Long-Term Water Quality Trends of the Ohio River and its Tributaries 1990-2007

Ohio River Valley Water Sanitation Commission
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Statistical analyses of data resulting from water quality monitoring conducted by the Ohio River Valley Water Sanitation Commission (ORSANCO)

A study in a series: 1977 to 1987, 1980 to 1990, 1990-2007

Ohio River Valley Water Sanitation Commission
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Abstract

ORSANCO first undertook a study of long-term temporal trends using the agency's own monitoring data in 1990, with 10-15 years of record at most monitoring stations. ORSANCO has since built another 18-year record to be tested for temporal trends. This study presents the results of that analysis and a comparison with the trends discovered in the earlier data set.

The Commission collects water quality samples at 17 locations on the Ohio River and near the mouth of 14 major Ohio River tributaries. Since 1990 the Commission has maintained a minimum of six sample events per year at each location. This study covers the 18-year period from January 1990 to December 2007, picking up where the previous ORSANCO trend analyses ended.

Sufficient data was available to test 18-year trends in seven non-metal water quality parameters: ammonia nitrogen, chloride, total hardness, nitrate-nitrite nitrogen, sulfate, total phosphorus, and total suspended solids. The introduction of a new sampling technique for metals in 2002 sufficiently changed the resulting data set such that this study examines only the 12-year record of total recoverable metals analysis through the end of 2002. The metals aluminum, magnesium, manganese, iron, and zinc have sufficient records for a 12-year trend test with a period ending in 2002.

A nonparametric test, the Seasonal Kendall, was performed both on direct concentrations and on a flow-adjusted basis to facilitate comparison with the Commission's earlier trend assessments. A nonparametric estimator of trend magnitude was calculated for all significant trends ($p < 0.10$).

Of 372 tests for trend (31 locations, 12 water quality parameters) 222 statistically significant ($p < 0.10$) trends were found. Analysis for the current period shows 54% increasing trends while the vast majority of trends (94%) discovered in the 1977 to 1990 studies were in the decreasing direction. One difference between the periods not indicated by that summary is that some parameters, for example copper and phenols, with decreases in the earlier period have apparently experienced declines such that infrequency of pollutant detections in the current period invalidates a test for continuing trends.

Important trends detected include increasing phosphorus concentrations at most Ohio River monitoring stations and increases in chloride concentrations at nearly all stations including tributaries. Sulfate concentrations in the Big Sandy River at the border of West Virginia and Kentucky have steadily increased and are reaching the level of the ORSANCO Water Quality Criterion of 250 milligrams per liter (mg/L).

Introduction

"Is it clean?"
Whether clear and slow or muddied and swift, people sometimes viscerally feel the changes in the Ohio River that come with recent rains and deep droughts. These seasonal and day to day changes in the river can make a sense of its cleanliness hard to grasp. Common perceptions often lead to jokes about the river's cleanliness which belittle its role in many lives. Millions of people live near the Ohio River and its major tributaries, with many communities using it as a primary drinking water source; the recent census[1] confirms still more millions live within the boundaries of the watershed that influences the quality of these waters. A long-term and geographically far-reaching perspective is necessary to fairly characterize the quality of the resource.

"Is it getting better?"
The Ohio River Valley Water Sanitation Commission (ORSANCO) is in a unique position to answer questions of long-term water quality trends. To address Ohio River pollution issues eight states created the Commission in 1948; 24 years before the passing of the 1972 Federal Water Pollution Control Act. Commission monitoring activities began in 1975, two years before President Carter signed major amendments to the law that then became known as the Clean Water Act. ORSANCO long-term monitoring programs span the entire 981-mile length of the Ohio River as it courses through six states. In 2008 ORSANCO monitoring continues into its 34th year. In the length of this monitoring record is a unique power to address the question "Is water quality improving?"

Previous Trend Analyses

ORSANCO undertook a study of temporal trends using its own monitoring data in 1990, with 10 to13 years of record at most monitoring stations. That document "*Water Quality Trends: Ohio River and Its Tributaries* covered the period from 1977 to 1987. In 1992 another report was issued, *Water Quality Trends: Ohio River and Its Tributaries 1980-1990: A Supplement to the 1977-1987 Study*, which covered the first full decade of Commission monitoring.

Since 1990, ORSANCO has amassed another 18-year record of monitoring data. This study presents the results of an analysis for the 18-year period from January 1990 through December 2007 and a comparison with the trends discovered in the earlier data set.

Methods

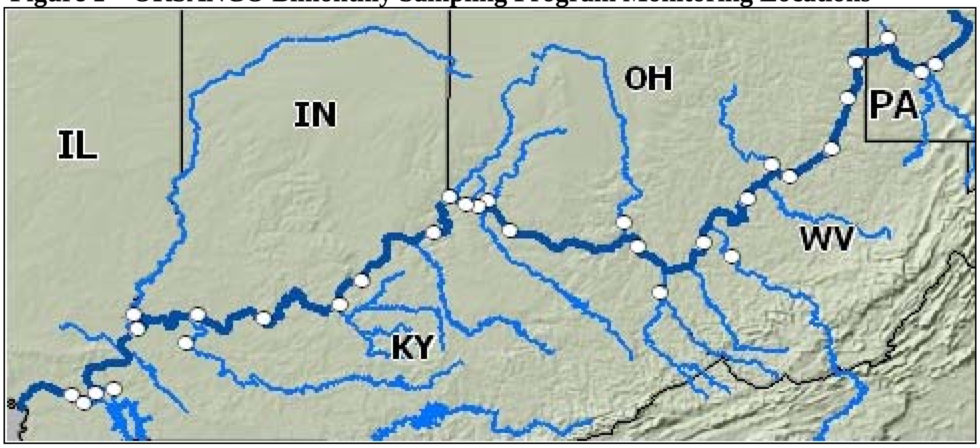
Long-Term Monitoring Programs

ORSANCO's Bimonthly Monitoring Program, in existence since 1975 and formerly called the Manual Sampling program, is the foundation for monitoring data used in this assessment. The Bimonthly Sampling program is comprised of 31 monitoring stations: 17

[1] The 2000 U.S. Census reports 25,000,000 people in the Ohio River Watershed while ORSANCO's most recent effort to quantify population using the river as a primary drinking source is 5.0 - 7.5 million.

locations on the main stem of the Ohio River and 14 points near the mouth of major tributaries. Most samples are collected from United States Army Corps of Engineers Locks and Dams with the remainder collected from bridge or bank locations. Locations of bimonthly sampling stations are shown in Figure 1.

Figure 1 – ORSANCO Bimonthly Sampling Program Monitoring Locations



The Bimonthly Sampling Program currently collects six samples per year, down from a monthly frequency that ended in 1992. A complete table of sampling event frequency by station is presented in Appendix A. The Program's current six-sample annual design is focused on providing long-term trend monitoring of the Ohio River. This low frequency of monitoring eliminates serial correlation in the data which can be troublesome for tests of trend. Samples are collected every second month, in January, March, May, July, September, and November.

Water Quality Parameters and Period of Record

Bimonthly Sampling Program non-metal water quality parameters include ammonia, total organic carbon, chloride, cyanide[2], hardness, nitrate/nitrite, phenolics, total phosphorus, sulfate, total kjeldahl nitrogen, and total suspended solids. An unbroken 18-year period of record exists for each of these parameters at each sampling location.

Metal Parameters

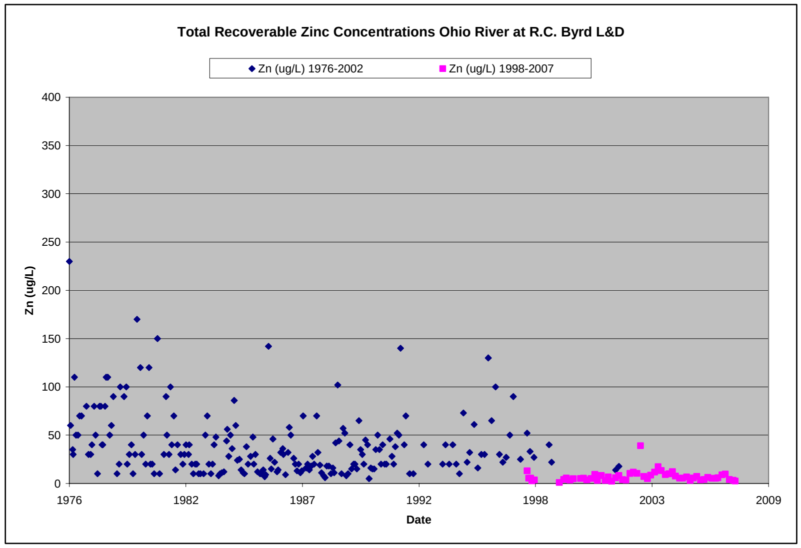
Metal parameters were analyzed through the Bimonthly sampling program through 2002. At that time a new "clean" protocol sampling method for metals was instituted. This new method included new sampling equipment, personnel, and laboratories and began ORSANCO's quantification of dissolved metals in the Ohio River. The change sufficiently altered the nature of results (see Figure 2, Total Recoverable Zinc Results Ohio River at R.C. Byrd Dam) that this study will examine metals for only the 12-year record though the end of the old technique (1990-2002).

All metals data generated by the old technique and examined in this study are total recoverable metal analyses. Sample collection equipment, techniques, and personnel were nearly constant over the study period. In light of this sampling consistency, and solely for

[2] Cyanide only analyzed during winter months at four upper river locations

the purposes of the trend analysis, it was assumed that contamination or laboratory method bias was consistent over the 12-year record, so that underlying trends and trend magnitudes are still meaningful even if actual concentrations are suspect.

Figure 2 – Zinc Ohio River at R.C. Byrd L&D



Metals which were part of the Bimonthly sampling program until 2002 include: aluminum, arsenic, barium, cadmium, chromium, copper, iron, lead, magnesium, manganese, mercury, nickel, selenium, silver and zinc. High detection limits and poor detection rates (>50%) prior to the change in metals techniques eliminate the data for most metals from a meaningful trend analysis. The metals aluminum, iron, magnesium, manganese, and zinc have sufficient records for a 12-year trend test with a period ending in 2002.

Data preparation

Laboratory detection limits can change over time at a single laboratory and often they are different between different laboratories. ORSANCO's recent 18-year bimonthly data set reflects both of these types of changes. Additionally, as program priorities and funding changes, sample frequency and parameters undergo periodic change. This data set also shows these issues of programmatic growth.

Detection Limits and Non-Detects

The rank-based Kendall statistic is resistant to censored values (non-detects) because in many cases the determination of rank can still be made between a detection and a non-detect. A comparison of two non-detects is recorded as a tie, with minimal effect on the outcome of the test unless many ties are present. Detection rates for water quality parameters of the Bimonthly Sampling Program are shown in Table 1.

A simple substitution method was used for non-detects. Non-detects were

Table 1 – Detection Rates

Bimonthly Sampling Program Detection Rates 1990-2007*				
Parameter	Detection Limit	Units	No. Analyses	Percent Detections
Magnesium (Mg)	0.5	mg/L	2732	100%
Iron (Fe)	20.0	ug/L	2780	99%
Hardness as CaCO3	1.0	mg/L	3974	99%
Sulfate (SO_4)	1.0	mg/L	3966	98%
Manganese (Mn)	10.0	ug/L	2782	98%
Chloride (Cl-)	1.0	mg/L	3314	98%
Nitrate-Nitrite (NO2-NO3-N)	0.0	mg/L	3781	97%
Total Organic Carbon (TOC)	0.5	mg/L	1755	97%
Total Kjeldahl Nitrogen (TKN)	0.2	mg/L	2051	94%
Total Suspended Solids (TSS)	1.0	mg/L	3502	94%
Aluminum (Al)	10.0	ug/L	2781	93%
Barium (Ba)	10.0	ug/L	1149	80%
Ammonia (NH_3)	0.03	mg/L	3818	70%
Total Phosphorus (TP)	0.01	mg/L	3819	65%
Zinc (Zn)	10.0	ug/L	2781	65%
Copper (Cu)	5.0	ug/L	2619	37%
Lead (Pb)	1.0	ug/L	2756	34%
Cyanide (CN)	5.0	ug/L	1507	22%
Phenolics	5.0	ug/L	3462	18%
Arsenic (As)	3.0	ug/L	1923	15%
Mercury (Hg)	0.2	ug/L	1926	11%
Nickel (Ni)	5.0	ug/L	1210	9%
Cadmium (Cd)	0.5	ug/L	2784	8%
Chromium (Cr)	5.0	ug/L	1200	8%
Selenium (Se)	3.0	ug/L	1210	2%
Silver (Ag)	0.5	ug/L	1210	0.2%
* metal detections prior to sampling method change in 2002				

equalized to the maximum detection limit of the period with substitution of one-half of that maximum detection limit. This censoring and substitution was applied on a by-station basis to limit the impact of individual laboratories on other portions of the study area.

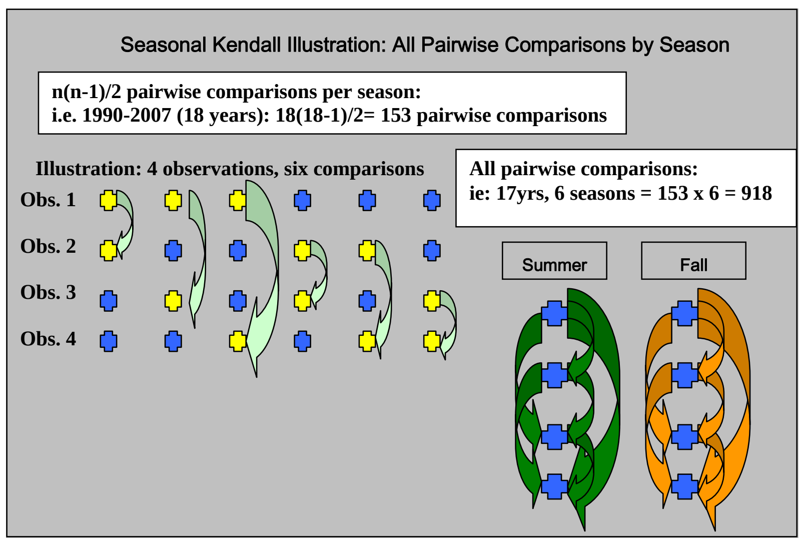
Multiple Samples per Time Period

Monthly sampling from the original Manual Sampling Program did not end until 1992. For the period January 1990 to December 1992 two samples exist for each of the six defined seasons of the current program. The data set was culled as recommended by Helsel and Hirsch (Helsel & Hirsh, 2002, pg 339). Multiple samples were eliminated by determining the sample collected closest to the center of each season and discarding the other sample(s) from the season in question.

Seasonal Kendall Test for Trend

A widely accepted test for trend in water quality data is the modified Kendall's tau test for correlation, called the Seasonal Kendall. This test was used in both of the previous ORSANCO trend assessments. The test has the duel advantages of being both nonparametric (rank-based) and employing a method to remove seasonality from the data set. Because the Seasonal Kendall test for trend is nonparametric, the test inherently removes extremes of magnitude in water quality observations from influencing the outcome of the statistical test.

Figure 3 – Seasonal Kendall Illustration



To address the annual cyclic nature of surface waters in a test for temporal trend, the Seasonal Kendall divides monitoring data into a number of "seasons" based on the lowest sampling frequency in the period of study. The seasons of the Bimonthly Sampling program are the six sample months: January, March, May, July, September, and November.

A rank-based trend test performed on each subset of data should eliminate repeating between-season increases and decreases that can mask an overall trend when those seasonal fluctuations are unaccounted for. The nonparametric correlation statistic Kendall's tau is calculated for each season individually and summed for a test representing the entire period of interest.

Calculation of Tau

Comparisons among the bivariate sample population (X_i, Y_i where X is time and Y a measure of water quality) are made to determine the existence of a trend. Comparisons determine the number of concordant (both X and Y increase) and discordant observations

(X and Y change in opposite directions). All possible pairwise comparisons within a season are made (see Figure 3). Pair comparisons are summed with concordant pairs equal to 1, discordant to -1 and ties of one or both variables equal to zero to find the intermediate statistic “S”. The equation for the Mann-Kendall test statistic as presented by Gilbert (1987):

$$S = \sum_{k=1}^{n-1} \sum_{j-k+1}^{n} \mathrm{sgn}(x_j - x_k)$$

Where: sgn = +1, -1, or 0

The calculation of Kendall’s tau is rank-based in that it counts only if a set of observations is greater than another. Equal weight is given regardless of the magnitude of the change. The S statistic is divided by the standard deviation of the population for Kendall’s tau, a number between one and negative one that indicates the presence of an increasing or decreasing trend.

Seasonal Component

The tau statistic for individual seasons is summed and again divided by the standard deviation (adjusted for ties) of the entire population for the seasonal Kendall test statistic (Z) representing the entire data set. The Z-statistic can then be compared to the standard normal distribution for evaluation of the null hypothesis (H_o = no trend present).

Flow Compensation

A model for flow compensation was used primarily for evaluation of results against previous ORSANCO trend analyses. Discharge compensation is intended to remove the effect of possible trends in stream water flows that can skew trend results for flow-dependant parameters.

Flow compensation was accomplished through the use of a log-log regression model for each parameter and station. This log-log model was used in the previous ORSANCO trend studies. Because the discharge compensation analysis was performed specifically to compare results with those studies, no other regression models (inverse, quadratic or mixtures) were evaluated. The strength of the log-log model was inspected prior to reporting results for each parameter and station.

Regression residuals were tested for normality by inspection of probability plots. This evaluation was used as a basic indicator of regression quality. Qualifying regression residuals were tested for trends over time by the Seasonal Kendall trend test: exactly the same calculations used for directly observed concentrations. Seasonal Kendall results for direct concentration tests are presented in Table 2. Flow-compensated results are shown in Table 3.

The 18-year period examined here likely outlasts multi-year hydrologic cycles that would skew shorter temporal tests for trend. This is evident in the few changes between the direct concentration tests and the flow-compensated results. Flow-adjusted results have been used specifically for between-study comparisons with previous monitoring periods. Regression residuals have not been used to estimate trend magnitude in units of milligrams per liter per year; slope estimates presented later are based on directly-measured concentrations.

Specific Calculation Protocol

Individual season tau values were calculated by the statistical software Statistica® by Statsoft. In the Statsoft product Kendall's tau-b as described by Helsel & Hirsch (Helsel &Hirsch, 2002) is produced by the Kendall tau calculation within the non-parametrics/correlations/advanced statistical module. The Statsoft software produced a tau value for each season, station, and parameter (N=2232). These values were transferred to a Microsoft Access database for further calculations. Individual season tau values (S) were combined into the Seasonal Kendall (S_k) within a Microsoft Access database using the procedure to correct for ties found in both Gilbert and Helsel and Hirsch:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p (t_p - 1)(2t_p + 5) \right]$$

Where:

q= number of tied groups
t_p= number of data in pth group

A customized query structure in Access summed the number of observations, tied values, and extent of tied values to satisfy the above equation for variance. The database could then report a final tau value and Z-score as defined by the equations (Helsel &Hirsch, 2002) below:

$$Z_{S_k} = \begin{cases} \dfrac{S_k - 1}{\sigma_{S_k}} & if \quad S_k > 0 \\ 0 & if \quad S_k = 0 \\ \dfrac{S_k + 1}{\sigma_{S_k}} & if \quad S_k < 0 \end{cases}$$

Where: S_k *= Seasonal Kendall Test Statistic*
σ_{sk} *= variance of S*
Z_{Sk} *= Z-score for Seasonal Kendall*

As in previous ORSANCO trend analyses results were considered significant at p<0.10. Results were considered strongly significant at p<0.05. Four trend classes are indicated in Seasonal Kendall test results tables with the following notation: strong significant increasing trend ("INC", p<0.05, $Z_{0.975}$ = 1.96), significant increasing trend ("inc", p<0.10, $Z_{0.95}$ = 1.64), strong significant decreasing trend ("DEC", p<0.05, $Z_{0.025}$ = -1.96), significant decreasing trend ("dec", p<0.10, $Z_{0.05}$ = -1.64). The notation of trend strength in statistical significance does not indicate the magnitude of an increasing or decreasing trend

Estimated Trend Magnitude

The magnitude of each significant trend was estimated by the use of the nonparametric slope estimator, the Sen-Theil Line. This line is the median slope of all pairwise slopes in the data set (Helsel & Hirsch, 2002). This slope estimate is resistant to outliers that skew the more common Ordinary Least Squares (OLS) slope. Nitrate-Nitrite concentrations on the Kanawha River at Winfield Dam (Figure 4) show the relationship of the OLS slope with the Sen-Theil slope for a data set with high leverage observations (data that strongly affect slope). In this case the OLS slope (0.025 mg/L/yr) is more than double that of the non-parametric slope estimator (0.01 mg/L/yr).

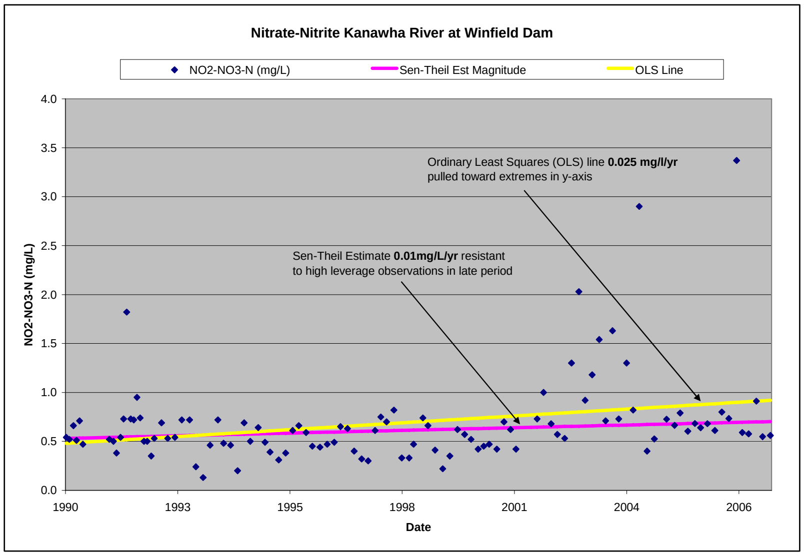
The specific slope estimate calculated here is termed the Seasonal Kendall Slope Estimator because the data was separated by season prior to the calculation of the Sen-Theil line. The Seasonal Kendall Slope Estimate is the median of all pairwise within-season slopes. For most stations 18 years of data and six data points per year produce 918 slopes (n(n-1)/2). The median value of the 918 slopes is the Seasonal Kendall Slope Estimator.

The slope estimator results in a trend estimate in milligrams per liter per year (mg/L/yr). While the statistical significance of the trend itself has been confirmed by the Seasonal Kendall test for each slope estimate presented, the magnitude of the trend in the case of near zero slope estimates is of questionable importance. Two methods to evaluate slope estimates are employed: direct comparison with other estimates of the same water quality parameter (Appendix C), and conversion of slopes to percent changes per year (reference is median concentration) presented in Appendix D.

Slope estimates in mg/L/yr can be directly compared only to other slope estimates for the same parameter. This comparison is available graphically in the column charts of Appendix C.

To discern the relative differences in trends between parameters, the slope estimate is evaluated against typical concentrations of the parameter. The median concentration for each station is compared with the trend estimates in mg/L/yr to covert the slope to a percent change per year, a more transferable indicator of rate of change between parameters (see Appendix D).

Figure 4 – Nitrate-Nitrite Kanawha River at Winfield Dam



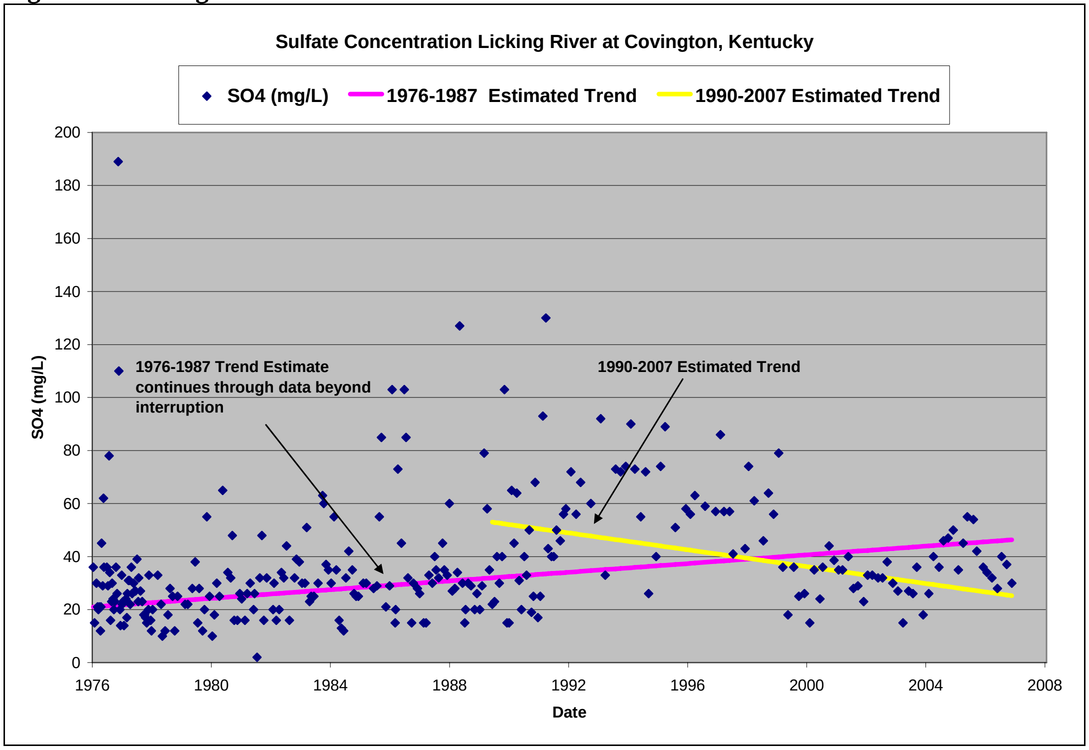
Results

Results of the Seasonal Kendall on non-flow-adjusted "direct" concentrations show a slight majority (54%) of detected trends at all stations were in the increasing direction. Of 372 possible tests (12 water quality parameters for 31 stations) 222 significant trends (increasing or decreasing) were found. Tributaries were neither more nor less likely than the Ohio River to show significant trends. For each water quality parameter discussion below, available ORSANCO or USEPA Recommended Water Quality Criteria has been used as a benchmark to evaluate the importance of trend magnitudes.

A Note about the Licking River 1993-1999

Concentrations of chloride, hardness, nitrate-nitrite, sulfate (Figure 5), and total suspended solids in the Licking River show a temporary increase from 1993 to 1999. It appears from graphical analysis to be an interruption of otherwise continuing trends. Unfortunately, due to the study period under consideration, this causes a loading of higher values in the early years with a subsequent return to lower values that the Seasonal Kendall test indicates is a significant decreasing trend. An effort to discover the cause of this phenomenon is underway; yet those findings are beyond the scope of this analysis.

Figure 5 - Licking River Estimated Sulfate Trend



Visual inspection of all data reported as significant trends was made to determine if temporary impacts like those that appear on the Licking caused other erroneous trend test results. Data patterns confounding trend tests results were not discovered at any other station.

Table 2 - Seasonal Kendall Test on Direct Concentrations

Bimonthly SiteName	River	Al	Cl-	Fe	Hardness	Mg	Mn	NH3-N	NO2-NO3-N	SO4	TP	TSS	Zn
Pittsburgh	Allegheny	O	INC	DEC	INC	INC	DEC	O	INC	O	O	O	dec
South Pittsburgh	Monongahela	O	INC	O	O	INC	DEC	O	inc	O	O	O	DEC
Beaver Falls	Beaver	O	INC	DEC	O	INC	DEC	O	dec	O	INC	O	O
New Cumberland	Ohio	DEC	INC	DEC	INC	INC	DEC	O	INC	O	DEC	DEC	DEC
Pike Island	Ohio	DEC	INC	DEC	O	inc	DEC	DEC	O	O	DEC	DEC	DEC
Hannibal	Ohio	O	INC	DEC	INC	INC	dec	O	O	O	O	O	DEC
Willow Island	Ohio	dec	INC	DEC	inc	INC	DEC	DEC	O	O	DEC	DEC	O
Marietta	Muskingum	DEC	O	DEC	O	INC	DEC	O	O	O	INC	DEC	DEC
Belleville	Ohio	DEC	INC	DEC	inc	INC	DEC	O	O	O	inc	DEC	DEC
Winfield	Kanawha	O	INC	O	INC	INC	inc	O	INC	INC	DEC	O	DEC
R.C. Byrd	Ohio	O	INC	O	O	INC	O	O	O	O	INC	inc	DEC
Louisa	Big Sandy	dec	O	dec	INC	INC	dec	INC	O	INC	O	DEC	DEC
Greenup	Ohio	DEC	INC	O	INC	INC	O	O	INC	O	INC	O	DEC
Lucasville	Scioto	O	inc	O	INC	INC	O	INC	DEC	O	INC	DEC	DEC
Meldahl	Ohio	O	INC	O	DEC	O	O	DEC	DEC	INC	O	O	DEC
Newtown	Little Miami	O	INC	O	inc	INC	O	inc	DEC	O	INC	DEC	dec
Covington	Licking	O	DEC	O	DEC	O	O	DEC	DEC	DEC	O	DEC	DEC
Anderson Ferry	Ohio	dec	INC	O	O	INC	O	INC	O	O	INC	O	O
Elizabethtown	Great Miami	O	O	O	O	inc	O	O	DEC	DEC	O	DEC	O
Markland	Ohio	O	INC	DEC	DEC	O	DEC	O	DEC	inc	INC	DEC	DEC
Louisville	Ohio	O	O	O	O	INC	O	dec	O	INC	INC	O	DEC
West Point	Ohio	DEC	INC	DEC	INC	INC	O	O	O	INC	INC	O	DEC
Cannelton	Ohio	O	INC	DEC	INC	INC	DEC	O	O	INC	INC	O	DEC
Newburgh	Ohio	O	INC	O	INC	INC	O	O	INC	INC	INC	O	DEC
Sebree	Green	dec	INC	O	INC	INC	O	O	INC	INC	INC	O	DEC
J.T. Myers	Ohio	O	INC	dec	INC	INC	DEC	O	O	INC	INC	O	DEC
Route 62 Bridge	Wabash		O	O	O	O	O	O	O	O	O	O	O
Smithland	Ohio	DEC	INC	DEC	INC	INC	dec	O	O	INC	INC	O	O
Pinkneyville	Cumberland	O	INC	inc	INC	INC	O	O	O	INC	INC	O	O
Paducah	Tennessee	DEC	INC	DEC	INC	INC	DEC	O	INC	INC	DEC	O	DEC
L&D 52	Ohio	DEC	INC	DEC	INC	INC	DEC	O	inc	INC	INC	O	DEC

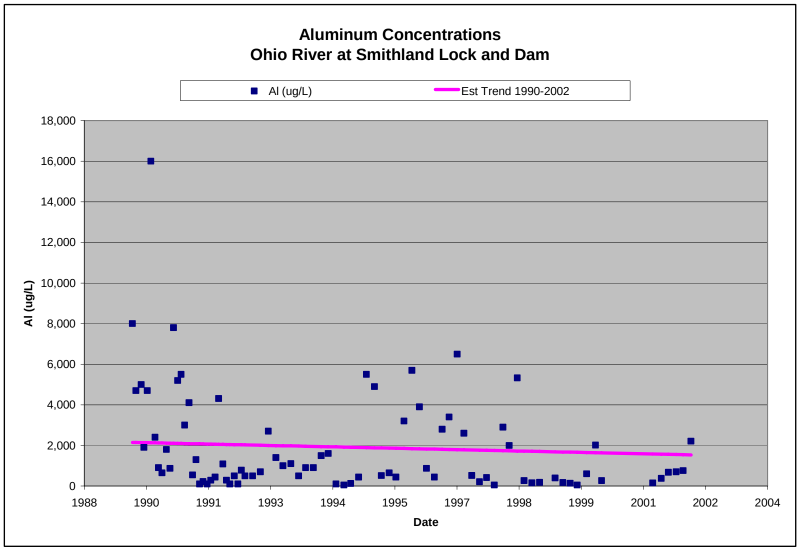
INC - Strong significant increasing trend ($p < 0.05$, Z0.025 = 1.96)
inc - Significant increasing trend ($p < 0.10$, Z0.05 = 1.6449))
O - No significant trend found
dec - Significant decreasing trend ($p < 0.10$, Z0.05 = 1.6449)
DEC - Strong significant decreasing trend ($p < 0.05$, Z0.025 = 1.96)

Note: Declining concentrations are not in themselves indicative of the absence of water quality impairments; i.e.: see narrative in the following section regarding aluminum concentrations.

Aluminum

Concentrations of aluminum in the Ohio River are generally below levels of concern in the upper portion of the basin. Downstream of the Scioto River, however, long-term average concentrations climb to levels above the USEPA National Recommended Concentration Maximum Criteria for total recoverable aluminum of 750 ug/L (USEPA, 2006).

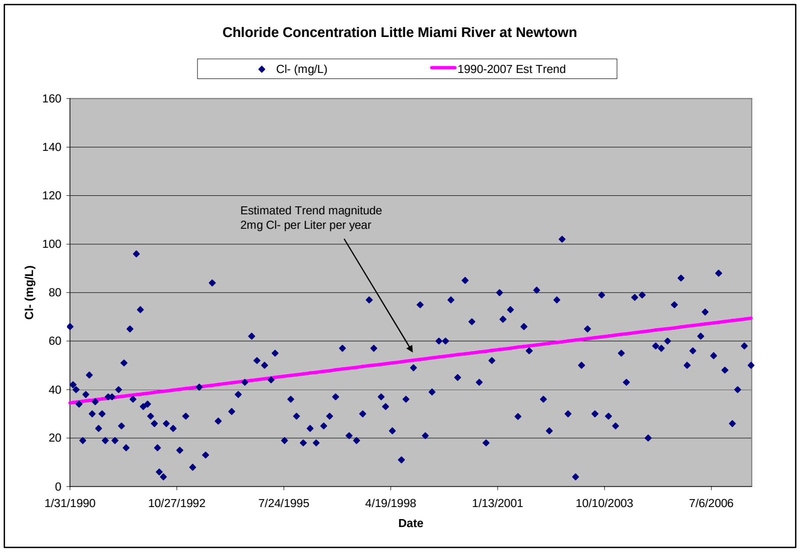
Figure 6 – Aluminum Ohio River at Smithland Dam



Thirteen of the 31 monitoring locations showed a trend in aluminum concentrations, all in the decreasing direction. The greatest decreases (in trend magnitude) found were at the lower river stations West Point, Smithland (Figure 6), and Lock and Dam 52. The slope estimates were similar for the three stations: from 50ug/L/yr at Smithland (see figure at right) to 75 ug/L/yr at L&D 52. That estimated trend magnitude is about 5% of the average concentration found in the Ohio River and its tributaries (~1,300ug/L).

The decreasing trends in aluminum are encouraging; however, concentrations of aluminum are frequently far greater than the USEPA recommended maximum concentration and would take many years *if the trends continue* to decline below that critical level. Aluminum was not part of the previous trend study covering the period from 1975-1990.

Figure 7 – Chloride Little Miami River at Newtown, Ohio



Chloride

Chloride was found to be increasing at most monitoring stations in the basin. Of 25 increasing trends discovered, all were strongly significant ($P<0.05$). Results met an even more stringent test of $p< 0.01$ for 23 of those stations. Estimated slope magnitudes for chloride average 0.75 mg/L/yr with one of the greatest magnitudes (2.0

mg/L/yr) found on the Little Miami River near Cincinnati (Figure 7). Chloride concentrations in the Ohio River and its tributaries average 30mg/L (median 26 mg/L), about ten percent of the ORSANCO water quality criteria of 250mg/L. The highest estimated trend and highest median concentration (48 mg/L) is found in the lowest portion of the Ohio River at Smithland Lock and Dam.

Based on current concentrations and trend magnitude at the Smithland station, projecting the chloride concentration ninetieth percentile (P90 = 95 mg/L, est. mag. 2.7 mg/L/yr) to the Water Quality Criterion of 250 mg/L (which would yield ten percent water quality criteria violations) it would take more than 58 years for the criterion to be exceeded. That period is seemingly an unreasonable range over which to predict; however, in 1967 ORSANCO's first director, Edward J. Cleary, writes: "a review of records dating back to 1914 revealed that over a period of 40 years the chloride-ion concentrations [in the Ohio River] had doubled" (Cleary, 1967). Despite this early observation of increasing Ohio River chloride levels, chloride was unfortunately not part of the two previous ORSANCO trend assessments.

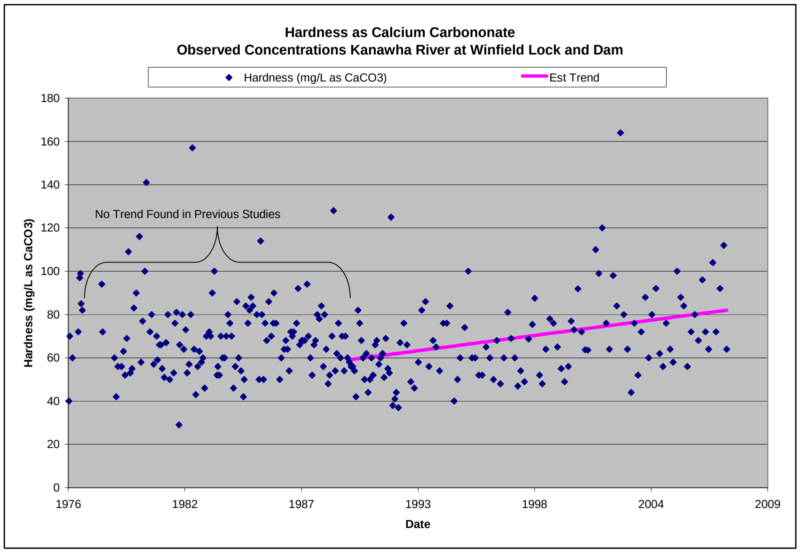
Iron

Iron concentrations are decreasing at all stations for which a trend was detected. Significant decreases were found at most upstream monitoring stations yet at only half of all stations combined – just one station (the Big Sandy River) between the Kanawha and Great Miami Rivers displays a decreasing trend. Decreases in iron concentration were estimated at about 35ug/L/yr, about five percent of median concentrations in the Ohio River and its tributaries. The median concentration of iron in the Ohio River was 1,000ug/L in the period preceding 1990. From 1990 to 2002 the median concentration in the Ohio River had dropped to 720ug/L.

Hardness

In fresh water, hardness is primarily a function of the presence of calcium and magnesium ions, though other metallic ions also contribute to water hardness. Hardness by Standard Method 2340 C is a measure of equivalence to a concentration of calcium carbonate (Hardness as $CaCO_3$) and is not a term specific enough to define its toxicity (USEPA, 1986). Water hardness is tested because increasing hardness reduces the toxicity of other dissolved metals. Many ORSANCO Water Quality Criteria for metals include hardness as a term in their calculation.

Figure 8 – Hardness Kanawha River at Winfield Dam



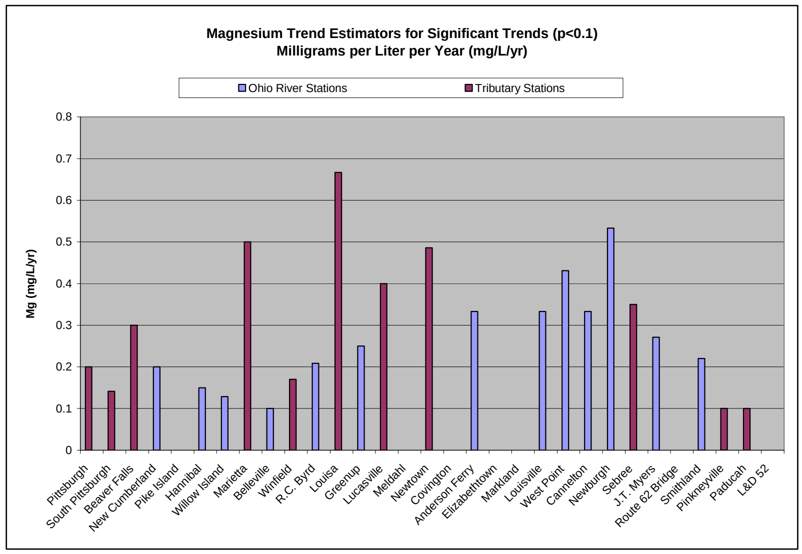
Hardness in the Ohio River is

generally stable. Significant trends were found; however, estimated magnitudes are about one percent of median concentrations. The greatest changes in hardness in the study period were seen in the Big Sandy and Kanawha Rivers. Hardness in the Kanawha River (Figure 8) displays a highly significant increasing trend ($p<0.000$) with an estimated magnitude of 1.3 mg/L/yr.

Magnesium

Nearly all stations show increasing trends in magnesium concentrations. Of 31 monitoring stations 27 were found to have significant increasing trends (25 stations highly significant: $p<0.05$, 2 stations $p<0.10$). No stations exhibited decreasing trends of this metal (Figure 9). Estimated trend magnitudes for all stations were about three percent of average concentrations with rates of about 0.5 mg/L/yr. Increasing trends in this metal are clear, yet of limited interest because other than it's contribution to the hardness of water (and resulting impact on the toxicity of other metals); magnesium has very little toxicity to humans or aquatic life in itself.

Figure 9 – Magnesium Trend Estimates



Manganese

All stations exhibiting a significant trend in manganese show decreasing concentrations over the period of study. ORSANCO does not have a criterion for manganese; however, the USEPA recommended criteria for the protection of human health is 50ug/L, a value exceeded by 75% of samples collected in the study period. Decreases in manganese are estimated at about 3 percent of average concentrations. These decreases are significant yet cannot reliably bring median concentrations or more importantly 90th percentile concentrations below 50ug/L in the near future.

Ammonia

Decreasing trends in ammonia concentrations were detected at five monitoring stations, four stations with strong significance ($p<0.05$). The Seasonal Kendall test result was statistically significant in these cases; however the trends were subtle and yielded estimated magnitudes of near zero in several cases. Increasing trends were also noted at three mid-river tributaries (the Big Sandy, Scioto, and Little Miami Rivers) as well as immediately downstream of Cincinnati at the Anderson Ferry monitoring station (Ohio River mile 477.5); however the Anderson Ferry station is the only of the four increasing trends to have a non-zero trend magnitude (+3 ug/L/yr).

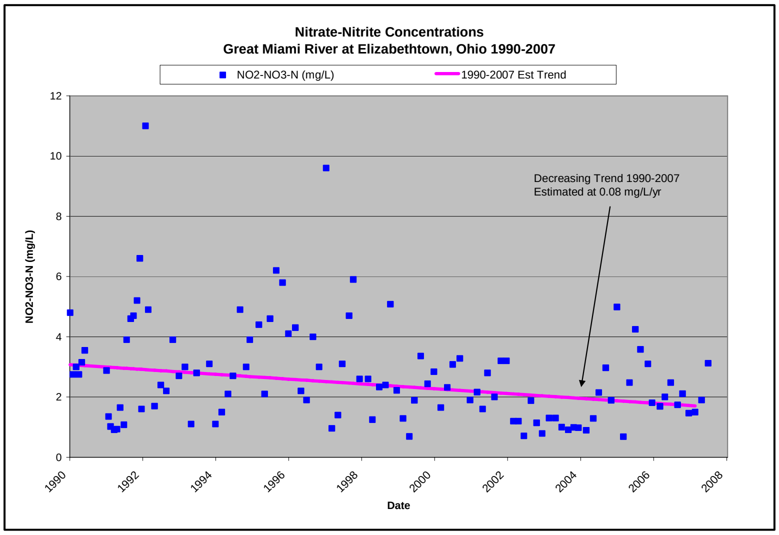
In previous ORSANCO trends analyses ammonia levels were found to be decreasing at all stations with sufficient data. It appears the decreases are slowing to the point where an 18-year study finds no significant trend for most stations. Estimated trend magnitudes in the 1990 study were ten times that of the current period while the trend assessment covering the period from 1980 to 1990 reported magnitudes four or five times that of the five trends detected in the current period.

Nitrate-Nitrite

Trends in nitrate-nitrite indicated increases in the upper and lower portions of the Ohio Basin and decreases in the middle river tributaries from the Scioto River to the Great Miami River. Nitrate increases were on the order of one to two percent of average concentrations while decreases were estimated at three to four percent of average concentrations per year. Of three Ohio River stations among the mid-river tributaries with decreasing concentrations, two: Meldahl and Markland Dams, showed a similar decreasing trend.

The four tributaries with decreasing trends were the Scioto, Little Miami, Licking, and Great Miami (see Figure 10) Rivers. With the exception of the Licking River, three of the four tributaries have the highest median concentrations over the study period. Concentration medians for these tributaries were about 2 mg/L, well below the ORSANCO Water Quality Criteria of 10mg/L. Decreasing trends could bring the tributaries in line with other average concentrations in about fifteen years if current trends continue.

Figure 10 – Nitrate-Nitrite Great Miami River at Elizabethtown



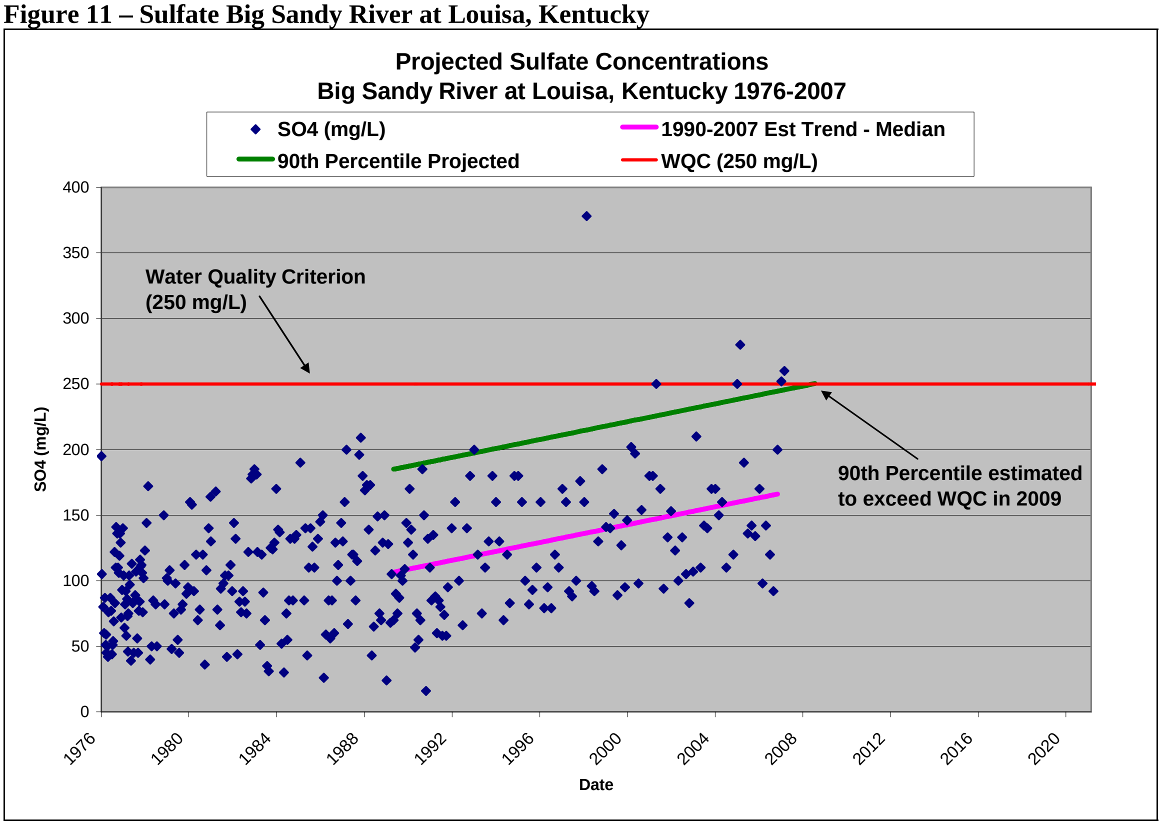
Sulfate

All significant sulfate trends detected were in the increasing direction. ORSANCO's water quality criteria for sulfate is 250mg/L, a value that is rarely exceeded. Since 1990 the criteria has been exceeded just seven times at just three stations: the Big Sandy River, Greenup Lock and Dam, and the Green River.

One of the strongest trends in the entire study is that of increasing sulfate concentrations on the Big Sandy River ($P < 0.0000$). The Big Sandy trend estimate was an increase of 3.38 mg/L/yr while the seven other significant trends were increasing less than one mg/L/yr. Furthermore it appears the Big Sandy trend has been present since monitoring began. In the previous trend study periods nearly all significant sulfate trends were in the decreasing direction yet the Big Sandy was found from 1980 to 1990 to have one of only two (the other on the Great Miami) increasing trends, that trend estimated at 2 mg/L/yr. In the earliest period (1977-1987) only the Green River was found to have an increasing trend.

Figure 11 shows sulfate concentrations in the Big Sandy River at Louisa, Kentucky from 1976 when monitoring began through November 2007, the latest available data. The graph also shows the estimated trend magnitude and applies that trend slope to the station's 90th percentile (1990-2007 $P_{0.9}$ = 185 mg SO_4/L). This exercise illustrates the point when 10% of results are expected to exceed the water quality criterion. By this estimate in 2009 the Big Sandy river segment could be classified as impaired due to sulfate.

Figure 11 – Sulfate Big Sandy River at Louisa, Kentucky

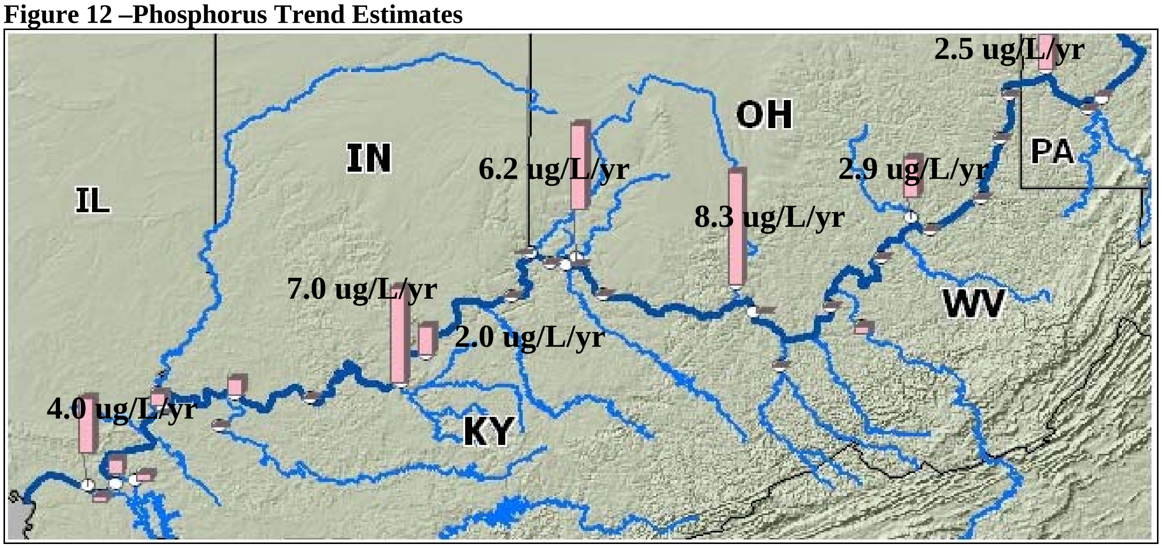


Total Phosphorus

Current proposals on phosphorus discharge from the Mississippi River Basin target 40% reductions in load to the Gulf of Mexico (MRBGMHTF, 2008) to meet his goal it is clear reductions are necessary in the Ohio Basin. Improving conditions (decreasing trends) are seen at just three stations. Median phosphorus concentrations in the Ohio River increase in a downstream direction, peaking downstream of Louisville, Kentucky at about 150 ug/L but remaining about 75ug/L to the most downstream station at L&D 52.

Phosphorus is on the increase at nearly every monitoring station with the exception of three upper Ohio stations: New Cumberland, Pike Island, and Willow Island Dams, and two tributaries: the Kanawha and Tennessee Rivers. Sixteen stations display an increasing trend, all highly significant ($p<0.01$) with one exception, the Little Miami River's increasing trend met a lower level of significance ($p<0.05$), yet that station also produces one of the three highest estimated trend magnitudes at 6.2 ug/L/year (see Figure 12). Estimated phosphorus trend magnitudes average just 2.5 % of median concentrations.

Figure 12 –Phosphorus Trend Estimates



Total Suspended Solids

The presence of suspended solids in the Ohio River is closely related to the level of flow and the distance from the sub-basin source of that flow. The water quality and habitat impact of high solids in the Ohio River is felt more in the levels of particulate-bound pollutants than in the deterioration of bottom substrate habitat as is the concern in smaller rivers and lakes.

Decreasing trends were found on six tributaries and at five Ohio River stations. Just one station showed a significant increasing trend, R.C. Byrd Lock and Dam at Ohio River mile 279.2, though that trend's significance ($p>0.09$) was among the lowest of reported trends. Trend magnitudes were estimated at less than one milligram per liter at most stations, about one percent of average concentrations.

Zinc

Concentrations of zinc are improving (decreasing) at all stations with a significant trend. Twenty-two stations including ten tributaries exhibited strong significant ($P<0.05$) downward trends. Two additional stations, both tributaries, met the lower probability mark of 90 percent ($p<0.10$). Decreases were about 2.5 percent of average concentrations, with the greatest decreases at Lock and Dam 52 with an estimated slope of 1.4 mg/L/year. Typically zinc is well below the ORSANCO Pollution Control Criterion (117ug/L at 100 mg/L hardness, 165ug/L at 150 mg/L hardness) at common hardness levels for the Ohio River.

Basinwide Observations

An indication of each water quality parameter's general trend in the entire basin can be summarized as it was in the previous ORSANCO trend assessments by the number of increasing and decreasing trends weighted by significance level of the tests for trend. The graph in Figure 13 displays the results of assigning a weight to each significance category as follows:

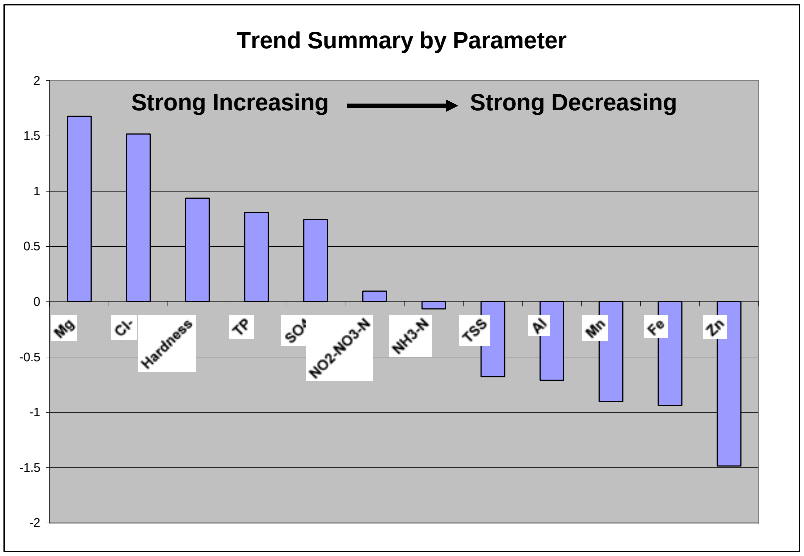
$$\frac{\sum (Npos_{p<0.05} * 2 + Npos_{p<0.10}) + (Nneg_{p<0.05} * -2 + Nneg_{p<0.10} * -1)}{Npossibletrends}$$

The graph clearly illustrates that most metals are on the decrease while nutrients and the non-metal pollutants are rising. This is borne out by a highly significant ($p<0.000$) difference between metal parameters and non-metal parameters in the following 2 x 2 contingency table:

Table 3 – Metals vs. Non-Metals Contingency Table

	Increasing Trends	Decreasing Trends
Metals	29	69
Non-Metals	90	34

Figure 13 – Basinwide Trend Summary



Further breakdown of results reveals that significantly more decreasing trends ($p=0.023$) are found in the upper river than the lower river. The upper/lower river distinction was drawn at Cincinnati, mile 470 of the 981-mile Ohio River. Tributaries were similarly split between the Scioto River and Little Miami Rivers. As would be expected from the information above, it is clear ($p=0.003$) that the increases in the lower river are mainly caused by the non-metal parameters.

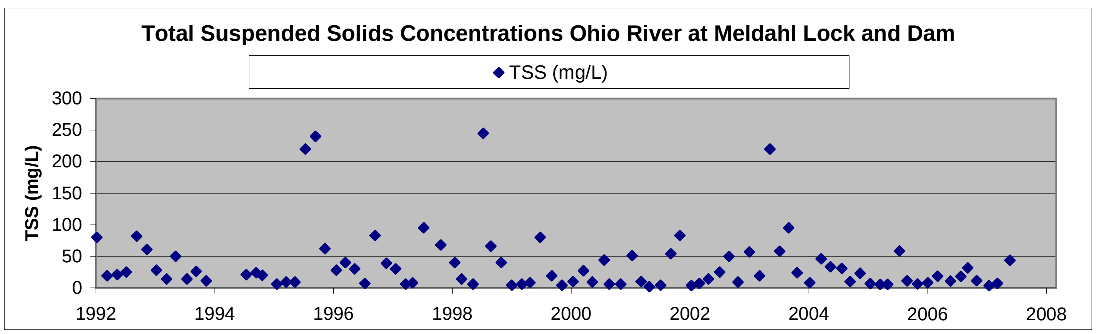
Flow Adjusted Results

Residuals, measurements in the y-direction from an observation to the regression line, from the log-log regression of flow with various water quality parameters were visually evaluated prior to reporting the following results. Although residuals tended to be large in some cases (an indication of weaker models), there are no cases in which residuals were strongly non-normal. Therefore, these results are presented unqualified. All flow-adjusted results are reported in Table 4 and used for comparison with earlier study periods in Table 5.

A majority of detected flow-adjusted trends (63%) were in the increasing direction. Of 276 possible tests (12 water quality parameters for 23 stations with flow data available), 152 significant trends were found. Trend detections in both directions were as likely on tributaries as on the Ohio itself. The use of a flow compensation model had little impact on the type and significance of trends reported. Flow compensation resulted in a slight reduction in the percentage of decreasing trends and a corresponding increase in the percentage of increasing trends.

The two graphs below in Figure 14 illustrate the effect of the regression model on a seasonal Kendall test for trend in Total Suspended Solids (TSS) at Meldahl Lock and Dam. The directly observed concentrations exhibit neither an obvious or statistically significant trend. Plotting the residuals of the log flow vs. log concentration model does not reveal a visually obvious trend, yet the Seasonal Kendall test on residuals produces a significant result (p=0.02) indicating a declining trend in TSS over the period.

Figure 14 – Flow Adjustment: TSS Ohio River at Meldahl L&D



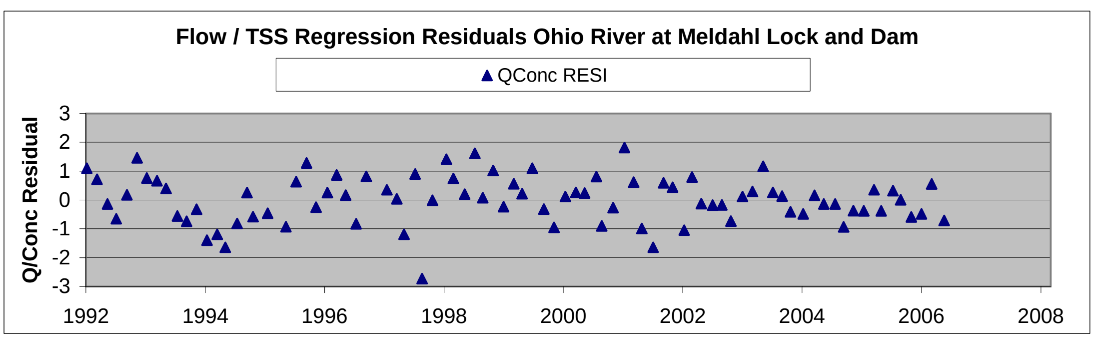


Table 4 - Seasonal Kendall Test on Flow-Adjusted Concentration

Bimonthly SiteName	River	Al	Cl-	Fe	Hardness	Mg	Mn	NH3-N	NO2-NO3-N	SO4	TP	TSS	Zn
Pittsburgh	Allegheny	O	INC	dec	INC	INC	DEC	O	INC	O	INC	O	dec
South Pittsburgh	Monongahela	O	INC	O	O	inc	O	O	inc	O	O	O	DEC
Beaver Falls	Beaver	O	INC	O	INC	INC	O	O	O	O	INC	O	O
New Cumberland	Ohio	--- Insufficient Flow Data ---											
Pike Island	Ohio	dec	INC	O	O	O	dec	DEC	O	O	DEC	DEC	DEC
Hannibal	Ohio	O	INC	O	INC	inc	O	O	inc	O	inc	O	DEC
Willow Island	Ohio	DEC	INC	DEC	INC	INC	DEC	DEC	O	O	O	DEC	O
Marietta	Muskingum	dec	O	O	O	INC	DEC	O	O	O	INC	DEC	DEC
Belleville	Ohio	DEC	INC	DEC	INC	INC	DEC	DEC	O	O	INC	DEC	DEC
Winfield	Kanawha	--- Insufficient Flow Data ---											
R.C. Byrd	Ohio	O	INC	INC	O	INC	inc	O	O	O	INC	INC	DEC
Louisa	Big Sandy	O	DEC	O	INC	INC	O	INC	inc	INC	O	O	O
Greenup	Ohio	O	INC	O	INC	inc	O	O	INC	O	INC	O	DEC
Lucasville	Scioto	DEC	INC	O	INC	INC	O	INC	DEC	inc	INC	DEC	DEC
Meldahl	Ohio	INC	INC	INC	DEC	O	O	DEC	DEC	INC	inc	DEC	O
Newtown	Little Miami	O	INC	O	O	O	O	INC	DEC	dec	INC	O	O
Covington	Licking	O	DEC	O	DEC	O	O	DEC	DEC	DEC	O	DEC	O
Anderson Ferry	Ohio	O	INC	INC	O	INC	INC	INC	O	O	INC	O	O
Elizabethtown	Great Miami	--- Insufficient Flow Data ---											
Markland	Ohio	O	INC	O	DEC	O	DEC	O	dec	O	O	DEC	O
Louisville	Ohio	O	INC	O	inc	INC	O	dec	O	INC	O	O	DEC
West Point	Ohio	DEC	INC	O	INC	INC	O	O	O	INC	INC	O	O
Cannelton	Ohio	O	INC	O	INC	INC	O	O	O	INC	INC	inc	O
Newburgh	Ohio	INC	INC	INC	INC	INC	inc	O	O	INC	INC	O	O
Sebree	Green	--- Insufficient Flow Data ---											
J.T. Myers	Ohio	DEC	INC	DEC	INC	INC	DEC	O	O	INC	O	DEC	DEC
Route 62 Bridge	Wabash	--- Insufficient Flow Data ---											
Smithland	Ohio	O	INC	O	INC	O	O	O	O	inc	INC	O	O
Pinkneyville	Cumberland	--- Insufficient Flow Data ---											
Paducah	Tennessee	--- Insufficient Flow Data ---											
L&D 52	Ohio	--- Insufficient Flow Data ---											

INC - Strong significant increasing trend ($p < 0.05$, $Z_{0.975} = 1.96$)

inc - Significant increasing trend ($p < 0.10$, $Z_{0.95} = 1.6449$))

O - No significant trend found

dec - Significant decreasing trend ($p < 0.10$, $Z_{0.05} = -1.6449$)

DEC - Strong significant decreasing trend ($p < 0.05$, $Z_{0.025} = -1.96$)

Comparison with Earlier Trend Studies

A 1992 ORSANCO trend study, as a supplement to the 1990 study, made the comparison between the first ten years of ORSANCO monitoring from 1977-1987 and the first even decade of monitoring from 1980 to 1990. The greatest change between the two studies was simply the addition of sufficient data for stations and water quality parameters with later start dates. The comparison of trend studies has been limited to the original 1977-1987 study and the current period because estimated trend magnitudes are unavailable for the 1980-1990 supplemental study.

In 1990 35 stations were tested for trends in 15 water quality parameters for a total of 525 possible trend results. 230 significant trends were discovered (44%) in the first data set from 1977 to 1987. The current study period (flow adjusted data set) included 23 stations and 12 water quality parameters, a total of 276 possible trends. In this period 152 significant trends (55%) were found. Because of discontinued monitoring locations and the unavailability of flow data for certain stations where flow was previously available direct comparisons between studies can be made for just 8 parameters at 19 stations (152 tests).

Use of the Seasonal Kendall is unnecessary to evaluate temporal trends for one parameter: phenolics. Concentrations of phenolics showed declines at twelve stations from 1977 to 1987, but were found to have insufficient data at all but one station when the period was moved just three years forward (1980-1990). In the current period, 1990-2007, phenolics are rarely detected (although detections do occur above the criterion) and no station has sufficient data for a trend analysis. Phenolics detection rates in the three periods declined each time from 65% detections 1977-1987 to 61% detection 1980-1990 and finally 18% detections 1990-2007.

Table 5 presents all results from each trend assessment while Table 6 summarizes the differences found between the periods.

Table 5 - Flow-Adjusted Seasonal Kendall Trend Analysis Results 1977 – 2007: 1977-1987, 1980-1990, and 1990-2006

Location		TSS			Ammonia			Sulfate			Zinc			Iron			Total Phosphorus			Hardness			Nitrate-Nitrite		
MP	Site	1977 to 1987	1980 to 1990	1990 to 2007	1977 to 1987	1980 to 1990	1990 to 2007	1977 to 1987	1980 to 1990	1990 to 2007	1977 to 1987	1980 to 1990	1990 to 2007	1977 to 1987	1980 to 1990	1990 to 2007	1977 to 1987	1980 to 1990	1990 to 2007	1977 to 1987	1980 to 1990	1990 to 2007	1977 to 1987	1980 to 1990	1990 to 2007
0.0	Monongahela	dec	DEC	O	DEC	DEC	O	DEC	DEC	O	DEC	DEC	DEC	O	DEC	O	DEC	DEC	O	DEC	-	O	dec	-	inc
0.0	Allegheny	O	DEC	O	DEC	DEC	O	DEC	DEC	O	DEC	DEC	dec	O	DEC	dec	dec	DEC	INC	O	-	INC	O	-	INC
15.2	South Heights	dec	DEC	SD	DEC	DEC	SD	dec	DEC	SD	DEC	DEC	SD	DEC	DEC	SD	DEC	DEC	SD	dec	-	SD	DEC	-	SD
25.4	Beaver	INC	O	O	DEC	DEC	O	DEC	DEC	O	DEC	DEC	O	O	O	O	O	DEC	INC	dec	-	INC	O	-	O
40.2	East Liverpool	O	DEC	SD	DEC	DEC	SD	DEC	O	SD	DEC	DEC	SD	DEC	DEC	SD	DEC	DEC	SD	O	-	SD	O	-	SD
86.8	Wheeling	O	DEC	SD	DEC	DEC	SD	O	O	SD	DEC	DEC	SD	O	DEC	SD	DEC	DEC	SD	O	-	SD	O	-	SD
126.4	Hannibal	O	DEC	O	DEC	DEC	O	O	O	O	DEC	DEC	DEC	O	DEC	O	dec	DEC	inc	O	-	INC	DEC	-	inc
161.8	Willow Island	DEC	O	DEC	DEC	DEC	DEC	O	O	O	DEC	DEC	O	O	DEC	DEC	O	DEC	O	DEC	-	INC	DEC	-	O
172.2	Muskingum	O	DEC	DEC	*	DEC	O	O	DEC	O	O	*	DEC	O	O	O	*	DEC	INC	DEC	-	O	*	-	O
203.9	Belleville	DEC	DEC	DEC	DEC	DEC	DEC	O	O	O	DEC	DEC	DEC	O	DEC	DEC	DEC	DEC	INC	DEC	-	INC	dec	-	O
260.0	Addison	DEC	DEC	SD	DEC	DEC	SD	O	O	SD	DEC	O	SD	DEC	DEC	SD	DEC	O	SD	DEC	-	SD	O	-	SD
265.7	Kanawha	DEC	DEC	NF	*	DEC	NF	O	O	NF	DEC	O	NF	O	DEC	NF	*	DEC	NF	O	-	NF	*	-	NF
279.2	Gallipolis	DEC	DEC	INC	DEC	DEC	O	O	O	O	DEC	DEC	DEC	O	DEC	INC	DEC	DEC	INC	DEC	-	O	dec	-	O
306.9	Huntington	DEC	O	SD	DEC	DEC	SD	O	DEC	SD	O	O	SD	DEC	O	SD	O	O	SD	O	-	SD	O	-	SD
317.1	Big Sandy	DEC	DEC	O	DEC	DEC	INC	O	INC	INC	DEC	DEC	O	DEC	DEC	O	DEC	DEC	O	Inc	-	INC	O	-	inc
350.7	Portsmouth	O	DEC	SD	DEC	DEC	SD	O		SD	O	DEC	SD	O	DEC	SD	DEC		SD	DEC	-	SD	O	-	SD
356.5	Scioto	O	DEC	DEC	*	DEC	INC	O	O	inc	DEC	O	DEC	O	O	O	*	O	INC	O	-	INC	*	-	DEC
408.5	Maysville	O	DEC	SD	*	DEC	SD	O		SD	O	DEC	SD	O	O	SD	*		SD	O	-	SD	*	-	SD
462.8	Cincinnati	O	DEC	O	*	DEC	INC	O	DEC	O	DEC	DEC	O	O	O	INC	*	O	INC	O	-	O	*	-	O
464.1	Little Miami	O	O	O	*	O	INC	O	O	dec	DEC	DEC	O	O	O	O	*	*	INC	O	-	O	*	-	DEC
470.2	Licking	O	O	DEC	DEC	DEC	DEC	Inc	O	DEC	DEC	DEC	O	O	O	O	DEC	O	O	O	-	DEC	O	-	DEC
490.0	North Bend	O	O	SD	*	O	SD	O	DEC	SD	dec	O	SD	O	O	SD	*	O	SD	O	-	SD	*	-	SD
491.1	Great Miami	O	DEC	NF	*	*	NF	O	INC	NF	DEC	DEC	NF	O	DEC	NF	*	O	NF	DEC	-	NF	*	-	NF
531.5	Markland	O	O	DEC	*	DEC	O	O	O	O	DEC	O	O	O	O	O	*	O	O	O	-	DEC	*	-	dec
600.6	Louisville	O	DEC	O	DEC	DEC	dec	O	O	INC	DEC	DEC	DEC	O	DEC	O	DEC	DEC	O	DEC	-	inc	O	-	O
625.9	West Point	DEC	O	O	O	DEC	O	O	DEC	INC	DEC	O	O	DEC	O	O	DEC	O	INC	DEC	-	INC	O	-	O
720.7	Cannelton	O	DEC	inc	*	*	O	O	DEC	INC	O	*	O	O	O	O	*	O	INC	O	-	INC	*	-	O
764.2	Green	O	O	NF	O	DEC	NF	INC	O	NF	DEC	O	NF	O	O	NF	DEC	O	NF	Inc	-	NF	inc	-	NF
791.5	Evansville	DEC	DEC	SD	DEC	DEC	SD	DEC	DEC	SD	DEC	*	SD	DEC	O	SD	DEC	O	SD	O	-	SD	O	-	SD
846.0	Uniontown	O	O	DEC	*	DEC	O	O	DEC	INC	O	*	DEC	O	O	DEC	*	O	O	O	-	INC	*	-	O
848.0	Wabash	O	O	NF	*	DEC	NF	O	O	NF	O	O	NF	O	O	NF	*	O	NF	O	-	NF	*	-	NF
918.5	Smithland	O	DEC	O	*	DEC	O	O		inc	O		O	O	O	O	*	O	INC	DEC	-	INC	*	-	O
920.4	Cumberland	*	*	NF	*	*	NF	*	*	NF	*	*	NF	*	*	NF	*	*	NF	*	-	NF	*	-	NF
934.5	Tennessee	*	DEC	NF	*	DEC	NF	*		NF	*		NF	*	O	NF	*	O	NF	*	-	NF	*	-	NF
952.3	Joppa	DEC	DEC	SD	DEC	DEC	SD	O	*	SD	O	INC	SD	O	O	SD	DEC	O	SD	dec	-	SD	O	-	SD

INC - Strong significant increasing trend ($p < 0.05$, $Z_{0.975} = 1.96$)
inc - Significant increasing trend ($p < 0.10$, $Z_{0.95} = 1.6449$))
O - No significant trend found
dec - Significant decreasing trend ($p < 0.10$, $Z_{0.05} = -1.6449$)
DEC - Strong significant decreasing trend ($p < 0.05$, $Z_{0.025} = -1.96$

NF – Insufficient flow data for compensation
SD – Station Discontinued
\- – Parameter not tested for trend

A general comparison of trend results from current and previous studies shows that a preponderance of declining trends were found in the early years while in the latest period the majority of water quality parameters are increasing. Just 5% of the trends detected from 1977 to 1987 were increasing while 63% of significant trends from the current period are increasing. All but three trends found in data sets previously insufficient for analysis were in the increasing direction.

Table 6 – Summary of Trend Changes from Earlier Study

Comparison Type	1977-1987 To 1990-2007 Change Type	N
Trend Reversal	INC to DEC	1
	DEC to INC	15
New Trend	O to DEC	15
	O to INC	18
Lost Trend	DEC to O	31
	INC to O	1
Unchanged Trend	INC to INC	1
	DEC to DEC	13
	O to O	33
New Data (Prev. Insufficient)	INS to O	12
	INS to INC	9
	INS to DEC	3

So while many of the declining trends discovered in early data were not found in the current period, just 16 individual station/parameters can be said to have a reversed trend (i.e., a decreasing trend now increasing) while 31 previously declining trends have flattened or become statistically insignificant given the information of the later sampling period.

As an example of what would seem to be typical of the overall tendency of fewer decreases and more increases in the latest data, the average trend slope estimate for phosphorus in the 1977-1987 period was a decrease of -12 ng/L while in the latest study the same average reflects an increase of 1.5 ug/L. Iron concentrations were decreasing by 148 ug/L/year on average in the previous period; while they are still decreasing today, the average slope is a decrease of just 34 ug/L/year.

Conclusions

Highlights of the Seasonal Kendall test on data from 1990 to 2007 at each station for each water quality parameter include:

- Phosphorus shows a highly significant (yet low magnitude) increasing trend at most Ohio River monitoring locations with a tendency toward zero or decreasing trends at the most upstream sites.
- Chloride concentrations indicate an increasing trend at nearly all stations.
- The nitrogen parameters ammonia and nitrate-nitrite show nearly equivalent increases and decreases yet the largest trend magnitudes and most decreases are concentrated in the middle river from the Scioto River to Markland Dam.
- Sulfate concentrations are on the increase at all locations downstream of Cincinnati. The greatest increase found is on the Big Sandy River where concentrations are also the highest in the study.
- Magnesium is the only metal parameter with a majority of increasing trends; all other metal parameters are dominated by decreasing trends.

Further Studies

The 1990 Study was quickly followed by a study of trends limited to the first full decade of the monitoring program: 1980-1990. To continue building in that fashion this analysis could be followed with a similar ten-year trend study of 1990-2000 and again in 2010 with the first decade of the 21stcentury. A 2010 study of metal trends since the beginning of the clean sampling technique would also be of interest as by that time ten years of monitoring will be reached for most stations.

Investigations into sources and causes behind important trends should be made. A priority should be collaboration with appropriate parties to evaluate sources of phosphorus increases in the lower river. Sulfate concentrations on the Big Sandy River, which are nearing the critical level of the water quality criterion for aquatic life (250 mg/L), should be addressed. The increases in chloride concentrations that are seen basinwide also require investigation. If sources of pollutant increases can be found for these trends it would be a valuable outcome of the long-term monitoring conducted by the Ohio River Valley Water Sanitation Commission.

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Appendix A – Sampling Event Frequency for the ORSANCO Bimonthly Sampling Program

Mile Point	Location	Monthly Sampling*							Monthly Sampling									
		1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
0.0	Pittsburgh												3	12	12	12	12	9
0.0	South Pittsburgh	6	31	36	30	34	25	18	13	12	12	12	12	12	12	12	12	12
25.4	Beaver Falls	3	31	36	32	35	28	20	12	12	12	12	12	12	12	12	12	12
54.4	New Cumberland																	
84.2	Pike Island																	
126.4	Hannibal			10	33	33	27	19	12	12	12	12	13	12	12	12	11	12
161.8	Willow Island	4	28	35	31	31	20	18	12	12	12	12	12	12	12	12	11	12
172.2	Marietta	4	29	35	32	30	20	18	12	12	12	12	12	12	12	12	12	12
203.9	Belleville	5	27	35	29	12	16	12	12	12	12	12	12	12	12	12	11	12
265.7	Winfield	5	31	31	23	18	12	16	12	12	12	12	12	12	12	12	12	12
279.2	R.C. Byrd	5	30	32	24	17	15	14	13	12	12	12	12	12	12	12	12	12
317.1	Louisa	5	36	31	24	14	15	16	13	12	12	12	12	12	12	12	12	12
341.0	Greenup																	
356.5	Lucasville	3	32	28	21	13	12	12	12	11	11	12	12	12	12	12	12	12
436.2	Meldahl																	
464.1	Newtown		14	30	20	12	12	11	13	12	12	12	12	12	12	12	12	12
470.2	Covington	5	30	41	23	16	13	15	12	11	12	12	12	12	12	12	12	12
477.5	Anderson Ferry																	
491.1	Elizabethtown	5	29	42	24	16	17	12	12	12	12	11	12	12	12	12	12	12
531.5	Markland	5	29	35	24	17	18	17	12	12	13	12	12	12	11	12	12	12
600.6	Louisville	3	27	35	26	20	19	17	12	12	12	12	12	12	12	12	11	11
625.9	West Point	3	26	34	23	18	18	16	12	12	12	12	11	12	12	12	11	12
720.7	Cannelton	5	32	40	27	21	17	16	12	12	12	12	12	12	12	12	12	12
776.0	Newburgh																	
784.2	Sebree	4	26	35	23	12	12	13	12	12	12	12	12	12	12	12	12	12
846.0	J.T. Myers	5	30	33	27	12	12	12	12	12	12	12	12	12	12	12	12	12
848.0	Route 62 Bridge																	
918.5	Smithland								12	12	12	12	12	12	12	12	12	12
920.4	Pinkneyville															9	12	12
934.5	Paducah																	
938.9	L&D 52																	

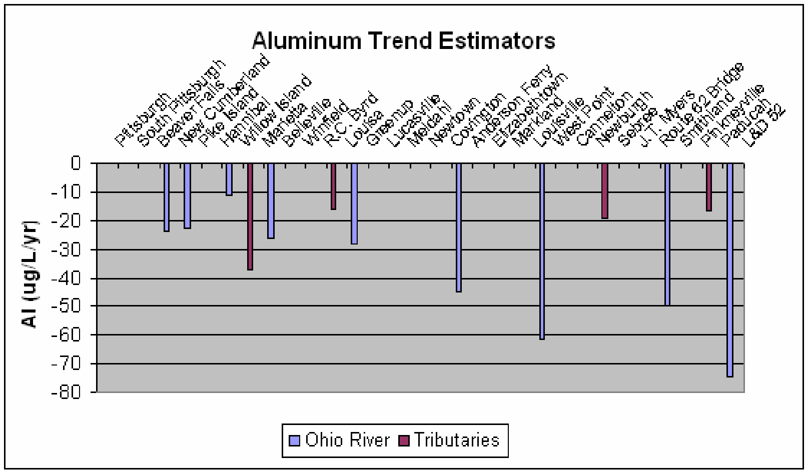
Mile Point	Location	Bimonthly Sampling															
		1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
0.0	Pittsburgh	3	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
0.0	South Pittsburgh	9	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
25.4	Beaver Falls	9	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
54.4	New Cumberland	3	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
84.2	Pike Island	3	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
126.4	Hannibal	9	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
161.8	Willow Island	9	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
172.2	Marietta	9	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
203.9	Belleville	9	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
265.7	Winfield	9	6	6	6	6	6	6	6	6	5	6	6	6	6	6	6
279.2	R.C. Byrd	9	6	6	6	6	6	6	6	5	6	6	6	6	6	6	6
317.1	Louisa	9	6	6	6	6	6	6	6	6	5	6	6	6	6	6	6
341.0	Greenup	3	6	6	6	6	6	6	6	6	6	6	6	6	9	12	9
356.5	Lucasville	9	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
436.2	Meldahl	3	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
464.1	Newtown	9	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
470.2	Covington	8	5	6	6	4	4	5	5	6	6	6	6	6	6	6	6
477.5	Anderson Ferry	3	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
491.1	Elizabethtown	9	6	6	6	6	6	6	6	6	5	6	6	6	6	6	6
531.5	Markland	9	6	6	6	6	6	6	6	5	6	6	6	6	6	6	6
600.6	Louisville	6					3	5	4	6	6	6	6	6	6	6	6
625.9	West Point	9	6	6	6	4	6	5	4	6	6	6	6	6	6	6	6
720.7	Cannelton	9	6	6	4	4	6	6	6	6	6	6	6	6	9	12	9
776.0	Newburgh	3	6	6	4	4	6	6	6	6	6	6	6	6	6	6	6
784.2	Sebree	9	6	6	4	4	6	6	6	6	6	6	6	6	6	6	6
846.0	J.T. Myers	9	6	6	4	4	6	6	6	6	6	6	6	6	6	6	6
848.0	Route 62 Bridge								6	6	6	6	6	6	6	6	6
918.5	Smithland	9	6	6	6	6	6	6	5	6	6	6	6	6	6	6	6
920.4	Pinkneyville	9	6	6	6	6	6	6	5	6	6	6	6	6	6	6	6
934.5	Paducah			3	6	6	6	6	5	6	6	6	6	6	6	6	6
938.9	L&D 52		3	6	6	6	6	6	5	6	6	6	6	6	6	6	6

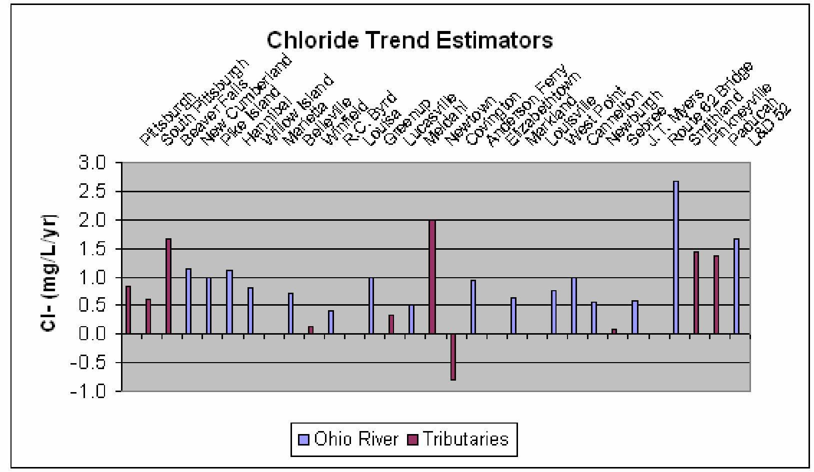
* Monthly sampling with more frequent observations of non-metal parameters
Note: Greenup and Cannelton part of a sub-study requiring monthly sampling in 2005, 2006, 2007

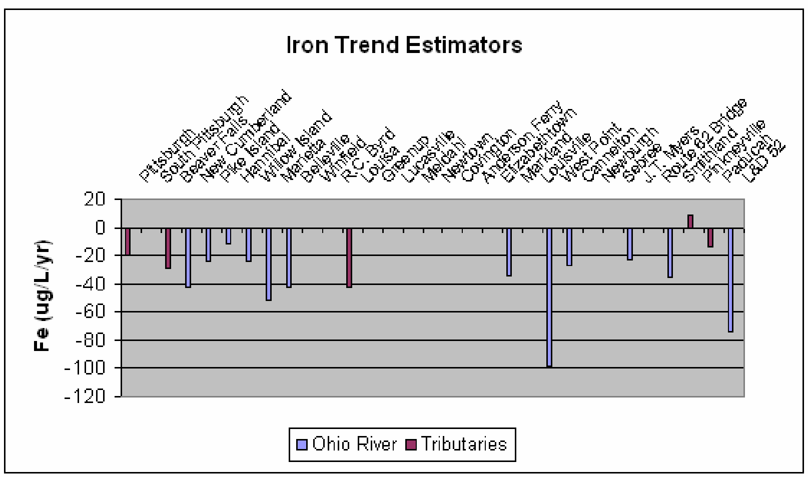
Appendix B – Estimated Trend Magnitudes for Significant Trends

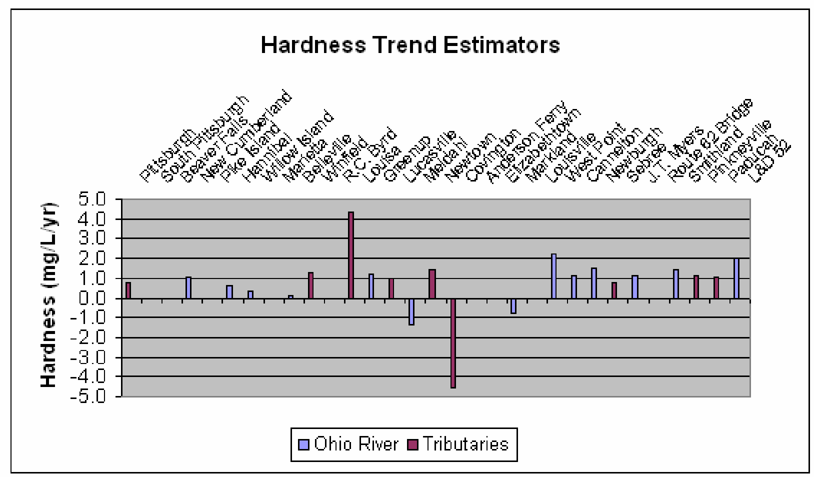
SiteName	River	Al (ug/L/yr)	Cl- (mg/L/yr)	Fe (ug/L/yr)	Hardness (mg/L/yr as CaCO3)	Mg (mg/L/yr)	Mn (ug/L/yr)	NH3-N (mg/L/yr)	NO2-NO3-N (mg/L/yr)	SO4 (mg/L/yr)	TP (mg/L/yr)	TSS (mg/L/yr)	Zn (ug/L/yr)
Pittsburgh	Allegheny		0.8	-20	0.8	0.2	-7.7		0.01				
South Pittsburgh	Monongahela		0.6			0.1	-3.3		0.00				
Beaver Falls	Beaver		1.7	-29		0.3	-3.6		-0.01		0.003		
New Cumberland	Ohio	-24	1.1	-42	1.0	0.2	-7.9		0.01			-0.3	
Pike Island	Ohio	-23	1.0	-24		0.2	-5.0	-0.001				-0.2	-1.0
Hannibal	Ohio		1.1	-12	0.6	0.2	-2.8						
Willow Island	Ohio	-11	0.8	-24	0.3	0.1	-6.9					-0.1	
Marietta	Muskingum	-37		-52		0.5	-7.5				0.003	-0.6	-0.2
Belleville	Ohio	-26	0.7	-42	0.1	0.1	-9.0					-0.4	
Winfield	Kanawha		0.1		1.3	0.2	1.4		0.01	0.9	-0.001		-0.3
R.C. Byrd	Ohio		0.4			0.2						0.3	
Louisa	Big Sandy	-16		-42	4.4	0.7	-1.3			3.4		-0.4	
Greenup	Ohio	-28	1.0		1.2	0.3			0.01				
Lucasville	Scioto		0.3		1.0	0.4			-0.04		0.008	-0.5	-0.7
Meldahl	Ohio		0.5		-1.3			-0.003	-0.03	0.8			
Newtown	Little Miami		2.0		1.4	0.5			-0.05		0.006	-0.3	
Covington	Licking		-0.8		-4.5			-0.003	-0.06	-1.5		-1.2	
Anderson Ferry	Ohio	-45	0.9			0.3		0.003					
Elizabethtown	Great Miami					0.2			-0.08	-0.6		-1.0	
Markland	Ohio		0.6	-35	-0.8		-4.4		-0.01	0.3		-0.5	
Louisville	Ohio					0.3				0.7	0.002		-0.2
West Point	Ohio	-61	0.8	-99	2.3	0.4				1.0	0.007		-0.5
Cannelton	Ohio		1.0	-27	1.1	0.3	-1.1			0.7			
Newburgh	Ohio		0.6		1.5	0.5			0.02	1.0	0.001		
Sebree	Green	-19	0.1		0.8	0.4			0.02	0.6			
J.T. Myers	Ohio		0.6	-23	1.2	0.3	-2.6			0.7			-1.0
Route 62 Bridge	Wabash												
Smithland	Ohio	-50	2.7	-35	1.4	0.2	-1.8			0.8	0.001		
Pinkneyville	Cumberland		1.4	9	1.1	0.1				0.3	0.000		
Paducah	Tennessee	-17	1.4	-14	1.1	0.1	-1.3		0.00	0.3	0.000		
L&D 52	Ohio	-75	1.7	-74	2.0	0.3	-3.5		0.02	1.0	0.004		-1.4

Appendix C – Estimated Trend Magnitude by Parameter

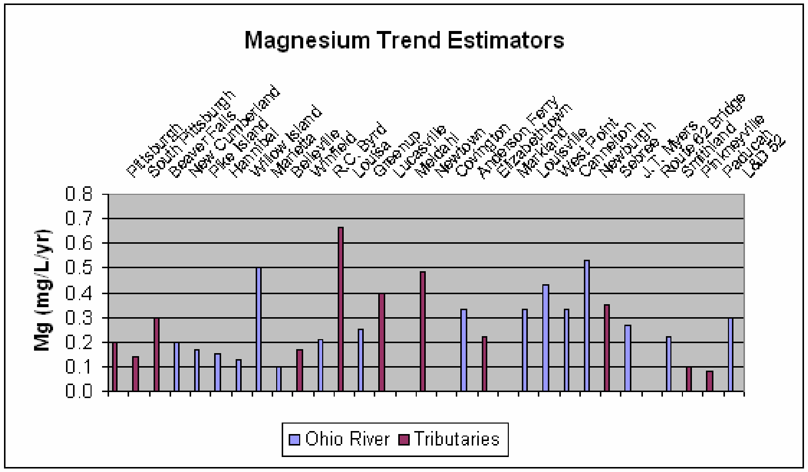


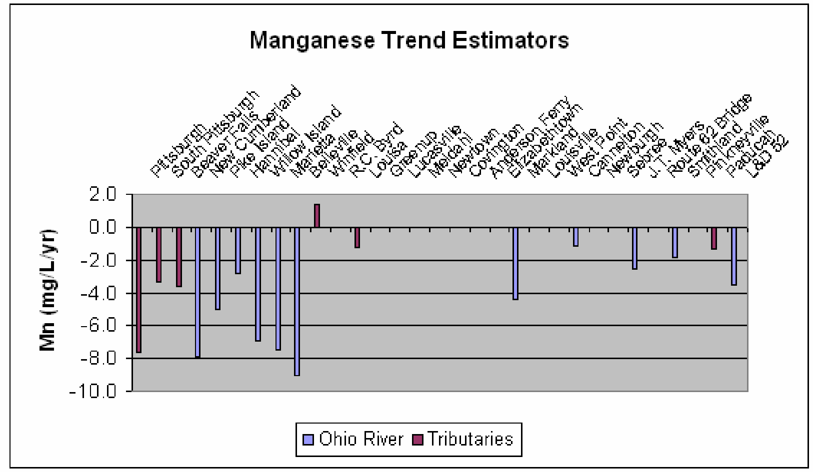


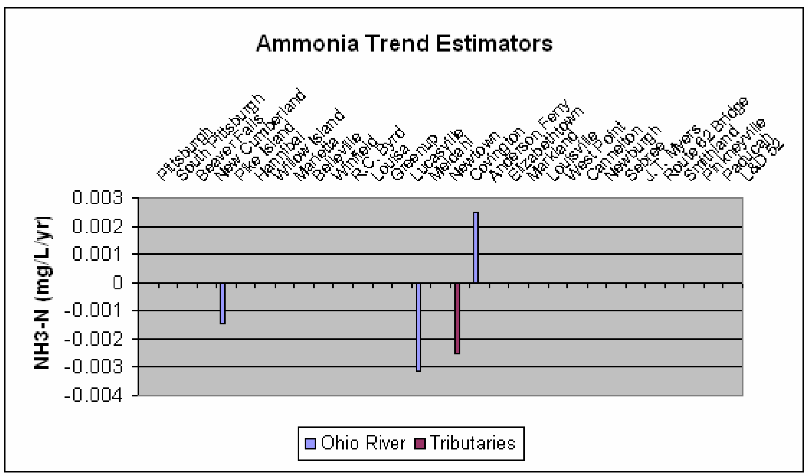


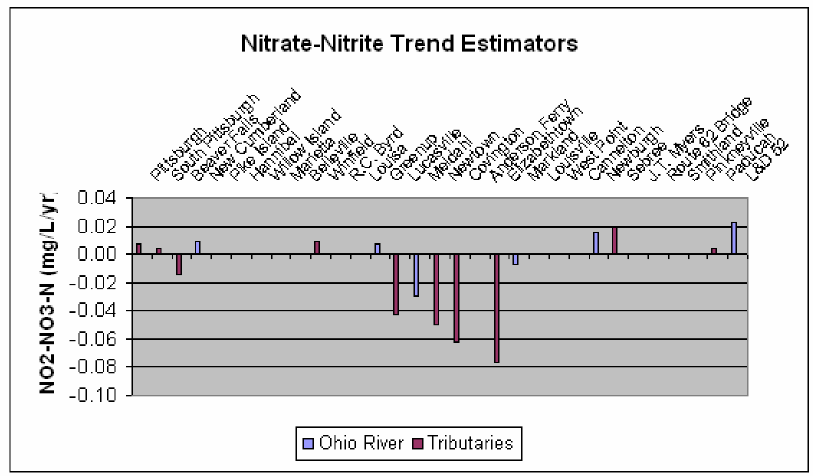


Appendix C (cont.) - Estimated Trend Magnitude by Parameter

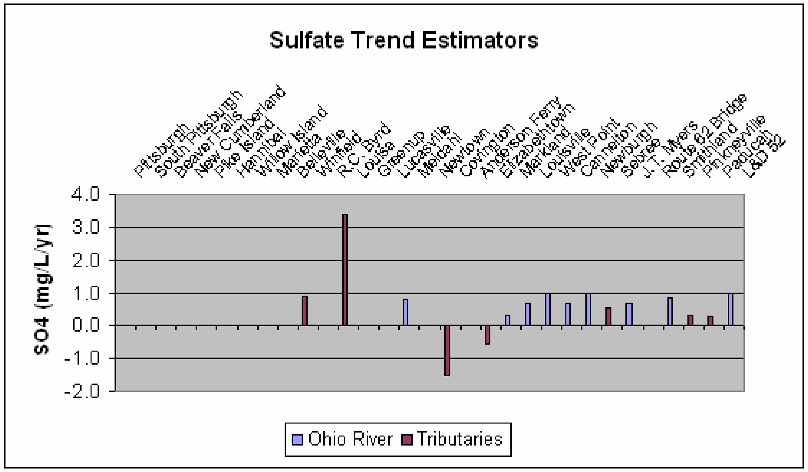


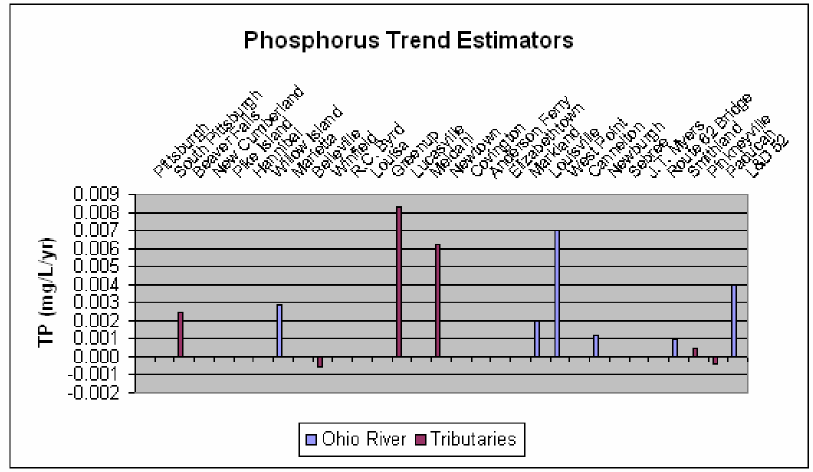


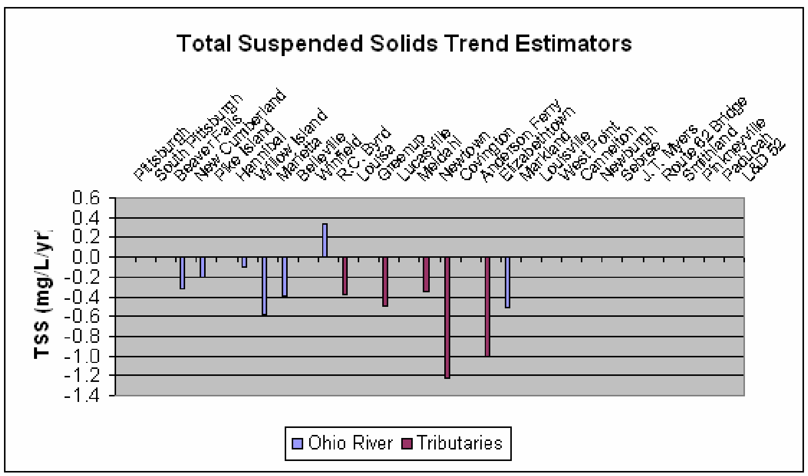


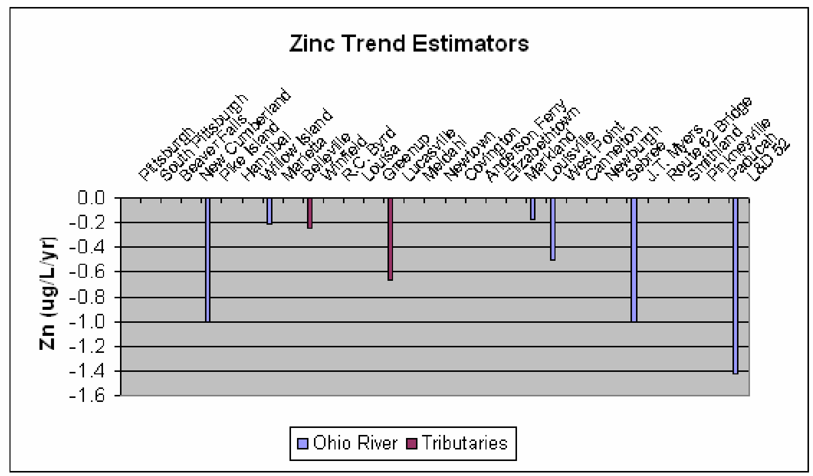


Appendix C (cont.) - Estimated Trend Magnitude by Parameter









Appendix D – Estimated Trend Magnitude as Percent of Median Concentrations

SiteName	River	Al	Cl-	Fe	Hardness	Mg	Mn	NH3-N	NO2-NO3-N	SO4	TP	TSS	Zn
Pittsburgh	Allegheny		4.1%	-3.2%	0.9%	3.1%	-4.0%		1.1%				
South Pittsburgh	Monongahela		3.4%			1.9%	-3.0%		0.6%				
Beaver Falls	Beaver		3.8%	-4.3%		3.0%	-2.9%		-0.9%		2.5%		
New Cumberland	Ohio	-7.9%	4.4%	-7.3%	0.9%	2.6%	-6.6%		1.0%			-3.6%	
Pike Island	Ohio	-6.3%	3.8%	-5.0%		2.1%	-3.8%	-1.8%				-2.9%	-5.2%
Hannibal	Ohio		3.7%	-2.6%	0.5%	1.8%	-3.0%						
Willow Island	Ohio	-3.7%	3.0%	-5.1%	0.3%	1.6%	-6.6%					-1.5%	
Marietta	Muskingum	-6.1%		-6.5%		2.6%	-4.7%				3.2%	-2.4%	-1.8%
Belleville	Ohio	-5.5%	2.4%	-7.1%	0.1%	1.0%	-8.2%					-3.9%	
Winfield	Kanawha	1.3%		2.0%	3.0%	2.5%		1.5%	2.7%	-1.1%		-2.3%	
R.C. Byrd	Ohio		1.7%			2.5%						2.0%	
Louisa	Big Sandy	-2.2%		-4.0%	2.4%	3.9%	-1.4%			2.6%		-1.5%	
Greenup	Ohio	-5.0%	4.5%		1.0%	2.8%			0.9%				
Lucasville	Scioto		0.8%		0.4%	1.7%			-1.9%		5.0%	-1.4%	-3.3%
Meldahl	Ohio		2.1%		-1.0%			-6.3%	-2.7%	1.3%			
Newtown	Little Miami		4.7%		0.6%	2.3%			-2.4%		3.9%	-1.8%	
Covington	Licking		-5.1%		-2.9%			-5.0%	-6.5%	-3.8%		-3.8%	
Anderson Ferry	Ohio	-5.6%	3.6%			3.3%		2.9%					
Elizabethtown	Great Miami					0.8%			-3.4%	-1.0%		-2.5%	
Markland	Ohio		2.4%	-3.5%	-0.5%		-6.3%		-0.6%	0.5%		-2.1%	
Louisville	Ohio					3.0%				1.1%	1.9%		-1.8%
West Point	Ohio	-6.2%	2.8%	-6.2%	1.5%	3.9%				1.5%	4.5%		-2.5%
Cannelton	Ohio		4.2%	-4.5%	0.8%	3.1%	-2.7%			1.1%			
Newburgh	Ohio		2.4%		1.0%	4.7%			1.3%	1.6%	1.4%		
Sebree	Green	-2.3%	0.9%		0.5%	3.8%			2.0%	1.1%			
J.T. Myers	Ohio		2.7%	-2.5%	0.8%	2.7%	-4.2%			1.1%			-6.9%
Route 62 Bridge	Wabash												
Smithland	Ohio	-7.3%	5.6%	-4.4%	0.9%	1.8%	-3.7%			1.5%	1.2%		
Pinkneyville	Cumberland		10.2%	1.8%	1.2%	2.1%				1.4%	0.7%		
Paducah	Tennessee	-5.4%	4.2%	-4.4%	1.6%	2.2%	-3.1%		1.1%	2.0%	-0.7%		
L&D 52	Ohio	-9.1%	3.7%	-10.1%	1.3%	2.7%	-5.7%		1.7%	1.9%	5.7%		-7.2%

Appendix E – Seasonal Kendall Test Summary by Parameter

Parameter	Location	River	Period of Record	Median Concentration	Tau	Tau Interpretation	P-value	Est. Trend Magnitude (units/L/yr)
Al (ug/L)	Pittsburgh	Allegheny	01/90 - 05/02	270	-0.10	O	0.4397	-1.7
	South Pittsburgh	Monongahela	01/90 - 05/02	400	0.04	O	0.7320	3.3
	Beaver Falls	Beaver	01/90 - 05/02	340	-0.17	O	0.1668	-5.0
	New Cumberland	Ohio	07/92 - 05/02	300	-0.57	DEC	**0.0001**	-23.7
	Pike Island	Ohio	07/92 - 05/02	360	-0.44	DEC	**0.0027**	-22.7
	Hannibal	Ohio	01/90 - 05/02	275	-0.16	O	0.1942	-8.0
	Willow Island	Ohio	01/90 - 05/02	300	-0.23	dec	**0.0675**	-11.0
	Marietta	Muskingum	01/90 - 05/02	610	-0.38	DEC	**0.0014**	-37.0
	Belleville	Ohio	01/90 - 05/02	470	-0.49	DEC	**0.0001**	-26.0
	Winfield	Kanawha	01/90 - 05/02	340	-0.18	O	0.1341	-7.5
	R.C. Byrd	Ohio	01/90 - 05/02	510	-0.15	O	0.2561	-16.8
	Louisa	Big Sandy	01/90 - 05/02	740	-0.24	dec	**0.0514**	-16.1
	Greenup	Ohio	07/92 - 05/02	570	-0.32	DEC	**0.0194**	-28.3
	Lucasville	Scioto	01/90 - 05/02	790	-0.15	O	0.2213	-26.0
	Meldahl	Ohio	07/92 - 05/02	600	-0.15	O	0.3042	-15.0
	Newtown	Little Miami	01/90 - 05/02	600	-0.07	O	0.5835	-5.5
	Covington	Licking	01/90 - 05/02	1050	0.03	O	0.8072	8.0
	Anderson Ferry	Ohio	07/92 - 05/02	795	-0.27	dec	**0.0809**	-44.6
	Elizabethtown	Great Miami	01/90 - 05/02	785	-0.16	O	0.1833	-23.5
	Markland	Ohio	01/90 - 05/02	700	-0.15	O	0.2340	-11.5
	Louisville	Ohio	01/90 - 05/02	590	-0.27	O	0.1381	-20.0
	West Point	Ohio	01/90 - 05/02	990	-0.62	DEC	**0.0000**	-61.3
	Cannelton	Ohio	01/90 - 05/02	490	-0.20	O	0.1029	-10.0
	Newburgh	Ohio	07/92 - 05/02	600	-0.11	O	0.4433	-14.3
	Sebree	Green	01/90 - 05/02	815	-0.21	dec	**0.0915**	-18.9
	J.T. Myers	Ohio	01/90 - 05/02	695	-0.20	O	0.1277	-23.8
	Smithland	Ohio	01/90 - 05/02	689	-0.32	DEC	**0.0128**	-50.0
	Pinkneyville	Cumberland	01/90 - 05/02	500	-0.13	O	0.3037	-4.6
	Paducah	Tennessee	01/90 - 05/02	310	-0.36	DEC	**0.0083**	-16.7
	L&D 52	Ohio	07/93 - 05/02	820	-0.39	DEC	**0.0089**	-74.6
Cl- (mg/L)	South Pittsburgh	Monongahela	01/90 - 11/07	18	0.52	INC	**0.0000**	0.62
	Pittsburgh	Allegheny	01/90 - 11/07	20	0.70	INC	**0.0000**	0.83
	Beaver Falls	Beaver	01/90 - 11/07	44	0.59	INC	**0.0000**	1.66
	New Cumberland	Ohio	07/92 - 11/07	26	0.63	INC	**0.0000**	1.14
	Pike Island	Ohio	07/92 - 11/07	26	0.57	INC	**0.0000**	1.00
	Hannibal	Ohio	07/92 - 11/07	31	0.50	INC	**0.0000**	1.12
	Willow Island	Ohio	07/92 - 09/07	27	0.50	INC	**0.0000**	0.80
	Marietta	Muskingum	01/90 - 11/07	42	-0.04	O	0.6644	-0.11
	Belleville	Ohio	07/92 - 11/07	29	0.47	INC	**0.0000**	0.70
	Winfield	Kanawha	01/90 - 11/07	11	0.32	INC	**0.0009**	0.14
	R.C. Byrd	Ohio	07/92 - 11/07	23	0.27	INC	**0.0105**	0.40
	Louisa	Big Sandy	01/90 - 11/07	15	0.08	O	0.4074	0.00
	Greenup	Ohio	07/92 - 11/07	22	0.58	INC	**0.0000**	1.00
	Lucasville	Scioto	01/90 - 11/07	40	0.19	inc	**0.0522**	0.33
	Meldahl	Ohio	07/92 - 11/07	24	0.35	INC	**0.0007**	0.50
	Newtown	Little Miami	01/90 - 11/07	43	0.55	INC	**0.0000**	2.00
	Covington	Licking	01/90 - 11/07	16	-0.34	DEC	**0.0006**	-0.81
	Anderson Ferry	Ohio	07/92 - 11/07	26	0.50	INC	**0.0000**	0.94
	Elizabethtown	Great Miami	01/90 - 11/07	52	-0.14	O	0.1446	-0.50
	Markland	Ohio	07/92 - 11/07	26	0.43	INC	**0.0000**	0.63
	Louisville	Ohio	07/97 - 11/07	28	0.18	O	0.1892	0.53
	West Point	Ohio	07/92 - 11/07	27	0.48	INC	**0.0000**	0.75
	Cannelton	Ohio	07/92 - 11/07	24	0.57	INC	**0.0000**	1.00
	Newburgh	Ohio	07/92 - 11/07	23	0.45	INC	**0.0000**	0.56
	Sebree	Green	01/90 - 11/07	9	0.24	INC	**0.0148**	0.08
	J.T. Myers	Ohio	07/92 - 11/07	22	0.43	INC	**0.0001**	0.58
	Route 62 Bridge	Wabash	01/99 - 11/07	27	-0.02	O	0.8662	0.00
	Smithland	Ohio	07/92 - 11/07	48	0.59	INC	**0.0000**	2.67
	Pinkneyville	Cumberland	01/90 - 11/07	14	0.74	INC	**0.0000**	1.43
	Paducah	Tennessee	01/90 - 11/07	33	0.58	INC	**0.0000**	1.35
	L&D 52	Ohio	07/93 - 11/07	45	0.42	INC	**0.0001**	1.67

Appendix E (cont.) – Seasonal Kendall Test Summary

Parameter	Location	River	Period of Record	Median Concentration	Tau	Tau Interpretation	P-value	Est. Trend Magnitude (units/L/yr)
Fe (ug/L)	South Pittsburgh	Monongahela	01/90 - 05/02	720	0.01	O	0.9315	-1.3
	Pittsburgh	Allegheny	01/90 - 05/02	630	-0.39	DEC	**0.0018**	-20.0
	Beaver Falls	Beaver	01/90 - 05/02	670	-0.41	DEC	**0.0007**	-29.0
	New Cumberland	Ohio	07/92 - 05/02	580	-0.61	DEC	**0.0000**	-42.1
	Pike Island	Ohio	07/92 - 05/02	475	-0.39	DEC	**0.0081**	-23.8
	Hannibal	Ohio	01/90 - 05/02	463	-0.26	DEC	**0.0346**	-12.0
	Willow Island	Ohio	01/90 - 05/02	470	-0.37	DEC	**0.0037**	-24.0
	Marietta	Muskingum	01/90 - 05/02	800	-0.34	DEC	**0.0043**	-52.0
	Belleville	Ohio	01/90 - 05/02	590	-0.46	DEC	**0.0004**	-42.0
	Winfield	Kanawha	01/90 - 05/02	455	-0.03	O	0.7968	0.0
	R.C. Byrd	Ohio	01/90 - 05/02	730	-0.13	O	0.3062	-17.5
	Louisa	Big Sandy	01/90 - 05/02	1050	-0.23	dec	**0.0605**	-42.0
	Greenup	Ohio	07/92 - 05/02	665	-0.16	O	0.2696	-8.0
	Lucasville	Scioto	01/90 - 05/02	900	-0.06	O	0.6435	-15.0
	Meldahl	Ohio	07/92 - 05/02	750	-0.14	O	0.3425	-21.4
	Newtown	Little Miami	01/90 - 05/02	750	-0.07	O	0.5581	-9.2
	Covington	Licking	01/90 - 05/02	1400	0.02	O	0.9048	3.0
	Anderson Ferry	Ohio	07/92 - 05/02	1000	-0.17	O	0.2736	-30.0
	Elizabethtown	Great Miami	01/90 - 05/02	833	-0.18	O	0.1429	-24.0
	Markland	Ohio	01/90 - 05/02	1000	-0.26	DEC	**0.0362**	-34.6
	Louisville	Ohio	01/90 - 05/02	770	-0.26	O	0.1645	-32.0
	West Point	Ohio	01/90 - 05/02	1600	-0.56	DEC	**0.0001**	-99.0
	Cannelton	Ohio	01/90 - 05/02	595	-0.31	DEC	**0.0135**	-26.7
	Newburgh	Ohio	07/92 - 05/02	550	-0.22	O	0.1275	-13.8
	Sebree	Green	01/90 - 05/02	970	-0.14	O	0.2691	-16.0
	J.T. Myers	Ohio	01/90 - 05/02	883	-0.25	dec	**0.0629**	-22.5
	Route 62 Bridge	Wabash	01/99 - 05/02	2640	0.11	O	0.7423	265.0
	Smithland	Ohio	01/90 - 05/02	785	-0.36	DEC	**0.0054**	-34.8
	Pinkneyville	Cumberland	01/90 - 05/02	510	0.20	inc	**0.0929**	9.0
	Paducah	Tennessee	01/90 - 05/02	315	-0.45	DEC	**0.0010**	-14.0
	L&D 52	Ohio	07/93 - 05/02	730	-0.47	DEC	**0.0017**	-74.0
Hardness (mg/L as CaCO3)	Pittsburgh	Allegheny	01/90 - 11/07	87	0.35	INC	**0.0003**	0.75
	South Pittsburgh	Monongahela	01/90 - 11/07	110	0.11	O	0.2536	0.31
	Beaver Falls	Beaver	01/90 - 11/07	152	0.11	O	0.2424	0.39
	New Cumberland	Ohio	07/92 - 11/07	110	0.34	INC	**0.0011**	1.04
	Pike Island	Ohio	07/92 - 11/07	119	0.07	O	0.4996	0.13
	Hannibal	Ohio	01/90 - 11/07	120	0.21	INC	**0.0292**	0.60
	Willow Island	Ohio	01/90 - 11/07	120	0.16	inc	**0.0987**	0.33
	Marietta	Muskingum	01/90 - 11/07	234	-0.02	O	0.8021	-0.05
	Belleville	Ohio	01/90 - 11/07	140	0.18	inc	**0.0618**	0.14
	Winfield	Kanawha	01/90 - 11/07	65	0.62	INC	**0.0000**	1.29
	R.C. Byrd	Ohio	01/90 - 11/07	110	0.06	O	0.5271	0.00
	Louisa	Big Sandy	01/90 - 11/07	180	0.77	INC	**0.0000**	4.36
	Greenup	Ohio	07/92 - 11/07	120	0.40	INC	**0.0001**	1.20
	Lucasville	Scioto	01/90 - 11/07	251	0.22	INC	**0.0229**	1.00
	Meldahl	Ohio	07/92 - 11/07	132	-0.37	DEC	**0.0004**	-1.33
	Newtown	Little Miami	01/90 - 11/07	237	0.17	inc	**0.0768**	1.40
	Covington	Licking	01/90 - 11/07	158	-0.39	DEC	**0.0001**	-4.54
	Anderson Ferry	Ohio	07/92 - 11/07	132	0.17	O	0.1013	0.44
	Elizabethtown	Great Miami	01/90 - 11/07	292	0.01	O	0.8953	0.00
	Markland	Ohio	01/90 - 11/07	140	-0.20	DEC	**0.0391**	-0.75
	Louisville	Ohio	01/90 - 11/07	148	0.18	O	0.1426	0.33
	West Point	Ohio	01/90 - 11/07	153	0.60	INC	**0.0000**	2.25
	Cannelton	Ohio	01/90 - 11/07	140	0.42	INC	**0.0000**	1.13
	Newburgh	Ohio	07/92 - 11/07	148	0.43	INC	**0.0001**	1.48
	Sebree	Green	01/90 - 11/07	144	0.32	INC	**0.0012**	0.78
	J.T. Myers	Ohio	01/90 - 11/07	140	0.38	INC	**0.0001**	1.17
	Route 62 Bridge	Wabash	01/99 - 11/07	232	0.07	O	0.5357	1.48
	Smithland	Ohio	01/90 - 11/07	160	0.42	INC	**0.0000**	1.41
	Pinkneyville	Cumberland	01/90 - 11/07	97	0.53	INC	**0.0000**	1.14
	Paducah	Tennessee	01/90 - 11/07	65	0.62	INC	**0.0000**	1.06
	L&D 52	Ohio	07/93 - 11/07	152	0.34	INC	**0.0016**	2.00

Appendix E (cont.) – Seasonal Kendall Test Summary

Parameter	Location	River	Period of Record	Median Concentration	Tau	Tau Interpretation	P-value	Est. Trend Magnitude (units/L/yr)
Mg (mg/L)	South Pittsburgh	Monongahela	01/90 - 05/02	8	0.32	INC	**0.0068**	0.14
	Pittsburgh	Allegheny	01/90 - 05/02	7	0.57	INC	**0.0000**	0.20
	Beaver Falls	Beaver	01/90 - 05/02	10	0.57	INC	**0.0000**	0.30
	New Cumberland	Ohio	07/92 - 05/02	8	0.51	INC	**0.0005**	0.20
	Pike Island	Ohio	07/92 - 05/02	8	0.27	inc	**0.0705**	0.17
	Hannibal	Ohio	01/90 - 05/02	8	0.32	INC	**0.0078**	0.15
	Willow Island	Ohio	01/90 - 05/02	8	0.32	INC	**0.0115**	0.13
	Marietta	Muskingum	01/90 - 05/02	19	0.55	INC	**0.0000**	0.50
	Belleville	Ohio	01/90 - 05/02	10	0.31	INC	**0.0141**	0.10
	Winfield	Kanawha	01/90 - 05/02	6	0.59	INC	**0.0000**	0.17
	R.C. Byrd	Ohio	01/90 - 05/02	9	0.58	INC	**0.0000**	0.21
	Louisa	Big Sandy	01/90 - 05/02	17	0.81	INC	**0.0000**	0.67
	Greenup	Ohio	07/92 - 05/02	9	0.69	INC	**0.0000**	0.25
	Lucasville	Scioto	01/90 - 05/02	23	0.43	INC	**0.0003**	0.40
	Meldahl	Ohio	07/92 - 05/02	11	-0.12	O	0.3892	0.00
	Newtown	Little Miami	01/90 - 05/02	21	0.30	INC	**0.0137**	0.49
	Covington	Licking	01/90 - 05/02	15	-0.06	O	0.6818	0.00
	Anderson Ferry	Ohio	07/92 - 05/02	10	0.71	INC	**0.0000**	0.33
	Elizabethtown	Great Miami	01/90 - 05/02	28	0.22	inc	**0.0810**	0.22
	Markland	Ohio	01/90 - 05/02	11	0.17	O	0.1770	0.10
	Louisville	Ohio	01/90 - 05/02	11	0.94	INC	**0.0000**	0.33
	West Point	Ohio	01/90 - 05/02	11	0.74	INC	**0.0000**	0.43
	Cannelton	Ohio	01/90 - 05/02	11	0.62	INC	**0.0000**	0.33
	Newburgh	Ohio	07/92 - 05/02	11	0.77	INC	**0.0000**	0.53
	Sebree	Green	01/90 - 05/02	9	0.49	INC	**0.0001**	0.35
	J.T. Myers	Ohio	01/90 - 05/02	10	0.60	INC	**0.0000**	0.27
	Route 62 Bridge	Wabash	01/99 - 05/02	20	0.33	O	0.1884	1.77
	Smithland	Ohio	01/90 - 05/02	12	0.35	INC	**0.0064**	0.22
	Pinkneyville	Cumberland	01/90 - 05/02	5	0.62	INC	**0.0000**	0.10
	Paducah	Tennessee	01/90 - 05/02	4	0.75	INC	**0.0000**	0.08
	L&D 52	Ohio	07/93 - 05/02	11	0.35	INC	**0.0198**	0.30
Mn (ug/L)	Pittsburgh	Allegheny	01/90 - 05/02	190	-0.60	DEC	**0.0000**	-7.67
	South Pittsburgh	Monongahela	01/90 - 05/02	110	-0.42	DEC	**0.0005**	-3.30
	Beaver Falls	Beaver	01/90 - 05/02	124	-0.39	DEC	**0.0011**	-3.60
	New Cumberland	Ohio	07/92 - 05/02	120	-0.65	DEC	**0.0000**	-7.90
	Pike Island	Ohio	07/92 - 05/02	133	-0.51	DEC	**0.0005**	-5.00
	Hannibal	Ohio	01/90 - 05/02	93	-0.22	dec	**0.0661**	-2.80
	Willow Island	Ohio	01/90 - 05/02	104	-0.59	DEC	**0.0000**	-6.90
	Marietta	Muskingum	01/90 - 05/02	160	-0.62	DEC	**0.0000**	-7.50
	Belleville	Ohio	01/90 - 05/02	110	-0.81	DEC	**0.0000**	-9.00
	Winfield	Kanawha	01/90 - 05/02	57	0.21	inc	**0.0844**	1.40
	R.C. Byrd	Ohio	01/90 - 05/02	107	0.02	O	0.8789	0.00
	Louisa	Big Sandy	01/90 - 05/02	90	-0.20	dec	**0.0942**	-1.25
	Greenup	Ohio	07/92 - 05/02	85	-0.22	O	0.1103	-1.50
	Lucasville	Scioto	01/90 - 05/02	60	-0.17	O	0.1621	-0.75
	Meldahl	Ohio	07/92 - 05/02	70	-0.13	O	0.3443	-1.86
	Newtown	Little Miami	01/90 - 05/02	48	0.01	O	0.9710	0.08
	Covington	Licking	01/90 - 05/02	110	0.04	O	0.7539	1.10
	Anderson Ferry	Ohio	07/92 - 05/02	93	-0.21	O	0.1761	-3.17
	Elizabethtown	Great Miami	01/90 - 05/02	60	-0.17	O	0.1667	-0.63
	Markland	Ohio	01/90 - 05/02	70	-0.53	DEC	**0.0000**	-4.38
	Louisville	Ohio	01/90 - 05/02	68	-0.26	O	0.1590	-1.10
	West Point	Ohio	01/90 - 05/02	109	-0.21	O	0.1268	-3.02
	Cannelton	Ohio	01/90 - 05/02	41	-0.27	DEC	**0.0330**	-1.11
	Newburgh	Ohio	07/92 - 05/02	45	-0.20	O	0.1800	-0.50
	Sebree	Green	01/90 - 05/02	130	-0.07	O	0.5955	-0.73
	J.T. Myers	Ohio	01/90 - 05/02	61	-0.34	DEC	**0.0108**	-2.56
	Route 62 Bridge	Wabash	01/99 - 05/02	154	-0.26	O	0.3239	-12.00
	Smithland	Ohio	01/90 - 05/02	50	-0.24	dec	**0.0571**	-1.84
	Pinkneyville	Cumberland	01/90 - 05/02	66	0.07	O	0.5465	0.55
	Paducah	Tennessee	01/90 - 05/02	43	-0.40	DEC	**0.0039**	-1.33
	L&D 52	Ohio	07/93 - 05/02	61	-0.38	DEC	**0.0114**	-3.50

Appendix E (cont.) – Seasonal Kendall Test Summary

Parameter	Location	River	Period of Record	Median Concentration	Tau	Tau Interpretation	P-value	Est. Trend Magnitude (units/L/yr)
NH3-N (mg/L)	Pittsburgh	Allegheny	01/90 - 11/07	0.05	-0.06	O	0.5337	0.000
	South Pittsburgh	Monongahela	01/90 - 11/07	0.08	0.06	O	0.5014	0.000
	Beaver Falls	Beaver	01/90 - 11/07	0.09	0.11	O	0.2395	0.001
	New Cumberland	Ohio	07/92 - 11/07	0.07	0.13	O	0.1986	0.000
	Pike Island	Ohio	07/92 - 11/07	0.08	-0.25	DEC	**0.0169**	-0.001
	Hannibal	Ohio	01/90 - 11/07	0.07	-0.15	O	0.1140	0.000
	Willow Island	Ohio	01/90 - 11/07	0.05	-0.23	DEC	**0.0081**	0.000
	Marietta	Muskingum	05/90 - 11/07	0.03	0.12	O	0.2069	0.000
	Belleville	Ohio	01/90 - 11/07	0.07	-0.15	O	0.1069	0.000
	Winfield	Kanawha	05/90 - 11/07	0.07	-0.07	O	0.4528	0.000
	R.C. Byrd	Ohio	01/90 - 11/07	0.06	0.01	O	0.9142	0.000
	Louisa	Big Sandy	01/90 - 11/07	0.02	0.20	INC	**0.0165**	0.000
	Greenup	Ohio	07/92 - 11/07	0.05	-0.05	O	0.6568	0.000
	Lucasville	Scioto	05/90 - 11/07	0.05	0.22	INC	**0.0224**	0.000
	Meldahl	Ohio	07/92 - 11/07	0.05	-0.32	DEC	**0.0017**	-0.003
	Newtown	Little Miami	05/90 - 11/07	0.06	0.16	inc	**0.0850**	0.000
	Covington	Licking	01/90 - 11/07	0.05	-0.36	DEC	**0.0002**	-0.003
	Anderson Ferry	Ohio	07/92 - 11/07	0.09	0.25	INC	**0.0173**	0.003
	Elizabethtown	Great Miami	05/90 - 11/07	0.04	0.00	O	0.9761	0.000
	Markland	Ohio	05/90 - 11/07	0.07	-0.13	O	0.1798	-0.001
	Louisville	Ohio	01/90 - 11/07	0.10	-0.22	dec	**0.0564**	0.000
	West Point	Ohio	01/90 - 11/07	0.14	0.09	O	0.3933	0.000
	Cannelton	Ohio	05/90 - 11/07	0.05	-0.02	O	0.8260	0.000
	Newburgh	Ohio	07/92 - 11/07	0.05	-0.01	O	0.9369	0.000
	Sebree	Green	01/90 - 11/07	0.04	0.13	O	0.1715	0.000
	J.T. Myers	Ohio	05/90 - 11/07	0.04	0.06	O	0.5547	0.000
	Route 62 Bridge	Wabash	01/99 - 11/07	0.03	-0.01	O	0.9659	0.000
	Smithland	Ohio	05/90 - 11/07	0.08	-0.02	O	0.8270	0.000
	Pinkneyville	Cumberland	05/90 - 11/07	0.04	0.09	O	0.3228	0.000
	Paducah	Tennessee	01/90 - 11/07	0.04	0.03	O	0.7545	0.000
	L&D 52	Ohio	07/93 - 11/07	0.06	0.02	O	0.8503	0.000
NO2-NO3-N (mg/L)	Pittsburgh	Allegheny	01/90 - 11/07	0.7	0.27	INC	**0.0058**	0.008
	South Pittsburgh	Monongahela	01/90 - 11/07	0.8	0.18	inc	**0.0594**	0.005
	Beaver Falls	Beaver	01/90 - 11/07	1.6	-0.18	dec	**0.0672**	-0.014
	New Cumberland	Ohio	07/92 - 11/07	1.0	0.29	INC	**0.0050**	0.010
	Pike Island	Ohio	07/92 - 11/07	0.9	0.06	O	0.5901	0.002
	Hannibal	Ohio	01/90 - 11/07	0.9	0.07	O	0.4428	0.000
	Willow Island	Ohio	01/90 - 11/07	1.0	-0.13	O	0.1926	-0.004
	Marietta	Muskingum	05/90 - 11/07	1.4	-0.04	O	0.7264	0.000
	Belleville	Ohio	01/90 - 11/07	1.0	-0.01	O	0.9158	0.000
	Winfield	Kanawha	05/90 - 11/07	0.6	0.37	INC	**0.0002**	0.009
	R.C. Byrd	Ohio	01/90 - 11/07	0.9	0.04	O	0.7009	0.000
	Louisa	Big Sandy	01/90 - 11/07	0.5	0.02	O	0.8509	0.000
	Greenup	Ohio	07/92 - 11/07	0.9	0.31	INC	**0.0032**	0.008
	Lucasville	Scioto	05/90 - 11/07	2.2	-0.28	DEC	**0.0045**	-0.042
	Meldahl	Ohio	07/92 - 11/07	1.1	-0.50	DEC	**0.0000**	-0.029
	Newtown	Little Miami	05/90 - 11/07	2.1	-0.35	DEC	**0.0004**	-0.050
	Covington	Licking	01/90 - 11/07	1.0	-0.49	DEC	**0.0000**	-0.062
	Anderson Ferry	Ohio	07/92 - 11/07	1.1	-0.11	O	0.2865	-0.007
	Elizabethtown	Great Miami	05/90 - 11/07	2.3	-0.44	DEC	**0.0000**	-0.076
	Markland	Ohio	05/90 - 11/07	1.1	-0.20	DEC	**0.0412**	-0.007
	Louisville	Ohio	01/90 - 11/07	1.2	0.12	O	0.3440	0.005
	West Point	Ohio	01/90 - 11/07	1.2	0.10	O	0.3247	0.004
	Cannelton	Ohio	05/90 - 11/07	1.2	-0.07	O	0.4700	-0.001
	Newburgh	Ohio	07/92 - 11/07	1.2	0.28	INC	**0.0100**	0.015
	Sebree	Green	01/90 - 11/07	1.0	0.41	INC	**0.0000**	0.020
	J.T. Myers	Ohio	05/90 - 11/07	1.2	-0.02	O	0.8337	-0.002
	Route 62 Bridge	Wabash	01/99 - 11/07	1.8	-0.02	O	0.9173	-0.006
	Smithland	Ohio	05/90 - 11/07	1.5	0.11	O	0.2582	0.005
	Pinkneyville	Cumberland	05/90 - 11/07	0.4	0.15	O	0.1425	0.003
	Paducah	Tennessee	01/90 - 11/07	0.4	0.26	INC	**0.0125**	0.004
	L&D 52	Ohio	07/93 - 11/07	1.3	0.18	inc	**0.0954**	0.022

Appendix E (cont.) – Seasonal Kendall Test Summary

Parameter	Location	River	Period of Record	Median Concentration	Tau	Tau Interpretation	P-value	Est. Trend Magnitude (units/L/yr)
SO4 (mg/L)	South Pittsburgh	Monongahela	01/90 - 11/07	80	0.09	O	0.3541	0.24
	Pittsburgh	Allegheny	01/90 - 11/07	50	0.05	O	0.6278	0.00
	Beaver Falls	Beaver	01/90 - 11/07	64	0.06	O	0.5236	0.13
	New Cumberland	Ohio	07/92 - 11/07	66	0.10	O	0.3590	0.29
	Pike Island	Ohio	07/92 - 11/07	74	0.06	O	0.5556	0.00
	Hannibal	Ohio	01/90 - 11/07	73	0.09	O	0.3532	0.10
	Willow Island	Ohio	01/90 - 09/07	72	-0.01	O	0.8895	-0.19
	Marietta	Muskingum	01/90 - 11/07	99	0.07	O	0.5005	0.24
	Belleville	Ohio	01/90 - 11/07	76	-0.02	O	0.8505	-0.13
	Winfield	Kanawha	01/90 - 11/07	33	0.52	INC	**0.0000**	0.89
	R.C. Byrd	Ohio	01/90 - 11/07	63	-0.01	O	0.9007	-0.10
	Louisa	Big Sandy	01/90 - 11/07	130	0.65	INC	**0.0000**	3.38
	Greenup	Ohio	07/92 - 11/07	69	0.10	O	0.3553	0.17
	Lucasville	Scioto	01/90 - 11/07	74	0.11	O	0.2342	0.33
	Meldahl	Ohio	07/92 - 11/07	62	0.33	INC	**0.0014**	0.80
	Newtown	Little Miami	01/90 - 11/07	42	-0.13	O	0.1968	-0.30
	Covington	Licking	01/90 - 11/07	40	-0.46	DEC	**0.0000**	-1.50
	Anderson Ferry	Ohio	07/92 - 11/07	65	0.13	O	0.2200	0.36
	Elizabethtown	Great Miami	01/90 - 11/07	54	-0.23	DEC	**0.0163**	-0.56
	Markland	Ohio	01/90 - 11/07	62	0.16	inc	**0.0919**	0.30
	Louisville	Ohio	01/90 - 11/07	61	0.27	INC	**0.0237**	0.66
	West Point	Ohio	01/90 - 11/07	66	0.39	INC	**0.0001**	1.00
	Cannelton	Ohio	01/90 - 11/07	61	0.28	INC	**0.0050**	0.67
	Newburgh	Ohio	07/92 - 11/07	62	0.34	INC	**0.0014**	1.00
	Sebree	Green	01/90 - 11/07	52	0.26	INC	**0.0090**	0.56
	J.T. Myers	Ohio	01/90 - 11/07	59	0.29	INC	**0.0029**	0.67
	Route 62 Bridge	Wabash	01/99 - 11/07	54	0.06	O	0.6315	0.67
	Smithland	Ohio	01/90 - 11/07	56	0.33	INC	**0.0006**	0.83
	Pinkneyville	Cumberland	01/90 - 11/07	22	0.32	INC	**0.0010**	0.30
	Paducah	Tennessee	01/90 - 11/07	14	0.51	INC	**0.0000**	0.29
	L&D 52	Ohio	07/93 - 11/07	54	0.29	INC	**0.0095**	1.00
TP (mg/L)	South Pittsburgh	Monongahela	01/90 - 11/07	0.05	-0.02	O	0.8834	0.0000
	Pittsburgh	Allegheny	01/90 - 11/07	0.05	0.03	O	0.8027	0.0000
	Beaver Falls	Beaver	01/90 - 11/07	0.10	0.53	INC	**0.0000**	0.0025
	New Cumberland	Ohio	07/92 - 11/07	0.05	-0.53	DEC	**0.0000**	0.0000
	Pike Island	Ohio	07/92 - 11/07	0.05	-0.34	DEC	**0.0049**	0.0000
	Hannibal	Ohio	01/90 - 11/07	0.05	0.05	O	0.6282	0.0000
	Willow Island	Ohio	01/90 - 11/07	0.05	-0.23	DEC	**0.0404**	0.0000
	Marietta	Muskingum	05/90 - 11/07	0.09	0.69	INC	**0.0000**	0.0029
	Belleville	Ohio	01/90 - 11/07	0.05	0.21	inc	**0.0537**	0.0000
	Winfield	Kanawha	05/90 - 11/07	0.05	-0.66	DEC	**0.0000**	-0.0006
	R.C. Byrd	Ohio	01/90 - 11/07	0.05	0.43	INC	**0.0001**	0.0000
	Louisa	Big Sandy	01/90 - 11/07	0.05	-0.15	O	0.1804	0.0000
	Greenup	Ohio	07/92 - 11/07	0.05	0.33	INC	**0.0058**	0.0000
	Lucasville	Scioto	05/90 - 11/07	0.17	0.87	INC	**0.0000**	0.0083
	Meldahl	Ohio	07/92 - 11/07	0.05	0.15	O	0.2300	0.0000
	Newtown	Little Miami	05/90 - 11/07	0.16	0.53	INC	**0.0000**	0.0062
	Covington	Licking	01/90 - 11/07	0.13	0.12	O	0.3479	0.0000
	Anderson Ferry	Ohio	07/92 - 11/07	0.05	0.42	INC	**0.0008**	0.0000
	Elizabethtown	Great Miami	05/90 - 11/07	0.20	-0.05	O	0.7042	0.0000
	Markland	Ohio	05/90 - 11/07	0.07	0.25	INC	**0.0355**	0.0000
	Louisville	Ohio	01/90 - 11/07	0.10	0.31	INC	**0.0352**	0.0020
	West Point	Ohio	01/90 - 11/07	0.16	0.80	INC	**0.0000**	0.0070
	Cannelton	Ohio	05/90 - 11/07	0.08	0.30	INC	**0.0137**	0.0000
	Newburgh	Ohio	07/92 - 11/07	0.08	0.43	INC	**0.0010**	0.0012
	Sebree	Green	01/90 - 11/07	0.06	0.27	INC	**0.0246**	0.0000
	J.T. Myers	Ohio	05/90 - 11/07	0.09	0.37	INC	**0.0023**	0.0000
	Route 62 Bridge	Wabash	01/99 - 11/07	0.20	-0.02	O	0.9263	-0.0009
	Smithland	Ohio	05/90 - 11/07	0.08	0.32	INC	**0.0078**	0.0010
	Pinkneyville	Cumberland	05/90 - 11/07	0.07	0.54	INC	**0.0000**	0.0005
	Paducah	Tennessee	01/90 - 11/07	0.06	-0.40	DEC	**0.0015**	-0.0004
	L&D 52	Ohio	07/93 - 11/07	0.07	0.91	INC	**0.0000**	0.0040

Appendix E (cont.) – Seasonal Kendall Test Summary

Parameter	Location	River	Period of Record	Median Concentration	Tau	Tau Interpretation	P-value	Est. Trend Magnitude (units/L/yr)
TSS (mg/L)	South Pittsburgh	Monongahela	01/90 - 11/07	12	0.18	O	0.1321	0.11
	Pittsburgh	Allegheny	01/90 - 11/07	9	0.19	O	0.1165	0.15
	Beaver Falls	Beaver	01/90 - 11/07	14	0.07	O	0.5442	0.07
	New Cumberland	Ohio	07/92 - 11/07	9	-0.62	DEC	**0.0000**	-0.32
	Pike Island	Ohio	07/92 - 11/07	7	-0.38	DEC	**0.0032**	-0.20
	Hannibal	Ohio	01/90 - 11/07	8	0.08	O	0.5350	0.00
	Willow Island	Ohio	01/90 - 09/07	7	-0.27	DEC	**0.0235**	-0.10
	Marietta	Muskingum	01/90 - 11/07	24	-0.41	DEC	**0.0006**	-0.58
	Belleville	Ohio	01/90 - 11/07	10	-0.57	DEC	**0.0000**	-0.39
	Winfield	Kanawha	01/90 - 11/07	9	-0.18	O	0.1295	-0.07
	R.C. Byrd	Ohio	01/90 - 11/07	17	0.20	inc	**0.0924**	0.33
	Louisa	Big Sandy	01/90 - 11/07	26	-0.30	DEC	**0.0137**	-0.38
	Greenup	Ohio	07/92 - 11/07	13	0.05	O	0.7295	0.09
	Lucasville	Scioto	01/90 - 11/07	36	-0.28	DEC	**0.0204**	-0.50
	Meldahl	Ohio	07/92 - 11/07	19	-0.21	O	0.1099	-0.34
	Newtown	Little Miami	01/90 - 11/07	19	-0.24	DEC	**0.0431**	-0.34
	Covington	Licking	01/90 - 11/07	32	-0.51	DEC	**0.0000**	-1.22
	Anderson Ferry	Ohio	07/92 - 11/07	24	-0.07	O	0.6157	-0.02
	Elizabethtown	Great Miami	01/90 - 11/07	40	-0.40	DEC	**0.0010**	-1.00
	Markland	Ohio	01/90 - 11/07	25	-0.28	DEC	**0.0211**	-0.51
	Louisville	Ohio	01/90 - 11/07	22	0.20	O	0.1736	0.32
	West Point	Ohio	01/90 - 11/07	47	0.11	O	0.3773	0.33
	Cannelton	Ohio	01/90 - 11/07	15	0.06	O	0.6386	0.09
	Newburgh	Ohio	07/92 - 11/07	27	0.06	O	0.6426	0.08
	Sebree	Green	01/90 - 11/07	32	0.12	O	0.3482	0.10
	J.T. Myers	Ohio	01/90 - 11/07	29	-0.02	O	0.8815	-0.04
	Route 62 Bridge	Wabash	01/99 - 11/07	71	0.03	O	0.8729	0.33
	Smithland	Ohio	01/90 - 11/07	22	0.03	O	0.7993	0.00
	Pinkneyville	Cumberland	01/90 - 11/07	17	0.12	O	0.3286	0.08
	Paducah	Tennessee	07/94 - 11/07	7	-0.18	O	0.2018	-0.10
	L&D 52	Ohio	07/93 - 11/07	21	0.18	O	0.2044	0.33
Zn (ug/L)	Pittsburgh	Allegheny	01/90 - 05/02	10	-0.21	dec	**0.0711**	0.00
	South Pittsburgh	Monongahela	01/90 - 05/02	22	-0.35	DEC	**0.0017**	0.00
	Beaver Falls	Beaver	01/90 - 05/02	30	0.06	O	0.6265	0.00
	New Cumberland	Ohio	07/92 - 05/02	10	-0.45	DEC	**0.0008**	0.00
	Pike Island	Ohio	07/92 - 05/02	19	-0.48	DEC	**0.0006**	-1.00
	Hannibal	Ohio	01/90 - 05/02	13	-0.38	DEC	**0.0007**	0.00
	Willow Island	Ohio	01/90 - 05/02	14	-0.18	O	0.1454	0.00
	Marietta	Muskingum	01/90 - 05/02	12	-0.44	DEC	**0.0001**	-0.21
	Belleville	Ohio	01/90 - 05/02	19	-0.24	DEC	**0.0497**	0.00
	Winfield	Kanawha	01/90 - 05/02	11	-0.47	DEC	**0.0000**	-0.25
	R.C. Byrd	Ohio	01/90 - 05/02	20	-0.30	DEC	**0.0127**	0.00
	Louisa	Big Sandy	01/90 - 05/02	10	-0.25	DEC	**0.0268**	0.00
	Greenup	Ohio	07/92 - 05/02	10	-0.46	DEC	**0.0002**	0.00
	Lucasville	Scioto	01/90 - 05/02	20	-0.38	DEC	**0.0009**	-0.67
	Meldahl	Ohio	07/92 - 05/02	11	-0.36	DEC	**0.0045**	0.00
	Newtown	Little Miami	01/90 - 05/02	10	-0.19	dec	**0.0759**	0.00
	Covington	Licking	01/90 - 05/02	12	-0.37	DEC	**0.0017**	0.00
	Anderson Ferry	Ohio	07/92 - 05/02	10	-0.08	O	0.5714	0.00
	Elizabethtown	Great Miami	01/90 - 05/02	20	-0.12	O	0.3324	0.00
	Markland	Ohio	01/90 - 05/02	10	-0.30	DEC	**0.0075**	0.00
	Louisville	Ohio	01/90 - 05/02	10	-0.67	DEC	**0.0000**	-0.18
	West Point	Ohio	01/90 - 05/02	20	-0.49	DEC	**0.0002**	-0.50
	Cannelton	Ohio	01/90 - 05/02	10	-0.38	DEC	**0.0007**	0.00
	Newburgh	Ohio	07/92 - 05/02	10	-0.50	DEC	**0.0000**	0.00
	Sebree	Green	01/90 - 05/02	10	-0.57	DEC	**0.0000**	0.00
	J.T. Myers	Ohio	01/90 - 05/02	14	-0.64	DEC	**0.0000**	-1.00
	Route 62 Bridge	Wabash	01/99 - 05/02	10	0.08	O	0.7756	0.00
	Smithland	Ohio	01/90 - 05/02	29	-0.05	O	0.6901	0.00
	Pinkneyville	Cumberland	01/90 - 05/02	10	-0.15	O	0.1658	0.00
	Paducah	Tennessee	01/90 - 05/02	10	-0.38	DEC	**0.0028**	0.00
	L&D 52	Ohio	07/93 - 05/02	20	-0.64	DEC	**0.0000**	-1.43