

Computer Model Analysis for Control Planning of Sanitary-Sewer Overflows

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Abstract

The Nation's sanitary-sewer infrastructure is aging with some sewers dating back over 100 years. There are more than 19,500 municipal sanitary-sewer collection systems nationwide serving an estimated 150 million people and comprising about 800,000 km (500,000 mi) of municipally owned sewer lines. There are about 40,000 sanitary-sewer overflow (SSO) events per year nationwide. Potential health and environmental risks associated with poor performance of many of these systems highlight the need to increase federal regulatory oversight of the management, operation, and maintenance of these systems. The U.S. Environmental Protection Agency (EPA) is preparing to issue a SSO Rule that will add control and mitigation of SSOs to the National Pollutant Discharge Elimination System (NPDES) permit requirements.

The major elements of the SSO Rule are that it requires a SSO municipality to: (1) provide adequate capacity to convey base dry-weather and peak wet-weather flows (WWF) for all parts of the collection system, and (2) take all feasible steps to stop and mitigate the impact of SSOs. Since building connection lateral sewers can contribute as much as 70 to 80% of the total infiltration/inflow (I/I), a significant amount of I/I will not be abated, even after proper operation and maintenance and usual rehabilitation of street sewers only. This remaining I/I must be addressed in the SSO community's capacity assurance plan.

It has been found that SSOs are generally difficult to witness or document because they usually occur during rain events when people are indoors or the overflow locations are out of sight. To answer where and when a SSO may occur, it is necessary to know the flow conveyance capacity at various parts of the collection system under normal dry-weather and stressed wet-weather conditions. To capture the system response to the dynamic nature of WWF generation and base-flow variations, a systemwide hydraulic evaluation using dynamic models would be advantageous. This evaluation is often necessary for identifying the causes and locations of the SSO problem to allow the development and evaluation of the most cost-effective engineering solutions. A dynamic model calculates backwater and the location and amount of sewer surcharge, an absolute necessity for an accurate assessment of the collection system for any SSO project.

This paper also presents: (1) a review of rainfall-derived-infiltration/inflow (RDII) quantification methods that can reasonably be used for application to sanitary sewer systems throughout the Nation; (2) a brief review and comment of sewer models that have been used for SSO analysis and mitigation planning; (3) project components and data gathering and processing for conducting a systemwide modeling analysis and developing a SSO control plan; and (4) a case study at Henrico County, Virginia to illustrate the application of a collection system modeling approach to plan for sanitary-sewer system improvements.

National Problem

Municipal sanitary sewer collection systems play a critical role in protecting public health in our cities and towns. They are designed to convey wastewater from their sources to publicly owned treatment works (POTW). Collection systems consist of sewers, pumping stations, force mains, manholes, and all other facilities used to collect wastewater from individual residential, industrial, and commercial sources. The performance of these systems can significantly influence the performance of POTW and contribute to the closings of recreational beaches. In the United States (U.S.), there are about 19,500 municipal sanitary sewer collection systems nationwide serving an estimated 150 million people and comprising about 800,000 km (500,000 mi) of municipally owned pipes in publicly owned systems and probably another 800,000 km (500,000 mi) of privately owned pipes that deliver wastewater into these systems. The U.S. Environmental Protection Agency (EPA) estimates that these systems would have a replacement value of \$1 to 2 trillion. Another source estimates that wastewater treatment and collection systems represent about 10 to 15% of the total infrastructure value in the U.S. (NCPWI, 1988).

Much of the Nation's sanitary sewer infrastructure has been installed over a long time period, with some sewers dating back over 100 years. An ASCE study under cooperative agreement with EPA (Black & Veatch, 1999) conducted a survey that involved 42 wastewater utilities of various sizes and population serving about 26 million people across the continental U.S. The survey indicated that the age of collection systems ranged from new to 117 years, with an average age of 33 years. About 18% of sewers were built in the last 10 years, 41% in the last 20 years, 82% in the last 50 years, and 98% in the last 100 years. The average sewer density in this survey was about 6 m (21 ft) of sewer/capita, or about 6.2 km/km² (10 mi/mi²) of service area.

Sanitary-sewer overflows (SSOs) are untreated sewage overflows from sanitary-sewer collection systems to streets, private property, basements, and receiving waters. SSOs will likely occur when flows exceed the capacity of a sewer and sewers surcharge excessively or when there are blockages in sewers and sewer carrying capacities are reduced. Usually, SSOs are most prevalent during and immediately after wet weather when flows are high due to inflow and infiltration (I/I). In addition to I/I, contributing factors to SSOs include sewer blockages from root intrusion, grease build-up, sedimentation, and debris which are not wet weather related. SSOs usually contain high levels of pathogenic microorganisms, suspended solids, toxic pollutants, floatables, nutrients, oxygen-demanding organic components, and oil and grease. SSO effects are many, including: (1) closing of beach and recreational areas; (2) prevention of fishing and shellfish harvesting; (3) public health risks associated with raw sewage in roadways, drainage ditches, basements and surface waters; (4) inhibition of potential development from sewer connection moratoriums; and (5) financial liability of a community from public relation problems. In San Diego, CA, SSOs have threatened drinking water supplies, creating the potential for serious adverse public health impact (Golden, 1996).

Available data indicates that essentially all large collection systems experience periodic SSOs and between one-third and two-thirds of the Nation's sanitary-sewer collection systems have problems with SSOs or peak flows at POTW. It is estimated that there are about 40,000 SSO events per year nationwide. The national cost estimate to mitigate SSOs for the next 20-year period is \$108 billion (1994 dollars) to attain zero overflows per year per municipality (EPA,

1996a) and about \$78 billion and \$63 billion, respectively, to attain one and two overflows per year (EPA, 1998).

I/I is caused by stormwater, groundwater, and faults in the sewer system allowing their entry. The causes of I/I are not the same. Infiltration is the water entering a sewer system and service connections from the ground through such means as defective pipes, pipe joints, improper connections, or manhole walls. Inflow is the water discharged into a sewer system and service connections from various sources (e.g., roof leaders, sumps, yard and area drains, foundation drains, cooling water discharges, drains from springs and swampy areas, manhole covers, cross connections from storm sewers and combined sewers, catchbasins, surface runoff, street and other washwater, and irrigation runoff.) Once the infiltrated waters and inflow waters combine within the sewer system, their net effect is the same (i.e., robbed sewer capacities and usurped capacities of system facilities such as pumping, treatment, and overflow regulators.)

EPA Approach : Cost-effective I/I Control to SSO Rule

For about two decades, from the 1970s to the 1980s, the impetus for sewer infrastructure work in a municipality was dictated by the Federal Water Pollution Control Act Amendments of 1972 which focused on POTW and their discharges. It required all applicants for federal construction grants for POTW to verify that sewer systems discharging into POTW were not subject to “excessive I/I,” which is the quantity of I/I that can be economically eliminated from a sewer system by rehabilitation. In other words, the Act required potential grantees to compare the cost of sewer rehabilitation (including replacement) with the cost of transportation to and treatment at a POTW. Sewer systems determined to have “excessive I/I” were eligible for rehabilitation in the construction grant while systems with “non-excessive I/I” were not. Cesareo and Field (1975) described the procedures to perform a cost-effectiveness analysis of I/I control of a sewer system as it is related to transport and treatment.

From 1978-1989, the total outlay of construction grant funds required for the identification of sewer I/I problems was about \$2 billion (EPA, 1991). These costs included costs for preliminary I/I analysis or a detailed sewer system evaluation survey. The total cost associated with replacement and/or major rehabilitation of existing sewer systems was about \$1.8 billion. Major rehabilitation was defined as extensive repair of existing sewers on the verge of collapse, structurally unsound, or beyond the scope of normal maintenance programs.

In the early 1990s, as much of the Nation’s collection system infrastructure continued to age and deteriorate, there was a growing concern over the health and environmental risks of SSOs. In response, EPA organized a National SSO Policy Workgroup in 1993 to institute and implement a national SSO control policy. In 1995, EPA sponsored a National Conference on SSOs which resulted in many important papers on SSO control (EPA, 1996b). In May 1999, President Clinton directed EPA to develop and issue a strong national regulation in one year to prevent SSOs from contaminating our Nation’s beaches and jeopardizing the health of our Nation’s families. After an extended review of the draft Rule by various EPA regional offices and stakeholder organizations under the Bush administration, the Rule is expected to be formally published shortly in the federal register for public comments.

Proposed SSO Rule

The proposed SSO Rule will consist of the following components that are proposed to be

included in all National Pollutant Discharge Elimination System (NPDES) permit requirements for POTW served by sanitary-sewer collection systems:

- Capacity, Management, Operation and Maintenance (CMOM) program for municipal sanitary-sewer collection systems;
- Prohibition on municipal sanitary-sewer system discharges;
- Reporting, recordkeeping, and public notification requirements for municipal sanitary-sewer collection and SSOs; and,
- Remote treatment facilities.

The parts of the proposed SSO Rule that are likely to require substantial engineering analysis efforts are contained in the CMOM program. This program requires that a NPDES permittee must:

- (1) properly operate and maintain all parts of the collection system;
- (2) provide adequate capacity to convey base and peak flows for all parts of the collection system;
- (3) take all feasible steps to stop and mitigate the impact of SSOs; and,
- (4) provide public notification of overflow events.

Requirement (1) of the CMOM program specifies that municipalities conduct inflow elimination or reduction, cost-effective sewer rehabilitation, and collection system inspection with associated clean out and repair. As building connection lateral sewers contribute as much as 70 to 80% of I/I, a significant amount of I/I will not be abated even after proper operation and maintenance (O&M) and rehabilitation of street sewers. This remaining I/I would be included in meeting CMOM requirements (2) and (3) by which municipalities must develop a capacity assurance plan to convey peak wet-weather flows (WWF) and a plan to mitigate SSOs.

Flow Prediction of Rainfall Derived Infiltration/Inflow (RDII)

RDII is that portion of a sewer flow hydrograph above the normal dry-weather flow (DWF) pattern. It is a sewer flow response to rainfall or snowmelt in a sewershed. The term of “I/I” probably first appeared in the 1960s. Prior to that time, the main focus was the determination of “infiltration” in DWF. “Inflow,” referred to as the “stormwater” contribution, was recognized but was only casually addressed (ASCE, 1962; HES, 1968). With the influx of federal money and enforcement of federal requirements in mid-1970s, the amount of “I/I” data surged as did the interest of flow prediction of RDII from monitoring data particularly since late 1980s.

RDII has long been recognized as a major factor in the sizing of sewer pipes and treatment plants. It was found by testing that as much as 2,380 L/s (150 gpm) may leak through a manhole cover as stormwater inflow (Rawn, 1936). With manholes placed 90 to 150 m (300 to 500 ft) apart, this would amount to 0.10 to 0.05 m³/s/km (3.5 to 2.0 Mgal/d/mi) of sewer pipe (Babbitt, 1947). In the early 20th century, the U.S. recognized that improper connections of roof drains, street inlets, and foundation and cellar drains to sanitary sewers, in combination with the poor quality of house lateral construction, depleted the reserved sewer capacities that were usually built-in for the future growth of an area. These unwanted entries of stormwater to sanitary sewers was considered a “misuse” or “abuse” of the system that should be “prohibited” (Metcalf & Eddy, 1928). The amount of this extraneous water had never been adequately reported in general terms because of the difficulty in quantifying the flows accurately. To cope with this problem in the design of sewers, various provisions for design flow rates were adopted

by various State's Board of Health. For example, the Illinois State Board used 1.1 to 1.3 m³/d (300 to 350 gal/d) for each person to be served. The Missouri State Board specified the use of per capita flows ranging from 1.9 to 3.8 m³/d (500 to 1,000 gal/d) depending upon infiltration, anticipated stormwater connections, and possible future development (Babbit, 1947). For the design of the sanitary-sewer system for the Beargrass Interceptor District in Louisville, KY, the maximum sewage rates of 3310, 1890, and 1510 L/capita-d (875, 500, and 400 gal/capita-d) were used respectively for areas draining 4, 100, and 400 ha (10, 250, and 1000 acres) (Metcalf & Eddy, 1928). These rates included groundwater infiltration (GWI) of about 18,700 L/ha-d (2,000 gal/acre-d). Earlier, the design flows for the City's sewers were based on a per capita flow rate of about 1.1 m³/d (300 gal/d). Flow monitoring data such as from the City of Houston, TX shows that wet-weather peaking factors (peak WWF to average DWF ratio) of 30 are commonly recorded, and factors reaching 50 have been recorded in individual basins (Jenq *et al.*, 1996). Hence, better flow prediction methods with parameters calibrated with site-specific data must be used to insure that sewers are provided with adequate conveyance capacity throughout the design life of the system. A reliable estimate of RDII is critical in developing an effective and cost-effective plan to control SSOs.

Wright *et al.* (2001) provided a literature review of RDII estimation techniques that appeared since 1993. The methods are grossly classified into three groups: volume-based "Rational" method (or R-value method), unit hydrograph method, and physical processes modeling method. The volume-based method does not provide temporal information which is needed for sewer conveyance capacity assessment. Like the volume-based method, the unit hydrograph methods are empirical methods based on observations of rainfall and flow. The paper discusses various unit hydrograph methods, including: the synthetic unit hydrograph (SUH); the data-derived unit hydrograph using multiple regression to directly derive a linear function relating rainfall and flow; and, the conceptually-derived unit hydrograph using a system of cascading linear reservoirs. The so-called RTK method, included as an option in the EPA Stormwater Management Model (SWMM) Runoff Block (Huber *et al.*, 1988), is probably the most popular SUH method. This method uses three triangular hydrographs to estimate the wide range of response times associated with the effect of fast inflow and slower GWI. The R parameter is the fraction of rainfall volume entering the sewer system as RDII, T is the time to peak, and K is the ratio of time of recession to T. The physically based model advocated by Wright *et al.* (2001) is the SWMM Runoff Block with modifications by Kadota and Djebbar (1998). This model has physical parameters that can be used to reflect the reduction of RDII associated with the extent of sewer rehabilitation work completed. This approach can be useful in developing a SSO control program as RDII reduction is usually a viable component.

A recent Water Environment Research Foundation (WERF) publication (Bennett *et al.*, 1999; Schultz *et al.*, 2001) has an expanded review of literature back to the 1980s. They identified eight broad categories of RDII quantification methods and performed a critical review study of these methods using the monitored rainfall-flow data in Minneapolis-St. Paul, MN; Portland, OR; and Montgomery, AL. The eight categories are: constant unit rates; percentage of rainfall volume (R-value); percentage of streamflow; SUH; probabilistic method; rainfall/flow regression; synthetic streamflow regression; and methods embedded in hydraulic software. In practice, any of these methods should be used with the site-specific database of rain and flow observations during both wet and dry periods. Although no one method is universally applicable, this research concluded that the SUH and rainfall/flow regression methods were the most accurate at predicting peak flows and event volumes. In an actual application, the

objective, intent, and purpose of the studies as well as the availability of data, time, and staff should be considered in selecting the most appropriate flow estimation method. Crawford *et al.* (1999) discussed the limitations of the constant rate, regression analysis, and “R-value” methods. To overcome these limitations, they suggest that unit RDII rates should appropriately increase with the age of the sewer system; a separate series of regressions should be developed to represent the seasonal nature of the rainfall-I/I processes; and “R-values” extrapolated from available data for greater intensity and less frequent design storm events should be appropriately tapered to account for the upper limit of peak flows that the leaky sewers can take. If no flow data are available, the constant unit rate methods may be applicable (Schultz *et al.*, 2001).

Collection System Hydraulic Analysis

Collection System Models. The CMOM program implicitly requires municipalities to conduct a hydraulic analysis of their collection system. SSOs are generally difficult to witness or document as they usually occur during rain events when people are indoors or are out of sight (e.g., at unmarked/unauthorized overflow locations and basements.) To answer where and when a SSO may occur, it is necessary to know the flow conveyance capacity at various parts of the collection system under normal dry weather and stressed wet weather conditions. To capture the system response to the dynamic nature of WWF generation and baseflow variations, a systemwide hydraulic evaluation using dynamic models would be advantageous. This evaluation is often necessary for identifying the causes and locations of the SSO problem to allow the development and evaluation of the most cost-effective engineering solutions. A dynamic model takes into consideration travel times and storage routing effects in a pipe network. It calculates backwater and the amount of sewer surcharge, an absolute necessity for an accurate assessment of the collection system for any SSO project. A collection system model, after its parameters have been properly developed and flow predictions verified with field monitored flow data, will allow engineers to locate SSOs under various hydrologic storm-event conditions. In addition, it facilitates performing “what if” analyses for assessing various viable remedial actions to reduce or possibly eliminate SSOs.

There is only a handful of comprehensive “dynamic” sewer models reported in the literature that are capable of handling flow routing under backwater and surcharge conditions. These models were first developed in the early 1970s and later improved for mitigation planning and design of combined-sewer overflow (CSO) pollution. It is only in the early 1990s that these models began to be applied to SSO-related analysis when EPA began discussions with SSO communities on the possibility of a national SSO Control Policy.

In the U.S., the most popular and widely used sewer model is SWMM Extran (Roesner *et al.*, 1988). From 1988 through 1999, the EPA Center for Exposure Assessment Modeling in Athens, GA, distributed approximately 3,600 copies of SWMM. Extran has the ability to solve the complete dynamic equations of motion (Saint-Venant equations); therefore, it can simulate backwater, surcharging, pressure flow, and looped connections and other hydraulic complexities. These are the conditions that are often encountered in combined- and sanitary-sewer systems. SWMM set the minimum standards for other sewer models (e.g., HydroWorks from Wallingford Software in Great Britain and Mouse from the Danish Hydraulic Institute, two of the most prominent proprietary hydrologic/hydraulic sewer system models being used in Europe and the U.S.) Other proprietary sewer routing models in the marketplace include Haestad Methods’ SewerCAD and Pizer’s Hydra. Because of the secretive nature of these proprietary models, it is

difficult for users and non-users to understand the computation details embedded in the models.

Modeling for SSO Mitigation Planning. Viable alternatives for mitigating SSOs include: (1) sewer system cleaning and maintenance to remove restrictions; (2) reduction of I/I through point repairs of defective pipe segments and manholes and comprehensive sewer rehabilitation which include pipe replacement, grouting, and lining; (3) reduction of peak WWF through flow-equalization storage; (4) expansion of sewer carrying capacity through trunk sewer and pump station/force main improvements; (5) improvements of POTW hydraulic capacity and processes; and, (6) satellite treatment at the SSO location. Field and O'Connor (1997) presented a SSO control strategy using a combination of maximizing flow to the wastewater treatment plant and maximizing treatment capacity by process changes and retrofitting. While municipalities should continue to implement alternatives (1) and (2) to the point they are cost effective, this paper will address and illustrate the need to perform hydrological and hydraulic analyses of a sewer system using dynamic models to facilitate evaluation of alternatives (3) through (6). Alternatives (3) through (6) constitute the principal components of the transport/storage/treatment concept approach for abating SSOs.

The collection system modeling effort for the planning and design of SSO control may include all or parts of the following components:

Development of dry-weather wastewater flow projections. This may include the use of existing and projected future land use and population data, estimated base wastewater flows from water consumption records, and flow monitoring data and analysis for derivation of average diurnal DWF and GWI rates.

Prediction of RDII. This will require the determination of hydrometeorological criteria (e.g., design storms for event simulation or precipitation data for continuous simulation), predictive modeling for RDII, and the estimation and verification of RDII model parameters.

Capacity analysis of existing sewer system under present and future conditions. The components include the definition of capacity evaluation criteria (e.g., what constitutes “adequate” capacity under dry and wet weather conditions?), sewer system model selection, sewershed data (e.g., DWF and WWF), sewer system data (e.g., pipes, pumps, storage basins), and sewer modeling analyses.

Wastewater treatment facility analysis. This may include a determination of the hydraulic and process capacity of unit processes in the treatment train, analyses of influent and effluent flows and pollutant characteristics, and existing flow equalization volume and additional volume required to accommodate various peak WWF conditions.

Development of capital improvement program (CIP). This will include sizing facilities (e.g., sewers, storage basins/tanks, pump stations, force mains, and POTW hydraulic capacity expansion and process retrofitting) that are required to abate SSOs, estimating the cost of various facility sizes, evaluating the cost-effectiveness of various alternatives, and developing the phased implementation program to meet the available capital investment budget.

Case Study - Henrico County, VA

This section briefly describes how a systemwide collection system modeling approach benefited the County of Henrico, VA in the planning and design of its SSO control facilities. Lai *et al.* (2001) provides more details of the modeling processes and interpretation of the results. The County is adjacent to and forms the northern boundary of the City of Richmond. The County's

sewerage facilities include a collection system comprised of over 2,000 km (1,240 mi) of sewerlines and 21 sewage pump stations (capacity ranging from 0.04 to 3.3 m³/s [1 to 75 Mgal/d]) for conveying wastewater from a 632 km² (244 mi²) area to the 2.0 m³/s (45 Mgal/d) POTW. The system also includes two wet-weather open equalization storage basins of 15,100- and 11,360-m³ (3- and 4-Mgal) capacities. The average DWF is about 1.75 m³/s (40 Mgal/d) which include base wastewater flow plus GWI. In wet weather, RDII resulted in daily average flows above 1.97 m³/s (45 Mgal/d) for more than 10% of the time and peak flows exceeding 4.82 m³/s (110 Mgal/d).

The County's sewer system is expansive. The developed land in the County is projected to increase from about 194 km² (75 mi²) in 1993 to about 310 km² (120 mi²) by year 2040. Similarly, the County's population is expected to increase from about 225,000 to 380,000 in the same period. In 1993, the County began to actively plan for the future needs of its sewerage system. In 1997, a Wastewater Facilities Plan that delineates a phased implementation program of capital improvement projects was developed and implemented.

The SWMM Extran model of the County's sewer system was used to analyze the capacity of the major facilities and the performance of the collection system under existing and future design flow conditions. The model included most of the sewers that are 305-mm (12-in.) in diameter and larger and some 203-mm (8-in.) sewers. The total length of 3,400 sewer segments included in the model is about 282 km (175 mi) or about 15% of the County sewers by length. To facilitate the modeling effort, the system was divided into eight separate modeling areas. Pump stations represent a good boundary condition for separating model areas, as flows and water surface elevations upstream of a pump station are not affected by the hydraulic conditions downstream. At the model boundaries, only the pumped flow needs to be transferred from the upstream to the downstream model areas.

The two basic types of input data to the Extran model are the data describing the physical attributes of the sewer system and the inflow hydrographs at the sewer junctions where flows enter the system. Extran models the sewer pipes as "conduits" and the manholes as "junctions." The required conduit and junction data were obtained from the County's digitized database and missing data were filled-in from sewer maps. MapInfoTM software was used to link the sewer-system database to a graphical representation of the system in order to facilitate data input preparation and verification and display of model results.

The present County sewer system was subdivided into 339 sewersheds and future development into 58 sewersheds. Both DWF and WWF from a sewershed were assumed to enter the system model at a sewer junction. In addition to average base wastewater flow, the DWF from each sewershed included 2.8 m³/ha-d (300 gal/acre-d) of GWI. This value represented the systemwide average derived from the analyses of the County SCADA system data at 21 pump stations. The RDII model uses three triangular unit hydrographs, representing the short time response (direct connections), medium time response, and relatively longer time response (infiltration) to rainwater entering the sewer system. Each unit hydrograph is defined by three parameters: the fraction of rainfall that enters a sewer; time to peak flow; and time of flow recession. These parameters may vary from area to area, reflecting flow characteristics (e.g., tightness of sewers and groundwater table) for different parts of the County's sewer system. These parameters were calibrated and verified using appropriate flow-meter data. Once calibrated and verified, this method may be used to predict RDII flows into the sewer system for other design rainfall events. The County used a 1-year frequency design storm of 24-h duration for planning its wastewater facilities.

The results of the hydraulic modeling for 1-year design storm flows showed that wet-weather overflows or excessive sewer surcharging could occur in several areas of the system under present conditions, and that additional deficiencies (locations and amounts) would develop in future years. Excess flow in upstream locations indicated that the sewer reaches at and near those locations would be excessively surcharged in wet weather. Remedial actions such as replacement of the sewers with larger diameter pipes, or construction of parallel relief sewers, would likely be required. Excess flow implied a deficient pumping capacity and an expansion of the station or construction of an equalization storage facility may be required. As capital improvements to the County's conveyance system resulted in more flows being transported for treatment, an evaluation of the impacts of these increased flows to the County's POTW was also performed. The issues were the plant's hydraulic capacity and pollutant mass-based discharge limits in the plant's NPDES permit.

Capital improvement projects for the County's sewerage system through the year 2040 were identified and developed from a combined consideration of required facility sizes determined from Extran model simulation results under present and future (years 2010, 2020, 2030, and 2040) conditions and the associated costs of these facilities. The chosen projects included POTW expansion; new pumps at existing stations and new pump stations; existing storage basin expansion and new basins; and, relief sewers and force mains. These projects addressed existing system deficiencies and matched the rate and distribution of growth that were projected to occur throughout the County in the coming years. They were divided into phases to accommodate the County's budget and provide flexibility in the future for constructing improvements when they are needed. The estimated capital costs of these projects were \$158 million from present through year 2010 and \$200 million from year 2010 through 2040, all in 1997 dollars.

The County has been aggressively implementing the proposed CIP. In addition to about \$7 million a year for sewer rehabilitation work and emergency repair, mostly in the eastern portion of the County's sewer system, the County is expanding its POTW capacity to 3.3 m³/s (75 Mgal/d) by 2002 and increasing one pump station capacity from 0.88 to 1.1 m³/s (20 to 25 Mgal/d). In addition, several designs are under way including two pump station expansions, two new storage tanks, one new pipeline storage facility, one existing storage basin expansion, and one existing storage basin cover.

The County is also developing a geographical information system (GIS) which will include layers for the water and wastewater systems. This will facilitate water and wastewater system planning and maintenance. A major effort is underway to compile all data related to water and wastewater systems and services in geographically synchronized and electronically compatible formats to help store, update, analyze, and display geographic and engineering data and information. All the water and sewer systems are to be digitized and all manholes georeferenced. The GIS layers will include zoning, real estate, land-use plan, streets, roadways, topographic data, drainage basins, and sewershed boundaries. The digital utilities map is expected to be completed in late 2001. As a result of new and more accurate utility data from this GIS effort it is likely that an update on the existing Extran model will be made.

Conclusions

The Nation's sanitary sewer infrastructure is aging with some sewers dating back over 100 years. Potential health and environmental risks associated with poor performance of many of these

systems highlight the need to increase federal regulatory oversight of the management, operation, and maintenance of these systems. As a result, EPA is in the final stage of preparing and issuing a SSO Rule that will add control of SSOs in the NPDES permit requirements for a municipality. This paper provided a preview of the Rule particularly with respect to the CMOM program requirements for municipal sanitary-sewer collection systems. The CMOM program implicitly requires municipalities to conduct a hydraulic analysis of their collection system to identify the sources and likely causes of the overflow.

To perform SSO control planning, the following points can be made from a review of literature and experience learned from the case study presented in this paper:

- To capture the system response to the dynamic nature of WWF generation and baseflow variations, a systemwide hydraulic evaluation using dynamic models would be advantageous. This evaluation is often necessary for identifying the causes and locations of SSOs to allow the development and evaluation of the most cost-effective engineering solutions. Advanced dynamic models calculate the amount of backwater and sewer surcharge which directly relates to SSOs and is an absolute necessity for an accurate assessment of the collection system for any SSO control planning project.
- A reliable estimate of RDII is probably the most critical element in developing an effective and cost-effective plan to control SSOs. There are eight prediction methods in the literature and all should be used with the site-specific database of rain and flow observations during both dry and wet periods. A recent WERF research project concluded that the SUH and rainfall/flow regression methods are two of the most accurate methods for predicting peak flows and event volumes.
- As capital improvements to a conveyance system will result in more flows being transported for treatment, an evaluation of the impacts of these increased flows to the POTW must be performed. As increased flows are routed to a POTW, the plant expansion will need to stay ahead of the flow increases in order to ensure continued discharge permit compliance.
- The final product of SSO control planning is a capital improvement, phased implementation program for guiding the SSO community to match its capital outlay with financial capability in future years. The timing of project implementation should also consider existing and future system deficiencies determined from sewer models and match the rate and distribution of projected growth in the coming years. It is therefore essential to first properly define and quantify “system deficiencies” from model output in any SSO control planning project.

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