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Project Summary

Hourly Diurnal Flow Variations in Publicly-Owned Wastewater Treatment Facilities

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Hourly diurnal flow variations at wastewater treatment plants subject unit operations to fluctuations that influence their performance. These variations are rarely addressed in the design of these facilities.

A survey of 39 sanitary sewer collection systems was undertaken to determine the magnitude of hourly peak flows and to identify the collection system parameters that were most influential in affecting the observed peaks. Significant collection system parameters identified included industrial contribution, average age of the collection system, depth to the groundwater, and low-lift, pre-plant pumping stations.

Collection systems with large industrial contributions were observed to have higher peak flows than those with small industrial contributions. Variations in observed peak flows were exhibited between spring and summer periods for old systems and for those with high groundwater as a result of infiltration during the spring season. Low-lift, pre-plant pumping stations, depending on their capacity and control, can create extremely high peak flows and pulses that do not reflect normal diurnal influent flow patterns.

The mean average peak hourly flow per day for nonindustrial collection systems, excluding inflow, was found to be 1.23 times the annual average daily flow. This value did not significantly vary with flow rate, but the variation around this mean value decreased with increasing flow.

This Project Summary was developed by EPA's Municipal Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Hydraulic and organic variations of wastewater flow at publicly owned wastewater treatment works (POTW's) represent design items that the engineer must address before he undertakes his process and hydraulic design. In the absence of monitored flow, traditional design practice for the hydraulic sizing of unit wastewater treatment processes has relied on the application of peaking factors to estimate peak sanitary design flows. These factors are commonly defined as the ratio of peak to average flow, and they have been presented in terms of fixed values or as a function of influent flow rates or collection system population. To estimate the total peak flow, the designer must add components for infiltration and inflow to the total peak sanitary flow. More recent investigations have sought to develop empirical equations to facilitate the prediction of extreme peak flows that include both dry- and wet-weather events.

The characteristics of the collection system are largely responsible for the magnitude and variations in influent flows to wastewater treatment plants. The correlation of collection system parameters with peaking and flow variation has had limited previous investigation. As a result, peaking has been addressed as a function of flow rate or equivalent population.

Background

Typical diurnal variations in influent flow are depicted by a wave form. The flow variation is characterized by two peaks (resulting from morning and early evening water usage) and decreasing flows late at night and early in the morning. The maximum flow of the diurnal flow period is defined as the "peak hourly flow." Variations in the wave form of any given collection system can be expected to occur on a day-to-day basis. These variations can take the form of time lags, advances in the wave form, or increases or decreases in observed peaks. Systems with excessive inflow can be expected to exhibit wave forms and peak values in response to storm events and abnormal diurnal flow patterns. These peaks are not included in this report.

To facilitate communication, a set of definitions for both peaking and collection system parameters was established for use throughout the study. A summary of these definitions is presented in Table 1.

Various collection system parameters have generally been assumed to have an impact on peaking and hydraulic diurnal variations. These collection system parameters include annual average flow and population, percent of industrial contribution, topography, average annual rainfall, soil type, shape of collection system, groundwater table, average age of system, number of pumping stations, and bypasses.

Table 1. *Definitions: Peaking Factors*

Peaking Factor	
1. Annual peaking factor (APF) =	$\frac{\textit{Peak Flow}}{\textit{Annual Average Daily Flow (ADF)}}$
2. Sample peaking factor (SPF) =	$\frac{\textit{Peak Flow}}{\textit{Average Sample Time Period Flow}}$
Peak Flow	
3. Peaking duration	*Unit of time that the peak represents (peak 15 minutes; peak hour; peak day).*
4. Peaking period	*The time period over which the peak period is compared (peak hr/day; peak day/year).*
5. Sample time period	*The period of time from which the data are assessed.*
6. Sample analysis	*Maximum value: Minimum value in the sample time period.* *Average value: Average value in the sample time period.* *Minimum value: Minimum value in the sample time period.*
7. Peaking factor examples	*Average peak hr/day per 10-day period* *hr ← Peaking duration* *10-day ← Sample time period* *day ← Peaking period* *Average ← Sample analysis*
Average Flow	
8. Annual average daily flow (ADF)	*The annual volume of influent treatment plant wastewater divided by 365 days, normally expressed in mgd.*
9. Average sample time period flow	*The volume of influent treatment plant wastewater during the sample time period divided by the number of days in the sample time period.*

Methodology

An initial survey of 145 POTW's was undertaken to identify separate sanitary sewer systems that has (1) annual average daily flows between 189 and 378,500 m^3/day (0.05 and 100 mgd), (2) properly calibrated diurnal influent flow recorders and records of these flows, and (3) sufficient information on collection system parameters. Further selection was based on the need both to identify sewer systems with an equal distribution of collection system parameters and to establish (to the extent possible) an equal geographic distribution of facilities investigated throughout the country.

Preliminary screening of the 145 POTW's using the above collection system criteria resulted in the selection of 39 systems for study. Continuous flow data from each of the 39 facilities was obtained for 10 days during the spring and 10 days during the summer. Flow data during the spring and summer were obtained to assess their seasonal differences between peaking values observed. Annual records from one facility were obtained to determine how well small sample time periods represented longer periods. Flow data for the spring and summer periods were reviewed, and systems where flow predominated were eliminated from the analysis.

Data collected were analyzed in a series of steps designed to identify collection system parameters most influencing peak flows and to quantify those parameters as much as possible within the scope of this work. The influence of flow rate and sample time period of the peaking factor were also investigated. Finally, the special case of pump-dominated collection systems was examined. Two independent approaches were used to identify significant collection system parameters and to quantify their impacts. They are termed "collection system comparative assessments" and "data cluster analysis."

Results and Discussion

Differentiation of individual collection system parameters as they impact peak flows is an extremely difficult task since each individual system contains numerous variables. Quantification of these variables exceeded the scope of this investigation. Nonetheless, three significant parameters stood out as dominant throughout the comparative analysis. these included industrial contributions, average age of the collection system, and depth to groundwater.

Systems with industrial or institutional contributions greater than 40 percent of the total collection system flow (when compared with systems with less than 40 percent) exhibited higher maximum hourly peaking factors, higher average hourly peaking factors, greater seasonal variations in average hourly peaking factors, and peak hours that differed from the nonindustrial systems.

Collection systems that were old (more than 25 years) and experienced high groundwater exhibited marked seasonal (spring to summer) variations in observed peaking factors. This marked variation was not apparent in systems that did not have these characteristics. Unlike other systems, old systems with high groundwater exhibit spring peaking factors 1.1 to 1.5 times those observed in the summer. This phenomenon results from greater susceptibility to infiltration during the spring season and increases both the flow and the annual peaking factor.

Table 2 presents the mean of all average hourly peaking factors (PF_A) and maximum hourly peaking factors (PF_M) for both spring and summer and for the total 20 days of data. For nonindustrial systems, the mean of all average hourly peaking factors was 1.23, 1.30, and 1.22 for the total 20 days, spring and summer values, respectively.

Examination of mean values for industrial systems with flow contributions greater than 40 percent reflect the higher average peaks exhibited by most industrial systems (as illustrated by the 1.32, 1.42, and 1.30 average hourly peaking factors for the total 20 days, spring, and summer periods, respectively.) Table 2 also lists a mean value of 1.59 for peak industrial seasons, where increase in industrial activity increased the peak flows observed.

Within the range of values tested, the average hourly peaking factors for most nonindustrial systems did not vary significantly with flow rates and maintained a mean value of approximately 1.23.

Maximum hourly peaking factor values exhibited some slight decrease with flow, but the outlying values produced poor correlation with any attempted flow/peaking factor relationship. As flow increased, however, the standard deviation or fluctuation around the average peak hour per day decreased. This result implies that greater flow variation around the mean value can be expected in the lower-flow ranges, whereas smaller flow variations are expected in the higher-flow ranges.

*Table 2. Mean Average Hourly and Maximum Hourly Peaking Factors**

I. 14 Nonindustrial Systems

PF_A = 1.23 for 20 days
PF_A = 1.30 for 10 days in spring
PF_A = 1.22 for 10 days in summer

II. 14 Nonindustrial Systems

PF_M = 1.70 for 20 days
PF_M = 1.61 for 10 days in spring
PF_M = 1.54 for 10 days in summer

III. 7 Industrial Systems

PF_A = 1.32 for 20 days
PF_A = 1.42 for 10 days in spring
PF_A = 1.30 for 10 days in summer
PF_A = 1.59 for industrial season (either 10 days in spring or 10 days in summer)

IV. 7 Industrial Systems

PF_M = 2.05 for 20 days
PF_M = 1.76 for 10 days in spring
PF_M = 1.63 for 10 days in summer

**The mean peaking factors summarized in this table are calculated independently from sample data taken during the applicable time period. Thus 20-day mean peaking factors cannot be calculated simply by noting the 10-day spring and summer mean peaking factors shown here. Section 4 of the report elaborates on the statistical approach used to calculate these peaking factors.*

Annual flow data for one facility was collected and analyzed for 1 full year, for 20 days during the spring, and for 10 days during the summer. Some shifting in the peak hour exists among the time periods. The annual, spring, and summer peak hours occurred for approximately 1,500, 1,300, and 1,400 hours, respectively. The average hourly and maximum hourly peaking factors for the annual time period were 1.35 and 2.70, respectively. For the spring period, these values were 1.38 and 1.80, respectively; for the summer periods, these values were 1.05 and 1.15, respectively. For the 20-day sample time period, these values were 1.18 and 1.80, respectively.

Maximum hourly peaking factors increased as the time period increased. Data from limited time periods (i.e., spring or summer) do not represent the annual time period. Note that the annual flow ratio includes potential inflow, which was not eliminated when these data were examined. The result is that the maximum observed events will be greater. The average analysis over the year tends to reduce the severity of inflow.

The average hourly peaking factor for the annual period of 1.35 was very close to the 1.38 observed during the spring period. The summer period's low value of 1.05 was the result of a decreasing population and flow rate during the summer in the collection system. The sanitary sewer system was classified as an industrial system because of the high institutional flow that decreased during the summer months. The annual value (PF_A) of 1.35 was slightly higher than the mean value of 1.32 for the industrial collection systems previously examined.

Many wastewater treatment plants contain low-lift pumping stations. Depending on the station's design, it can control the diurnal variations and peaking at the facility. The pumping station can minimize or eliminate the collection system as a factor. Eight facilities surveyed fell into this particular category.

Maximum instantaneous flow ratios (peaking factors) varied from 1.3 to 4.7. The frequency of pulses or number of peaks per hour ranged from 1 to 17. Minimum instantaneous flow ratios ranged from 0 to 0.8.

Clearly, low-lift pumping stations designed to provide the required head and capacity without consideration of peaking effects can be the dominant factor influencing peak-flow magnitudes received at a facility.

Conclusions

Sanitary sewer collection system factors found to have the most impact on the average hourly peaking factor include the percentage of the total flow to the POTW contributed by industries or institutions, the average age of the system, the depth to groundwater, and the impact of low-lift, pre-plant pumping stations.

Collection systems with industrial or institutional flow contributions greater than 40 percent were found consistently to have higher daily peak flows than those below 40 percent. Industrial flows can also be seasonal, with flows during the industrial season resulting in higher peaking factors. Peak flow hours of the day tended to occur at earlier hours in industry-dominated systems.

Nonindustrial collection systems with an average age greater than 25 years and high groundwater tables are more susceptible to infiltration and, as a result, exhibit higher peaking factors during the spring or infiltration season.

The mean average hourly peak flow for nonindustrial systems, excluding inflow, was found to be 1.23 times the annual average daily flow ($PF_A = 1.23$) and did not vary significantly with the average collection system flow rate.

As collection system flow rate increases, variations around the mean value decrease. The mean flow estimate for larger systems has greater reliability than that of smaller systems.

Individual average hourly peaking factor values for the spring were as much as 1.5 times those that occurred during the summer for old-age systems with high groundwater tables.

The mean average hourly peaking factor for industry-dominated systems was found to be 1.32 ($PF_A = 1.32$). The industrial season mean average hourly peaking factor was found to be 1.59.

The peak hours for nonindustrial collection systems fell predominantly between 10 a.m. and 4 p.m. Industrial and institutional system peaks fell largely between 10 a.m. and 2 p.m.

The mean maximum hourly ($PF_M = 1.70$) peaking factor for nonindustrial collection systems was found to be 1.70 for 20 days of data. Maximum hourly peaking factors were calculated as high as 2.82 during the 20-day sampling period. Maximum hourly peaking factors increased with increasing sampling time periods.

Instantaneous maximum peaking factors for low-lift, pump-dominated systems ranged from 1.3 to 4.7, and the minimum instantaneous flow factors varied from 0 to 0.8. Low-lift pumping stations designed to provide the required head and capacity without consideration of peaking effects can be the most dominant factor influencing peak-flow magnitudes.

Recommendations

Several factors significantly affect daily dry-weather influent flow peaks and fluctuations at POTW's. The following factors must be addressed in any study of influent wastewater so that unit operations of the treatment plant can be properly designed and operated.

Industrial wastewater discharge schedules as well as magnitude and make-up should be defined to determine the wastewater impact on treatment plant performance. When industrial wastewater contributes greater than 40 percent of the total flow to the POTW, careful assessment should be made of its impact on peak flows.

Surveys characterizing influent wastewater from nonindustrial sanitary sewer collection systems greater than 25 years old should pay particular attention to potential seasonal infiltration from high groundwater tables.

Low-lift, pre-plant pumping station operation can be the most important factor influencing hydraulic diurnal flow variations experienced at the POTW. Pump capacity and control should be taken into account in the design of new POTW's or in the investigation of performance problems in existing facilities.

Though this report primarily addresses hydraulic flow variations at the POTW's, wastewater constituent characteristics also vary. Wastewater hydraulic and concentration measurements must both be made for proper characterization of the total mass loading entering the treatment plant.

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The complete report, entitled "Hourly Diurnal Flow Variations in Publicly-Owned Wastewater Treatment Facilities," (Order No. PB 82-107 954; Cost: $11.00, subject to change) will be available only from:
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