THE IMPACT OF RAINFALL ON FLOWS AND LOADINGS AT GEORGIA'S WASTEWATER TREATMENT PLANTS

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Abstract. Inflow and Infiltration (I/I) is extraneous water that enters a sewage treatment plant via groundwater infiltration or direct stormwater entry into sewers. This study is an attempt to quantify I/I impacts based on an assessment of influent and effluent data from twenty-four wastewater treatment plants (WWTPs) in Georgia with design capacities of 37,850 m^3/d (10-mgd) or greater. Twelve-months of operating data from the 2003 calendar year were evaluated. The objectives of the study were to determine the effect of rainfall intensity on the volumetric flow rate to each WWTP; and the relationship between flow rate and the influent biochemical oxygen demand (BOD) and influent Total Suspended Solids (TSS) concentrations. Moderate to strong correlations were observed between rainfall intensity and volumetric flow rate; and volumetric flow rate and influent BOD and TSS concentrations. Weak correlations were observed for some of the relationships when applied to the complete data set; however, stronger correlations were achieved by performing statistical analyses of variance and pooling subsets of the data. Peaking factors were similar to those reported in the literature.

INTRODUCTION

During the last few decades, much attention has been focused on the quality, control and treatment of wet-weather flow (WWF) and its impact on receiving streams. The increased volumes of water in sewerage systems, primarily through infiltration/inflow during storm events, has municipalities assessing various alternatives for reducing these increased volumes of water. In an effort to manage these overflows, retrofitting and replacing antiquated sewer systems has become a necessity and is therefore a major capital and O&M cost for municipalities.

This study was undertaken to investigate the relationship, if any, between rainfall intensity (I) and volumetric flow rate (Q), and between Q and influent five day biochemical oxygen demand (BOD_5) and Total Suspended Solids (TSS) concentrations. Another objective was to determine various peaking factors for flows and BOD and TSS concentrations. Resolution of these relationships will provide information that can be used in the design and operation of WWTPs.

Background

Several studies have focused on flow rate and influent wastewater characteristics to elucidate the relationship, if any, between these parameters; however, correlations between flow and influent parameters have not been well documented in the literature.

An evaluation of fifteen, well-operated WWTPs with design capacities ranging from 0.013 to 0.700 m3/s was performed by Berthouex and Fan (1986). They reported that high influent flows resulted in 11% of the reported BOD plant upsets and 19% of the TSS plant upsets.

Bertrand-Krajewski et al. (1995) presented flow and pollutant data for a combined sewer system with a catchment area of 61 hectares (ha) that discharges to an activated sludge plant. During one storm, the flow to the treatment plant was approximately 3.08 times the dry weather flow (DWF). Influent mass loads to the WWTP were 10, 7, and 1.2 times greater than the dry weather loads (DWL) for TSS, BOD, and NH_3, respectively. The effluent TSS mass load discharged to the river was 7 times greater than that discharged during DWF conditions. The authors indicated that the volatile suspended solids (VSS) concentration in the aeration basin was reduced causing the treatment efficiency to be affected for several days following a storm event.

Based on ten storm events to a small WWTP, Rouleau et al. (1997) concluded that storm events contribute a significant increase in flow (up to 55%) and particulate matter consisting of TSS and chemical oxygen demand (COD), along with a dilutional effect on dissolved pollutants such as ammonia. Effluent quality deteriorated during increased flows due to a rising sludge blanket in the secondary clarifiers resulting in suspended solids carryover.

A 3-year study by Giokas et al. (2002) investigated the effect of influent wastewater flow variation on treatment plant performance. The authors' conclusion was that treatment plant performance decreased during increased flows that were associated with rainfall events Decreased performance at high flows was primarily attributed to decreased detention times in the treatment processes.

The effect of wet weather on influent wastewater characteristics and treatment plant performance was evaluated by Stricker et al. (2003). Significant results of their 1-year study indicated that daily flow is much more variable during wet weather days; influent and effluent

COD loads increased and were more variable during storm events, and influent Total Kjeldahl Nitrogen (TKN) loads increased by approximately 25%. They recommended that a cumulative statistical approach at the 95% percentile based on both wet weather and dry weather data be used in establishing influent design loads for COD and TSS.

Flow and wastewater loading peaking factors for eleven WWTPs ranging in size from 0.004 – 4.4 m3/s (0.1-100 mgd) were developed by Munksgaard and Young (1980). Their data indicated consistent relationships between peak flow and the annual average flow and between the peak load and the annual average load.

METHODOLOGY

Rainfall Data

Rainfall data for the state of Georgia was acquired from the National Climatic Data Center (2005), a division of the National Oceanic and Atmospheric Administration (NOAA). The addresses of the WWTPs in this study were used to determine the most applicable station to the individual sites. Average monthly rainfall was plotted against average monthly Q to each facility. Trend lines and square of the correlation coefficient (R^2) values were determined for each of the twenty-four WWTPs using linear regression analyses.

Wastewater Operating Data

The Georgia Environmental Protection Division (EPD) provided Discharge Monitoring Reports, DMRs (2003) for each of the twenty-four WWTPs evaluated. These DMRs contained monthly influent and effluent concentrations of BOD_5, carbonaceous biochemical oxygen demand $CBOD_5$, TSS, and flow data. One year's worth of operating data for the 2003 calendar year was used in this study. The Crooked Creek North WWTP data on influent/effluent TSS was unavailable.

Data Reduction

Numerous plots of the operating data and rainfall data were prepared for each facility. Linear regression analyses were performed to create the line of best fit and the square of the correlation coefficient (R^2) was estimated. An R^2 value of > 0.16 was assumed to yield moderate correlation (Franzblau, 1958). Plots were created in order to determine correlations between various parameters: average monthly rainfall intensity versus average monthly Q; average monthly Q versus average monthly influent BOD concentration; and average monthly Q versus average monthly TSS concentration

We realized from the on-set that a specific constituent in the influent to a WWTP would be affected by several parameters. For instance, the influent BOD concentration would be impacted and related to the rainfall, flow rate, and BOD from industrial discharges. We also recognized that it would not be possible to evaluate the effects of two independent variables on the dependent variable (two-factor analysis of variance, ANOVA) since we had no control over the experimental design. This became evident after making the initial plots of the data for individual facilities since correlations varied from very weak to moderate to strong. When the entire data set from all twenty-four facilities were used, very weak to weak correlations were observed. In order to develop more broadly based relationships, the data were pooled together after performing single-factor analysis of variance on flow rate. This made it possible to develop regression equations for similar sized facilities. ANOVAs were performed at an alpha value or level of significance of 0.05.

RESULTS AND DISCUSSION

Analysis of Individual WWTP Data

Rainfall versus Flow. Our first objective was to evaluate the relationship between I and Q. Our hypothesis was that flow rate would increase as rainfall intensity increased. All twenty-four facilities showed a similar trend having a positive slope line of best fit.

Two facilities yielded an $R^2 = 0.16 – 0.36$ indicating a moderate correlation, eight yielded an $R^2 = 0.36 – 0.64$ meaning a marked correlation, and fourteen yielded an $R^2 = 0.64 – 1.0$ meaning a high correlation (Franzblau, 1958).

BOD Concentration versus Flow. Twenty-two of the twenty-four facilities exhibited a negative relationship between influent BOD concentration and influent flow rate. Eighteen of the twenty-two treatment facilities with a negative-slope line of best fit yielded an $R^2 > 0.16$ for average monthly Q versus average monthly influent BOD concentration. Seven facilities yielded moderate correlations, seven yield marked correlations, and four yielded strong correlations. This trend shows that the influent BOD concentration decreases with an increase in the influent flow rate. This suggests that the BOD concentration is being diluted by larger flow. We suggest that the increase in rainfall coincides with an increase in infiltration and inflow into the sewer system, resulting in the increased flow and lower BOD values. The high correlations that we found between rainfall and flow rate supports this conclusion.

TSS Concentration versus Flow. Since influent and effluent TSS data are not collected at the Crooked Creek North WWTP (facility 10), correlation equations could not be developed for it. Fifteen of twenty-three facilities showed the line of best fit having a negative slope similar to the Q versus influent BOD data. This indicates that the influent TSS concentration decreases with an increase in the influent flow rate. Nine of the fifteen facilities produced plots with an R^2 value ≥ 0.16 or greater indicating moderate or better correlations between Q and influent TSS concentration. One facility yielded a moderate correlation, five yielded marked correlations, and three yielded high correlations.

Flow Peaking Factors. Peaking factors for Q were derived from the flow data provided in the DMRs. The annual average daily flow (ADF) was calculated by averaging all flow data from 2003. The maximum monthly average daily flow (MMADF) was determined for each facility by selecting the largest average monthly flow. The peak daily flow (PDF) was taken as the highest daily flow recorded at the given facility during a specific month. Table 1 presents the average and range of peaking factors. The average MMADF: ADF and PDF: ADF peaking factors were 1.29 and 1.56, respectively. The ratio of sustained averaged peak flows to annual average daily flows ranges from about 1.5 to 3.0 (Metcalf and Eddy, 2003). Reynolds and Richards (1996) reported that the maximum monthly wastewater flow to average monthly wastewater flow was 1.08. Our value of 1.29 for MMADF: ADF is slightly less than the values reported in Metcalf and Eddy (2003) and slightly above the value reported by Reynolds and Richards (1996).

Table 1. Summary of Flow Peaking Factors.

Parameter	**Average**	**Range**
Max Monthly Average Daily Flow: Average Daily Flow	1.29	1.11 – 1.78
Peak Daily Flow: Average Daily Flow	1.56	1.28 – 2.44

Concentration Peaking Factors. Influent concentration peaking factors for BOD and TSS were derived from the data provided in the DMRs. The average daily BOD and TSS concentrations were determined by averaging all values for BOD and TSS, respectively, for the 2003 calendar year. The maximum monthly and peak daily concentrations were estimated similarly to the MMADFs and PDFs. The maximum monthly value represents the largest average monthly concentration, whereas, the peak daily value represents the largest daily concentration observed during a given month. Table 2 lists the average and range of values for the BOD and TSS concentration peaking factors. The average maximum monthly concentration (MMC): average daily concentration (ADC) peaking factors for BOD and TSS were virtually the same at 1.34 and 1.36, respectively. Influent data to the Main Street WWTP in Pensacola, Florida (Black & Veatch, 1991) indicated that the MMC: ADC for BOD and TSS were 1.16 and 1.24, respectively. Our MMC: ADC concentration peaking factors are slightly larger than the values reported at the Main Street WWTP. The peak daily concentration (PDC): ADC peaking factors for BOD and TSS were 1.68 and 2.10, respectively.

Table 2. Summary of BOD and TSS Concentration Peaking Factors.

Parameter	**Average**	**Range**
Max Monthly BOD Concentration: Average Daily BOD Concentration	1.34	1.07 – 2.04
Peak Daily BOD Concentration: Average Daily BOD Concentration	1.68	1.19 – 2.49
Max Monthly TSS Concentration: Average Daily TSS Concentration	1.36	1.12 – 1.79
Peak Daily TSS Concentration: Average Daily TSS Concentration	2.10	1.10 – 2.69

Analysis of Pooled WWTP Data

Data from select WWTPs were pooled together to develop more broadly based correlation equations between various parameters (e.g. between flow rate and influent BOD concentration). Single-factor analysis of variances on rainfall, flow rate, and influent BOD and TSS concentrations were performed to facilitate pooling of the data. The ANOVAs were conducted at a 0.05 level of significance.

WWTPs were pooled together for the statistical analyses based on similar flow capacities. A single factor ANOVA on the flow data from the R. M. Clayton facility, was not performed because it has the largest design capacity and could not be pooled with the other WWTPs.

For each set of pooled WWTP data, $F < F_{crit}$ indicating there is no significant difference between WWTPs evaluated for the specified parameter. For plots of pooled data for rainfall versus flow, BOD concentration versus flow, and TSS concentration versus flow, all of the plots show moderate to high correlations between the respective parameters. The correlation equations that were derived from the pooled subset plots have R^2 values ≥ 0.16.

SIGNIFICANCE OF PROJECT

This study has demonstrated that moderate to strong correlations exist between rainfall intensity and volumetric flow rate, flow rate and influent BOD concentrations, and flow rate and influent TSS concentrations. Moderate to marked correlations were observed between rainfall intensity and influent BOD concentration and rainfall intensity and influent TSS concentration. These relationships may be developed for individual WWTPs or for pooled data sets (e.g. facilities with similar design capacities or similar influent characteristics, etc.). It is anticipated that stronger correlations between the various parameters would be observed at specific WWTPs for those municipalities that collect their own rainfall data. The peaking factors for volumetric flow rates, influent BOD and TSS concentrations, and influent BOD and TSS influent mass loadings presented in Tables 1-2 are especially useful. Practicing engineers may use these values when preparing preliminary design loadings for influent flows and loadings for new WWTPs and/or expansion of existing facilities in Georgia. These peaking factors may be applied to designs in other states, however, as with any type of data, caution should be observed and the final design values should be checked against recommendations or requirements established by each state's regulatory agency.

CONCLUSIONS

Major conclusions from this study include:

- Moderate to strong correlations were observed between average monthly I and Q for all twenty-four WWTPs.
- Correlations between Q and influent BOD concentration were established for eighteen out of twenty-four facilities. Seven moderate, seven marked, and four high correlations were observed.
- Nine out of twenty-three facilities showed a correlation between Q and influent TSS concentration. One moderate, five marked, and three high correlations were observed.
- Average daily and maximum monthly peaking factors for flow and influent BOD and TSS concentrations were established.

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