CHAPTER 4.6 INTEGRATED WATER QUALITY INDEX RESULTS

The Integrated Water Quality (IWQ) trend analysis is a new statistical procedure developed to detect long term trends by maximizing the amount of data used. The IWQ is a seasonally-derived nonparametric scoring procedure that is applied to various waterbody types at the watershed scale. The impetus for the creation of the IWQ was the desire to detect and explain changes in water quality over time more descriptively than the traditional 303(d)/305(b) Integrated Report does. More stream segments and estuarine / reservoirs polygons are added to the 303(d) list of impaired waters with every two-year cycle. However, as resources have shifted towards restoration efforts in watersheds, attention has been given to the development of a new statistical approach that would capture changes in water quality at broader spatial scales. The IWQ was developed by D.H. Smith and R.E. Stewart at the Virginia Department of Environmental Quality with the encouragement and support of L. Merrill with the U.S. Environmental Protection Agency, Region 3.

Statistically significant improving trends in water quality were revealed across the Commonwealth with the modified seasonal Kendall trend analysis (see Chapter 4.5). This analysis was performed on 436 stations designated for trend analysis, over a twenty-year period. In contrast, the IWQ approach incorporates 5,776 stations for the same time frame, allowing for a broader examination.

Data Selection

Data were selected from DEQ's in-house water quality database where waters are categorized as stream/river, reservoir, or estuary. Further selection of the data based on the station STORET Level 3 Code was necessary to include a broader selection of data other than just data from trend stations. The data, as defined by their Level 3 attribute, were selected from the following monitoring programs: Ambient Probabilistic, Ambient Watershed, Biological Monitoring, Special Study, TMDL, and Ambient Trend.

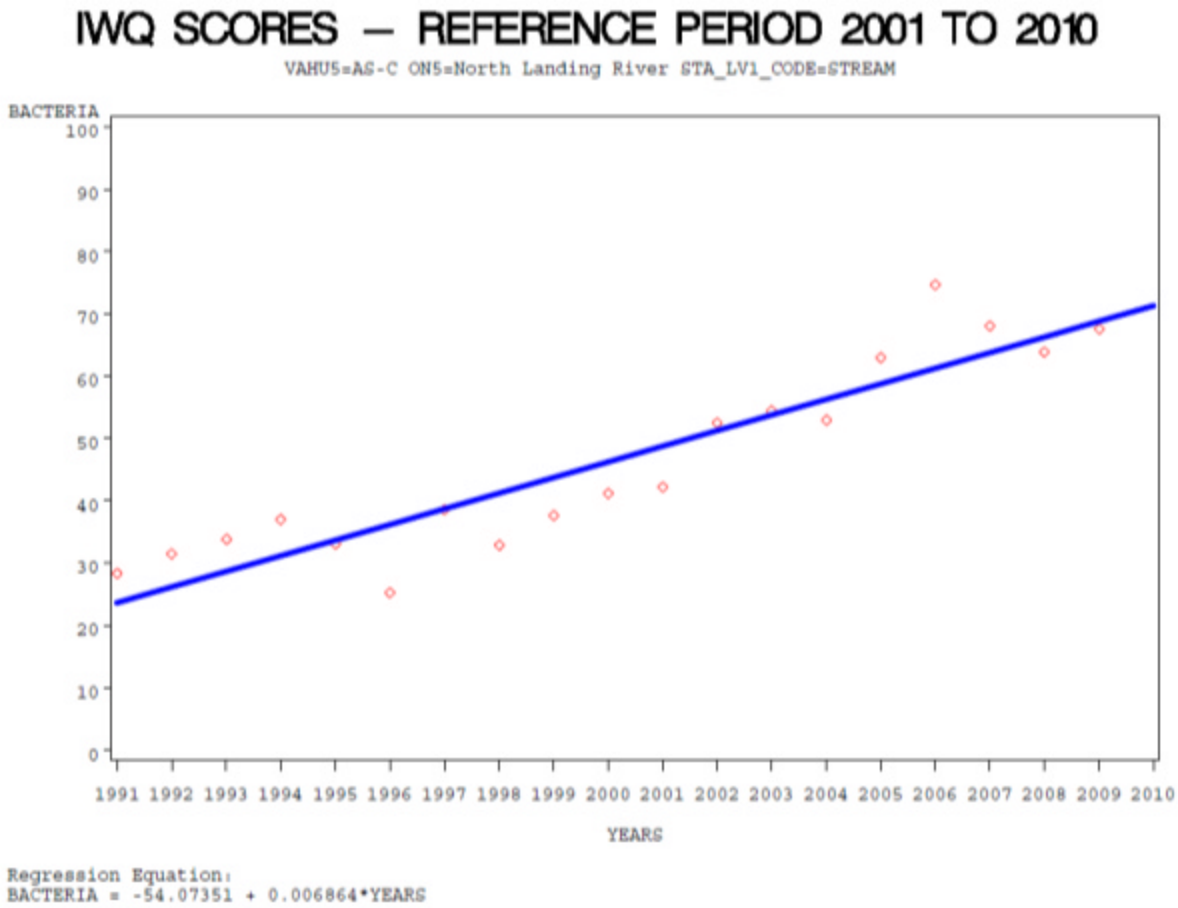
The variables of interest were bacteria, chlorophyll *a*, *E. coli*, *Enterococci*, nitrogen, oxygen saturation, pH, phosphorus, specific conductivity, suspended solids, and temperature. For the purpose of this report the discussion is limited to the four key parameters addressed in the previous chapter, i.e., bacteria, nitrogen, phosphorus, and suspended solids. As with the Kendall trend analysis, the period of record for the IWQ analysis was 1991 to 2010.

Methodology

The IWQ uses a reference time period to derive the upper quartile, lower quartile and the interquartile range used as reference concentrations. Raw water quality concentrations are then compared to the reference concentrations and scored accordingly. The most recent ten-year block of data, 2001-2010, was selected as the reference period selected. These data represent the best quality controlled data and were collected using more sensitive instrumentation relative to what was used in the past. The quartiles and inter quartile range are calculated from the reference period for each water quality variable by month, by water body type (stream/river, estuary, reservoir), and by watershed (HUC 5th order 10 digit watersheds). This type of stratification is called "by group processing". "By group processing" is important because variations in season and waterbody type within a watershed are locally confined and used to generate very specific reference conditions.

Once the reference concentrations are calculated, each individual water quality measurement for all stations for the entire period of 1991 to 2010 is compared to the reference numbers again by month, by water body type, and by watershed. When a data point is in the lower quartile meaning lower concentration, high quality, a score of 100 is given. The interquartile range receives a score of 50 and the upper quartile, higher concentration lower water quality, is set to zero. Next the average score by year by waterbody type and by watershed is calculated. Scores are plotted by year and the long term trend in water quality is calculated via linear regression (score vs. year) including the confidence interval (p). An example of the graphical output for each watershed, variable, and water body is seen in Figure 4.6-1. The yearly individual score is represented by the red open diamond and the regression is the bold blue line. In this particular example, the bacteria score is generally increasing from year to year, which indicates decreasing (improving) trends in bacteria concentration. The IWQ uses this convention throughout, i.e., a positive slope indicating improving water quality.

Figure 4.6-1 Bacteria Water Quality Trends, North Landing River



The IWQ methodology is very robust against censored data, which are values reported as less than the analytical detection limit or—in the case of bacterial colonies—those above an upper value. Inspection

of raw data coded as being below the detection limit indicate almost every censored value falls in the lower quartile, regardless of changes to the detection limit. Data coded as being above upper detection limits occur infrequently, only for bacteria measurements, and fall in the upper quartile regardless of censoring point.

Statistically significant improving water quality trends are defined as by those regressions with a 90% confidence value and a slope greater than 0.0. For those statistically significant declines in water quality, regressions with a 90% confidence value and a slope less than 0.0 are identified as having "SIGNIFICANT DECLINES." Confidence values of 75% to 90% are either "IMPROVING" or "DECLINING" with positive or negative slopes respectively. All other data is considered either "NO CHANGE" or "INSUFFICIENT DATA."

A further note on the selection of the reference time period window is worth mentioning. Traditional integrated reporting has focused on a static time period or baseline of the year 2000 from which comparisons with each new report are made. However, as progress in restoring water quality is made, reference concentrations are also expected to change for the better. Thus, a moving reference period of the most recent data is used to prevent the IWQ trend from becoming asymptotic. This also reduces any impact that changes in analytical detection limits--which occur with improvements in laboratory technology—may have on comparisons over time.

One of the great advantages of the seasonal nonparametric IWQ is that once the raw numeric water quality data have been scored against its own set of reference values, the scores can be combined from disparate sources. For example, the U.S. EPA Chesapeake Bay Program Office maintains data from multiple state agencies and associations for the mainstem Bay and her tributaries. These data have been generated under standardized quality control procedures from sample collection to analysis. However, it was determined that two laboratories involved in the analysis of Bay program data were not using the same furnace temperature for the analytical method that determines total suspended solids. The datasets produced by these laboratories are distinctive in a way that can only be explained by methodological differences. The IWQ mitigates the lack of data comparability by generating two sets of reference values, one for each laboratory's record of data, and then scoring the two sets of raw data against the matching quartiles. These scores can then be combined into a single data set.

The IWQ could also be used to aggregate benthic macroinvertebrate scores across different ecoregions and jurisdictions. Collection methods and scoring metrics vary among agencies and organizations collecting biological data for assessment. However, all techniques produce a range of data that can allow for the derivation of reference quartiles.

Results

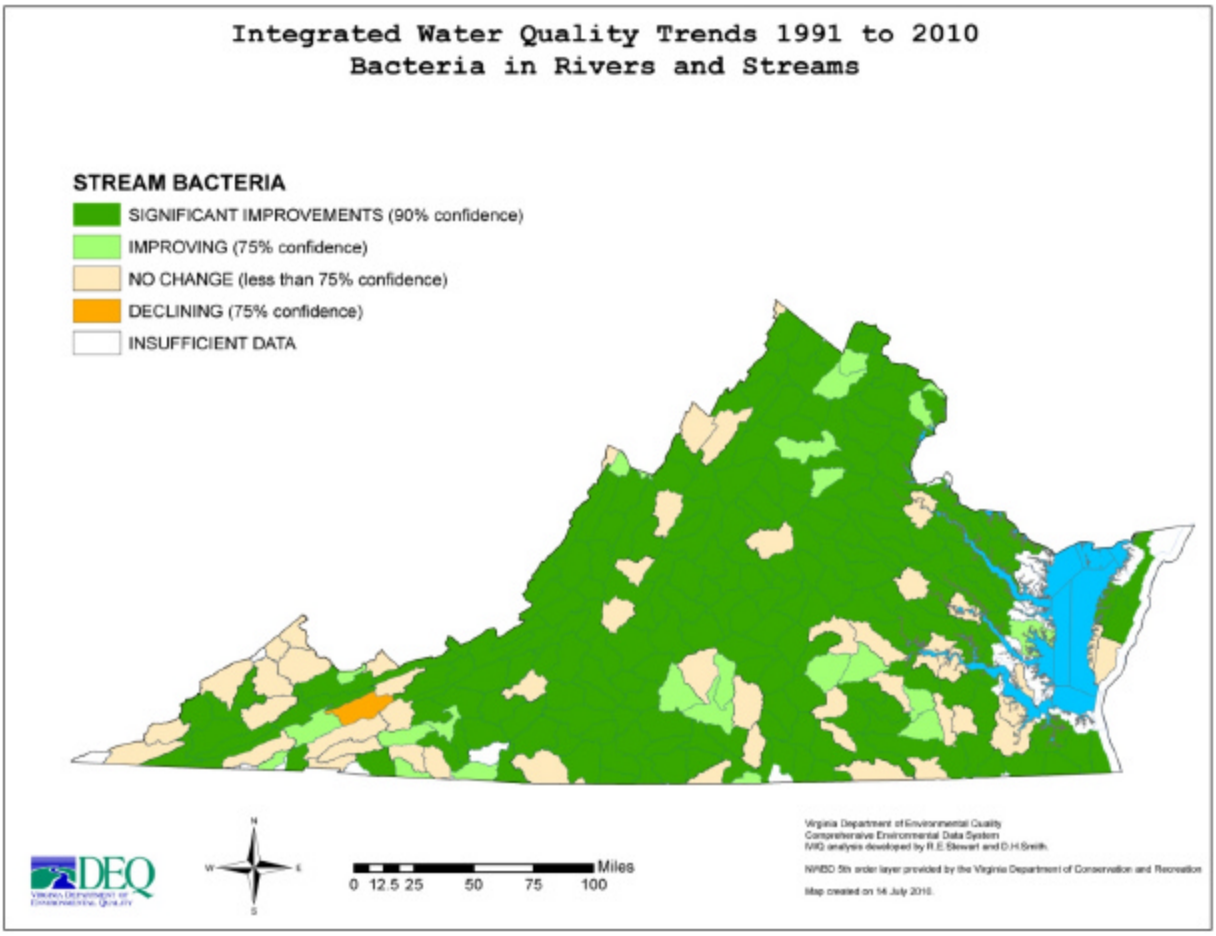
There are 315 5th-order hydrologic unit codes (10 digit) in the Commonwealth of Virginia. All appropriate data were pooled for each 5th order watershed and analyzed using the IWQ methodology. As with the Kendall trend analysis we focused on four key indicator variables, bacteria, nitrogen, phosphorus, and suspended solids in estuaries, streams/rivers, and lakes.

Bacteria

Water quality for bacteria as detected using the IWQ reflects the results of the modified seasonal Kendall analysis—no statistically significant declining trends in conditions for bacteria were detected in the Final 2012

Commonwealth's rivers and streams over the past twenty years. Two-hundred and four (204) watersheds out of 315 showed significant improvements in water quality for bacteria (see Figure 4.6-2).

Figure 4.6-2 IWQ Trends for Bacteria in Rivers and Streams

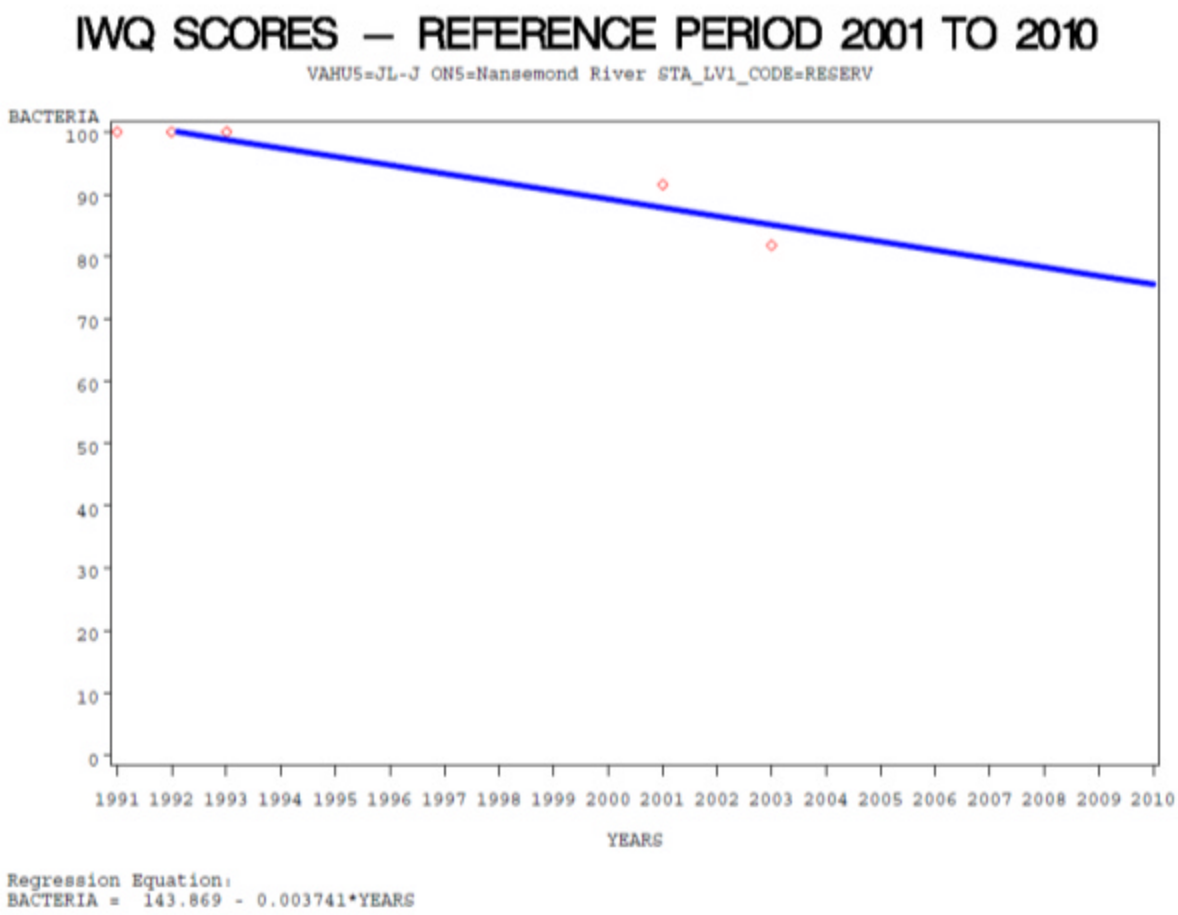


Only two estuaries out of 54 exhibited a declining trend in water quality for bacteria. The upper York River watershed, YO-R, is immediately downstream of West Point, Virginia, at the confluence of the Pamunkey and Mattaponi Rivers. A combination of nonpoint and point sources associated with the Town of West Point may be contributing to the increase in bacteria concentrations in this stretch of the upper York River watershed. The other watershed with declining water quality for bacteria is the Hampton Roads watershed, JL-L. Closer inspection of this watershed reveals that monitoring stations are spread across areas of Hampton in Mill Creek, Hampton River near King Street, Willoughby Bay, the Elizabeth River off Craney Island, and the main stem lower James River. In other words, this watershed is comprised of disparate waters, influenced by different sources of pollution and land use patterns. Thus, care should be taken when interpreting results based on the 5th-order HUC, especially with respect to large rivers or estuaries that may include stations on widely-spaced separate shores. The 6th-order HUC may be a more appropriate scale to characterize these areas, provided there is sufficient data.

Only one watershed out of 61 with reservoir/lake data for bacteria indicated a decline in water quality for bacteria. The results from this watershed, lower James River JL-J, should be considered with caution as there were many reservoir stations representing several lakes and only data from 1991, 1992, 1993, 2001, and 2003 were present. The graphical statistical output for this watershed and waterbody is seen in Figure 4.6-3. Of the 61 watersheds, seven exhibited statistically significant improvements in bacteria water quality.

In summary, water quality conditions for bacteria have greatly improved in the Commonwealth over the last twenty years as indicated by the modified seasonal Kendall results and confirmed with the IWQ results. A possible explanation for these improvements is the implementation of restoration efforts related to the TMDL program, which began the first implementation plans in 2000.

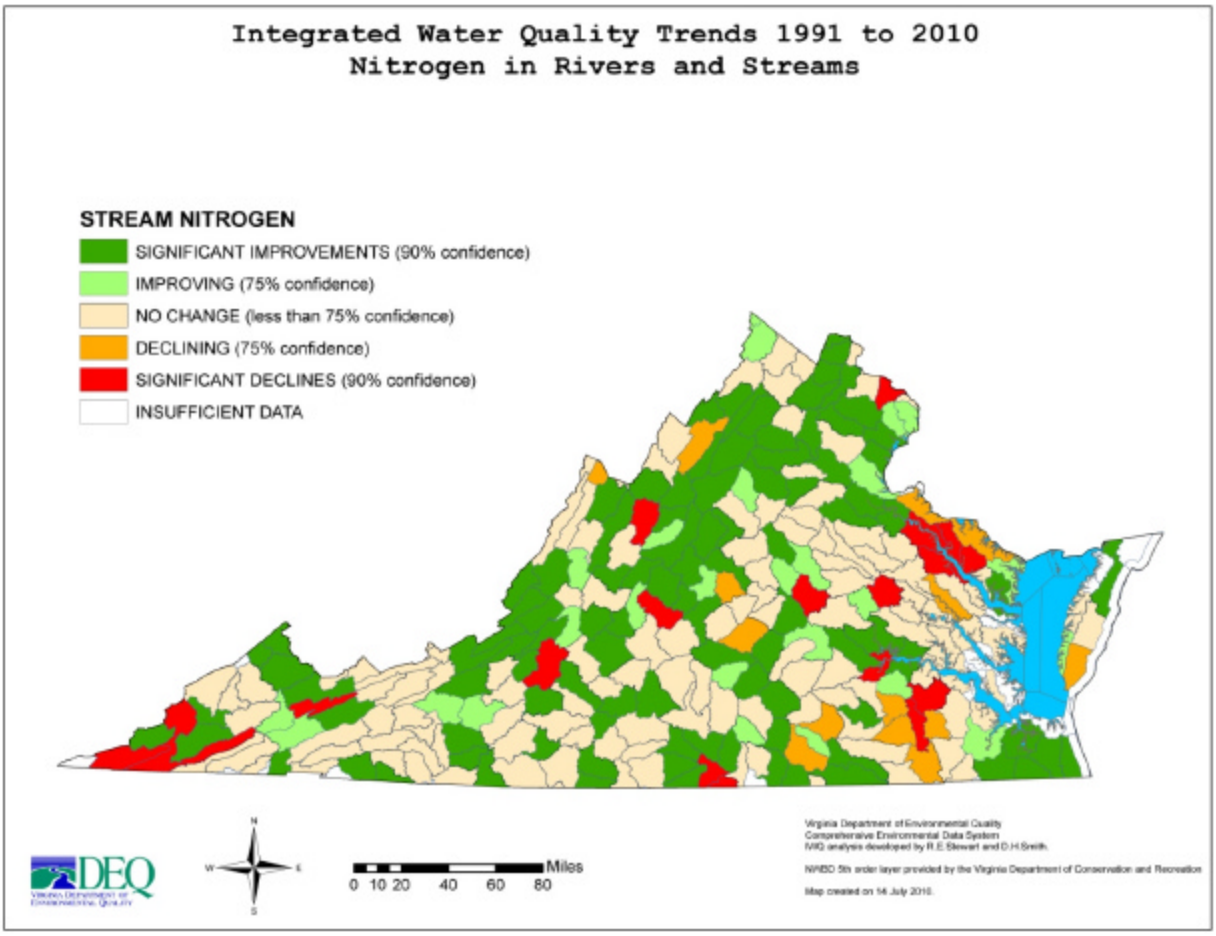
Figure 4.6-3 Bacteria Declining Water Quality, Lower James River



Nitrogen

Almost one-third (103) of the 315 watershed indicated significant improvements in stream/river water quality conditions for nitrogen (see Figure 4.6-4). Nineteen watersheds had significant declines in water quality for nitrogen.

Figure 4.6-4 Nitrogen Trends in Water Quality for Streams and Rivers



Of the 54 estuaries analyzed for long-term trends in nitrogen, 31 showed statistically significant improvement and none showed significant declines.

Of the 60 watersheds that included monitoring on reservoirs, 14 showed significant improvements and three had significant declines in water quality. Those three watersheds in decline include the Fort Pickett Reservoir in the Upper Chowan (Nottoway) basin (three lake stations and a spotty period of record), the Falling Creek watershed on the lower James (only two stations with only four years of monitoring), and the lower North River watershed in the upper Potomac/Shenandoah basin (three separate lakes sampled in only three years out of the twenty.)

Phosphorus

Almost one-third (96) of the 315 watershed indicated significant improvements in stream/river water quality conditions for phosphorus, see Figure 4.6-5. Phosphorus water quality conditions significantly declined in ten watersheds, four of which had less than complete records over the twenty year period. The six watersheds with declining phosphorus conditions include:

AS-B Northwest River, Dismal Swamp/Albemarle Sound,

CB-B Dragon Swamp, Chesapeake Minor Tributaries Western Shore,

JL-D Upper Chickahominy River, Lower James (see Figure 4.6-6).

RA-N Occupacia Creek, Rappahannock,

RA-Q Lancaster Creek, Rappahannock, and

TP-C Wallen Creek, Tennessee/Powell.

Forty-three out of 54 estuaries analyzed indicated significant improvements in water quality for phosphorus and none declined.

Of the sixty watersheds with lakes, fourteen had significant phosphorus improvements and three had significant declines. The three lakes that exhibited increasing concentrations in phosphorus were RD-P Terrible Creek Roanoke/Dan (insufficient period of record), RL-F Middle Lake Gaston Lower Roanoke (insufficient period of record), and YO-F Lake Anna York (short period of record).

Figure 4.6-5 Phosphorus Trends in Water Quality for Streams and Rivers

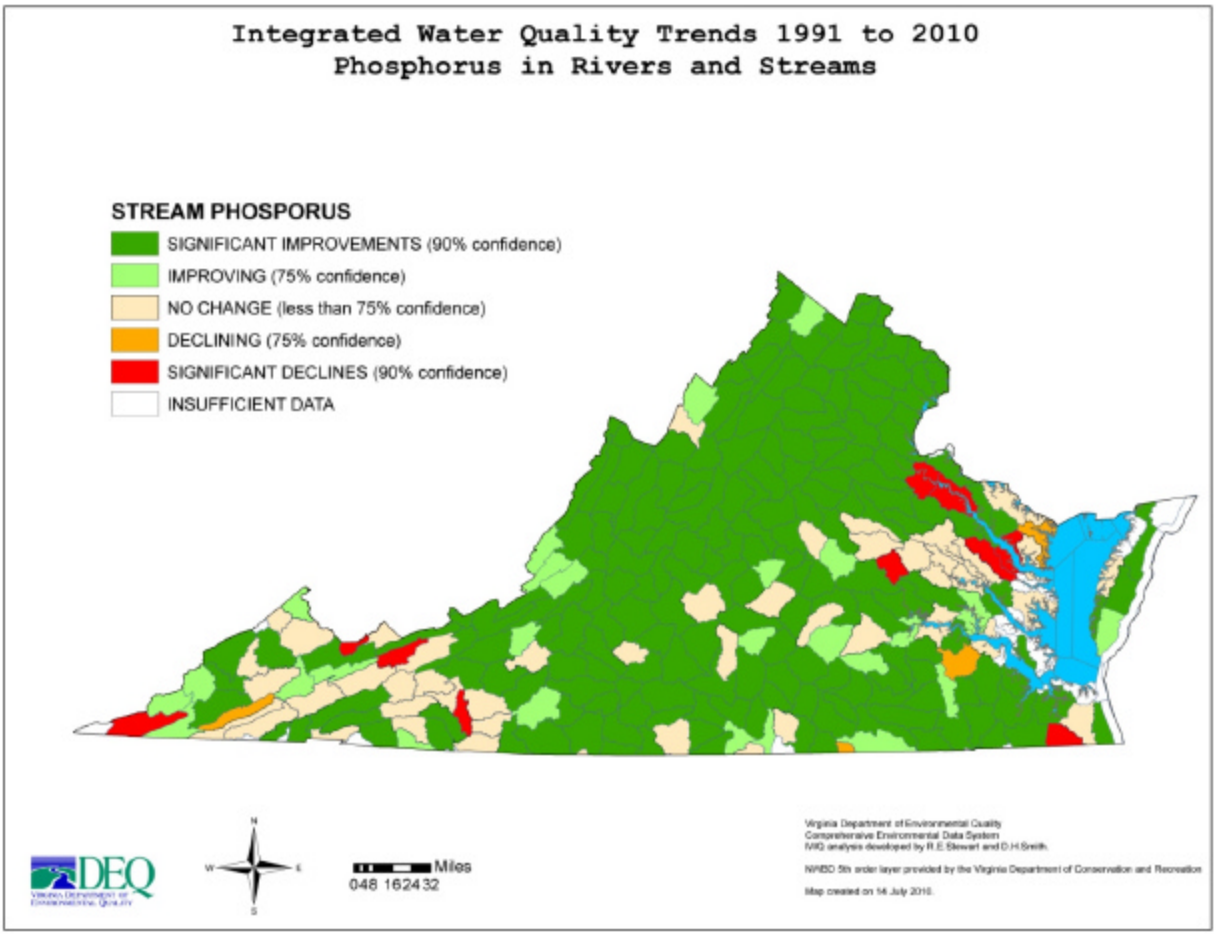
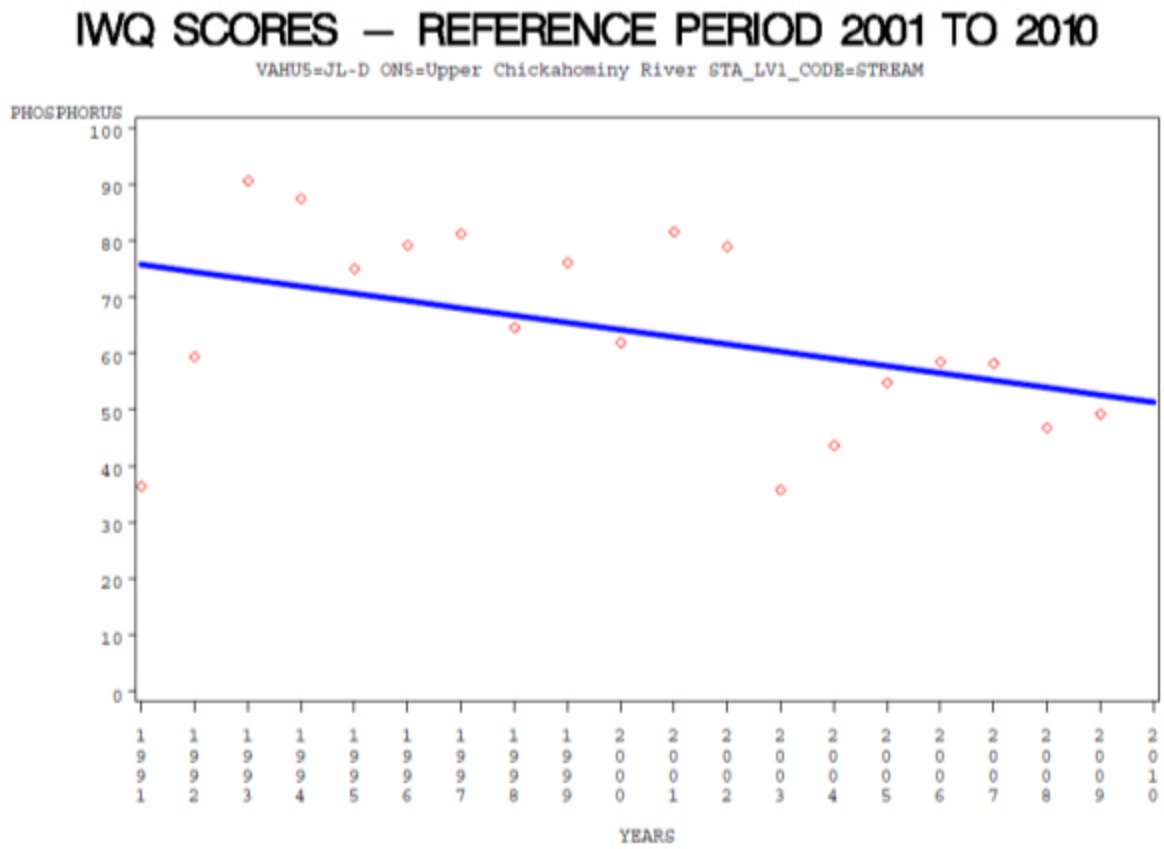


Figure 4.6-6 Phosphorus Declining Water Quality, Upper Chickahominy River-Lower James

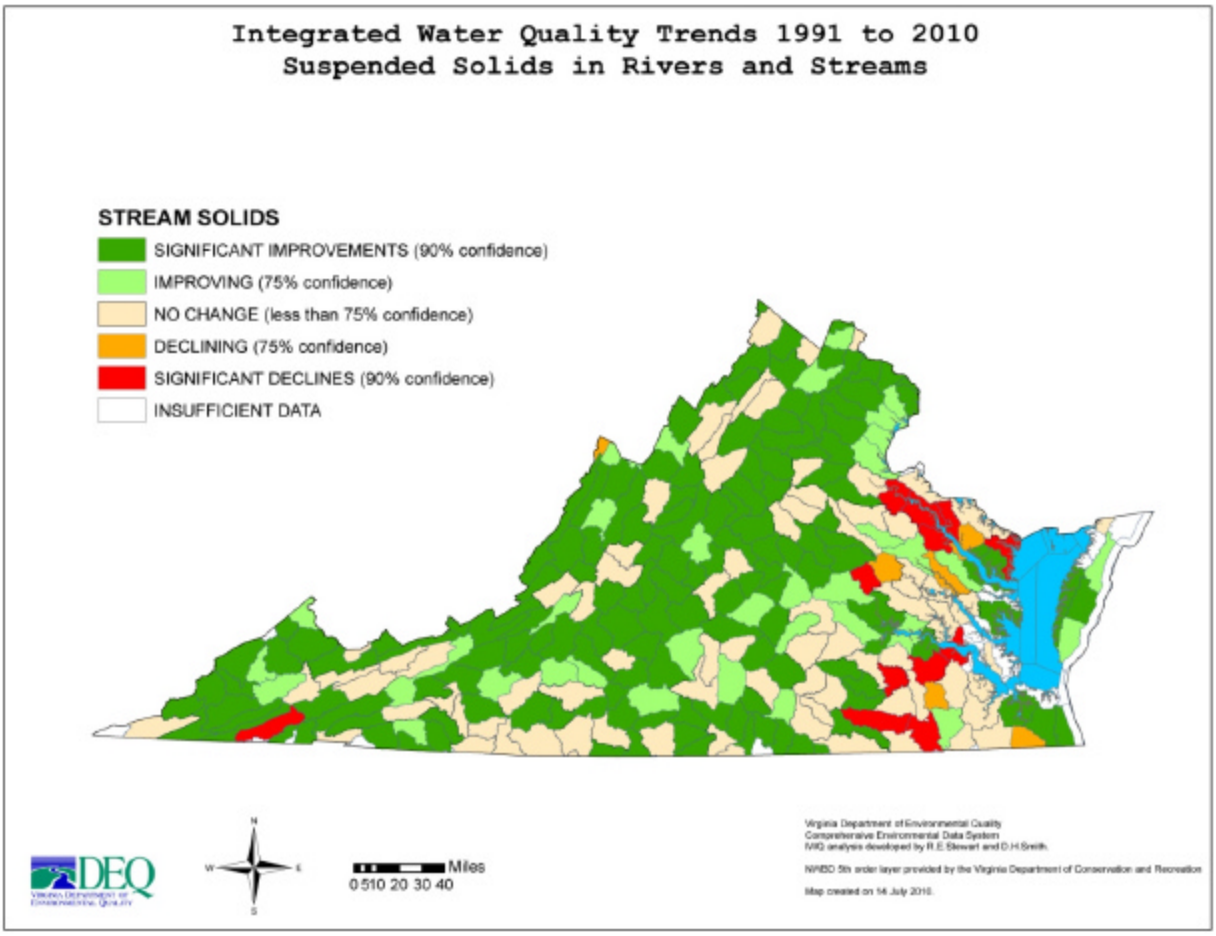


Regression Equation:
PHOSPHORUS = 115.5575 - 0.003517*YEARS

Suspended Solids

Approximately one-half (150) of the 315 watersheds analyzed for trends in streams and rivers had statistically significant improvements in suspended solids (decreasing concentrations) over the twenty-year period. Of those with significant declines, 10 watersheds were located east of the Interstate 95 corridor, and the only other watershed, Abrams Creek in the Tennessee/Holston basin was west (see Figure 4.6-7).

Figure 4.6-7 Suspended Sediment Trends in Water Quality for Streams and Rivers



Five estuarine watersheds had significant declines in suspended solids water quality,

AO-E Magothy Bay, Atlantic Coastal Delmarva,

JL-K Elizabeth River, Lower James,

PL-P Quantico Creek, Lower Potomac,

PL-T Nomini Creek, Lower Potomac and

YO-J Middle Pamunkey River, York.

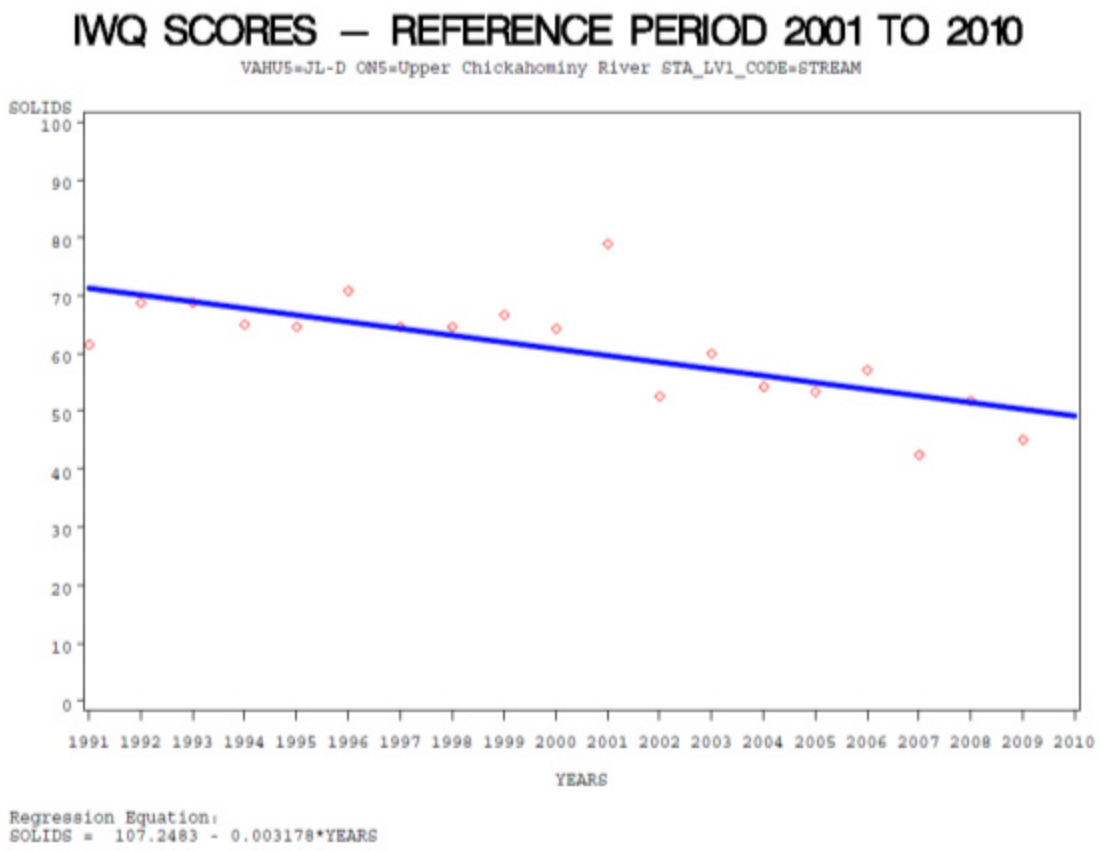
Only 17 of 54 estuarine watersheds had improving quality water for solids. One lake watershed showed a significant decline in solids, however the period of record would indicate further sampling is necessary to accurately characterize the trend. Water quality significantly improved in seven lake watersheds.

Application

The usefulness of the IWQ methodology is demonstrated by comparison of the results in Figure 4.6-8. The dissolved oxygen concentration at this watershed showed a statistically significant increase over the twenty-year period. The pH also increased during this time with a 97% confidence value. The increasing DO and pH could be a result of eutrophication caused by the increasing phosphorus concentration.

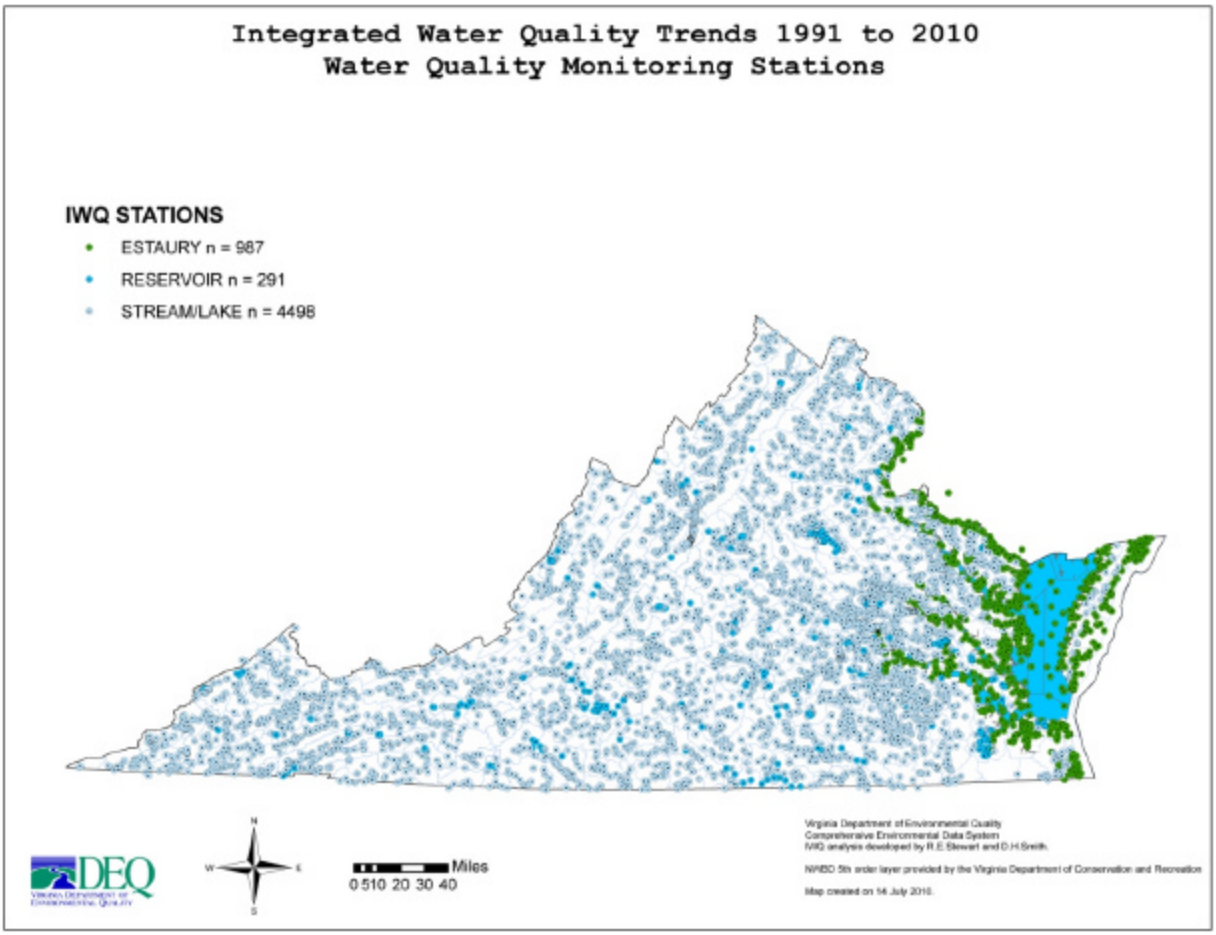
Further inspection of the data by station and season is needed to fully understand this trend. An investigation of land use patterns may provide insight into causes for the decline.

Figure 4.6-8 Suspended Solids Declining Water Quality, Upper Chickahominy River-Lower James



Interpretation of water quality data using Geographic Information System (GIS) technology allows water quality professionals to strategically target problem areas. When used in conjunction with a data management tool such as SAS (9.1.3), the IWQ tool has the potential to handle enormous datasets. For the analysis presented here, it was used to analyze 142,516 sample collection events at 5,776 stations (see Figure 4.6-9). Thus, this innovative approach maximizes the utility of agency monitoring data and emphasizes the importance that each monitoring program has on DEQ's ability to characterize water quality in both time and space.

Figure 4.6-9 VADEQ Stations Used in the IWQ Analysis



All the graphical data for each watershed, waterbody, and variable are viewable at: IWQ_HUC_10.pdf. Tabular numeric data presented here are available for viewing at: STREAM.xls, ESTUARY.XLS, and LAKE.xls. In addition to the four key variables presented here these tabular files contain the results for chlorophyll, pH, temperature, specific conductivity, oxygen saturation, *E.coli*, and *Enterococci*.

APPENDIX SAS PROGRAMS

IWQ.SAS

IWQ_MAPS.SAS