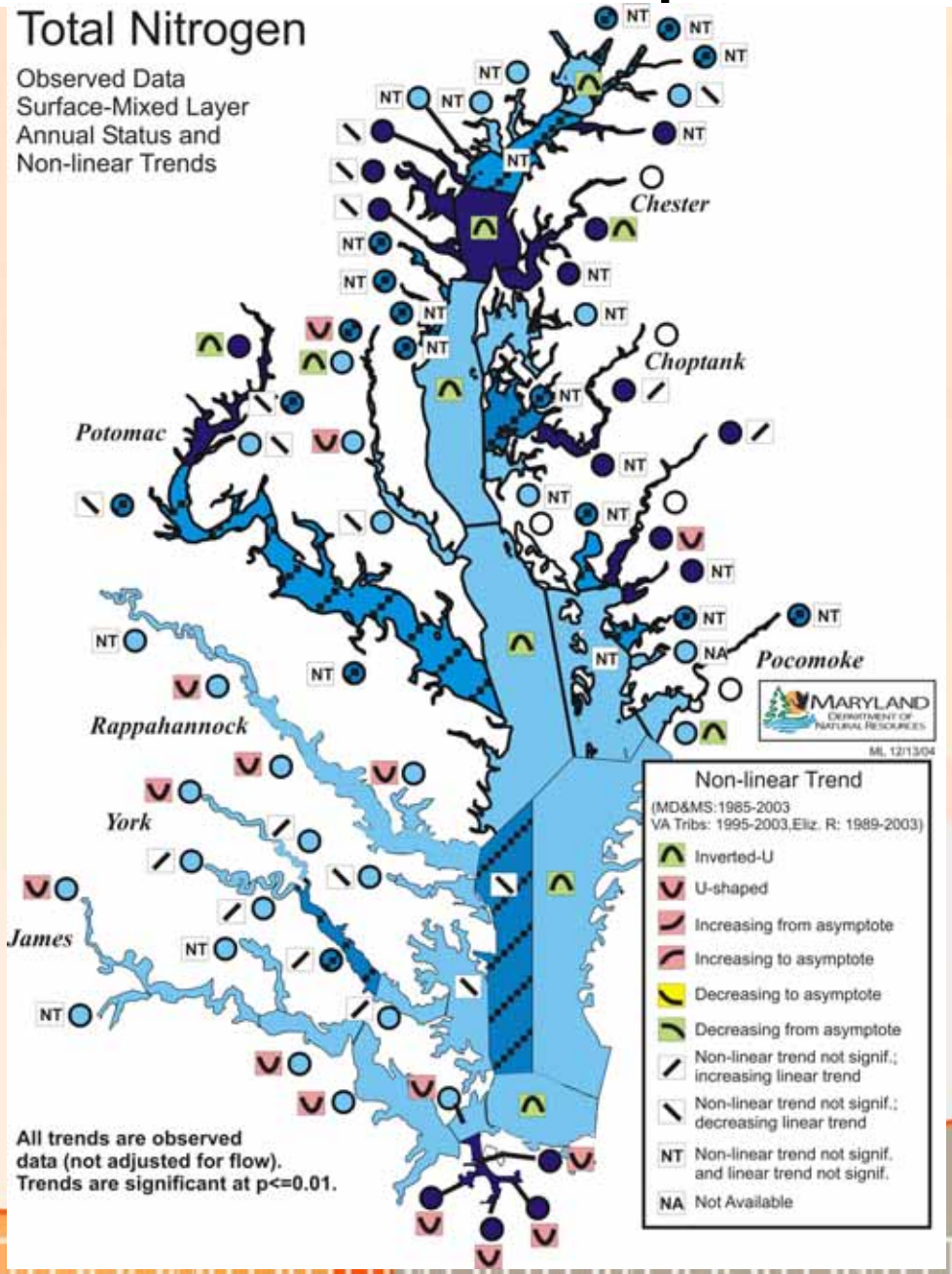
- If quadratic term is significant, then can determine significance of post-inflection trend.
- Determine parabola direction and what that means for the indicator in question (increasing or degrading).
- One simple method is to calculate 95% confidence limits and check whether they encompass the inflection point at the end of the period of record.



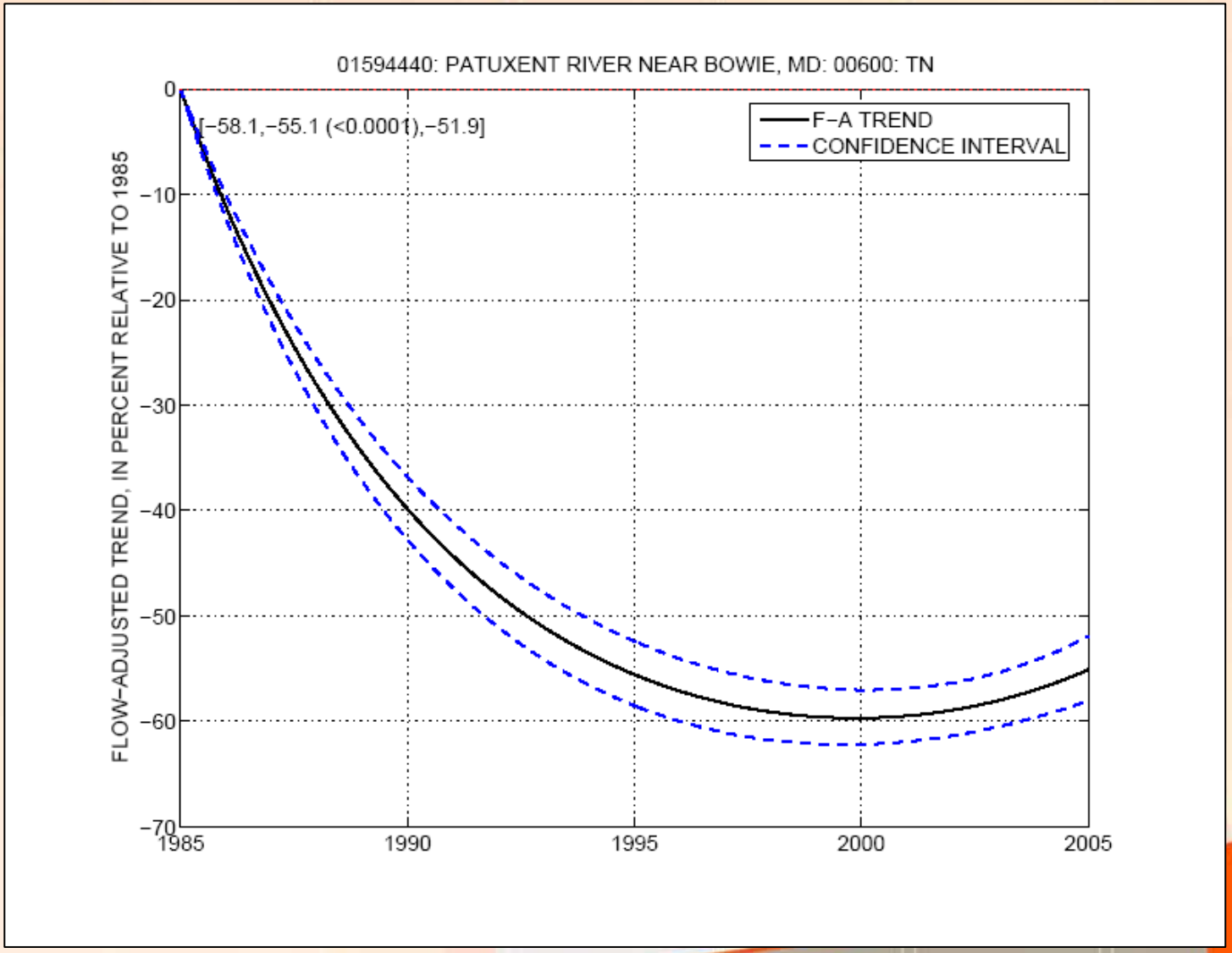
Why analyze both trends?



Chesapeake trend reporting



USGS F-A River Input trends



Trends advantages and drawbacks

Advantages

- Can answer key management and political questions (are conditions getting better or worse?)
- Easy to represent visually
- Can be mapped
- Has some predictive value

Drawbacks

- Requires several years of data
- Underlying statistical analyses complex
- Temporal autocorrelation can bias results
- Requires a modicum of explanation, especially in regards to linear vs. non-linear analysis

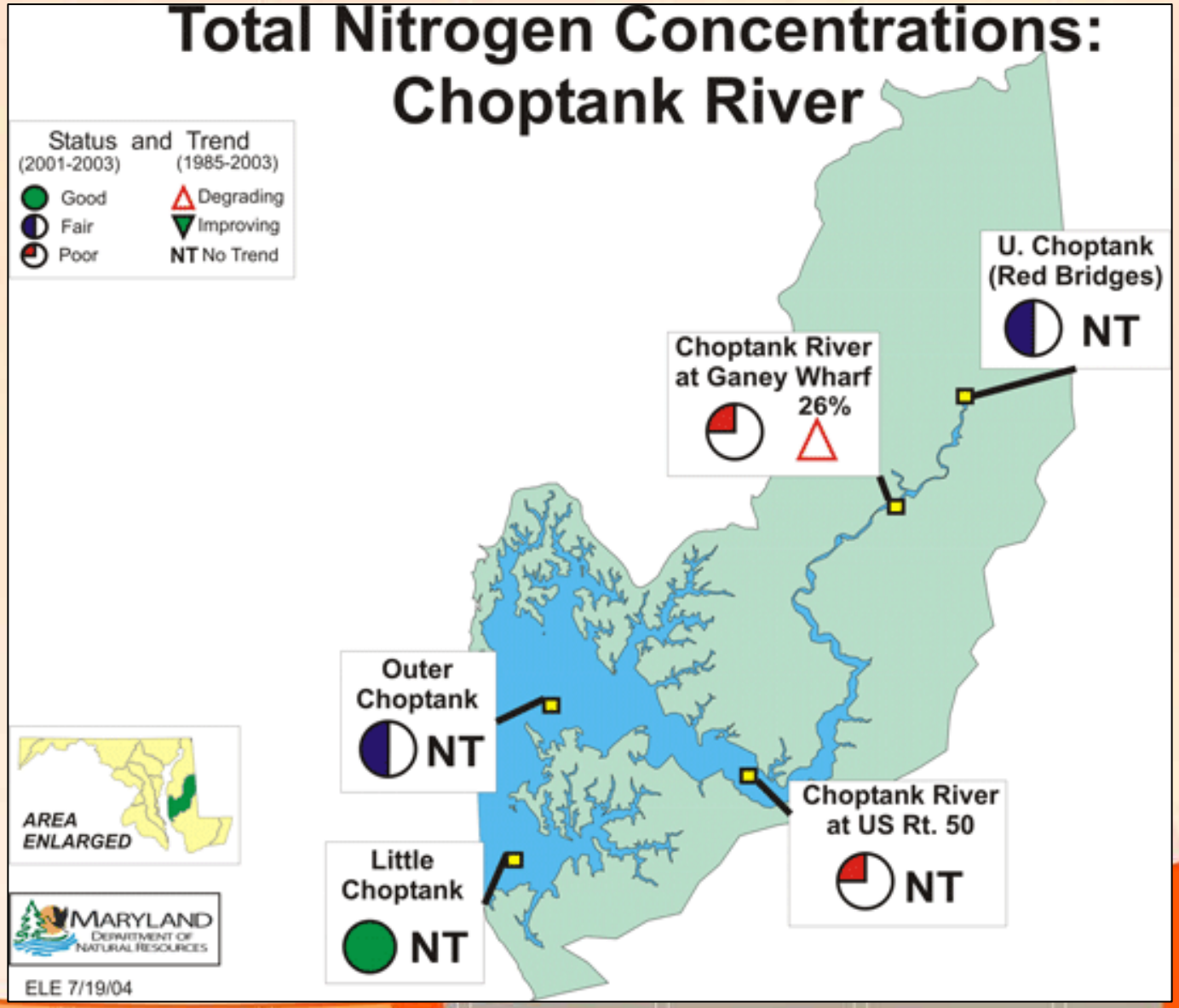
Water quality status development

- Indicators
- Monitoring
- Thresholds
- Analysis (comparison to thresholds)

Historical Chesapeake Bay status

- For all parameters except DO, used first six years of data as benchmark (pooled by salinity regime).
- Set cutpoints for GOOD, FAIR, POOR using cumulative logistic function (divided benchmark dataset into thirds) of median monthly samples by salinity zone.
- Compared most recent three-year medians to that dataset to delineate status (Wilcoxon sign rank test).
- Currently, this is being phased out since it only provides a *relative* status.
- For bottom DO, use 5 and 2 mg/L thresholds for status.
- CBP currently in midst of criteria development.

Some Chesapeake Bay results



Chesapeake Bay criteria

Designated Use	**Dissolved Oxygen** (milligrams per liter)	**Chlorophyll *a***	**Water Clarity** (% surface light)
Migratory Spawning and Nursery (Feb. – May)	6 mg/L in tidal fresh waters only (7-day mean) 5 mg/L (instantaneous minimum)		
Shallow Water (SAV growing seasons)	Same as open water		Lower salinity: 13% Higher salinity: 22%
Open Water (year round)	5.5 mg/L in tidal fresh waters and 5 mg/L in higher salinity waters (30-day mean) 4 mg/L (7-day mean) 3.2 mg/L (instantaneous min)	Narrative criteria	
Deep Water (June – Sept.)	3 mg/L (30-day mean) 2.3 mg/L (1-day mean) 1.7 mg/L (instantaneous minimum)		
Deep Channel (June – Sept.)	1 mg/L (instantaneous minimum)		

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Coastal Bays thresholds

Indicator	Thresholds
Total Nitrogen	<0.55 mg/L – Better than SAV objective 0.55 – **0.64** mg/L – Meets SAV objective **0.64** – **1** mg/L – Does not meet SAV objective **1** – 2 mg/L – Does not meet STAC threshold >2 mg/L – Does not meet objectives
Total Phosphorus	<0.025 mg/L – Better than SAV objective 0.025 - **0.037** mg/L – Meets SAV objective **0.037** – 0.043 mg/L – Does not meet SAV objective 0.043 – **0.01** mg/L – Meets STAC threshold >**0.01** mg/L – Does not meet objectives
Chlorophyll a	<7.5 µg/L – Better than SAV objective 7.5 – **15** µg/L – Meets SAV objective **15** – 30 µg/L – Meets DO objective 30 – **50** µg/L – Borderline DO objective >**50** µg/L – Does not meet objectives
Dissolved Oxygen	>7 mg/L – Better than objective 7 – 6 mg/L – Meets objective 6 – **5** mg/L – Meets TMDL daytime objective **5** – **3** mg/L – Threatened <**3** mg/L – Does not meet objectives

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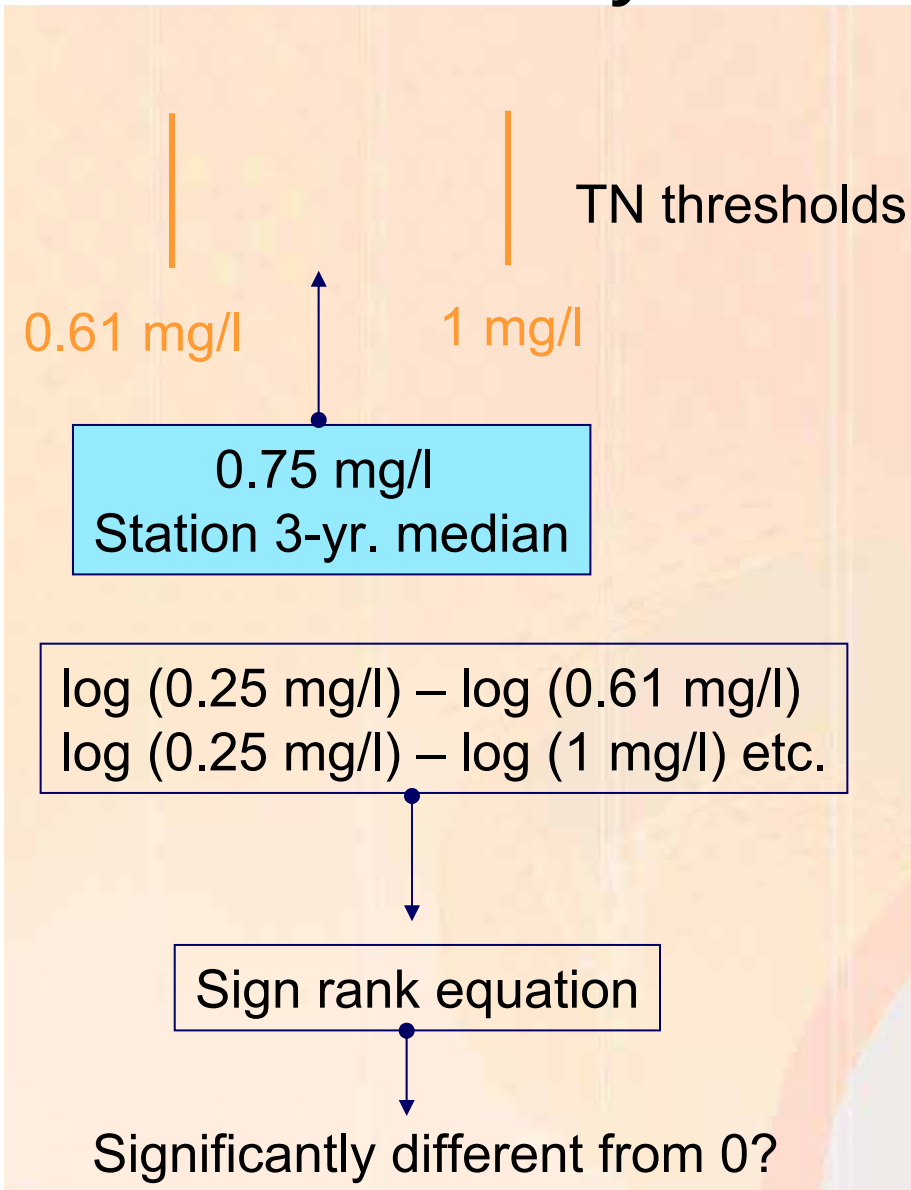
Status analysis based on thresholds

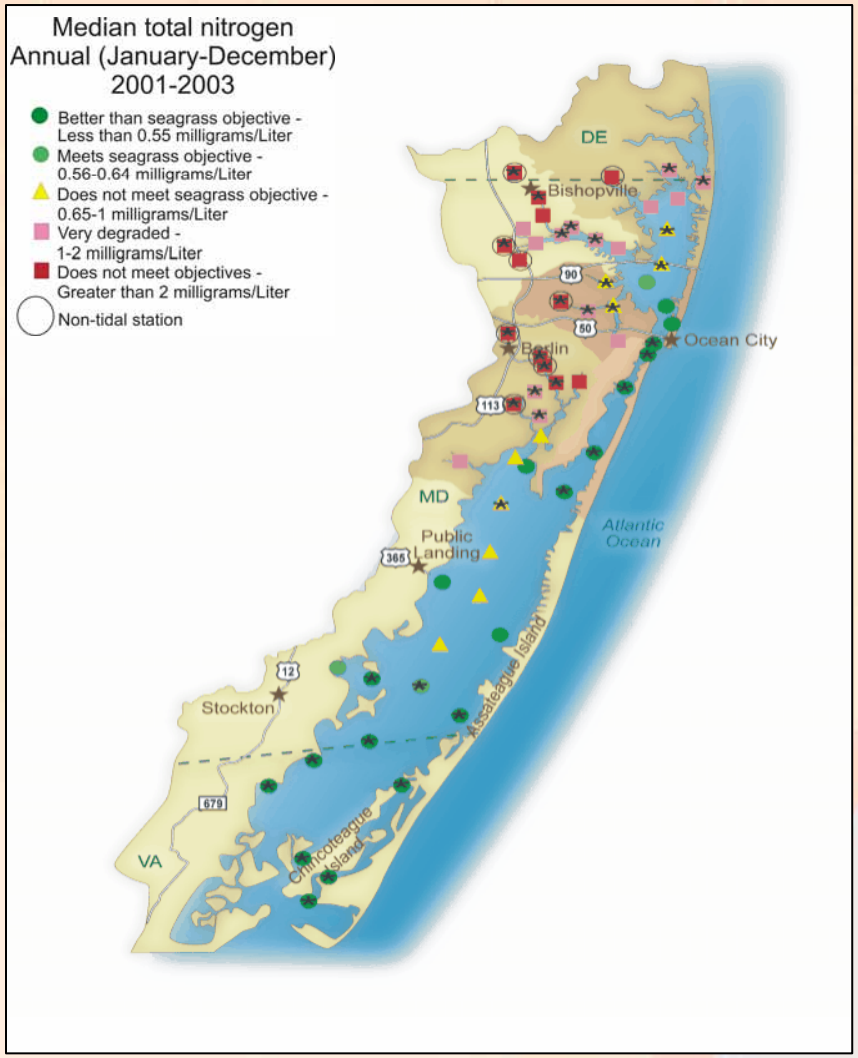
- Chlorophyll assessed during combined seagrass growing season (March – November)
- Dissolved oxygen assessed during the summer season (June through September)
- Total nitrogen and phosphorus assessed during whole year
- Calculate three-year medians

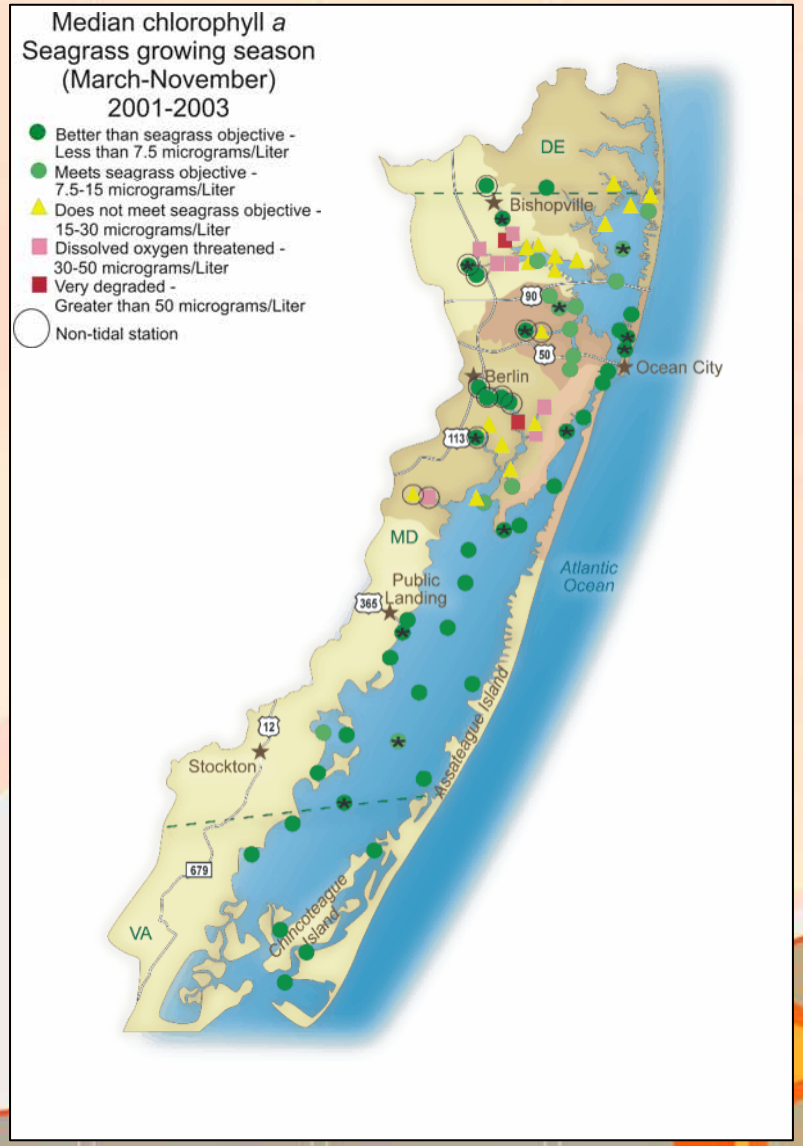
Status analysis based on thresholds



- Hypothesize that the three-year median for each parameter at each station falls significantly within a threshold category.
- Apply statistical testing (Wilcoxon sign rank test) to determine significance.
- Actual program tests whether log differences (log concentration – log threshold) are significantly different from zero at $p<0.05$.

Some Coastal Bays results





Status advantages and drawbacks

Advantages

- Simple analysis
- Simple interpretation
- Based on biologically relevant thresholds
- Results can be easily mapped (presentation is key)

Drawbacks

- Thresholds/criteria are difficult to develop, especially with multiple stakeholders
- Central tendency (median vs. mean vs. geometric mean)
- Three-year status scores may not be comparable (weather patterns, etc.)
- Temporal and spatial coverage lacking

Acknowledgements

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