Library Reference 6.1

Trends in Onondaga Lake Nearshore Monitoring Data
Onondaga Lake Ambient Monitoring Program – 2011 Report

prepared for

Ecologic, LLC
&
Onondaga County Department of Water Environment Protection

by

William W. Walker, Jr., Ph.D.
&
Jeffrey D. Walker, M.Eng.

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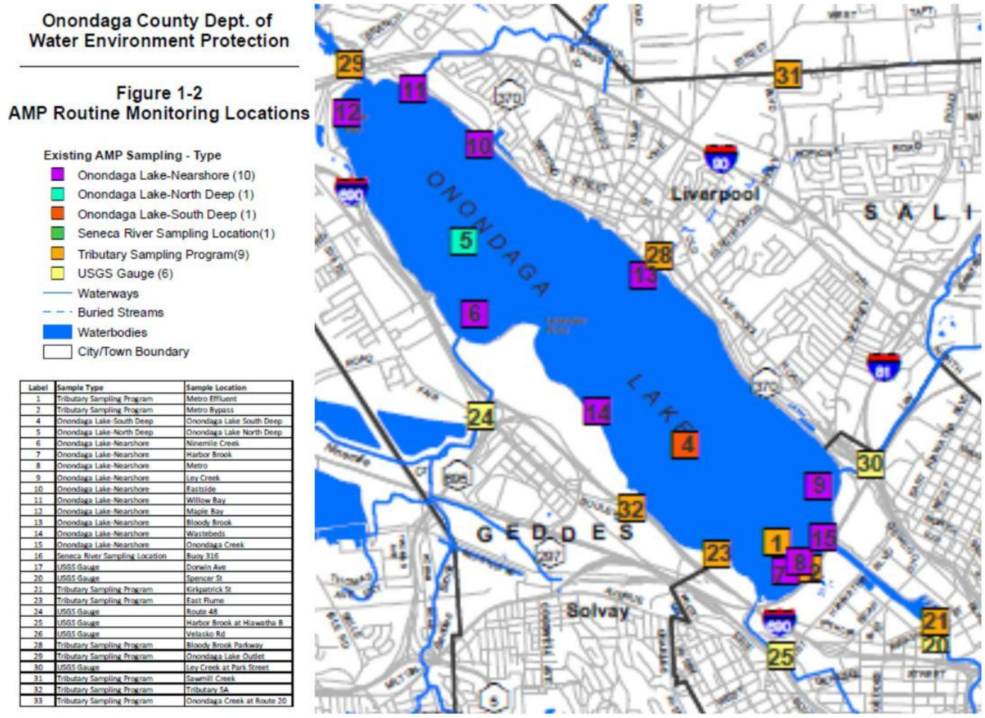
Introduction

The Onondaga Lake Ambient Monitoring Program supports an accelerated effort to restore water quality and related ecological parameters (OCDDS, 1998; Walker, 1991). A statistical framework has been developed to support development of cost-effective monitoring plans for tracking trends potentially related to implementation of management measures (Walker, 2007). An important management objective is to restore the considerable recreational potential that exists in its open waters, shoreline areas, and adjacent urban parks. While bacteria and transparency levels have generally met water quality standards and guidance values at most sites over the past few years, the lake is primarily used for boating, fishing, and aesthetic enjoyment. One component of the AMP focuses on near-shore water quality adjacent to recreational areas impacted by discharges from various sources including (a) combined sewer overflows, (b) urban runoff, (c) partially-treated wastewater discharges during high-runoff periods, (d) unidentified leaking sewers, (e) rural runoff, and (f) substantial bird populations. Excepting the last category, these discharges tend to be greatest during periods of high rainfall and runoff, the control of which is key to achieving management goals.

The lake monitoring program has a long history dating back to the late 1960's for the open lake waters and the 1970's for some of the shoreline sites (Walker, 1991). In 1999, the AMP was expanded to provide weekly observations and special storm event monitoring at near-shore sites in parameters that are directly related to recreational uses. The current monitoring design and protocols are described in OCDWEP (2011). Parameter coverage includes water transparency (Secchi depth), turbidity, fecal coliform bacteria, and *Escherichia coli* (E. coli) bacteria. Specific benchmarks include the New York State Department of Environmental Conservation (NYSDEC) guidance value for Secchi Depth (> 4 ft or 1.2 meters) and standard for fecal coliform (monthly geometric mean < 200 cfu/100ml computed from at least 5 samples). This report describes statistical analyses of the 1999-2010 nearshore data to characterize spatial and temporal variations and to evaluate long-term trends in water transparency and bacteria levels. Details are provided in the Appendix.

Figure 1: Sampling Stations



Label	Sample Type	Sample Location
1	Tributary Sampling Program	Metro Effluent
2	Tributary Sampling Program	Metro Bypass
4	Onondaga Lake-South Deep	Onondaga Lake South Deep
5	Onondaga Lake-North Deep	Onondaga Lake North Deep
6	Onondaga Lake-Nearshore	Ninemile Creek
7	Onondaga Lake-Nearshore	Harbor Brook
8	Onondaga Lake-Nearshore	Metro
9	Onondaga Lake-Nearshore	Ley Creek
10	Onondaga Lake-Nearshore	Eastside
11	Onondaga Lake-Nearshore	Willow Bay
12	Onondaga Lake-Nearshore	Maple Bay
13	Onondaga Lake-Nearshore	Bloody Brook
14	Onondaga Lake-Nearshore	Wastebeds
15	Onondaga Lake-Nearshore	Onondaga Creek
16	Seneca River Sampling Location	Buoy 316
17	USGS Gauge	Dorwin Ave
20	USGS Gauge	Spencer St
21	Tributary Sampling Program	Kirkpatrick St
23	Tributary Sampling Program	East Flume
24	USGS Gauge	Route 48
25	USGS Gauge	Harbor Brook at Hiawatha B
26	USGS Gauge	Velasko Rd
28	Tributary Sampling Program	Bloody Brook Parkway
29	Tributary Sampling Program	Onondaga Lake Outlet
30	USGS Gauge	Ley Creek at Park Street
31	Tributary Sampling Program	Sawmill Creek
32	Tributary Sampling Program	Tributary 5A
33	Tributary Sampling Program	Onondaga Creek at Route 20

Data Compilation

Figure 1 shows the locations of AMP nearshore, open lake, and tributary monitoring sites. The Appendix provides an inventory of samples by site, year, sampling program, and weather (antecedent rainfall). The data analyses focus on data collected at nine long-term nearshore sites (purple) since 1999. The AMP design includes both weekly periodic sampling (~2,364 fecal coliform samples in 1999-2010) and special intensive sampling during and following storm events in 1999-2003 and 2006-2009 (~610 samples). Prior to 2002, three sites (Mid-South (a.k.a. Metro), Ley Creek, and Harbor Brook) were sampled monthly. Relatively new sites cover shoreline areas adjacent to the Allied Waste Beds (2006-2010) and the mouth of Onondaga Creek (2009-2010). Because of the short period of record, the latter stations have been excluded from the trend analyses. The open lake site (South Deep) provides a useful benchmark for comparison with nearshore data.

Spatially pooled data from the 9 long-term sites (where monitoring began between 1999 and 2002) were also analyzed to evaluate trends on a regional basis. Aggregation into southern and northern lakeshore sites captures the predominant spatial variations in bacteria and turbidity levels, which generally reflect proximity to the major sources at the south end of the Lake. The southern cluster (LS_S) includes Ley Creek (LEY), Mid-South (MID_S), and Harbor Brook (HARB). The northern cluster (LS_N) includes Ninemile Creek (9MILE), Maple Bay (MAPLE), Willow Bay (WIL), Lake Park (LKPK), and Bloody Brook (BLBK). A more detailed analysis would distinguish between the west and east shore sites.

Pooled data from all of the longterm lakeshore sites were also analyzed (LS_S). The South Deep station (SOUTH) provided a basis for comparison to the near-shore stations.

To maximize statistical power, the data analyses utilize all of the routine weekly and storm event samples collected in May-September of 1999-2010 at sites with at least 8 years of data. The power concept is a cornerstone for designing monitoring programs under the AMP Statistical Framework (Walker, 1998; Walker, 2007). Statistical power for detecting trends generally depends on the duration of the dataset, inherent year-to-year variability in the data, precision of the annual mean values, and the significance level ("p" value) applied in testing trend hypotheses. Power can be enhanced by increasing monitoring frequency or using simple statistical models to explain portions of the year-to-year or within-year variability, such as correlations with antecedent rainfall, as discussed below.

While including special storm-event samples may introduce some bias in the long-term means towards wet weather conditions, separate analyses of the wet-weather and dry-weather samples and binning of the data at monthly intervals before computing the annual geometric means minimizes the effects of irregularities in sampling frequency on the long-term trend analyses. Overall, 56% of the fecal coliform samples were collected on "wet" days, as compared with 46% in all 3-day intervals in the May-September 1999-2010 period (see sample inventory). Similar analysis that excluded special storm-event samples or utilized 2002-2010 data showed little influence on the overall results and conclusions.

Water Quality Metrics

Four primary water quality metrics are analyzed:

- *Secchi Depth* - expressed as frequency of measured depths < 1.2 meters. As indicated by flags in the AMP database, ~71% of the nearshore Secchi measurements were constrained by the lake bottom due to shallow depths in 2008-2010. Prior to 2008, qualifiers were not recorded in the database. Because bottom depths at all sites are generally greater than 1.2 meters, the Secchi depth data are useful for trend analyses when expressed as frequency of values < 1.2 meters (the NYSDEC guidance value of 4 feet, one of the key AMP metrics). Results for Secchi depth are also reported in the Appendix for reference purposes, but should be taken with caution due to the bottom depth constraints.

- *Turbidity (NTU)* - $\log_{10}$ transformed. Turbidity is a useful surrogate for Secchi depth as it is not constrained by the lake bottom. A turbidity measurement of 5 NTU ($\log_{10}[5] = 0.7$) corresponds approximately to a Secchi depth of 1.2 meters. Spatial and temporal patterns indicate that turbidity typically reflects algal abundance, although inorganic particles are likely to be a factor at some sites following major storm events. Turbidity levels tend to be less dependent on antecedent rainfall, as compared with bacteria.

- *Fecal Coliform bacteria (cfu/100 ml)* - $\log_{10}$ transformed. The NYSDEC water quality standard for fecal coliform is 200 cfu/100 ml ($\log_{10}[200]=2.3$) expressed as the monthly geometric mean computed from at least 5 samples per month. This applies to Class B sites (northern nearshore, except for Ninemile). A secondary fecal coliform metric (frequency of values > 100 cfu/100 ml) was also analyzed to reflect the frequency of elevated counts approaching the standard. Since those frequencies were relatively low, this metric has low statistical power for trend analysis.

- *E. coli bacteria (cfu/100mL)* - $\log_{10}$ transformed. E. coli data were adjusted for the change in minimum detection limit in 2006, which was lowered from 5 to 1 cfu/100mL. To maintain consistency in this dataset, all data over the period of record were limited to a minimum concentration of 5 cfu/100mL since changes in the minimum detection limit could significantly impact the results of the trend analysis.

To reflect the log-normal distribution typically observed in water quality data, turbidity and bacteria data were transformed by taking the base-10 logarithm of each measured value. Seasonal Kendall tests were performed on monthly geometric means, which were computed as arithmetic means of the $\log_{10}$-transformed data. Each metric was averaged by month prior to computing annual geometric means, which were used in two alternative trend analysis methods described below (Mann-Kendall and linear regression).

Hydrologic Conditions

Storm-driven discharges from urban and agricultural areas can trigger significant increases in turbidity and bacteria levels due to wash-off of pollutants from land surfaces and overflow of combined sewers. Evaluating long-term trends can be difficult due to high variability of these data and their dependence on antecedent hydrologic conditions. Bacteria counts tend to have much higher inherent variability as compared with other water quality measurements (Walker, 2007).

To reflect the strong dependence on antecedent rainfall observed in the bacteria data (see box plots, scatter plots) and increase power for trend detection, each sampling event was classified as “wet” or “dry” using a 3-day antecedent rainfall breakpoint of 0.2 inches measured at Hancock Airport (1,302 and 1,672 total samples, respectively). The 3-day antecedent rain is computed from daily rainfall using for formula: $P_{3\text{-day}}(t) = 0.5 \times P(t) + P(t-1) + P(t-2) + 0.5 \times P(t-3)$. This assumes that the sites are sampled around noon and that rainfall is evenly distributed over the day on average. More accurate classifications could be derived from the hourly precipitation data, as would be appropriate for a more detailed analysis of the storm-event responses. Based upon the sample inventories and cumulative frequency distribution of the 3-day antecedent precipitation for sampling dates relative to the 1985-2010 period of record, the historical data provide a good representation of lake water quality under the full range of hydrologic conditions.

Trend analyses were performed separately for dry, wet, and all samples. To account for differences in the frequencies of wet vs. dry samples in each year, the data were also adjusted to reduce the effects of antecedent rainfall in each sampling event. Linear regression models were developed for each site relating the parameter value (i.e. fecal coliform concentration) to the 3-day antecedent precipitation. The regression slopes were used to adjust the observed values to a common 3-day antecedent precipitation of 0.35 inches, which is the long-term mean 3-day antecedent precipitation, by the formula: $\text{Value}_{\text{Adjusted}} = \text{Value}_{\text{Observed}} + b\,(0.35 - P_{3\text{-day}})$ where b is the slope of the linear regression and $P_{3\text{-day}}$ is the 3-day antecedent precipitation for the day when the sample was collected. The adjusted values provided a fourth set of samples for the trend analyses that are adjusted to the long-term average May-September 3-

day precipitation (0.35 inches). A similar algorithm was used to account for yearly rainfall variations in tracking long-term trends in tributary phosphorus loads (Walker, 2007; Walker, 2010).

Statistical Methods

A number of statistical methods can be used to analyze trends in water quality data (Helsel & Hirsch, 2002). Such methods can be broadly categorized as either parametric or non-parametric. Parametric methods generally require a number of underlying assumptions about the distribution (i.e. normality) and independence of the data (i.e. random with low serial correlation). In general, the latter two assumptions can be approximately satisfied by computing annual geometric means first and testing trend hypotheses using linear regression. This requires reasonably consistent monitoring frequencies and protocols over the years. Non-parametric methods are based on the ranks of the observations rather than the values themselves, and are typically more robust to outliers and other abnormalities common to water quality observations.

The AMP database (Walker, 2004) includes Excel 2003 software developed specifically to facilitate statistical analysis of the AMP data. The relational database consists of a series of linked Excel and Access tables that are routinely updated by OCDWEP staff. The database interface provides access to software to generate data inventories, trend analysis, tributary load calculations, historical loads, data queries, and user-defined analyses driven by Excel pivot tables. The analysis described below provides an opportunity to explore potentials for updating the existing database to utilize new features of Excel 2010 and open-source R statistical software, which includes routines specifically developed to support analysis of water quality data and powerful graphics routines. While R has a steep learning curve, it can be easily automated (once debugged) to provide routine reports linked to the database.

The Appendix provides results of nearshore data analyzes conducted using both the existing AMP software and R software. Three categories of trend tests were used to identify statistically-significant changes in the near-shore transparency and bacteria data:

- *Linear Regression* – a parametric method that computes the slope of the observations over time using ordinary least squares regression.
- *Mann-Kendall Test* – a non-parametric method that compares the change in observation ranks over time. The Sen slope estimate provides a non-parametric estimate of the change in each variable over time.
- *Seasonal Kendall Test* – a variation of the Mann-Kendall test where the data are first grouped by month of the year and the Mann-Kendall test is then performed on each group of monthly data. The results of each month are combined into an overall measure of trend significance. This method is used in the AMP software.

Trend analyses using each of these methods were conducted in the R software environment[1], which is a powerful statistical software package that is becoming increasing popular among data analysts and

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[1] http://www.r-project.org/

modelers from virtually all scientific and engineering disciplines. R is an open-source version of the commercially available S/S-Plus software package, which was developed at Bell Labs beginning in the 1970's. R is an implementation of S and is released under the GNU General Public License (GPL) version 2[2], which permits commercial use. It is similar to other commercial software such as SAS and STATA, but provides greater flexibility by providing access to the source code which allows the user to better understand underlying algorithms and data structures.

Qian (2010) describes R applications to environmental and ecological data. R is comprised of a "core" set of modules and functions for basic statistical analysis and graphics. In addition to the core modules, there are many additional packages[3] developed by R users from various disciplines that provide more advanced functions for specific applications. For this analysis, the *wq* package[4] developed by Alan Jassby, aquatic ecologist and professor emeritus at UC Davis, and James Cloern, senior research scientist at the USGS, provided functions for the non-parametric trend analyses. Graphics were generated using the *ggplot2* package[5], which was developed by Hadley Wickham, assistant professor of statistics at Rice University.

Results for Fecal Coliforms

Results for fecal coliforms are described in detail below and used as a platform for explaining the various output formats. Results for other metrics are given in the Appendix and exhibit similar patterns with respect to variations in means and trends relative to lake regions and weather, although to varying degrees.

Fecal coliform results are presented in the formats described below. Results for all metrics can be viewed by following the hyperlinks.

- Box Plots: Figure 2 shows the frequency distributions of the individual fecal coliform counts as a function of station and antecedent rainfall. Fecal coliform levels are clearly higher during wet weather, especially at the southern sites (Mid-South, Harbor Brook, Ley Creek) and Onondaga Creek Outlet (shown in the Appendix).

- Yearly Time Series: Figure 3 shows the yearly time series of $\log_{10}$-mean fecal coliform counts at each station under dry and wet weather conditions. Differences between dry and wet weather are also clearly evident in these charts. Decreasing trends are apparent in the wet-weather data from southern sites (Harbor Brook, Mid-South, Ley Creek) and the adjacent Bloody Brook site. These patterns are generally consistent with reductions in storm-driven bacteria sources (runoff, CSOs, Metro Bypass). In contrast, the dry weather data indicate increasing trends at the Harbor and Mid-South stations. These increases likely reflect the intentional decrease in chlorine doses in the Metro discharge beginning in 2004, as evident in the 2001-2010 trend charts from the AMP database (samples, monthly geometric means). Despite the increases, dry weather values remain

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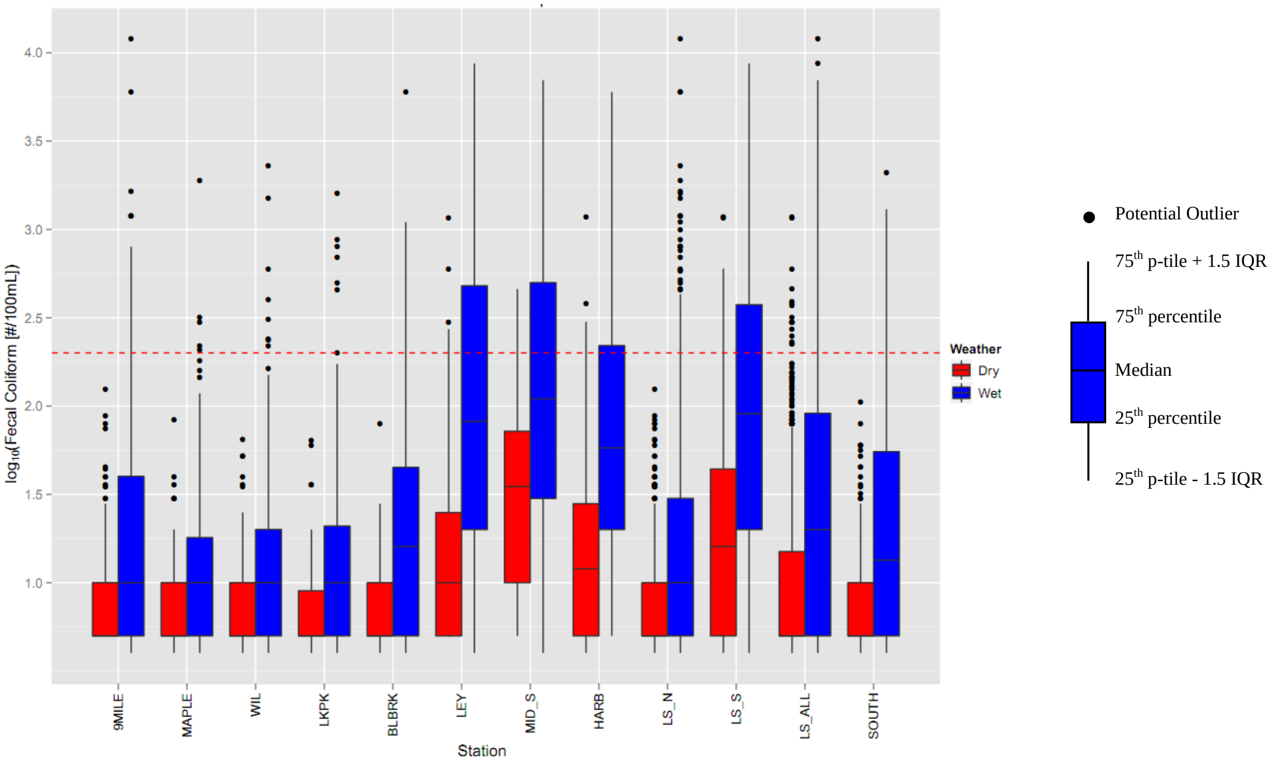
[2] http://www.gnu.org/licenses/gpl-2.0.html
[3] http://cran.r-project.org/
[4] http://cran.r-project.org/web/packages/wq/index.html
[5] http://had.co.nz/ggplot2/

significantly below the wet-weather values and further increases are unlikely if the historical trend reflects the change in chlorination practice.

- Monthly Time Series: Figure 4 shows monthly geometric mean time series computed from all samples. These values would be used to measure compliance with the fecal coliform standard (200 cfu/100 ml), as indicated by the dashed red line at a $\log_{10}$ value of 2.3. While it provides a useful benchmark for all sites, the standard applies only to Class B sites (open waters and northern nearshore sites, excluding Ninemile Creek, see site index). As indicated in Figure 5, the Seasonal Kendall test applied to monthly geometric means of all data indicates significant increasing trend at Mid-South (MID_S, Class C) and decreasing trend at Bloody Brook (BLBK, Class B). In the 2003-2010 period, monthly geometric means exceeded 200 cfu/100 ml in only 3 out of 60 months at the Mid_South site and in zero months at the other sites. While compliance does not appear to be an issue at the lake sites, the nearshore bacteria data are very useful for tracking the effectiveness of stormwater controls that reduce loads of bacteria, as well as other constituents.

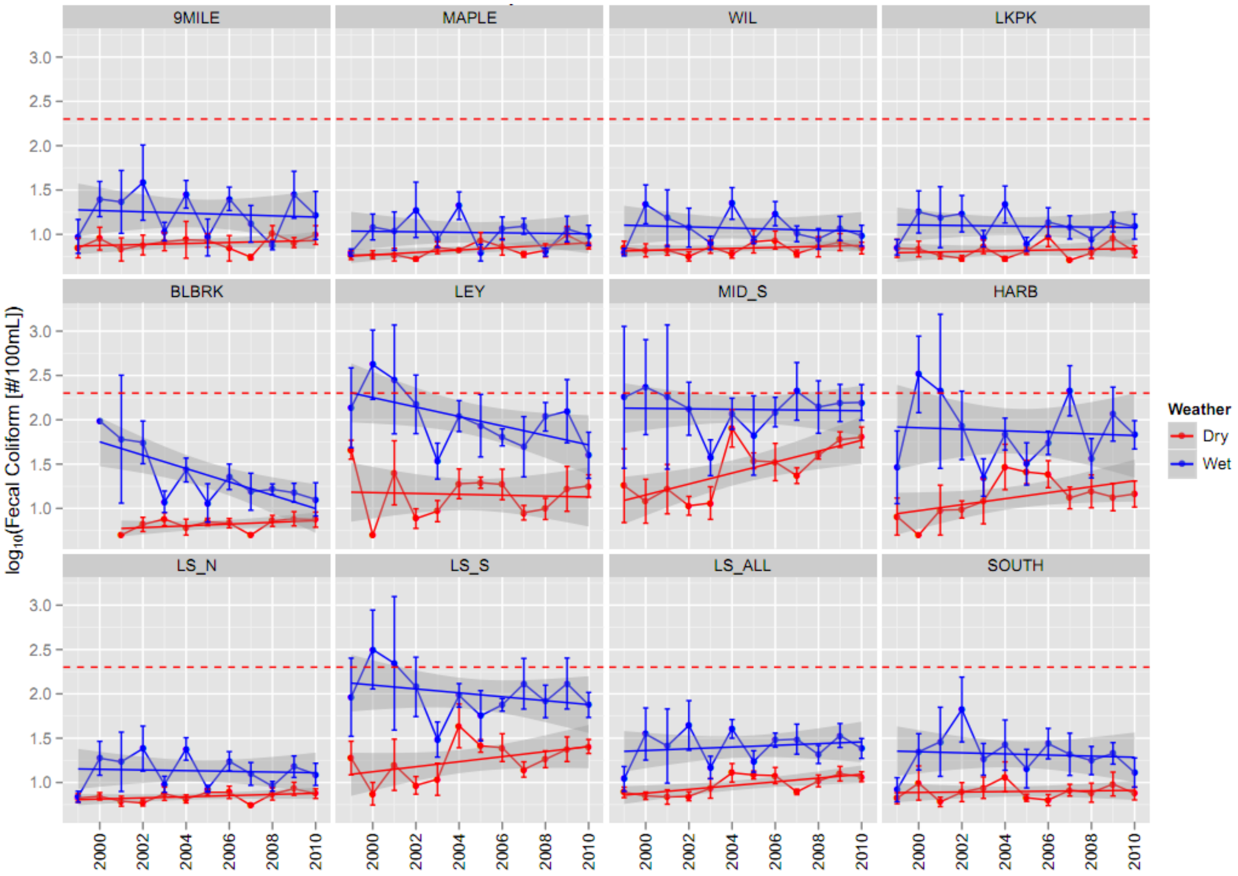
- Trend Slopes: Figure 5 shows the estimated trend slopes using different colors to reflect statistical method (red – Mann-Kendall of annual geomean, green – Linear Regression of annual geomean, blue - Seasonal Kendall of monthly geomean) and different symbols to reflect significance levels (hollow: not significant with $p > 0.10$, cross: moderately significant at $0.05 < p \le 0.10$, filled: highly significant at $p \le 0.05$). A trend slope of +0.05 log10 units per year (b) corresponds to a trend of ~12% /year [computed as (10^b – 1) x 100%] in the long-term geometric mean for the corresponding site and weather condition. Although the slopes differ among the three tests by varying amounts for each data subset, they generally lead to similar conclusions and provide a more robust analysis than if only a single test were performed. The trend slopes and significance tests generally confirm inferences drawn from the yearly time series charts. Significant increasing trends in the wet-weather data are indicated by one or more of the statistical methods at the Bloody Brook and Ley Creek sites. Significant increasing trends in the dry-weather data are indicated at the Mid-South and Harbor Brook sites.

Figure 2: Fecal Coliform Boxplots for Dry and Wet Weather Samples



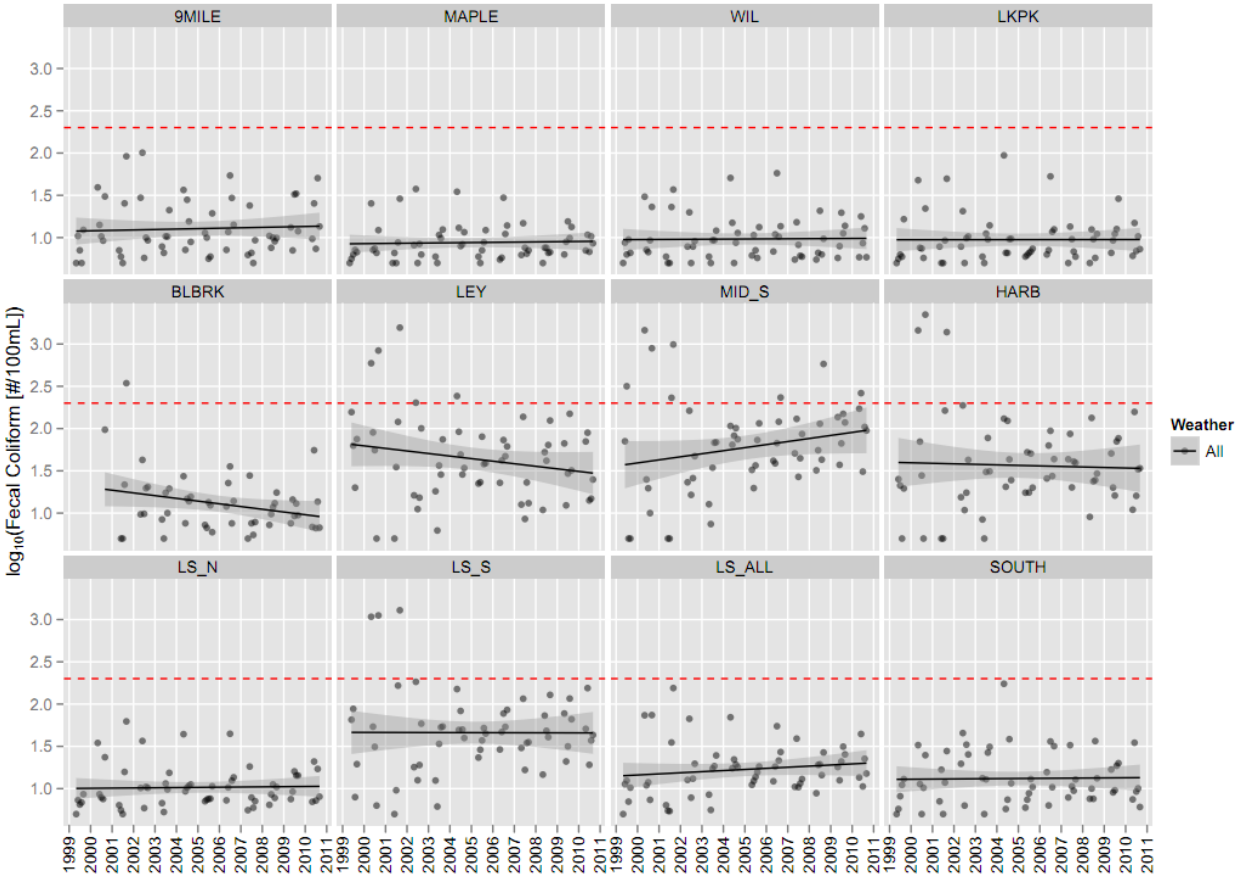
Legend: Boxplots of observed fecal coliform for each site by dry (red) and wet (green) weather and precip-adjusted values (blue). Dotted red line denotes fecal coliform standard: monthly geometric mean < 200 cfu/100 ml ($\log_{10}(200)=2.3$).

Figure 3: Fecal Coliform Annual Geometric Means for Dry and Wet Weather Samples



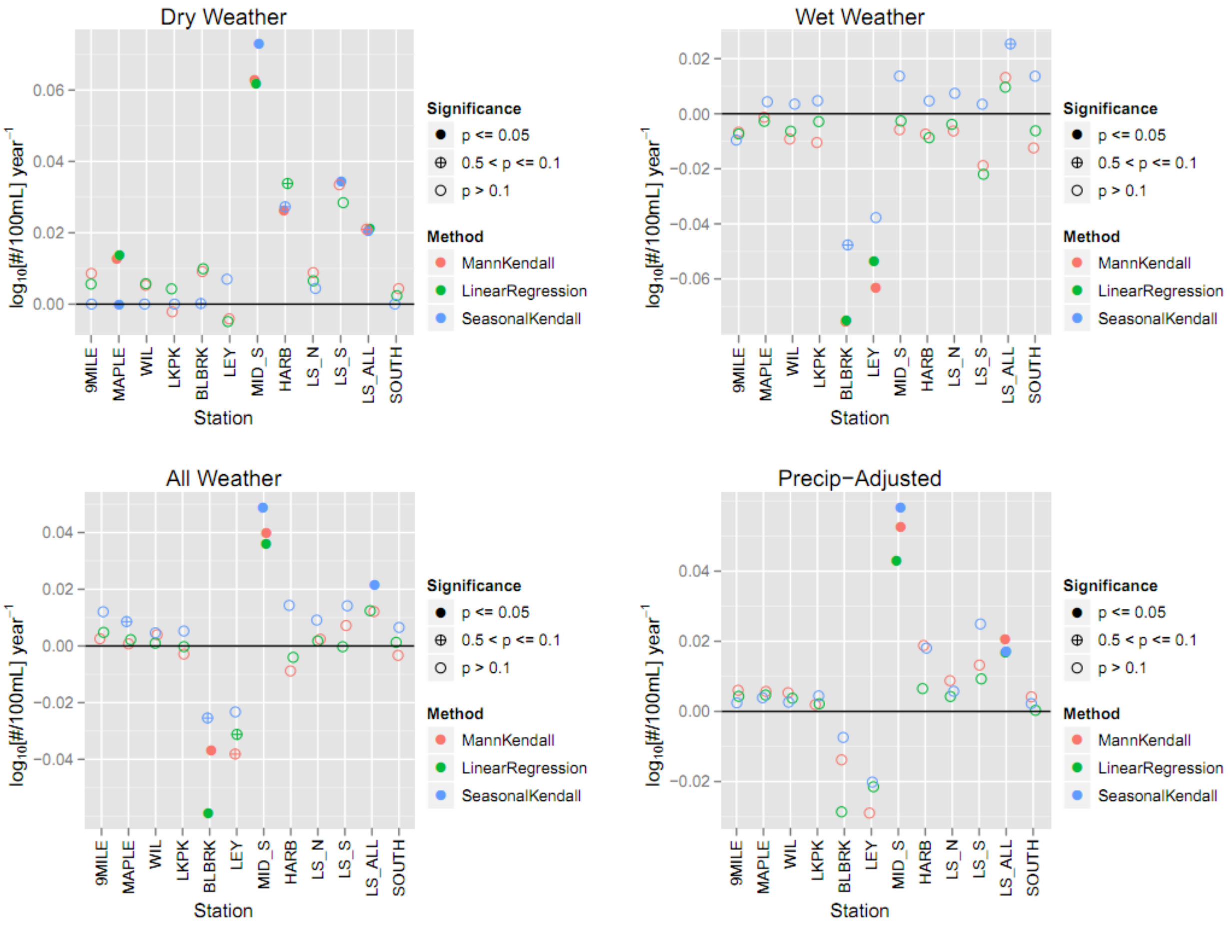
Legend: Time series of annual geometric mean fecal coliform at each site for dry (red) and wet (blue) weather. Error bars denote +/- 1 standard error based on standard deviation of monthly geomeans. Trend lines are linear regressions with 95% confidence intervals.

Figure 4: Fecal Coliform Monthly Geometric Mean including All Routine and Storm-Event Data



Legend: Time series of monthly geometric mean fecal coliform at each site based on all measured values (black) and the precipitation-adjusted values (green). Trend lines are linear regressions with 95% confidence intervals. The red dashed line shows the fecal coliform standard (monthly geometric mean < 200 cfu/100 ml, where $\log_{10}(200)=2.3$).

Figure 5: Fecal Coliform Trend Slopes for Dry/Wet Weather, All and Adjusted Data

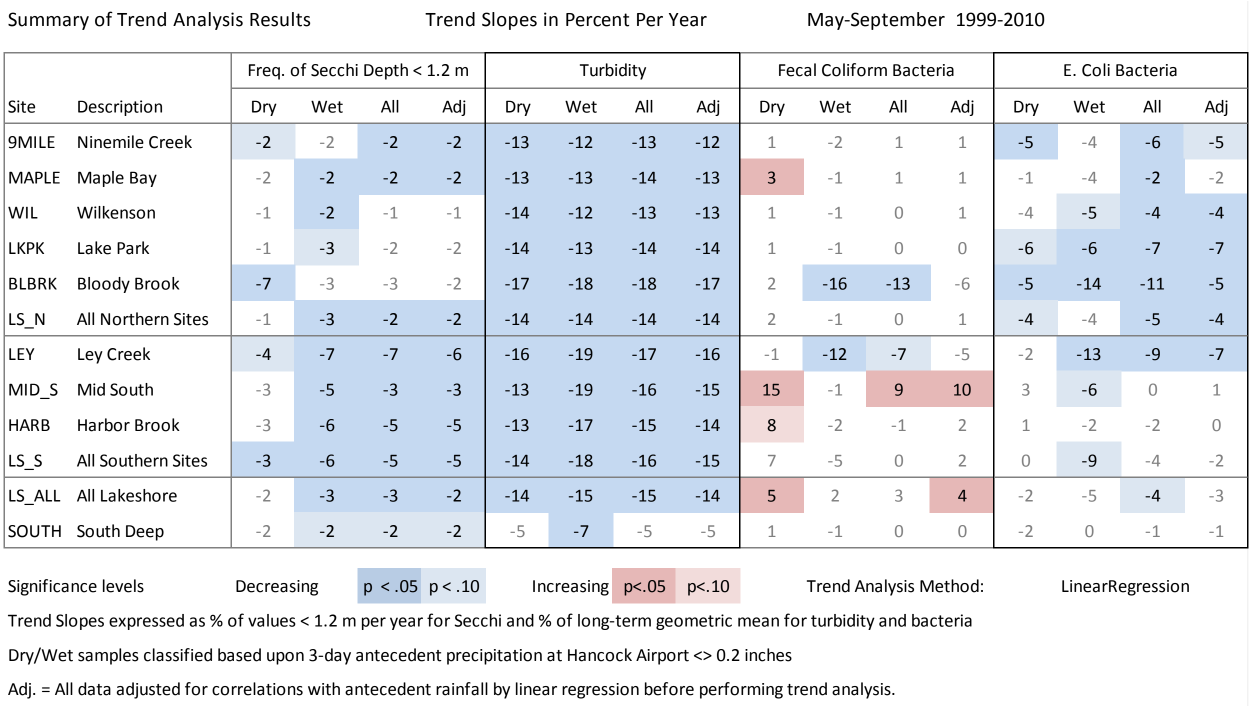


Legend: Slopes and significance of parameter and non-parametric trend tests for each station and weather condition. Symbols denote significance: hollow – not significant, crossed – moderately significant, filled – highly significant. Colors denote test method: red – Mann-Kendall of annual geomean, green – Linear Regression of annual geomean, blue - Seasonal Kendall of monthly geomean.

Summary of Results for All Metrics

The Appendix contains results of exploratory analyses performed for each metric, site, and precipitation category to elucidate spatial and temporal patterns in the data. Spatial variations and rainfall dependence are depicted in box plots and bar charts. Trends in sample values, monthly means, and yearly means are shown using color-coded symbols to indicate the dry-weather, wet-weather, all-weather, and precipitation-adjusted metrics. Trend slopes and statistical significance are summarized in tables and scatter charts. Separate analyses of dry and wet samples generally provides the most effective displays of the data and captures the dominant patterns with respect to spatial variations, storm dependence, and trends.

Table 1: Summary of Trend Analysis Results



Summary of Trend Analysis Results Trend Slopes in Percent Per Year May-September 1999-2010

		Freq. of Secchi Depth < 1.2 m				Turbidity				Fecal Coliform Bacteria				E. Coli Bacteria			
Site	Description	Dry	Wet	All	Adj	Dry	Wet	All	Adj	Dry	Wet	All	Adj	Dry	Wet	All	Adj
9MILE	Ninemile Creek	-2	-2	-2	-2	-13	-12	-13	-12	1	-2	1	1	-5	-4	-6	-5
MAPLE	Maple Bay	-2	-2	-2	-2	-13	-13	-14	-13	3	-1	1	1	-1	-4	-2	-2
WIL	Wilkenson	-1	-2	-1	-1	-14	-12	-13	-13	1	-1	0	1	-4	-5	-4	-4
LKPK	Lake Park	-1	-3	-2	-2	-14	-13	-14	-14	1	-1	0	0	-6	-6	-7	-7
BLBRK	Bloody Brook	-7	-3	-3	-2	-17	-18	-18	-17	2	-16	-13	-6	-5	-14	-11	-5
LS_N	All Northern Sites	-1	-3	-2	-2	-14	-14	-14	-14	2	-1	0	1	-4	-4	-5	-4
LEY	Ley Creek	-4	-7	-7	-6	-16	-19	-17	-16	-1	-12	-7	-5	-2	-13	-9	-7
MID_S	Mid South	-3	-5	-3	-3	-13	-19	-16	-15	15	-1	9	10	3	-6	0	1
HARB	Harbor Brook	-3	-6	-5	-5	-13	-17	-15	-14	8	-2	-1	2	1	-2	-2	0
LS_S	All Southern Sites	-3	-6	-5	-5	-14	-18	-16	-15	7	-5	0	2	0	-9	-4	-2
LS_ALL	All Lakeshore	-2	-3	-3	-2	-14	-15	-15	-14	5	2	3	4	-2	-5	-4	-3
SOUTH	South Deep	-2	-2	-2	-2	-5	-7	-5	-5	1	-1	0	0	-2	0	-1	-1

Significance levels Decreasing p < .05 p < .10 Increasing p<.05 p<.10 Trend Analysis Method: LinearRegression

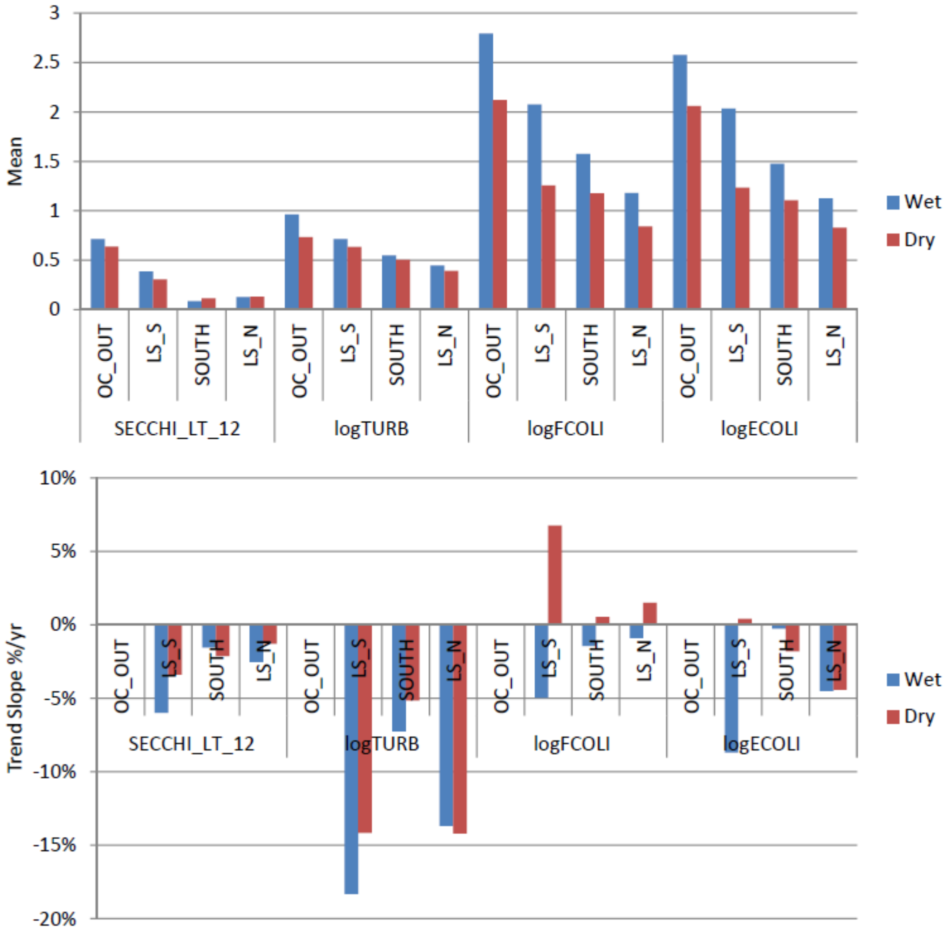
Trend Slopes expressed as % of values < 1.2 m per year for Secchi and % of long-term geometric mean for turbidity and bacteria

Dry/Wet samples classified based upon 3-day antecedent precipitation at Hancock Airport <> 0.2 inches

Adj. = All data adjusted for correlations with antecedent rainfall by linear regression before performing trend analysis.

Table 1 summarizes trend slopes and significance levels for each site and variable based upon linear regression. Slopes are expressed as a percent change in the long-term geometric mean for turbidity and bacteria [10^ $\log_{10}$[Slope] – 1) x 100%] and as percent per year for Secchi depth excursion frequency. The values are highlighted according to increasing (red) or decreasing (blue) trends and shaded by level of significance (darker: high significance at $p < 0.05$, lighter: moderate significance at $p < 0.10$, none: not significant at $p > 0.10$). Results from the other statistical tests were similar with respect to trend magnitudes and significance for each parameter, although the Seasonal Kendall yielded test fewer significant results. This may reflect the fact that dominant within-year variations in the data are associated with antecedent rainfall, as opposed to season (month).

Figure 6: Means and Trends by Variable, Lake Region, and Weather



Trend Slopes = percent of long-term geometric mean per year (% of weekly values per year for Freq Secchi < 1.2 m)
Onondaga Creek Outlet Site (OC_OUT) wes sampled in 2008-2010 (trends not tested).
Stations sorted in south-north direction. LS_N = northern nearshore; LS-S = southern nearshore; SOUTH = South Deep.

Figure 6 shows long-term mean values and trend slopes by lake region for each variable and weather condition. This display captures the essential features of the results.

- Long-term geometric mean values for each metric exhibit south-to-north decreasing gradients in both wet and dry weather, as expected based upon the locations of the major tributaries and importance of storm-driven sources. Values for the South Deep open-lake site (SOUTH) generally fall between values for the southern and northern lakeshore sites. Results for Bloody Brook (BLBRK) generally fall between the northern and southern sites. This is consistent with its geographic location (Figure 1).
- Decreasing trends in turbidity (-12 to -19% per year) and frequency of Secchi Depths < 1.2 meters (-7 to -2% per year) are apparent throughout the lake under wet and dry weather conditions. Stronger trends in turbidity may reflect greater precision in the measurements. While

Secchi depth and turbidity are closely related, turbidity is a more accurate measure of water clarity and is not affected by the water depth at each station.

- Improving trends in turbidity and Secchi are slightly more pronounced during wet weather as compared with dry weather. This is consistent with the hypothesis that water clarity is controlled both by algal cells, which tend to be persistent in wet and dry weather, and by storm-driven loads of inorganic suspended solids from the watershed, which have shorter time scales because of the high rates of sedimentation in the lake.

- Improvements in water clarity can be linked primarily to significant reductions of phosphorus and chlorophyll-a levels observed at the open lake sites over the past several years following reductions in phosphorus loads from the Metro outlet (see 10-year trends in phosphorus and chlorophyll-a).

- Increasing trends in fecal coliform bacteria under dry weather are apparent at the Harbor Brook and Mid-South stations (8 to 15% per year). These increases are likely to reflect the intentional decrease in chlorine doses in the Metro discharge in 2004, as evident in the 2001-2010 fecal coliform trend charts generated by the AMP database (samples, monthly geometric means).

- Decreasing trends in fecal coliform and E. coli bacteria (-13 to -16 % per year) are evident during wet weather at Ley Creek and adjacent Bloody Brook sites. These trends may be linked to implementation of source controls in the adjacent Ley Creek and/or Bloody Brook watersheds.

- Decreasing trends in E. coli bacteria are also indicated at northern sites in both dry and wet weather (-4 to -14% per year) and at southern sites in wet weather (-6 to -13% per year).

- Means and trends generally tend to be less pronounced at the northern sites as compared with the southern sites. This is expected to some extent because bacteria levels and excursion frequencies were lower in 1999-2002 so there was less room for improvement relative to the southern sites at the start of the monitoring program.

- The AMP database trend analyses for 2001-2010 without regard to rainfall indicates significant increasing trends in monthly geometric mean fecal coliform levels at Dorwin Avenue on Onondaga Creek (Trend = 7%/yr, p=.06) and at Route 48 on Ninemile Creek (Trend = 12%/yr, p=.08), both of which primarily reflect rural runoff. No trends are indicated at downstream sites that are impacted by urban runoff and CSOs. The time series graphics suggest that yearly minimum values increased while yearly maximum values were constant or decreased. Variations in sampling strategy (routine vs. storm event) could impact the time series. Consideration of antecedent rainfall would significantly enhance the analysis and interpretation of the tributary data and provide a basis for interpreting the nearshore trends and evaluating the effectiveness of stormwater controls.

Conclusions and Recommendations

Long-term trends in Secchi depth, turbidity and bacteria levels at nearshore sites between 1999 and 2010 have been analyzed using various statistical methods. General conclusions and recommendations are summarized below.

1. Results summarized in the previous section indicate increases in water clarity under both dry and wet weather throughout the lake. Decreases in fecal coliform and E. coli bacteria are evident at several sites during wet weather. Increases in fecal coliform at southern sites during dry weather can be attributed to an intentional change in disinfection practices at the Metro plant in 2004.

2. For the weekly datasets, separate analyses of dry and wet weather samples provides greater power for detecting signals related to implementation of point-source vs. nonpoint-source controls. While pooling all samples provides larger datasets and would be expected to increase power for detecting trends, the associated introduction of variance related to weather works in the opposite direction (Walker, 2007).

3. Statistical adjustment for rainfall dependence does not appear to impact conclusions regarding the magnitudes and statistical significance of trends. Analyzing the dry and wet weather data separately is preferred to pooling the samples from multiple stations, with or without adjustment.

4. The trend slopes and significance tests generally confirm inferences drawn from visual inspection of the annual time series when dry and wet weather samples are distinguished.

5. Although the slopes differ among the three tests by varying amounts for each data subset, they generally lead to similar conclusions and provide a more robust analysis than if only a single test were performed.

6. Despite low fecal coliform levels relative to the compliance limit, the bacteria data are very useful for tracking the effectiveness of measures to control CSO's, rural runoff, and urban runoff when effects of antecedent precipitation are considered. Reductions in bacteria levels are likely associated with reductions in other constituents, including nutrients and suspended solids.

7. Recommendations for future work include :

    a. Similar analyses of data from the lake tributary sites to elucidate trends in bacteria loads and geometric mean concentrations during dry and wet weather, and to facilitate interpretation of the nearshore data.

    b. Updating the AMP Statistical framework to include data from the nearshore sites and to develop improved trend-detection algorithms that account for antecedent rainfall.

    c. Refinement of criteria for distinguishing wet-weather from dry-weather samples, as compared with a simple 3-day antecedent rainfall breakpoint of 0.2 inches. This would include consideration of hourly data and different averaging periods.

d. Analysis of intensive data from individual storm events.

e. Updating the AMP database to incorporate improvements in Excel and R software. These improvements would facilitate statistical analyses and automate production of effective data displays and tables for AMP yearly reports, appendices, and OCDEWP web site.

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Appendix

http://www.wwwalker.net/onondaga/report_2011/index.htm