Methods for Assessing Urban Storm Water Pollution

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Abstract

This paper presents methods for quantifying urban development conditions and characterizing the impact of urbanization on storm water pollution. Based on data collected by the City of Austin (COA), it was found that storm water pollutant mean concentrations can be correlated with development indices and watershed sizes. Use of the arithmetic mean of event mean concentrations (EMCs) to characterize storm water pollution may lead to biased results if the EMC data set is not large enough or not carefully reviewed.

Introduction

The City of Austin (COA) has had several storm water monitoring programs since 1975. The objectives of the programs are to evaluate the impacts of urban development on storm water pollution and to identify Best Management Practices (BMPs) for mitigating these impacts. Based partially on the findings (COA, 1984) of the monitoring programs, the City has implemented a series of watershed ordinances (COA, 1986-92) and protection programs.

Funded by the City's Drainage Utility (COA, 1992), the COA currently has two storm water monitoring programs (COA, 1993). One program is establishing a network of forty-five (45) runoff monitoring stations to test land use and structural BMPs. The other program monitors in-stream storm water quality at eleven (11) creek locations through a COA/USGS (U.S. Geological Survey) cooperative project. Of these fifty-six (56) stations, data for twenty-nine (29) stations were available for this study and are shown in Table 1. This study proposes methods to characterize urban storm water pollution using concentration data and information generated from previous COA studies.

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TABLE 1

DESCRIPTION OF MONITORING STATIONS

Watershed Description	No. of Stations Monitored	Drainage Area (acres)	Impervious Cover (%)	No. of Storms Adequately Sampled
Size:				
Large Watershed	12	1,416 - 79,360	3 - 47	7 - 25
Small Watershed	17	1 - 371	3 - 97	7 - 29
TOTAL*	29			
Land Use:				
Undeveloped	6	3 - 79,360	3 - 5	7 - 20
SF Residential	6	26 - 371	21 - 39	7 - 29
MF Residential/Office	4	1 - 3	50 - 88	9 - 25
Commercial/Industrial	5	3 - 197	65 - 97	8 - 23
Transportation	1	10	81	22
Mixed	7	1,416 - 32,832	12 - 47	12 - 25
TOTAL*	29			
Watershed Type:				
Urban	8	3 - 7,872	43 - 97	9 - 25
Suburban	15	1 - 32,832	12 - 39	7 - 29
Rural	6	301 - 79,360	3 - 5	7 - 20
TOTAL*	29			

* 29 monitoring stations listed by watershed size, land-use, and watershed type.

TABLE 2

STATISTICS FOR THE REGRESSION* OF INSTANTANEOUS CONCENTRATIONS ON STORMWATER RUNOFF FLOW RATES

Watershed	Drainage Area (acres)	Imp. Cover (%)	Pollutant Parameters TSS R-square**	TOC R-square	TKN R-square	TP R-square
Walnut Ck @ Webberville Rd.	14,272	25	**0.43**	**0.42**	0.08	**0.20**
Shoal Creek @ 12th St.	7,808	47	**0.67**	**0.33**	0.23	**0.35**
Waller Creek @ 38th St.	1,416	43	**0.63**	**0.18**	0.34	**0.53**
Hart Lane @ NW Austin	371	39	**0.30**	0.01	0.02	**0.09**
Lost Creek @ SW Austin	160	27	**0.30**	0.02	0.04	**0.29**
Barton Creek Square Mall	47	86	**0.21**	0.007	0.001	0.02
Lavaca St.	14	97	**0.35**	0.0007	0.06	**0.23**

* A normal error regression represents $C = a_0 Q^{a_1}$, where C is instantaneous concentration, Q is the corresponding flow rate, and a_0 and a_1 are regression coefficients.

** R-square is the coefficient of determination. Bold R-square values indicate a significant regression.

Previous Studies

Previous COA studies (COA, 1990) on storm water pollution indicated that for most of the runoff pollutant parameters, there is no significant difference in the average event mean concentrations between residential and adequately-maintained commercial sites. However, some differences exist between undeveloped, residential, and less-maintained commercial sites. The average EMCs for large, mixed land-use, creek basins are generally greater than those of small, single land-use watersheds. Most of the City's creeks are affected primarily by storm water pollution because there are few significant point sources. In order to compute runoff pollutant loads, a relationship between basin runoff coefficient (Rv, the ratio of the average annual runoff to average annual rainfall depth) and percent impervious cover was developed. This relationship can be described by a quadratic polynomial equation (COA, 1992). The equation was substantiated by additional data from this study. In general, a linear approximation of the runoff coefficient versus imperviousness relationship tends to overestimate Rv values, especially for low impervious cover sites. For any low to medium impervious cover site, the single event runoff coefficient generally increases with increasing depth of storm rainfall. The average Rv for this site should not be calculated as the arithmetic mean of all Rv values unless there is a sufficient number (to be described later) of these values. Gilbert (Gilbert, 1987) suggested that the arithmetic mean may be a biased estimation of the population mean if the coefficient of variation of the data is greater than 1.2.

Definitions of Variables

Mean concentration (MC): MC is either the arithmetic mean of event mean concentrations or the flow-weighted mean of instantaneous concentrations for a pollutant parameter for any specific watershed. Flow-weighted mean is the flow-volume weighted average of instantaneous concentrations corresponding to different classes of runoff flow rates (to be further explained).

Percent impervious cover (IC): IC is the ratio of gross impervious area in a watershed to the drainage area of the watershed, expressed as a percentage of the drainage area.

Undeveloped site (UNDS): UNDS is a basin or watershed in which little area has been disturbed by human activity. The ground of the basin is mostly covered by natural vegetation.

Development index (DI): DI is a quantity that represents one or any combination of three variables, including percent impervious cover, land use index, and watershed type index. Land use is classified into five types: undeveloped; single family residential (SF); office or multi-family residential (MF); commercial and industrial (Com/Ind); and roadway. Watershed type means the degree of cleanliness which is determined mainly by the age of roads and structures, and the housekeeping practices in the area. In addition, it may also be identified by the watershed's relative location in the metropolitan area. For the Austin area, the watershed-types are urban, suburban, or rural watershed which correspond to the definitions used in Austin's Comprehensive Watershed Ordinance (COA, 1986).

Mean Concentrations for a Specific Site

The use of the average of event mean concentrations (EMCs) for characterizing storm water pollution for a specific site may lead to biased results if the EMC data are not carefully reviewed and treated. Primarily, it is important to determine whether or not the EMC values represent the average concentrations of the corresponding storm runoff. The majority of the runoff volume (e.g., 80% or more) from a rainfall event should be sampled in order to provide sufficient data for the estimation of an EMC. For any monitored rainfall event, the number of samples should range from three (3) to as many as sixteen (16) depending on the complexity of the hydrograph. An EMC value should not be used if the sampling does not cover the full range of the hydrograph. Secondly, the flow measurement system should be designed carefully and the quality of the data thoroughly reviewed. The measurement of flow in a storm drain system is fairly difficult considering the changing flow conditions during a storm. Inaccurate discharge values can result in erroneous flow volume calculations, which will impact the EMC estimation for the storm. Finally, the flow-weighted mean concentration (FWMC) can be computed as a verification. The FWMC should be approximately the average of EMCs if there is sufficient flow and instantaneous concentration data. In order to calculate the FWMC, the flow rate of runoff should be divided into several classes (e.g., 0.003-0.3, 0.31-1.50, 1.51-3.00, and 3.01-9.00 cubic meter per second). Corresponding to each flow rate class, there is a concentration value and a measurement of percent volume of the average annual flow. The FWMC is the sum of the products of the concentration values and the percent volumes of the average annual flow.

If the average of the EMCs is used to represent watershed mean concentrations, the number of the sampled events should be sufficient to cover the entire range of rainfall classifications. As shown in Figure 1, EMC values decrease with an increase in storm runoff volume. This relationship is not clearly shown unless the number of sampled events are sufficient and the corresponding EMC values are grouped. Also, the EMC values may be dependent on build-up conditions at the onset of rainfall events. Based on the SWMM Manual (U. of Florida, 1988), a COA study (COA, 1994) derived the relationship between load and the number of dry days for specific land uses. As shown in Figure 2, the total suspended solids (TSS) load accumulated at a roadway site is significantly related to the number of dry days before a storm, although there is considerable scatter in the data.

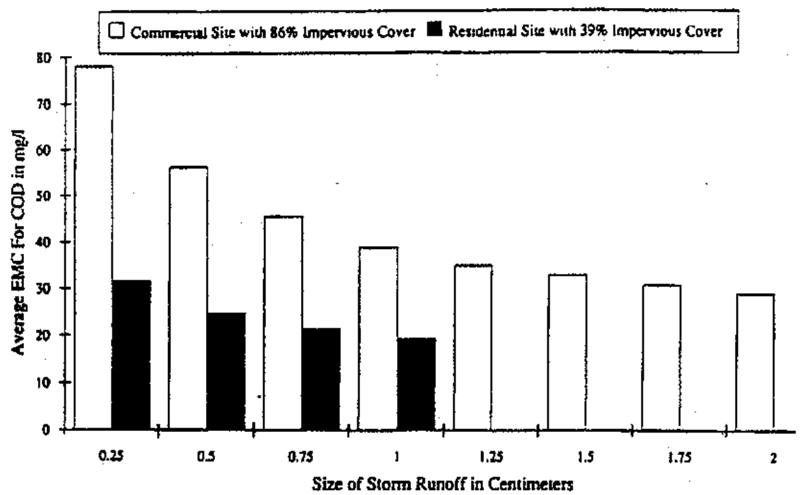

FIGURE 1. RELATIONSHIP BETWEEN AVERAGE EMC AND SIZE OF STORM RUNOFF

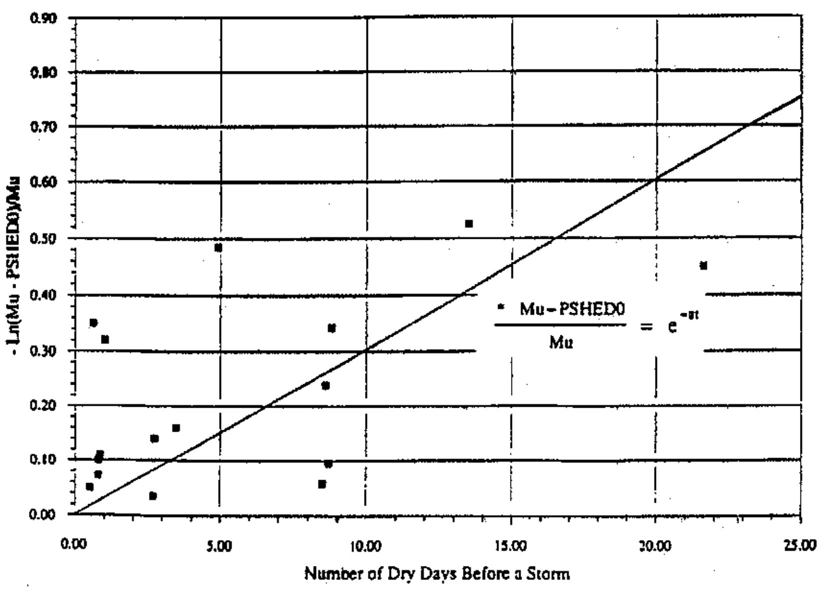

FIGURE 2. AN EXPONENTIAL TYPE BUILD - UP EQUATION DERIVED FOR A ROADWAY LAND USE SITE - FOR TSS

* An exponential type build-up equation (as shown in SWMM manual) was assumed, where Mu is the upper limit of load which can be accumulated on the ground, t is the number of dry days before a storm. PSHEDO is the load on the ground before a storm corresponding to t, and a is regression coefficient.

The EMC values can also vary with the runoff flow rates during rainfall events since the instantaneous concentration for some parameters is related to the flow rate (Table 2). The relationship tends to increase with the increase in of drainage area, and is probably the result of increases in peak flow in relation to both drainage area and growing urbanization. The increases in peak flow typically result in increased channel and bank erosion (COA/ECSD, 1992; Schueler, 1987). If the relationship between instantaneous concentration and flow rate is significant, the mean concentrations of a site should be represented by the flow-weighted mean concentrations. The average EMCs can represent the site mean concentrations only if the EMCs were computed from a sufficient number of storms which cover the full range of flow rates.

For the Austin area, a storm water monitoring period should generally run between two (2) to four (4) years in order to adequately represent the entire range of classifications of rainfall events. Typically this would provide about twenty to thirty (20-30) EMCs. To ensure accurate representation of the different classifications of storm event, the number of dry days before a storm should be divided into a minimum of two (2) classes (e.g., less or equal than two dry days and greater than two dry days) and the size of storm divided into a minimum of three classes (e.g., less or equal than 1.90 cm, 1.91 to 4.50 cm, and greater than 4.5 cm). Therefore the number of combinations of these two factors (the number of dry days and the size of storm) is six (2 x 3). Considering that a minimum of three replicates is needed for each class of events, the number of adequately-sampled events should be at least eighteen (18). For the rainfall conditions in the Austin area, this will require a minimum of two (2) years of monitoring to satisfy. Because of the difficulty of maintaining and operating a large number of monitoring stations, and the potential for drought conditions to occur during the sampling period, this minimum time requirement of two years is typically not sufficient. Therefore it is prudent to plan for storm water monitoring over at least a three (3)-year period.

Derivation of Development Index

The development index (DI) represents watershed development conditions which can be quantified using one or any combination of three variables: percent impervious cover, land-use index (LI), and watershed-type index (WTI). In this study, DI is assumed to be a linear combination of LI and WTI. The following is an example of computation for obtaining DI:

Step one: Develop a matrix of mean concentration (MI) values for the relationship of land-use types to pollutant parameters. Given five (5) pollutant parameters, the matrix is as follows:

Land-use	TSS	TOC	NO_3	TKN	TP
Undeveloped	77	7	0.13	0.32	0.04
SF Residential	151	12	0.70	1.60	0.28
MF Res./Office	97	14	0.63	1.76	0.38
Com./Ind.	216	14	0.61	2.24	0.46
Roadway	320	25	0.40	1.20	0.22

Step two: Standardize all mean concentration values to a dimensionless variable which has a randomly-assigned arithmetic mean and standard deviation (in this example, M = 3, and S = 1.581 for a series of numbers 1, 2, 3, 4, and 5). Using SAS STANDARD procedure (SAS Institute, 1987), the standardized mean concentration is

$$\text{Stan MC} = [(MC - \overline{MC}) / \sigma_{MC}][S] + M \qquad [1]$$

where $\overline{MC}$ is the arithmetic mean of MC values for the five land use types for each of the five pollutant parameters, and σ_{MC} is the standard deviation of these five MC values. Corresponding to the MC matrix above, the standardized MC matrix is:

Land-use	TSS	TOC	NO_3	TKN	TP	Avg.
Undeveloped	1.47	1.23	0.52	0.58	0.68	0.90
SF Residential	2.67	2.42	4.38	3.39	3.06	3.18
MF Res./Office	1.80	2.85	3.95	3.74	3.99	3.27
Com./Ind.	3.70	2.94	3.79	4.79	4.82	4.00
Roadway	5.37	5.55	2.36	2.51	2.44	3.65

The values in the matrix above are the land-use indices for each pollutant parameter. The values in the column labeled "Avg." are the overall land-use indices for each of the land-use types.

Step three: The watershed-type index (WTI) can be derived in the same manner as steps 1-2. In this case the matrix of MC values consists of watershed types (rural, suburban, and Urban) and pollutant parameters.

Step four: Assuming the development index is a linear combination of LI and WTI in the following form:

$$DI = (LI + WTI)/2, \qquad [2]$$

then the development index of a watershed can be computed for each of the pollutant parameters in the matrix.

Assessing Storm Water Pollution

The values of mean concentrations and development indices for several pollutant parameters and for all twenty-nine monitoring sites were computed. The pollutant parameters evaluated using local data are total suspended solids (TSS), chemical oxygen demand (COD), 5-day biochemical oxygen demand (BOD5), total organic carbon (TOC), total phosphorus (TP), total nitrogen (TN), nitrite plus nitrate (NO_2+NO_3), total kjeldahl nitrogen (TKN), ammonia (NH_3), total lead (TPb), fecal coliform (Fe. Col.), and fecal streptococci (Fe. Stp.). These are standard parameters considered in assessing non-point source pollution from storm water (EPA, 1983; Shueler, 1987).

Mean concentrations for some parameters such as TP, TKN, TN, COD, and TPb can correlate well with the development indices. As shown in Figure 3, the TP mean concentration for any specific watershed in the area can be reasonably estimated from the development condition of the watershed, i.e., the land-use index and the watershed-type index of TP. Additionally, the percent watershed imperviousness is also an adequate index for estimating mean concentrations for the above mentioned pollutant parameters. On the other hand, regressions of mean concentrations on development indices for other parameters are less significant. As shown in Figure 4, the mean concentration values of nitrite plus nitrate corresponding to the higher values of the development indices vary independently from the development index. There are no significant differences in concentrations among watersheds of all the development conditions except for the undeveloped sites. To further review the data, the NO_2+NO_3 concentrations are generally higher for the SF residential land-use sites, probably because of fertilizer applications.

For the TSS-related parameters such as TSS, TP, TKN, and TOC, the mean concentrations are significantly related to the drainage area of the watershed, as described earlier in this paper. As shown in Figure 3, the relationships between TP concentrations and development indices are represented by two separate regression lines [for watershed size ≤ 405 hectares (1000 acres) and > 405 hectares (1000 acres)].

Conclusions

Based on the findings, the following conclusions can be drawn:

1. This study used data collected from the City of Austin's storm water monitoring programs. Although the data is preliminary, its quantity and quality are

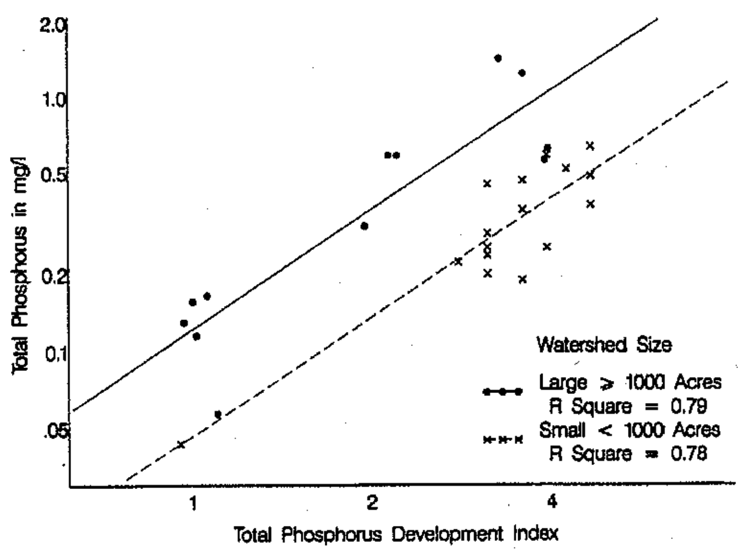

FIGURE 3. RELATIONSHIP OF MEAN CONCENTRATION OF TOTAL PHOSPHORUS TO DEVELOPMENT INDEX

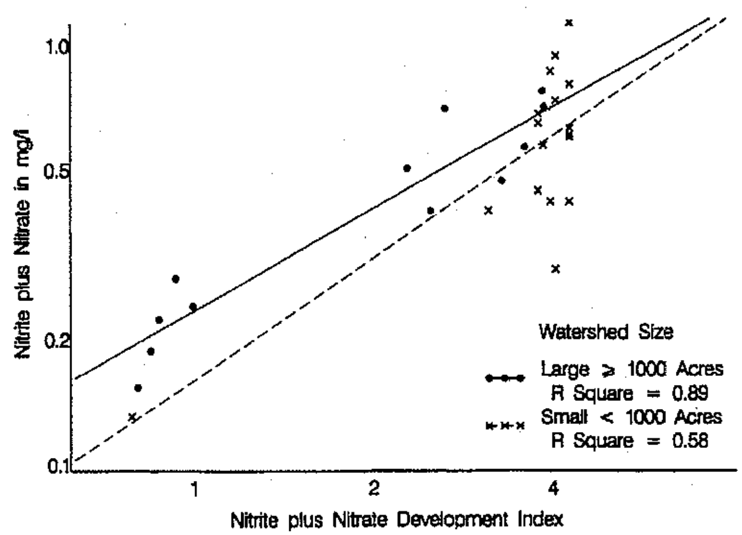

FIGURE 4. RELATIONSHIP OF MEAN CONCENTRATION OF NITRITE PLUS NITRATE TO DEVELOPMENT INDEX

sufficient for the development of a simplified method to characterize urban storm water pollution.

2. The impacts of urban development on storm water quality can be identified by the relationships of watershed mean concentrations to development indices. A development index may be a linear combination of land-use and watershed-type indices which characterize basin development conditions. This index correlates well with the percentage of impervious cover. For some parameters such as TSS, TP, TKN, and TOC, the described relationships also depend on the sizes of watersheds or drainage areas.

3. The use of average EMCs to represent watershed mean concentrations is adequate only if the sizes and antecedent conditions of the sampled events adequately represent the entire range of the rainfall event classifications. It is recommended that the EMC data presented by different organizations not be combined for analysis unless the methods and procedures for obtaining such data are carefully reviewed.

4. The use of arithmetic means to characterize average conditions of EMCs and runoff coefficients may be biased if the size of data sets is insufficient or the coefficients of variation are large (greater than 1.2). This is particularly true in computing the average runoff coefficient for a watershed since the runoff coefficient generally increases with increasing depth of storm rainfall. It is suggested that the population mean of the EMCs or runoff coefficients for any watershed can be best represented by the median, the adjusted geometric mean (Gilbert, 1987), or the flow-weighted mean of the observed EMC or runoff coefficient values.

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Practical Experience with Filippi Flow Limiters

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Abstract

The Filippi stormwater flow limiter belongs to the group of "weirs" of the type "one side overflow weir." The Filippi limiter, due to its specially profiled shape, allows for excellent hydraulic control of flow, but has little effect on solid/particulate separation.

There are many potential applications for the Filippi limiter:

- In combined sewer systems
- Upstream wastewater treatment plants or runoff storage tanks
- Surface water collection (first flushes of concentrated runoff) to be diverted to wastewater treatment facilities.

The excellent hydraulic control is obtained by its unique configuration - venturi channel at the inlet, changes in flow direction, short specially-shaped single-sided overflow edge, and guiding grooves at the outlet to prevent blockage.

The Filippi limiter is patented in most countries, and has successfully been used in various European countries since 1982.

Introduction

Stormwater overflow, overflow weirs, regulators, rainwater overflows, etc. are commonly used technical terms. The most appropriate term to describe the Filippi device is "flow limiter." These flow limiters may not only be used in combined sewers to avoid flooding, but also upstream of wastewater treatment facilities and runoff storage tanks or settling basins. Another potential application for such precise flow limiters would be to divert the first flush of concentrated runoff to a wastewater treatment plant.

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ABSTRACT

This proceedings, *Stormwater NPDES Related Monitoring Needs*, consists of papers presented at the Engineering Foundation Conference held in Colorado, August 7-12, 1994. The Conference brought together 90 experts in the field of urban stormwater management to discuss the current state of the U.S. Environmental Protection Agency's Nonpoint Pollution Discharge Elimination System (NPDES) regulations related to discharges of urban stormwater, and the monitoring requirements under those regulations. The objective was to summarize the current state of stormwater monitoring with respect to meeting these regulatory requirements, and to lay out an agenda for the future. Technical sessions included: 1) An overview of stormwater monitoring needs; 2) locating illicit connections; 3) system runoff characterization; 4) NPDES compliance monitoring; 5) policy and institutional issues o NPDES monitoring; 6) BMP monitoring for data transferability; 7) monitoring receiving water trends; and 8) stormwater and best management practice (BMP) monitoring. There were also extensive discussions, as well as a number of adhoc meetings. A major conclusion reached by the conferees was that existing monitoring requirements will not yield the information necessary to determine impacts on the environment or to evaluate the effectiveness of BMPs.

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FOREWORD

The Urban Water Resources Research Council (UWRRC) of the American Society of Civil Engineers has for 30 years been a leader in the transfer of urban stormwater technology among researchers, practitioners and administrators. One of the principal means of accomplishing this transfer has been through a series of Engineering Foundation Conferences, held in the United States and abroad, as well as International Symposia and technical sessions at professional conferences.

The Council has recognized for some time that there have been numerous concerns related to the monitoring requirements of the current U. S. Environmental Protection Agency NPDES regulations, and particularly those governing discharges of stormwater to the environment. Because of these concerns, and because the Council itself felt that there were many technical and administrative problems with these regulations, the Council organized this Conference on stormwater NPDES related monitoring needs. It was the aim of the Conference to bring together experts in all fields related to these needs, including those from the regulatory agencies and the regulated community. What resulted was a mix of perspectives and expertise representing industry and state and local governments, together with their technical staffs and consultants.

All of the papers presented in the regular sessions were by invitation, and were reviewed and accepted for publication by both the Conference Chairman and by the Proceedings Editor. Papers in Appendix A (Poster Papers) were unsolicited, and only received an editorial review for format, etc. All papers are eligible for discussion in the Journal of the Water Resources Planning and Management Division of the American Society of Civil Engineers (ASCE). All papers are eligible for ASCE awards.

The Proceedings are organized by "session", corresponding to the actual conference sessions. Formal papers are presented first, followed by a session discussion which may include both material presented by an author which is not necessarily in his paper, as well as comments/questions from participants, and the answers to those questions furnished by the author (or, in some cases, by other conference participants).