# Analysis of Changes in Creek Storm Water Quality following the Enactment of the Comprehensive Watershed Ordinance and the Urban Watershed Amendments

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*Storm water quality monitoring data from City of Austin creeks were examined for trends related to ordinances and other efforts designed to control nonpoint source pollution. Data from USGS stations for five Austin creeks were used; three creeks were in watersheds covered by the Comprehensive Watershed Ordinance and two in watersheds covered by the Urban Watersheds Amendments. These ordinances required treatment of stormwater runoff and the implementation of pollution prevention measures. The periods following the enactment of the ordinances show lower concentrations of total suspended solids in all creeks. Total dissolved solids, volatile suspended solids, total organic carbon, total Kjeldahl nitrogen, total phosphorus, total nitrogen, ammonia, and fecal coliform bacteria decreased in some creeks. The only increase was in ion concentrations in Barton Creek. This improvement in most pollutant concentrations occurred even though construction increased during the period after ordinance enactment.*

## Introduction

The Comprehensive Watershed Ordinance (CWO) and the Urban Watershed Amendments (UWA) were enacted in an attempt to reduce the pollutant concentrations in Austin area creeks due to nonpoint sources. The CWO took effect on May 18, 1986, and was applicable throughout the City of Austin (COA) planning jurisdiction except in the urban watersheds. The CWO was the first COA water quality ordinance to consider impervious cover limits based on net site area (buildable area) rather than gross site area and to designate and protect critical environmental features. Urban watersheds were incorporated by the UWA on September 8, 1991.

The CWO included two basic types of protection measures, structural controls and non-structural controls (COA 1991):

Structural Controls

- During construction, temporary erosion and sedimentation control structures (e.g., silt fences, filter dikes, rock of brush berms)
- Permanent erosion and sedimentation control structures (e.g., revegetation, retaining walls, rip-rap, flow dissipaters)
- Permanent water quality basins to settle suspended solids and/or filter various pollutants carried in stormwater

Non-Structural Controls

- Limits on development density and square footage of impervious cover
- Designation of Critical Water Quality Zones and Water Quality Buffer Zones
- Restrictions on cuts and fills, development on steep slopes, vegetative clearing and spoil disposal
- Setbacks from Critical Environmental Features
- Restrictions on lot size, soil type, and slope for individual wastewater systems

- Transfers of development rights with allowable increases in development to provide incentive to construct outside of water quality zones.

The UWA for development and redevelopment:

- Requires treatment of stormwater runoff (Structural Controls)
- Establishes Critical Water Quality Zones
- Provides setbacks from Critical Environmental Features
- Creates need for Structural Controls Plan (Master Plan)

Thus both ordinances required structural controls providing treatment for storm water runoff, and non-structural controls endeavoring to prevent pollutants from entering storm water.

In an endeavor to document changes due to these ordinances we looked for changes in creek storm water quality using data from 1975-2004. Multiple linear regression and analysis of covariance methods were used.

## Methods

**Data Obtained**

USGS water quality and flow data from 1975 through 2004 was available for five (5) Austin Creek sites; Barton Creek at Loop 360 (08155300), Bull Creek at Loop 360 (08154700), Boggy Creek at 183 (08158050), Shoal Creek at 12th Street (08156800), and Walnut Creek at FM 969/Webberville Road (08158600) (Figure 1). These sites do not all have complete records for the entire period, but they have the longest records available with adequate data in both pre- and post-ordinance periods. Of these five creeks, Boggy and Shoal fall under the Urban Watersheds Amendments and Barton, Bull and Walnut under the Comprehensive Watersheds Ordinance.

Complicating factors in addition to incomplete records related to the analysis of this data include:

- Grandfathering of land parcels resulting in development under previous rules.
- Additional amendments such as the Composite Barton Springs Zone Amendments (Barton-1991), the SOS Referendum (Barton-1992), and the Water Supply Suburban (Bull-1995) which modified the ordinances over time.
- Large portions of the Barton Creek watershed are outside of the City's jurisdiction.
- Little Walnut, which is a major tributary of Walnut, falls under the Urban Watersheds Amendment rather than under the Comprehensive Watersheds Ordinance.
- Increases in impervious cover and percent developed, differing by watershed.
- Variability in storm characteristics.

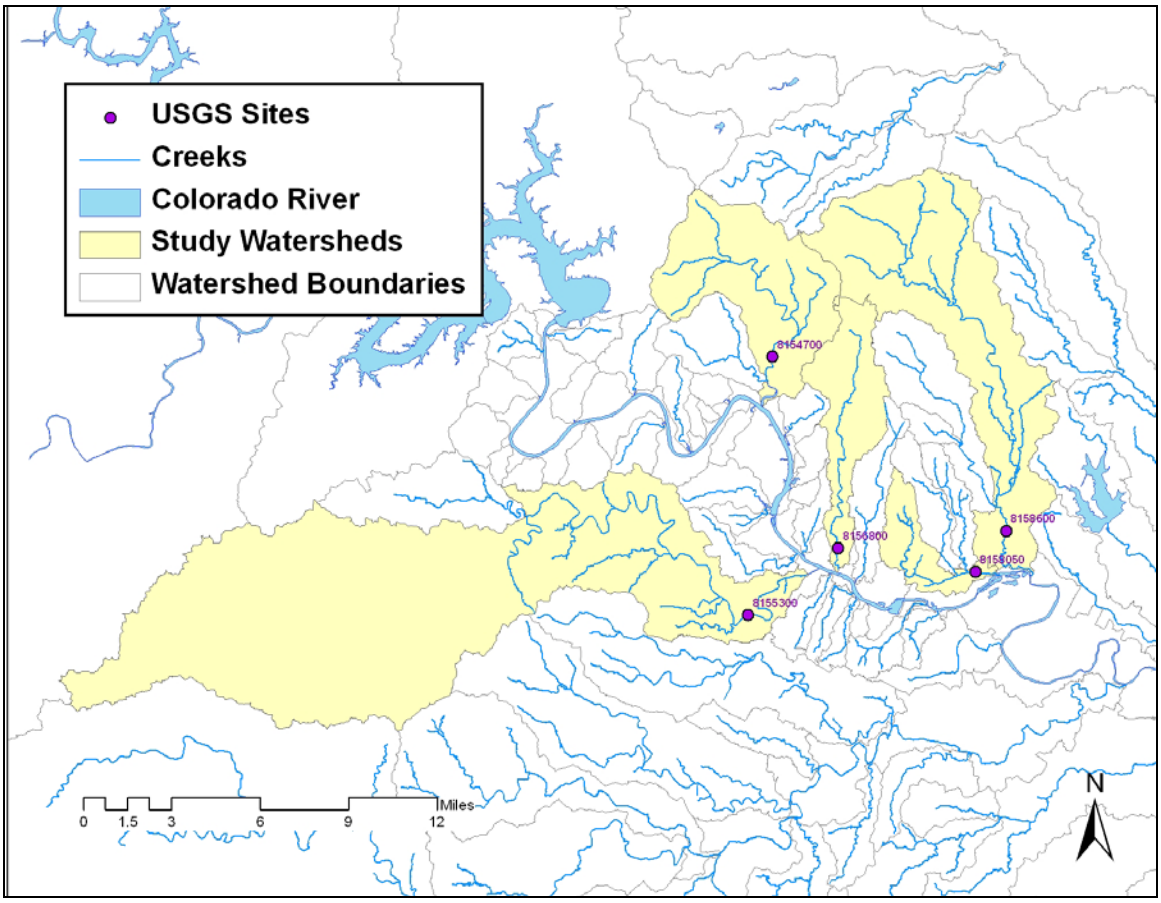



**Figure 1. Map of Watershed and USGS Sampling Sites.**

Parameters which were monitored both before and after the CWO/UWA include biological oxygen demand (BOD), total organic carbon (TOC), fecal coliform bacteria, the ions: chloride and sulfate, the nutrients: ammonia (NH3), nitrate (NO3), total Kjeldahl nitrogen (TKN), total nitrogen (TN), and total phosphorus (TP), and the solids: total suspended solids (TSS), total dissolved solids (TDS), and volatile suspended solids (VSS). Water quantity parameters for each storm included peak flow, storm volume, and storm duration. Event mean concentrations (EMCs) were calculated as specified in the Draft COA Large Watersheds Report, 2006. Storm data was screened for completeness and only storms with a score ≥ 50 were included in the analysis.

The number of building permits issued by the City of Austin was obtained for the years 1975-2004 from the City's Growth Watch (www.ci.austin.tx.us/growth). In 1996, the Growth Watch data was changed from number of permits to total square feet. However for three years, 1993-1995 both the number of permits and the total square feet were reported. Using this information the number of building permits for 1996 through 2004 was estimated from the total square feet. The number of building permits is used as an indicator of potential construction impacts city wide since the locations of the permits is not available for all of the data.

Preliminary data on the number and type of permanent Best Management Practices (called "ponds" or BMPs) for flood and water quality control, such as flood detention basins, sedimentation/filtration basins, wet ponds, etc. with plans that were approved by the City of Austin was obtained. This data is incomplete and not yet checked for accuracy, with data collection efforts ongoing. The date associated

with each pond is the date the plans were approved, not the date the pond construction was completed. Analyses associated with this data must be regarded as preliminary, not definitive.

Annual impervious cover estimates for the five watersheds are unavailable at this time.

**Trend Analysis for Pollutant EMCs for Sampled Storms in Area Creeks**
Multiple linear regression analysis was used to determine whether pollutant EMCs were changing over time. The dependent variable was the EMC for each water quality parameter. The independent variables were event peak flow and time. A relationship between storm size, as measured by peak flow during an event and pollutant EMCs has previously been demonstrated for Austin area creeks (COA 1997). Peak flow was entered first in the regression model as a covariate if the relationship between peak flow and EMCs was significant. Entering time second enables us to determine whether time accounts for a significant amount of variation in the EMC levels in addition to the variance already accounted for by storm size. TSS EMCs were adjusted to the mean of the peak storm flow by determining the linear relationship between peak flow and TSS EMCs. Then the difference between the predicted EMC at the observed peak flow and the predicted EMC at mean peak flow is calculated and subtracted from the observed EMC. Plots of peak flow, EMCs for TSS, and TSS EMCs adjusted to the mean of peak storm flow were generated.

**Bias Check: Trend Analysis for Storm Volume for Sampled Storms in Area Creeks**
A bias in the size of sampled storms over time could effect the interpretation of the trend analysis for pollutant levels. Linear regression analysis was used to see if the types of storms that were sampled changed over time. The dependent variable was storm volume. The independent variable was time.

**Comparison of Pollutant EMCs before and after the CWO/UWA**
Pollutant EMCs in the five creeks were compared for two time periods, 1975-1986 and 1987-2004 for Barton, Bull, and Walnut Creeks, and 1975-1991 and 1992-2004 for Boggy and Shoal Creeks. The earlier periods were before the CWO/UWA while the later periods were after their enactment. Peak storm flow was used as a covariate if it was significantly related to a given pollutant EMC. The peak flow weighted means for the parameters and the two periods were determined. The flow weighted means are the least-squares means from the analysis of variance with period as a class variable and peak flow as a covariate. Least-squares means, or population marginal means, are the expected value of the class means with all covariates at their mean value. Peak flow was used as a covariate to subtract out the effects of sampling different size storms during different years. The percent improvement, or the percent of a pollutant no longer found in a creek is estimated by determining the ratio of the post-ordinance marginal mean to the pre-ordinance marginal mean and subtracting from one.

**Bias Check: Comparison of Annual Creek Flow before and after the CWO/UWA**
Differences in annual creek flows due to climate variation during the two time periods could effect the interpretation of the ANOVA results for pollutant EMC levels before and after the CWO/UWA. In order to investigate this possible bias, annual flows in the five creeks were compared for two time periods, 1975-1986 versus 1987-2004 for Barton, Bull, and Walnut Creeks, and 1975-1991 versus 1992-2004 for Boggy and Shoal Creeks. The earlier periods were before the CWO/UWA while the later periods were after their enactment. Analysis of variance on annual average flow during the two time periods with annual rainfall as a covariate was done.

Annual rainfall was used as a covariate to subtract out the effects of variations in climate during different years. Changes in impervious cover, unless mitigated by BMPs will also affect the average annual flow. However estimates of annual impervious cover are unavailable at this time, and thus could not be used as a covariate.

**Comparison of Peak and Average Flows before and after the CWO/UWA**
Adding structural water quality controls to a watershed is expected to reduce the peak flow during storms and increase the duration of storm flow, which is equivalent to reducing the average flow. Peak and average flows for storm events in the five creeks were compared for two time periods, 1975-1986 versus 1987-2004 for Barton, Bull, and Walnut Creeks, and 1975-1991 versus 1992-2004 for Boggy and Shoal Creeks. Only storms with water quality data were included. Storm volume was used as a covariate. The volume weighted peak and average flow means for the two periods were determined. The volume weighted means are the least-squares means from the analysis of variance with period as a class variable and storm volume as a covariate. Least-squares means, or population marginal means, are the expected value of the class means with all covariates at their mean value. Volume was used as a covariate to subtract out the effects of sampling different size storms during different years.

## Results

## Trends in Pollutant EMCs

**TSS:** TSS may be viewed as a target pollutant since it has been used as an indicator of a variety of different types of urban pollutants. TSS levels are a measure of sediment load to surface and ground water bodies. TSS also typically has other pollutants associated with it, such as heavy metals and pesticides. Furthermore, it is a useful parameter to measure and study because it may be more easily removed than many other parameters by simple physical processes.

**Table 1. Number of Storms with TSS samples before and after the CWO/UWA**

| Creek | Before | After |
|---|---|---|
| Barton @ 360 | **8** | **28** |
| Bull @ 360 | **9** | **22** |
| Boggy @ 183 | **10** | **13** |
| Shoal @ 12th | **11** | **20** |
| Walnut @ 969 | **4** | **26** |

TSS event mean concentrations decreased significantly over time in all five creeks (Table 2). The peak flow, the TSS EMCs and the TSS EMCs adjusted to the mean peak flow for individual storms are shown in plots in Appendix A.

The slope or rate of change for TSS EMCs is much smaller in Barton Creek than in the other four creeks, which have similar slopes. The decrease in TSS concentrations in Boggy, Bull, Shoal, and Walnut Creeks is five times that in Barton Creek. Barton is the largest of the watershed and has the least development.

**Table 2. Parameter Estimates and Significance Levels for Multiple Regression of Storm Event Mean Concentrations of TSS on Peak flow Rate and Time.**

| Site | Dependent Variable | Parameter | Slope Estimate | Standard Error | Pr > \|t\| |
|---|---|---|---|---|---|
| Barton @ 360 | Event Mean Concentration of TSS (mg/L) | Intercept | 682.6838 | 246.1980 | 0.0091 |
| | | Peak_Flowrate | 0.0546 | 0.0123 | 0.0001 |
| | | date | -0.0401 | 0.0183 | 0.0359 |
| Bull @ 360 | Event Mean Concentration of TSS (mg/L) | Intercept | 2985.3931 | 589.3987 | 0.0000 |
| | | Peak_Flowrate | 0.1243 | 0.0454 | 0.0106 |
| | | date | -0.2013 | 0.0461 | 0.0002 |
| Boggy @ 183 | Event Mean Concentration of TSS (mg/L) | Intercept | 3021.8700 | 952.1415 | 0.0048 |
| | | Peak_Flowrate | 0.6576 | 0.1809 | 0.0016 |
| | | date | -0.2061 | 0.0697 | 0.0078 |
| Shoal @ 12th | Event Mean Concentration of TSS (mg/L) | Intercept | 2922.4828 | 583.1927 | 0.0000 |
| | | Peak_Flowrate | 0.6200 | 0.1720 | 0.0012 |
| | | date | -0.1838 | 0.0412 | 0.0001 |
| Walnut @ 969 | Event Mean Concentration of TSS (mg/L) | Intercept | 2842.3943 | 939.8834 | 0.0054 |
| | | Peak_Flowrate | 0.2033 | 0.0701 | 0.0074 |
| | | date | -0.1509 | 0.0721 | 0.0458 |

**Nutrients, Solids, Ions, Other Parameters**: Significant decreases were found in the nutrients: TP, NH3, TKN, and TN; in the solids: TSS, VSS, and TDS; and in TOC and fecal coliform bacteria (Table 3). The only pollutants with significant increases in EMCs over time were the ions: sulfate and chloride in Barton Creek. The limited change in TDS, especially chloride and sulfate, may suggest that chloride or sulfate are good measures for tracking the subtle impacts of development on water quality since they are not being stopped by structural BMPs. No significant changes were found in BOD or NO3. Changes were significant at the 0.05 level or the 0.10 level.

Some parameters had small or insufficient sample sizes in one of the periods. Only four samples were taken in Walnut Creek before the CWO reducing the power of the regression analysis. There was only one ion sample taken in the period after the UWA in Shoal and Boggy creeks.

**Table 3. Parameters with Significant Trends at the 0.05 (X) or 0.10 (X*) level from Multiple Regressions of EMCs on Peak flow Rate and Time. Trends are decreasing unless otherwise indicated. Shading indicates that the relationship with the covariate was significant.**

| | Solids | | | Other | | Nutrients | | | | Ions | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Site** | TSS | TDS | VSS | TOC | Fecal Coliform Bacteria | TP | NH3 | TKN | TN | CL | SO4 |
| Barton @ 360 | X | | X | X* | | | X | | | **UP** | **UP** |
| Bull @ 360 | X | | X* | X | | X* | X | X | X | | |
| Boggy @ 183 | X | X | X | X | X | X* | X | X* | | **Insufficient data** | |
| Shoal @ 12th | X | X | X* | X | | X* | | X* | X* | **Insufficient data** | |
| Walnut @ 969 | X | | | | | X* | | | | | |
| *** EMCs significant at the 0.10 level** | | | | **Peak flow sig. at the 0.05 level** | | | | **Peak flow sig. at the 0.10 level** | | | |

Many of the investigated parameters were significantly different at different peak flow levels, demonstrating the need for acknowledging and removing the effects of flow in the analyses. Parameters for which peak flow was significant are highlighted in Table 3. Relationships between EMCs and various non-linear functions of peak flow were also investigated, but were not used as they did not improve on the strength of the linear relationship with peak flow.

There was no significant bias in the size of storms sampled over time. Storm size was measured by storm volume. The results of the linear regression analysis used to test for bias are shown in Table 4.

**Table 4. Flow Bias Test: Parameter Estimates and Significance Levels for the Regression of Storm Volume on Time.**

| **Site** | **Dependent Variable** | **Parameter** | **Estimate** | **Standard Error** | **Pr > \|t\|** |
|---|---|---|---|---|---|
| **Barton @ 360** | Storm Volume | Intercept | 287161691 | 231215930 | 0.2223 |
| | | date | -13468 | 18187 | 0.4638 |
| **Bull @ 360** | Storm Volume | Intercept | 10479918 | 21348258 | 0.6271 |
| | | date | 422 | 1714 | 0.8073 |
| **Boggy @ 183** | Storm Volume | Intercept | 6122976 | 4831669 | 0.2155 |
| | | date | 271 | 424 | 0.5276 |
| **Shoal @ 12th** | Storm Volume | Intercept | 3328416 | 4370479 | 0.4509 |
| | | date | 294 | 360 | 0.4199 |
| **Walnut @ 969** | Storm Volume | Intercept | 35541417 | 50899747 | 0.4908 |
| | | date | -485 | 3918 | 0.9025 |

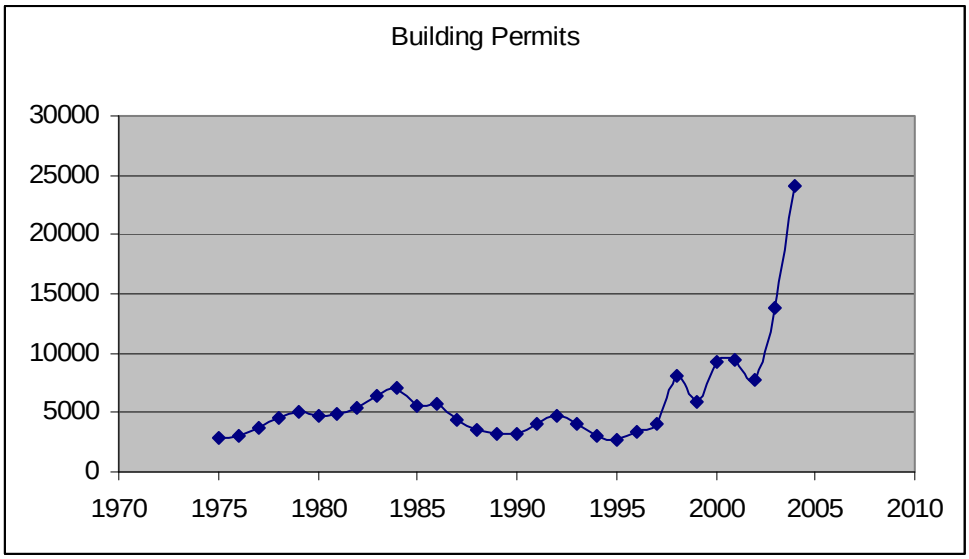
## TSS Trends and Relationships to Construction in the Post-Ordinance Period:

The multiple linear regression analysis was repeated for TSS, an indicator pollutant, for the period following the enactment of the CWO/UWA. TSS levels showed no trends during this period except in Boggy Creek where storm flow TSS EMCs continued to decline significantly from 1992 to 2004.

Building permits have increased in recent years (Figure 2). The number of building permits has been used as an indicator of potential construction impacts, and TSS in storm flow was significantly related to

the number of building permits city wide in the past (COA 1996). During the period following the enactment of the CWO/UWA, however, TSS is no longer significantly related to the number of city wide building permits.

**Figure 2. City of Austin Building Permits**




## Magnitude and Significance of the Change in EMCs from Before to After the CWO/UWA as Determined by Analysis of Variance

The two time periods under investigation were 1975-1986 versus 1987-2004 for Barton, Bull, and Walnut creeks, and 1975-1991 versus 1992-2004 for Boggy and Shoal creeks. The peak flow weighted means for the parameters and the two periods were determined. The flow weighted means are the least-squares means from the analysis of variance with period as a class variable and peak flow as a covariate. Least-squares means, or population marginal means, are the expected value of the class means with all covariates at their mean value. Peak flow was used as a covariate to subtract out the effects of sampling different size storms during different years. Significance levels and the period means for the EMCs at mean peak flow are shown in Table 5. Table 6 shows the percent improvement for each parameter. In some case the number is negative indicating a worsening situation. The mean peak flows for each creek are listed in Table 7. Note that Barton has the highest flow but the lowest TSS EMCs. Bar charts of the EMC period means, except for the ions, are also included in Appendix B.

Walnut Creek showed the least improvement relative to the number of pollutants which declined significantly. The other four creeks showed improvement in 6 or 7 parameters whereas Walnut Creeks showed improvement in just three parameters.

**Table 5. Period Means for EMCs at Mean Peak Storm Flow. Results in mg/L except for bacteria (col/100 mL).**

| | Solids | | | | | | Other | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | TSS | | TDS | | VSS | | BOD | | TOC | | Fecal Coliform Bacteria | |
| Site | Before | After | Before | After | Before | After | Before | After | Before | After | Before | After |
| Barton @ Loop 360 | 620 | 257 | 203 | 212 | 84 | 39 | 4.0 | 2.4 | 24 | 14 | 24,182 | 13,542 |
| Bull @ Loop 360 | 1,660 | 277 | 261 | 242 | 202 | 67 | 6.0 | 3.5 | 52 | 17 | 41,083 | 30,282 |
| Boggy @ 183 | 2,051 | 1,085 | 139 | 103 | 217 | 106 | 17.7 | 7.7 | 36 | 26 | 236,965 | 78,574 |
| Shoal @ 12th | 1,901 | 736 | 184 | 148 | 268 | 124 | 14.0 | 10.7 | 42 | 24 | 117,828 | 152,296 |
| Walnut @ 969 | 2,388 | 1,043 | 198 | 174 | 139 | 125 | 5.4 | 9.6 | 31 | 25 | 125,697 | 36,573 |

| | Nutrients | | | | | | | | Ions | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | TP | | NH3 | | TKN | | TN | | CL | | SO4 | |
| | Before | After | Before | After | Before | After | Before | After | Before | After | Before | After |
| Barton @ Loop 360 | 0.14 | 0.11 | 0.06 | 0.02 | 1.65 | 0.88 | 1.91 | 1.12 | 13.2 | 16.6 | 20 | 25 |
| Bull @ Loop 360 | 0.31 | 0.14 | 0.11 | 0.04 | 3.32 | 1.03 | 3.78 | 1.50 | 38.7 | 35.7 | 60 | 46 |
| Boggy @ 183 | 1.35 | 0.85 | 0.20 | 0.11 | 3.53 | 2.20 | 3.97 | 2.66 | **Insufficient data** | | | |
| Shoal @ 12th | 1.13 | 0.76 | 0.17 | 0.10 | 3.60 | 2.45 | 4.13 | 2.93 | **Insufficient data** | | | |
| Walnut @ 969 | 1.67 | 0.67 | 0.13 | 0.14 | 2.25 | 1.73 | 2.62 | 2.30 | 23.1 | 21.9 | 37 | 32 |
| Significant at the 0.05 level | | | | Significant at the 0.10 level | | | | | | | | |

The difference in pollutant concentrations between creeks is noteworthy. Barton Creek has the lowest concentrations for all parameters except TDS, in spite of the fact that it has the highest average peak flow. This is to be expected as Barton has the lowest impervious cover of the five watersheds.

A few differences are found in significance levels between the results of the regression analysis and the results of the analysis of variance. In each case, however, only a slight difference is present in the probability which determines significance. The probability may have been 0.08 and changes to 0.11, or 0.07 and changes to 0.05. Stormwater EMCs are notoriously variable, and the addition of more data over time is likely to confirm the improvements which we have identified in the area creeks. Thus, any parameter which is identified as changing significantly by either method deserves consideration.

**Table 6. Percent Improvement or Percent of Pollutant no Longer in Creek following the CWO/UWA**

| Site | TSS | TDS | VSS | BOD | TOC | Fecal Coliform Bacteria | TP | NH3 | TKN | TN | CL | SO4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Barton @ Loop 360 | 59% | -5% | 54% | 39% | 40% | 44% | 23% | 61% | 47% | 41% | -26% | -30% |
| Bull @ Loop 360 | 83% | 7% | 67% | 42% | 67% | 26% | 54% | 60% | 69% | 60% | 8% | 23% |
| Boggy @ 183 | 47% | 26% | 51% | 56% | 27% | 67% | 37% | 46% | 38% | 33% | | |
| Shoal @ 12th | 61% | 20% | 54% | 24% | 42% | -29% | 32% | 43% | 32% | 29% | | |
| Walnut @ 969 | 56% | 12% | 10% | -79% | 18% | 71% | 60% | -8% | 23% | 12% | 5% | 14% |
| Significant at the 0.05 level | | | | | | Significant at the 0.10 level | | | | | | |

**Table 7. Mean Peak Storm Flow for the Five Creeks**

| Creek | Mean Peak Storm Flow ($ft^3/s$) |
|---|---|
| Barton Creek @ Loop 360 | 2,890 |
| Bull Creek @ Loop 360 | 1,360 |
| Boggy Creek @ 183 | 1,420 |
| Shoal Creek @ 12th Street | 880 |
| Walnut Creek at MLK | 1,530 |

No significant bias was found resulting from flow differences over time since the annual flows in the five creeks are not statistically significantly different during the two time periods. Analysis of variance on annual average flow during the two time periods with annual rainfall as a covariate was done and the results are shown in Table 8.

**Table 8. Significance Levels for the ANOVA of Annual Flow between Periods with Annual Rainfall as a Covariate.**

| | | Pr > \|t\| | | |
|---|---|---|---|---|
| **Site** | **Dependent Variable** | **Intercept** | **Annual Rainfall** | **Period** |
| Bull @ 360 | Annual Flow | 0.0212 | <0.0001 | 0.2692 |
| Barton @ 360 | Annual Flow | 0.0086 | 0.0001 | 0.9128 |
| Shoal @12th | Annual Flow | 0.0113 | <0.0001 | 0.6005 |
| Boggy @ 183 | Annual Flow | 0.1562 | 0.0026 | 0.2173 |
| Walnut @ 969 | Annual Flow | 0.0037 | <0.0001 | 0.2779 |

## The Changes in Peak and Average Storm Flow from Before to After the CWO/UWA

The expected result of adding structural controls such as water quality basins to a watershed is the reduction of peak flow during storms and an increase in the duration of storm flow. This also reduces the average flow which is the storm volume divided by the storm duration. However, the simultaneous increase in impervious cover during development has the opposite effect. The water quantity data was checked to see if peak and average flows were lower following the implementation of the CWO/UWA (Figure 3). Lower peak flows could explain the decreases in the solids and other associated parameters such as TP, TKN, TN and TOC. Peak flows are significantly lower in Bull and Shoal Creeks and average flows are significantly lower in all but Walnut Creek. Walnut Creek had the smallest number of parameters which decreased following the CWO implementation: TSS, TP and fecal coliform bacteria. Walnut Creek also had only four storms sampled prior to the CWO, leading to a loss of power in the analyses.

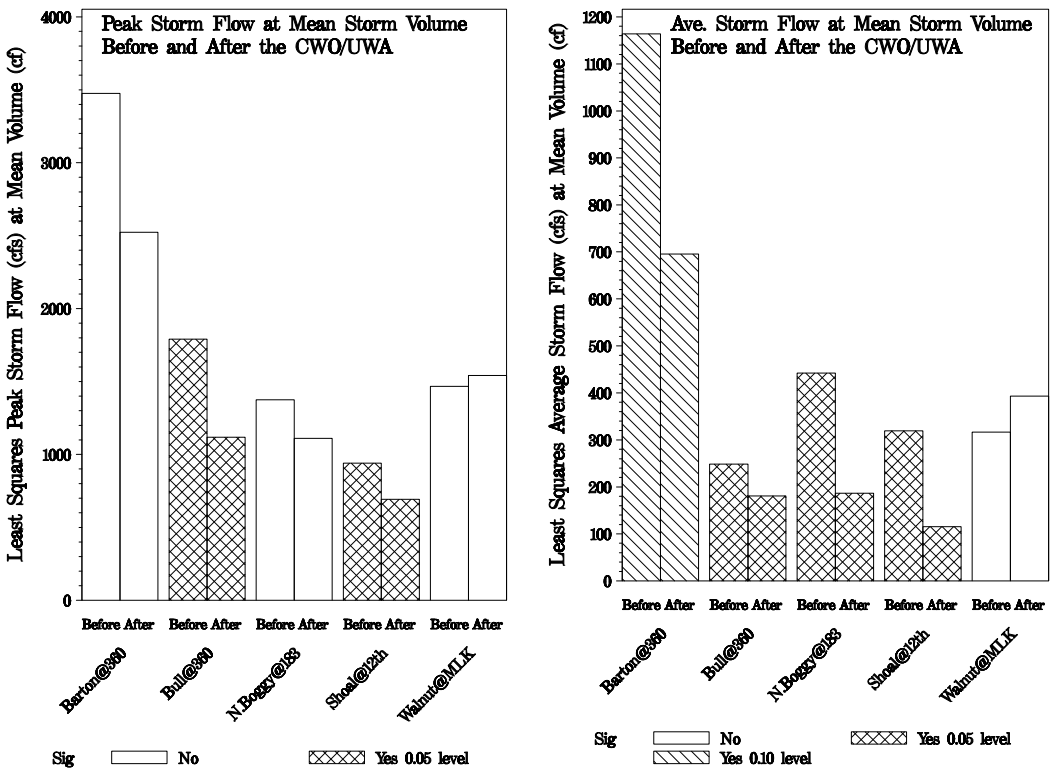



**Figure 3. Significant Changes in Peak and Average Flows after the CWO/UWA**

## Discussion

### Water Quality Improvement in Area Creeks

Analysis of the creek data indicated that water quality following the enactment of the Comprehensive Watershed Ordinance (1986) and the Urban Watershed Amendment (1991) was better than during the preceding monitoring period starting in 1975. Solids and total nutrients improved the most. Nitrate showed no improvement and BOD almost none, while the ions increased in Barton Creek. Following ordinance enactment only Boggy Creek continued to improve significantly (as measured by TSS). It is possible that Shoal Creek is also improving, but the improvement is not yet significant.

The structural and non-structural controls required by the CWO/UWA should reduce the amount of sediment in the creeks during storm water runoff and should also reduce the pollutants which are most easily trapped in control structures. This would explain why we have seen improvement in TSS but not in nitrate concentrations (COA 1997). Analysis of the flow data showed that peak and average flows were declining in most creeks. This also may be due to the implementation of the CWO/UWA.

It is not clear why Boggy Creek has continued to improve while the other creeks have not. Shoal Creek appears to be improving after the UWA as well (see the graphs for TSS in Appendix A) but the improvement is not significant. Two possibilities are stream restoration projects and the amount and type of development in Boggy and Shoal relative to Barton, Bull and Walnut.

Nineteen stream restoration projects designed to protect Boggy Creek and its' tributaries Fort Branch and Tannehill from erosion were completed between 1991 and 2003. Sixteen projects were completed in Shoal and eleven in Little Walnut Creek above the confluence with Walnut Creek. No projects were completed during this time frame in Barton Creek above Loop 360 or in Bull Creek (Table 9).

**Table 9. Completed Watershed Protection Stream Restoration Projects, 1991-2003**

## COMPLETED CAPITAL PROJECTS

1991 - 2003

| location | engineer designer | Watershed | date | solution |
|---|---|---|---|---|
| Lanier Drive | Jones&Neuse | Shoal | 1994 | concrete channel |
| West 49th Street | Jones&Neuse | Shoal | 1994 | gabion wall |
| Lamar Emergency Project | Clayton | Shoal | 1995 | Armor bend with gabion structure |
| Grover Channel | Hegemier | Shoal | 1995 | concrete wall |
| Shoal at 10th Street | Gowing | Shoal | 1995 | gabion wall |
| Greenlawn Parkway | Santos | Shoal | 1996 | concrete support of masonry wall |
| 45th Street | Chan | Shoal | 1996 | stabilize channel |
| SHL @ 26th | Walker | Shoal | 1998 | reconstruct streambank - armor stone |
| Poleyard - 5th to West Ave | PBSJ | Shoal | 1999 | reconstruct streambank - MSE |
| Shoal at 5th Street | Clayton | Shoal | 2002 | reconstruct streambank - MSE |
| NW Park to Foster Lane | Walker | Shoal | 2002 | reconstruct bank - MSE - grade control |
| Poquito Street | Walker | N. Boggy | 1991 | pipe extension - headwall |
| Alexander-Clifford | Walker | N. Boggy | 1991 | pipe extension |
| E. 40th Street | Jones&Neuse | N. Boggy | 1994 | concrete rip rap |
| BOG @ MLK | Santos | N. Boggy | 1996 | stacked boulders |
| Wight Cove | Hegemier | Fort Branch | 1991 | gabion wall |
| Wellington Drive | Hegemier | Fort Branch | 1991 | headwall |
| Vallecito Drive | Hegemier | Fort Branch | 1991 | inlet |
| Rolland Drive | Clayton | Fort Branch | 1991 | pipe extension |
| Elmsgrove Drive | Gebhard | Fort Branch | 1993 | gabions |
| Meander Drive | Gebhard | Fort Branch | 1993 | gabions |
| Penny Street | Jones&Neuse | Fort Branch | 1994 | regrade channel |
| Broadmoor Street | Gowing | Tannehill | 1991 | concrete flume |
| Andover Place | Gebhard | Tannehill | 1993 | gabions |
| Creekside Apartments | Espey | Tannehill | 1994 | gabion bank reconstruction |
| TAN @ Bennett Avenue | Santos | Tannehill | 1996 | armor bank |
| TAN @ Helen Street | Santos | Tannehill | 1996 | stabilize bank |
| Givens Park | Kelly | Tannehill | 1999 | reconstruct streambank - MSE |
| Highland Park Cemetery | Walker | Tannehill | 2000 | reconstruct bank - armor stone |
| Bartholomew Park | Kelly | Tannehill | 2001 | armor streambank - grade controls |
| Ray Avenue | Clayton | Little Walnut | 1992 | concrete wall |
| Langston Drive | Murfee | Little Walnut | 1993 | gabion wall |
| Bridgewater | Murfee | Little Walnut | 1997 | buyouts-reconstruct Banks - MSE |
| Quail Ridge | Murfee | Little Walnut | 1997 | gabion wall |
| Mearns Meadow | Murfee | Little Walnut | 1997 | concrete wall |
| Stonebridge | Murfee | Little Walnut | 1997 | concrete rip rap |
| CollinField | Murfee | Little Walnut | 1997 | concrete rip rap |
| Bangor Bend | Murfee | Little Walnut | 1997 | culvert extension, chnl reshaping |
| Parkfield | Murfee | Little Walnut | 1997 | gabions |
| Lakeside Drive | Murfee | Little Walnut | 1999 | buyouts - reconstruct Banks - MSE |
| Loyola Lane | Walker | Little Walnut | 2002 | reconstruct streambank - MSE |

## COMPLETED CREW PROJECTS

1991 - 2003

| location | engineer designer | Watershed | date | solution |
|---|---|---|---|---|
| 4709 Pecan Springs Road | Kelly | Fort Branch | 2000 | reconstruct streambank - MSE |
| Wellington/Gaston | Kelly | Fort Branch | 2001 | reconstruct channel - grade controls |
| 1012 Romeria Drive | Samson | Shoal | 1995 | concrete rip rap |
| 1103 Brentwood Street | Kelly | Shoal | 1998 | rock toe - soil retention blanket - fiber roll |
| 2613 Pembrook Trail | Kelly | Shoal | 2001 | reconstruct streambank - MSE |
| 1103 Brentwood Street | Clayton | Shoal | 2003 | armor bank with boulders |
| 1012 Karen Street | Clayton | Shoal | 2003 | armor bank with boulders |

Shoal and Boggy creeks had the least development in recent years as indicated by the percent change in undeveloped land between 1995 and 2003 and the watershed size (Table 10). While there is no longer the strong relationship between storm water TSS concentrations and construction that was observed during the 1980s (COA 1996), perhaps continued development in Walnut and Bull creeks is responsible for the lack of continued improvement in those creeks. Barton Creek has the lowest pollutant levels, the lowest impervious cover and not as much development as Shoal and Boggy creeks. Thus the lack of recent improvement in Barton Creek is expected.

**Table 10. Developed Land and Impervious Cover for the USGS Sites (draft subject to change).**

| | | | **Percent Watershed Area Classified as Developed *** | | | | | |
|---|---|---|---|---|---|---|---|---|
| USGS Site No. | USGS Site Name | Watershed Acres (1) | 1958 (2) | 1980 (3) | 1990 (4) | 1995 (5) | 1997 (6) | 1999 (7) |
| 8155300 | Barton at Loop 360 | 74,522 | | 4.0% | 6.3% | 9.2% | 10.0% | 10.8% |
| 8154700 | Bull at Loop 360 | 14,511 | | 11.0% | 30.0% | 42.2% | 50.0% | 55.0% |
| 8158050 | Boggy at US183 | 8,206 | | 78.0% | 79.0% | 81.0% | 82.0% | |
| 8156800 | Shoal at W 12th | 7,924 | | 87.0% | 89.2% | 92.3% | 94.0% | |
| 8158600 | Walnut at Webberville | 33,125 | 9.0% | 30.0% | 47.8% | 56.7% | 61.0% | |

| | | | **Calculated Impervious Cover** | | | | | |
|---|---|---|---|---|---|---|---|---|
| USGS Site No. | USGS Site Name | Watershed Acres (1) | 1958 | 1980 | 1990 | 1995 | 1997 (5) | 1999 (5,6,7) |
| 8155300 | Barton at Loop 360 | 74,522 | | 1.5% | 2.4% | 3.5% | 3.8% | 4.1% |
| 8154700 | Bull at Loop 360 | 14,511 | | 3.1% | 8.3% | 11.7% | 13.9% | 15.3% |
| 8158050 | Boggy at US183 | 8,206 | | 37.1% | 37.6% | 38.5% | 39.0% | |
| 8156800 | Shoal at W 12th | 7,924 | | 44.3% | 45.5% | 47.0% | 47.9% | |
| 8158600 | Walnut at Webberville | 33,125 | 4.2% | 13.9% | 22.2% | 26.3% | 28.3% | |

* Developed is defined as any land use except Park/Open Space and Undeveloped and, for 1995 and later data, Large Lot Single Family (which typically is farmland or rangeland with one or a few structures)

Value is calculated or otherwise extrapolated

(1) COA Watershed Protection Department, unpublished, 2000 - from new stream network delineation work.

(2) Corp of Engineers, Walnut Creek Expanded Flood Plain Information Study, May, 1980 and Williamson Creek Expanded Flood Plain Information Study, May, 1980

(3) City of Austin, Demographic and Land Use Projections and Distribution for the Growth Management Scenario to 2005, Appendix C.2., 1982.

(4) City of Austin Watershed Protection Department unpublished, 1998 - output from Phase 1 of the Master Plan

(5) City of Austin Watershed Protection Department unpublished, 2000 - from application of ISS "ASI" procedure

(6) Estimated from this dataset

(7) For BSZ stations, Planning and Environmental Conservation Services and Watershed Protection Departments for Barton Springs Zone Development Analysis, 1999
For Bull Creek, PBS&J Consultants and Watershed Protection Department for Water Supply Suburban Watersheds Report: Watershed Protection and Traffic Analysis, 1999.

## Conclusions

- The majority of the pollutant event mean concentrations for which we have pre- and post-ordinance data have decreased.
- TSS event mean concentrations have improved in all five creeks.
- Peak flow decreased and storm flow duration increased after ordinance implementation as would be expected from the provisions of the ordinances.
- Increased construction no longer guarantees substantive increase in pollutants in the creeks.
- The Comprehensive Watershed Ordinance (1986) and the Urban Watershed Amendment (1991) could be responsible for some of the improvement in creek storm water quality. Master Plan projects have also probably contributed to the improvement.

## Recommendations for Further Work

- Analysis of water quantity in storms without water quality data to assess more fully the changes in water quantity with ordinance enactment.
- The number of structural controls implemented since the CWO/UWA could be compared to the amount of improvement in each creek.
- Estimates of changes in water quality due to further stream restoration projects could be evaluated.

## References

City of Austin Growth Watch. http://www.ci.austin.tx.us/growth/default.htm

COA 1991. Background Information on City of Austin Water Quality Protection Efforts.

COA 1996. 1996 Analysis of Changes in Creek Water Quality with Construction Activity and Increased Development.

COA 1997. Characterization of Stormwater Pollution for the Austin, Texas Area. Water quality report Series COA-ERM/WQM 1997.

COA 2006. Draft COA Large Watersheds Report. Water Quality Monitoring Section, Environmental Resource Management, Watershed Protection and Development Review Department.

## Appendix A. Plots of Peak Flow, TSS EMCs and TSS EMCs adjusted to Mean Peak Flow

The first plot on each page shows the peak flows for the individual storms. The flows before and after the CWO/UWA are not significantly different. Then second plot shows the range of TSS EMCs for the sampled storms. The third plot is the one which shows visually the significant trends in TSS EMCs. In it the EMCs are all normalized to the same flow so that they can be directly compared to each other. The normalized flow is the mean peak flow for that creek.

The CWO took effect on May 18, 1986, and the UWA on September 8, 1991.

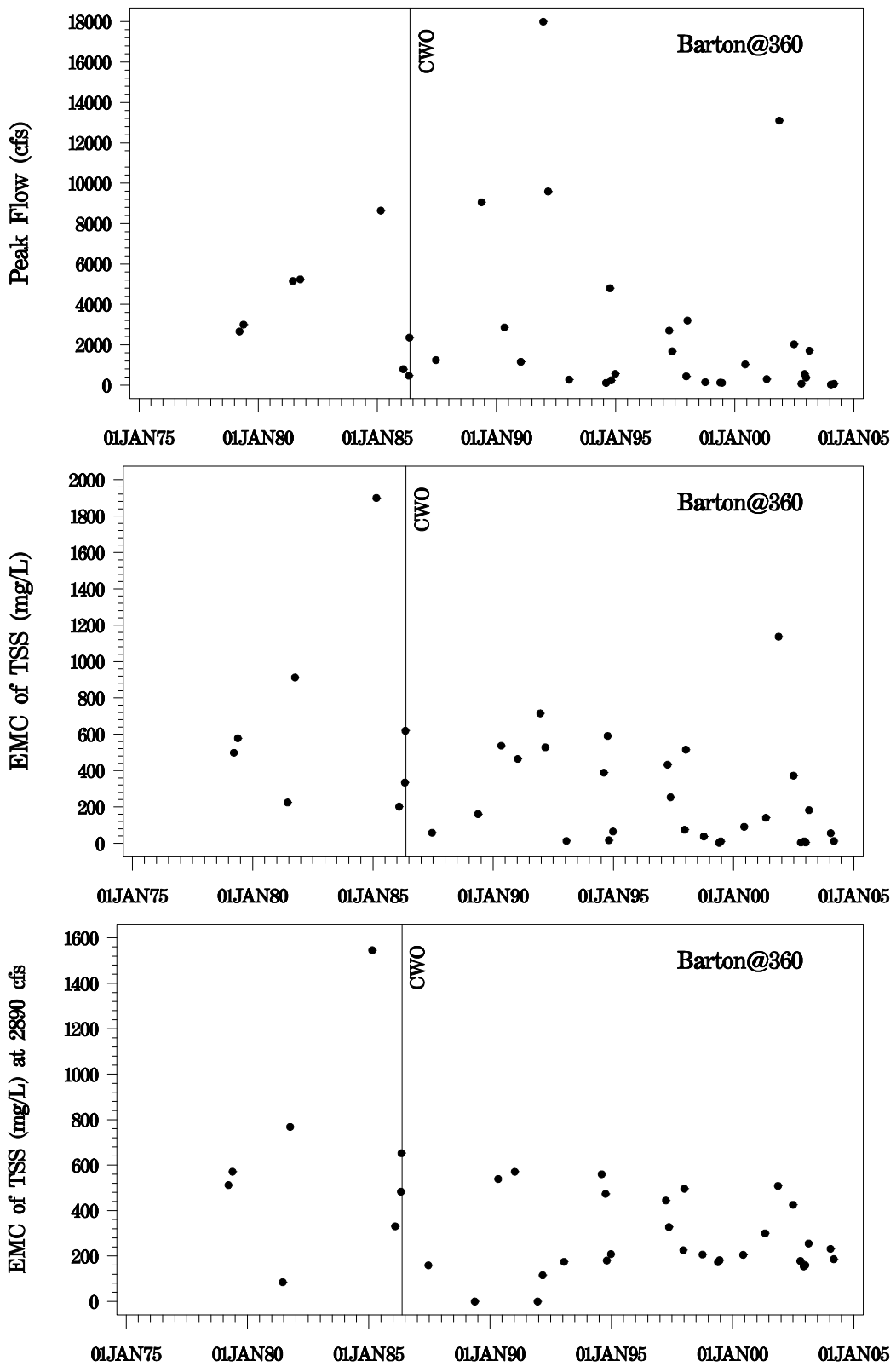



Figure A.1. Flow, Event Mean Concentrations (EMC) of TSS, and EMC adjusted to the Mean of Peak Storm Flows in Barton Creek at Loop 360

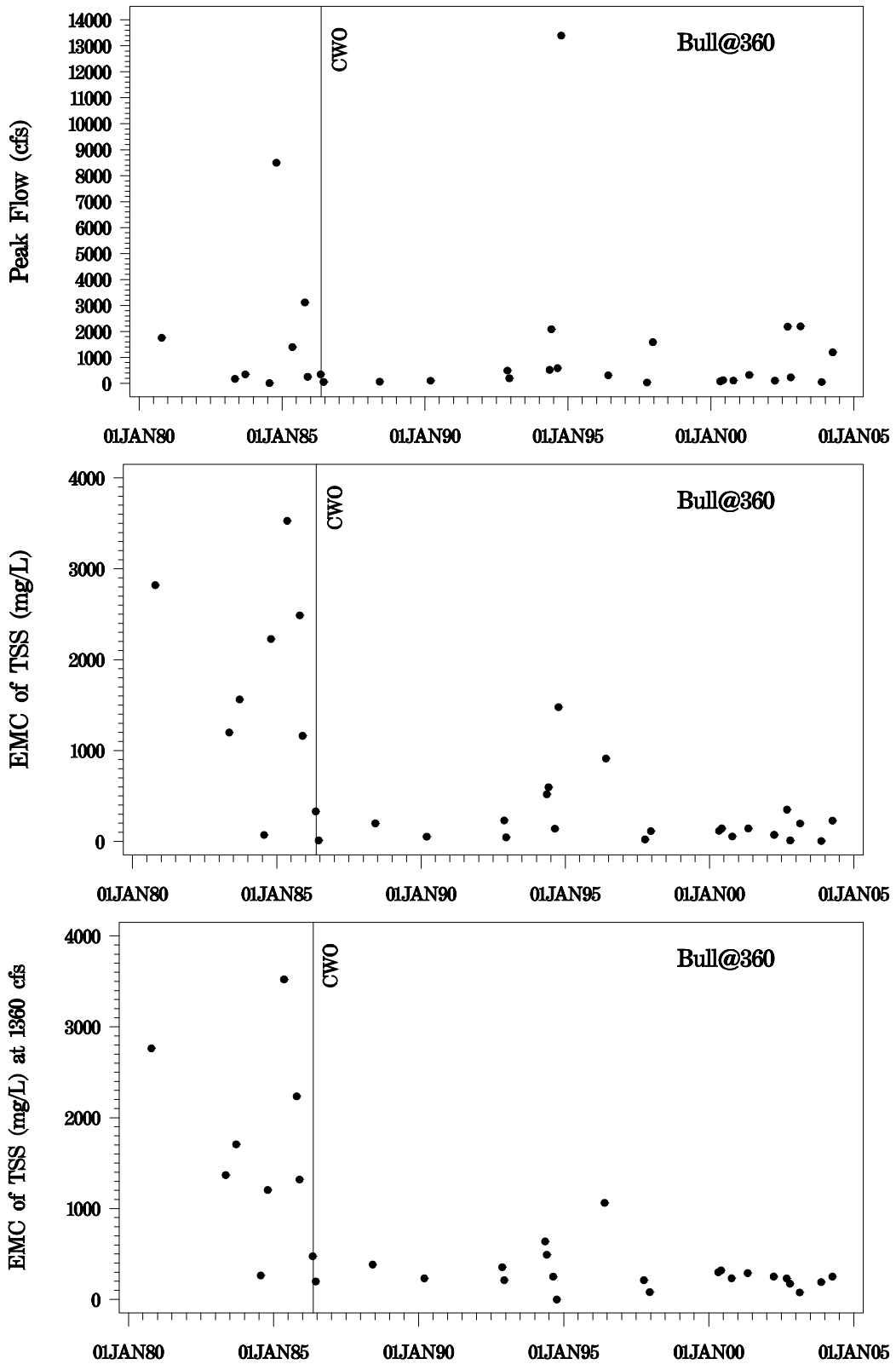



Figure A.2. Flow, Event Mean Concentrations (EMC) of TSS, and EMC adjusted to the Mean of Peak Storm Flows in Bull Creek at Loop 360

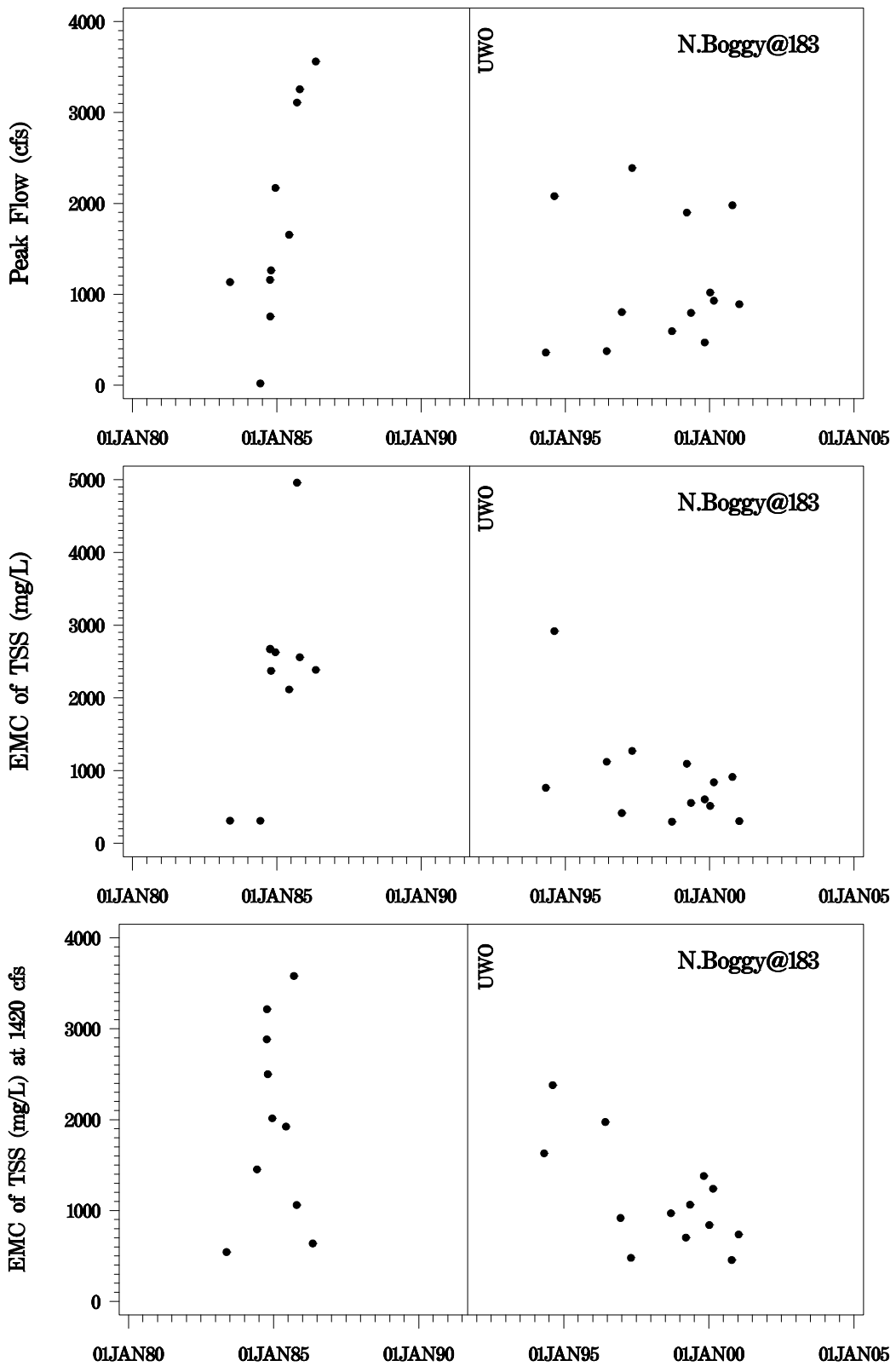



Figure A.3. Flow, Event Mean Concentrations (EMC) of TSS, and EMC adjusted to the Mean of Peak Storm Flows in Boggy Creek at 183

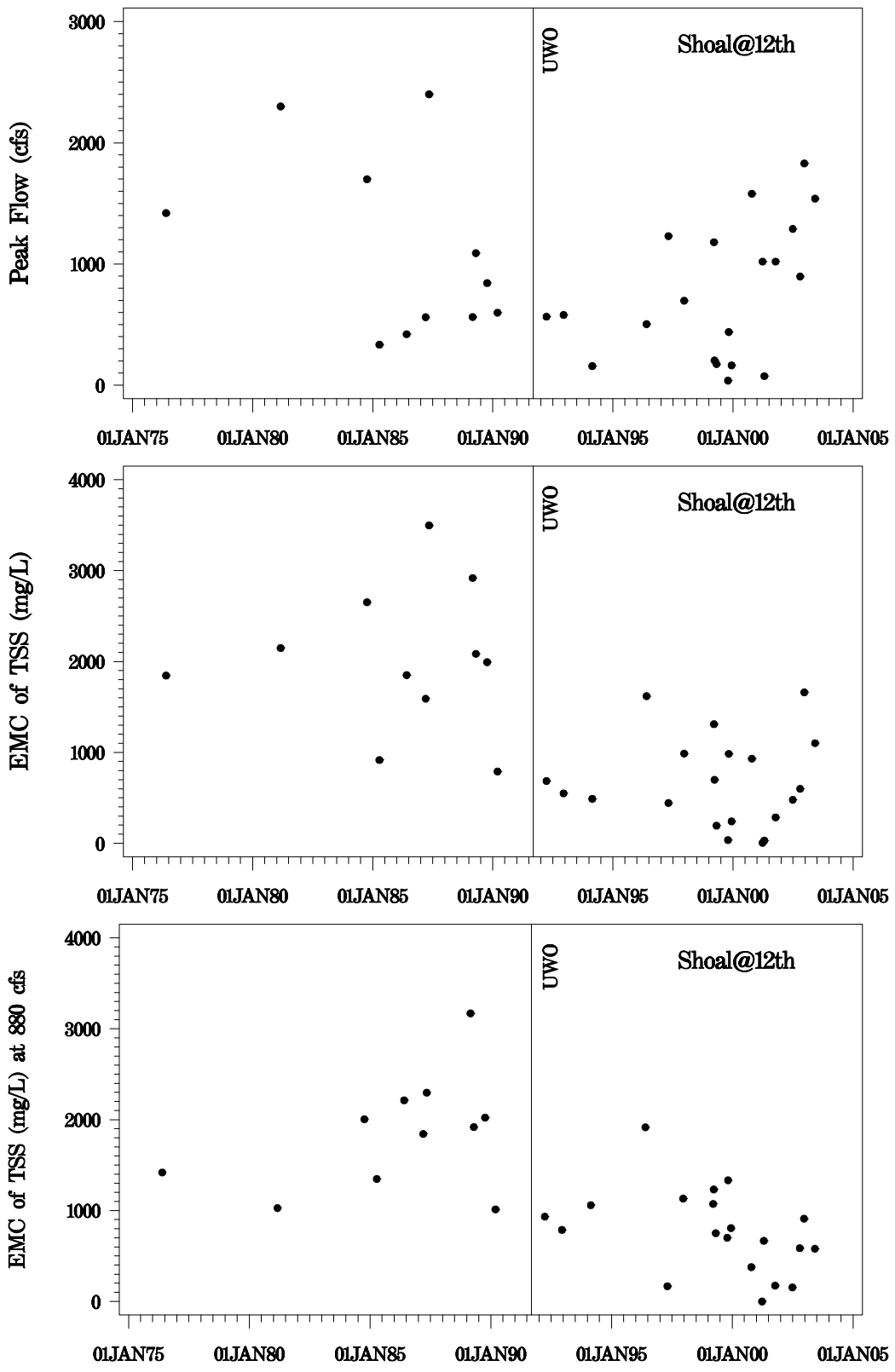



Figure A.4. Flow, Event Mean Concentrations (EMC) of TSS, and EMC adjusted to the Mean of Peak Storm Flows in Shoal Creek at 12th Street

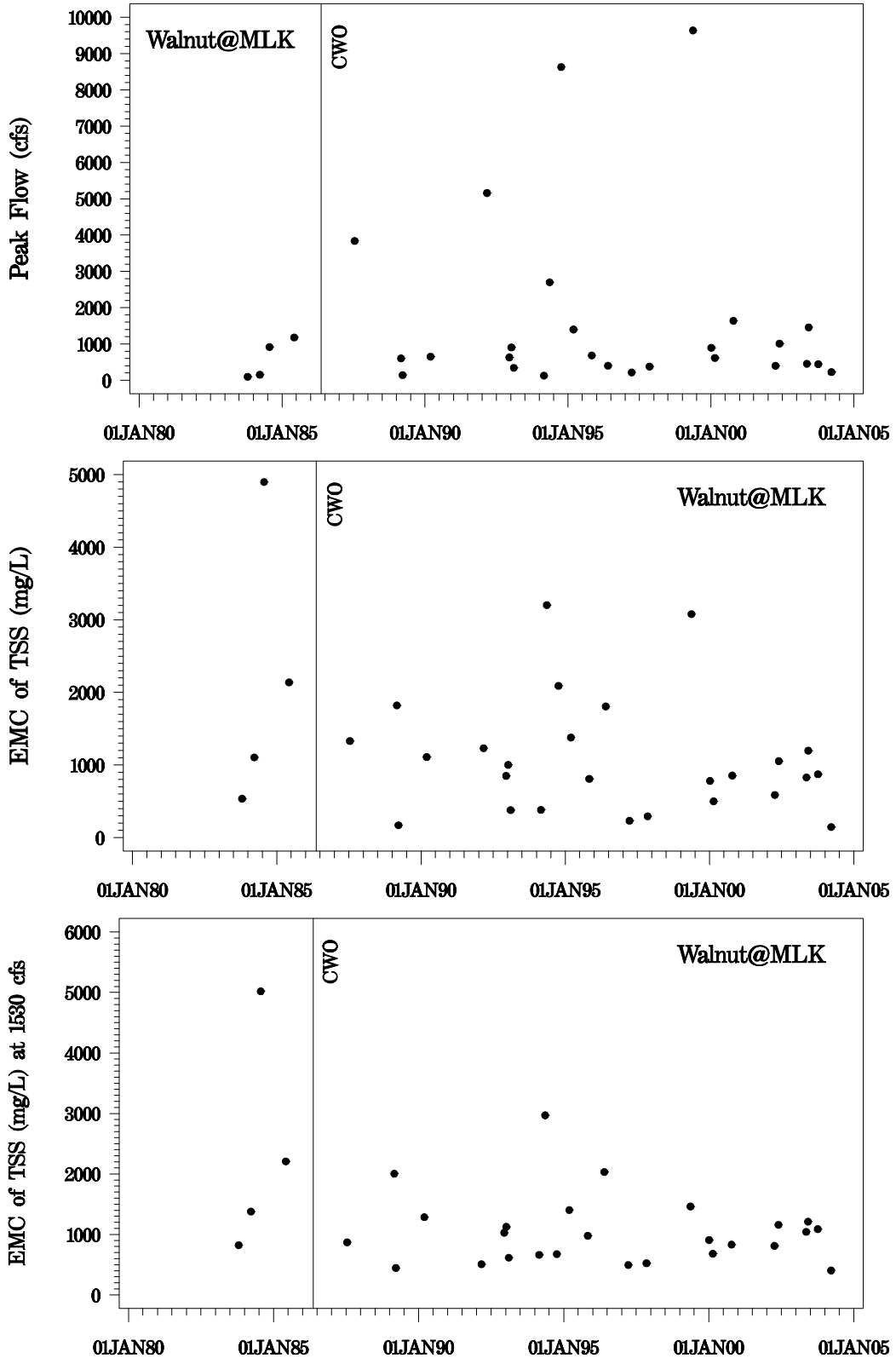
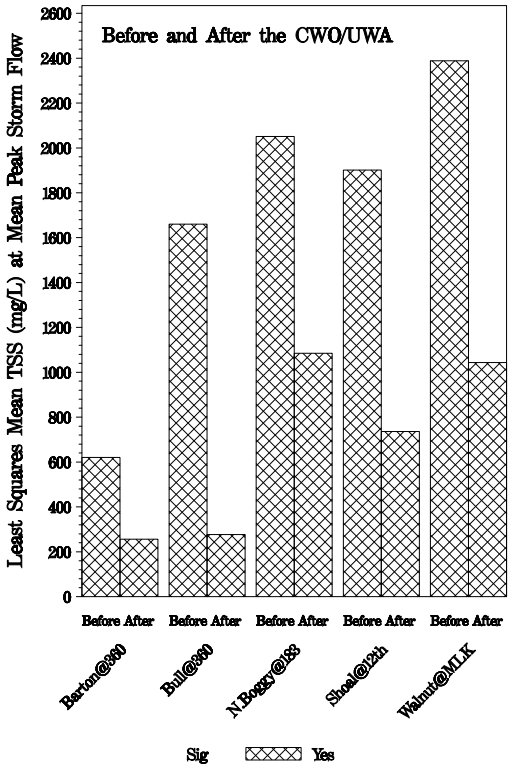
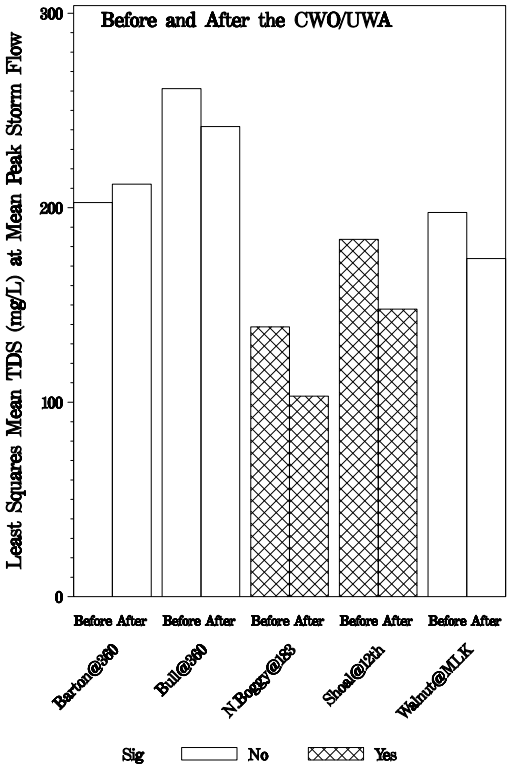



Figure A.5. Flow, Event Mean Concentrations (EMC) of TSS, and EMC adjusted to the Mean of Peak Storm Flows in Walnut Creek at MLK.

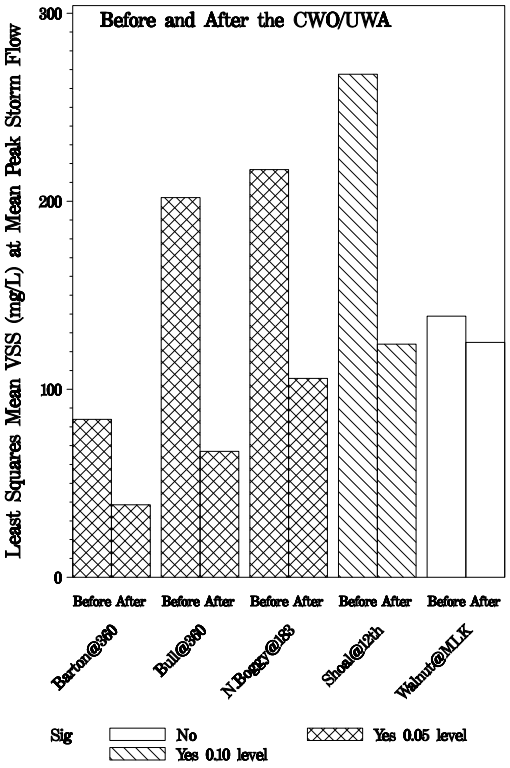
## Appendix B. Bar Graphs of EMCs at Mean Peak Flow with significance at the 0.05 level shaded.



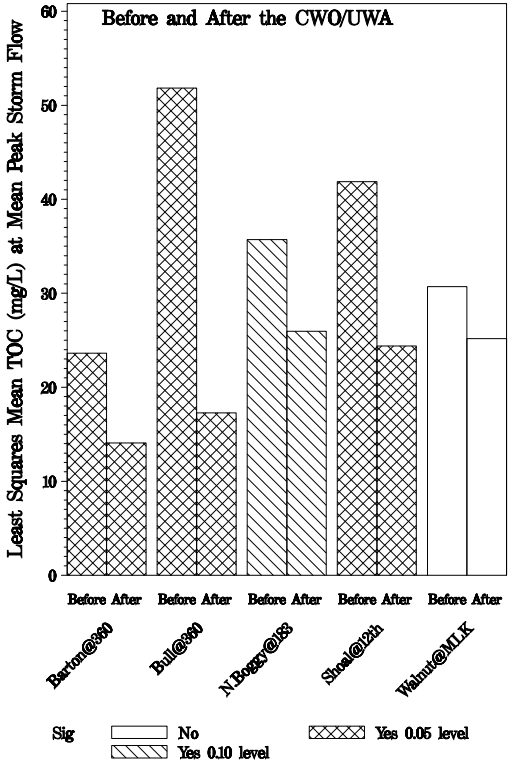

**TSS**

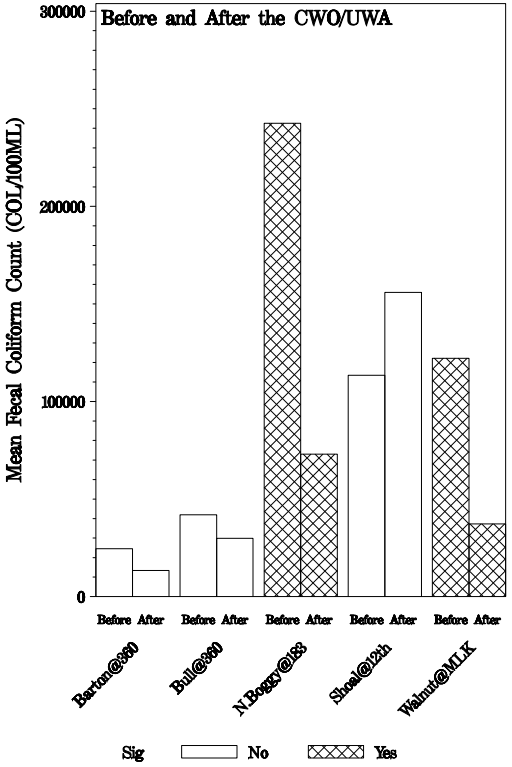


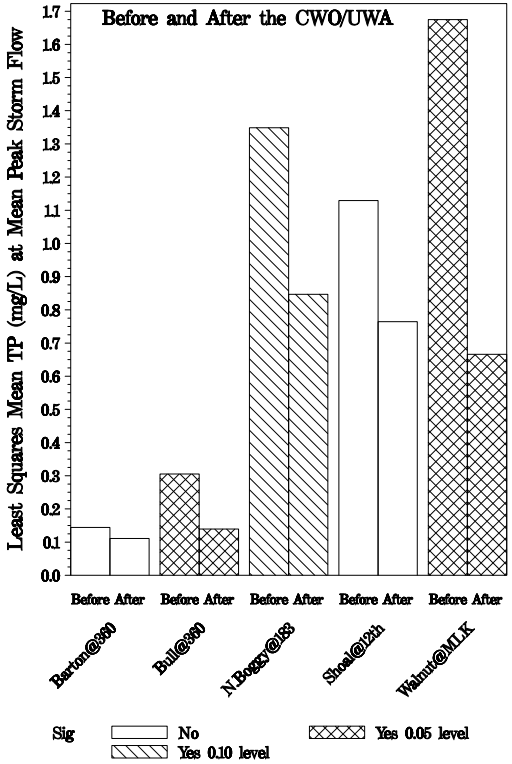

**TDS**



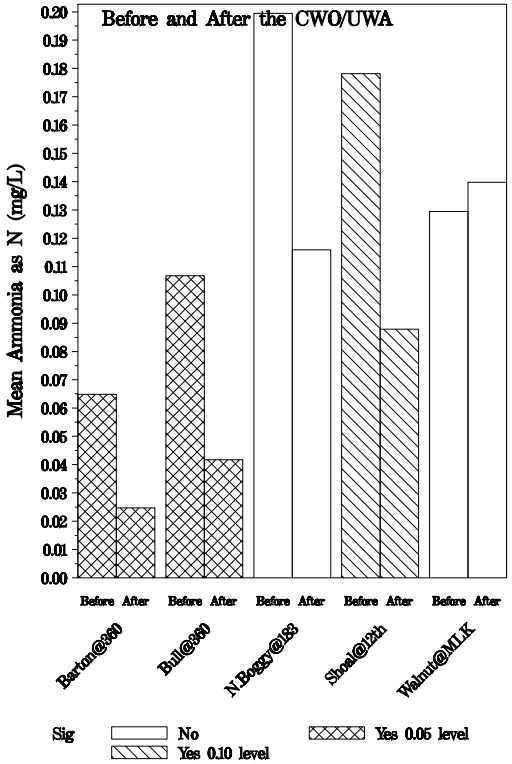

**VSS**

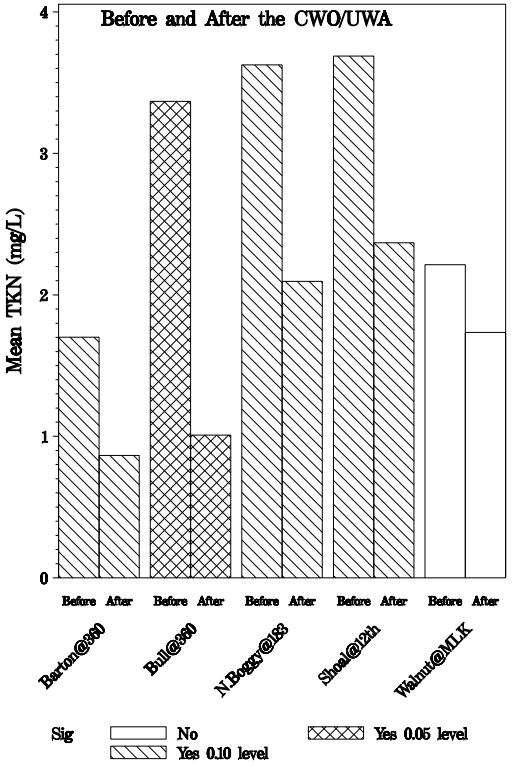


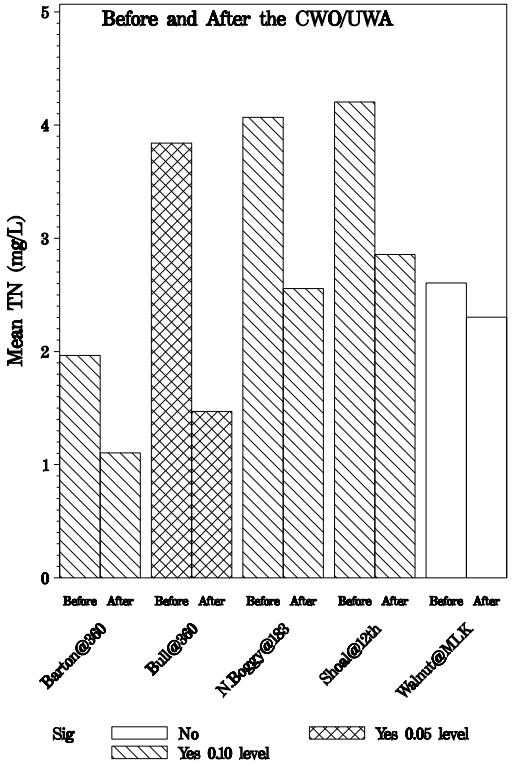




**TOC** **FECAL COLIFORM BACTERIA** **TP**




**AMMONIA** **TKN** **TN**