Stormwater quality as described in the National Stormwater Quality Database (NSQD)

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ABSTRACT

The University of Alabama and the Center for Watershed Protection were awarded a U.S. Environmental Protection Agency, Office of Water 104(b)3 grant in 2001 to collect and evaluate stormwater data from a portion of the NPDES (National Pollutant Discharge Elimination System) MS4 (municipal separate storm sewer system) stormwater permit holders. The initial version of this database, the National Stormwater Quality Database (NSQD, version 1.1) is currently being completed. These stormwater quality data and site descriptions are being collected and reviewed to describe the characteristics of national stormwater quality, to provide guidance for future sampling needs, and to enhance local stormwater management activities in areas having limited data. The monitoring data collected over nearly a ten-year period from more than 200 municipalities throughout the country have a great potential in characterizing the quality of stormwater runoff and comparing it against historical benchmarks. This project is creating a national database of stormwater monitoring data collected as part of the existing stormwater permit program, providing a scientific analysis of the data, and providing recommendations for improving the quality and management value of future NPDES monitoring efforts.

KEYWORDS

Separate stormwater; National Pollutant Discharge Elimination System (NPDES); municipal separate storm sewer system (MS4) monitoring data.

INTRODUCTION

The importance of this EPA-sponsored project is based on the scarcity of nationally summarized and accessible data from the existing U.S. EPA's NPDES (National Pollutant Discharge Elimination System) stormwater permit program. There have been some local and regional data summaries, but little has been done with nationwide data. A notable exception is the Camp, Dresser, and McGee (CDM) national stormwater database (Smullen and Cave 2002) that combined historical Nationwide Urban Runoff Program (NURP) (EPA 1983), available urban U.S. Geological survey (USGS), and selected NPDES data. Their main effort has been to describe the probability distributions of these data (and corresponding EMCs, the event mean concentrations). They concluded that concentrations for different land uses were not significantly different, so all their data were pooled into a single category.

Between 1978 and 1983, the EPA conducted the Nationwide Urban Runoff Program that examined stormwater quality from separate storm sewers in different land uses (EPA 1983). This program studied 81 outfalls in 28 communities throughout the U.S. and included the monitoring of approximately 2,300 storm events. The data was presented for several land use categories, although most of the information was obtained from residential lands. Since NURP, other important studies have been conducted that characterize stormwater. The USGS created a database with more than 1,100 storms from 98 monitoring sites in 20 metropolitan areas. The Federal Highway Administration (FHWA) analyzed stormwater runoff from 31 highways in 11 states during the 1970s and 1980s. Strecker (personal communication) is also collecting information from highway monitoring as part of a current NCHRP-funded project. The city of Austin also developed a database having more than 1,200 events.

Other regional databases also exist for US data, mostly using local NPDES data. These include the Los Angeles area database, the Santa Clara and Alameda County (California) databases, the Oregon Association of Clean Water Agencies Database, and the Dallas, Texas, area stormwater database. These regional data are included in the NSQD. However, the USGS and historical NURP data are not included in the NSQD due to lack of consistent descriptive information for the older drainage areas and because of the age of the data from those prior studies. Much of the NURP data is available in electronic form at the University of Alabama student American Water Resources Association web page at: http://www.eng.ua.edu/~awra/download.htm.

Outside the U.S., there have been important efforts to characterize stormwater. In Toronto, Canada, the Toronto Area Watershed Management Strategy Study (TAWMS) was conducted during 1983 and 1984 and extensively monitored industrial stormwater, along with snowmelt in the urban area, for example. Numerous other investigations in South Africa, the South Pacific, Europe and Latin America have also been conducted over the past 30 years, but no large-scale summaries of that data have been prepared. About 4,000 international references on stormwater have been reviewed and compiled since 1996 by the Urban Wet Weather Flows literature review team for publication in *Water Environment Research* (most recently by Clark, *et al*. 2001, 2002, 2003, 2004). An overall compilation of these literature reviews is available at: http://www.eng.ua.edu/~rpitt/Publications/Publications.shtml. These reviews include short summaries of the papers and are organized by major topics. Besides journal articles, many published conference proceedings are also represented (including the extensive conference proceedings from the 8th International Conference on Urban Storm Drainage held in Sydney, Australia, in 1999, the 9th International Conference on Urban Storm Drainage held in Portland, OR, in 2002, and the Toronto Stormwater and Urban Water Systems Modeling conference series, amongst many other specialty conferences).

The NSQD is unique in that detailed descriptions of the test areas and sampling conditions are also being tabulated, including aerial photographs and topographic maps that are being obtained from public domain Internet sources. This project also involved extensive QA/QC (quality assurance/quality control) evaluations of these data; and performing statistical analyses and summaries of these data. The final information will be published on the Internet (such as on an EPA OW-OWM, Office of Water and Office of Wastewater Management, site and on the Center for Watershed Protection's SMRC, Stormwater Manager's Resources Center, site at: http://www.stormwatercenter.net/). Some of the information is currently located at Pitt's teaching and research web site (including a complete Excel spreadsheet database listing the data plus extensive site descriptions and several papers describing the database and selected evaluations) at: http://www.eng.ua.edu/~rpitt/Research/ms4/mainms4.shtml

DATA COLLECTION AND ANALYSIS EFFORTS

The National Stormwater Quality Database, NSQD, version 1.1) contains separate stormwater system outfall quality data for about 4,000 separate events from 66 agencies and municipalities from 17 states. Good national coverage was obtained, although sparse representation was obtained for areas lacking large cities and some areas were not able to submit data in time for inclusion. The initial scope of the project was limited to areas in the southeast and mid-Atlantic areas, but additional data were able to be included. The northeast, the upper midwest, and north central states have the least representation in the database.

Some of the data submitted by municipalities could not be used for various reasons. One of the most common reasons was that the samples had been collected from receiving waters (such as Washington state, Nashville, and Chattanooga); only data from well-described separate stormwater system outfall locations were entered in the database. These can be open channel outfalls in completely developed areas, but are more commonly conventional outfall concrete pipes. Another major problem was that the sampling locations and/or the drainage areas were not adequately described. Most areas evaluated common stormwater constituents (TSS, COD, turbidity, some bacteria and nutrients, and several heavy metals), but few included organic toxicants. The most serious gap is the lack of runoff volume data for about half of the events, although all events have rainfall depth information. About 10% of the collected data needed manual verification during the QA/QC process. If faulty data remained in the database, spurious statistical analyses would have resulted.

The assembled data was entered into NSQD, including site descriptions (state, municipality, land use components, and EPA rain zone), sampling information (date, season, rain depth, runoff depth, sampling method, sample type, etc.), and constituent measurements (concentrations, grouped in categories). In addition, more detailed site, sampling, and analysis information was collected for most sampling sites and is also included as supplemental information. The reported land use information supplied by the communities was used, with verification of some areas with aerial photographs and maps.

Summary of U.S. NPDES Phase 1 Stormwater Data in the NSQD

Table 1 is a summary of selected data collected and entered into the database. The data are separated into 11 land use categories: residential, commercial, industrial, institutional, freeways, and open space, plus mixtures of these land uses. Summaries are shown for the major land use areas and for the total data set combined. The full database includes all of the data. The total number of observations and the percentage of observations above the detection limits are also shown on this summary table. In general, COV values range from 1.0 to 2.0 for the majority of pollutants across all major land uses.

Results and Conclusions

The following are brief observations associated with statistical analyses of the data. Several properties of the NSQD (and/or stormwater in general) made statistical analyses challenging, including:

- the very large number of samples represented in the NSQD resulted in statistically significant differences being identified, although the practical difference may not be very important,

Table 1. Summary of Selected Separate Stormwater Data Included in NSQD, ver. 1.1

	Precip. Depth (in)	TSS (mg/L)	COD (mg/L)	Fecal Coliform (mpn/100 mL)	NH3 (mg/L)	N02+NO3 (mg/L)	Phos., filtered (mg/L)
Overall Summary (3765)							
Number of observations	3186	3390	2751	1704	1909	3076	2477
% of samples above detection	100	98.8	98.4	91.2	71.7	97.3	85.1
Median	0.47	58	53	5091	0.44	0.6	0.13
Coefficient of variation	1.0	1.8	1.1	4.61	1.4	1.1	1.6
Residential (1081)							
Number of observations	915	991	796	446	595	927	738
% of samples above detection	100	98.6	98.9	88.3	81.5	97.4	84.2
Median	0.46	49	55	8345	0.32	0.6	0.17
Coefficient of variation	1.0	1.8	0.93	5.0	1.1	1.1	0.9
Commercial (503)							
Number of observations	421	458	373	233	299	425	323
% of samples above detection	100	98.3	98.4	88.0	83.3	98.1	81.1
Median	0.39	42	60	4300	0.50	0.6	0.11
Coefficient of variation	1.0	2.0	1.0	2.8	1.2	1.1	1.2
Industrial (525)							
Number of observations	438	428	362	297	254	418	325
% of samples above detection	100	99.1	98.9	87.9	85.8	96.2	87.1
Median	0.49	78	60	2500	0.50	0.73	0.11
Coefficient of variation	1.0	1.5	1.2	5.6	1.2	0.9	1.2
Freeways (185)							
Number of observations	182	134	67	49	79	25	22
% of samples above detection	100	99.3	98.5	100	87.3	96.0	95.5
Median	0.54	99	100	1700	1.07	0.28	0.20
Coefficient of variation	1.1	2.6	1.1	2.0	1.3	1.2	2.1
Open Space (49)							
Number of observations	41	44	43	23	32	44	44
% of samples above detection	100	95.5	76.74	91.3	18.8	84.1	79.6
Median	0.52	48.5	42.1	7200	0.18	0.59	0.13
Coefficient of variation	1.2	1.5	1.5	1.1	1.24	0.9	0.9

- the large number of undetected observations for many constituents (especially filtered metals, for example), and the varying detection limits associated with some measurements, made comparisons difficult, without proper data handling and appropriate statistical tests,
- large natural variations in stormwater quality at individual sampling locations requires large numbers of samples in order to be confident of the statistical results and to provide adequate power for the statistical tests. Although a very large number of data were available overall, “slicing and dicing” the data into subcategories frequently resulted in fewer observations than desired. One of the primary goals of our data analysis effort was to identify which factors were important in determining stormwater quality. We focused primarily on land use, geographical location, season, rain depth, impervious cover, drainage area, and sampling methods, for example.

Table 1. Summary of Selected Separate Stormwater Data Included in NSQD, ver.1.1 (continued)

	As, total (µg/L)	Cd, total (µg/L)	Cr, total (µg/L)	Cu, total (µg/L)	Cu, filtered (µg/L)	Pb, total (µg/L)	Pb, filtered (µg/L)	Zn, total (µg/L)	Zn, filtererd (µg/L)
Overall Summary (3765)									
Number of observations	1507	2575	1599	2724	411	2950	446	3008	382
% of samples above detection	49.9	40.8	70.2	87.4	83	77.7	49.8	96.6	96.1
Median	3.0	1.0	7.0	16	8.0	17.0	3.0	117	52
Coefficient of variation	2.6	3.7	1.5	2.2	1.6	1.8	2.0	3.3	3.9
Residential (1069)									
Number of observations	426	723	435	799	90	788	108	810	88
% of samples above detection	42.0	30.3	55.4	83.6	63.3	71.3	33.3	96.4	89.6
Median	3.0	0.5	4.6	12	7.0	12.0	3.0	73	31.5
Coefficient of variation	2.2	3.4	1.4	1.8	2.0	1.9	1.9	1.3	0.8
Commercial (497)									
Number of observations	213	358	235	387	48	377	59	392	49
% of samples above detection	32.9	43.0	58.7	92.8	79.2	85.4	52.5	99.0	100
Median	2.4	0.89	6.0	17	7.57	18.0	5.0	150	59
Coefficient of variation	3.0	2.7	0.9	1.5	0.8	1.6	1.6	1.2	1.4
Industrial (524)									
Number of observations	267	395	256	416	42	412	51	433	42
% of samples above detection	54.3	49.4	72.7	89.9	90.5	76.5	52.9	98.6	95.2
Median	4.0	2.0	14.0	22	8.0	25.0	5.0	210	112
Coefficient of variation	1.4	2.3	1.2	2.0	0.7	1.8	1.6	2.3	3.6
Freeways (185)									
Number of observations	61	95	76	97	130	107	126	93	105
% of samples above detection	55.7	71.6	98.7	99.0	99.2	100	50.0	96.8	99.1
Median	2.4	1.0	8.3	34.7	10.9	25	1.8	200	51
Coefficient of variation	0.7	0.9	0.7	1.0	1.5	1.5	1.7	1.0	1.9
Open Space (68)									
Number of observations	19	38	36	39		45		45	
% of samples above detection	31.6	55.3	36.1	74.4		42.2		71.1	
Median	4.0	0.38	5.4	10		10.0		40	
Coefficient of variation	0.4	1.9	1.7	2.0		1.7		1.3	

These attributes of the data were examined in detail and have been presented previously (Pitt, *et al*. 2004a and b; Maestre, *et al*. 2004, and 2005). Several chapters of Maestre's Ph.D. dissertation that address these issues in detail are also available on Pitt's research website at: http://unix.eng.ua.edu/~rpitt/Research/ms4/Paper/Mainms4paper.html. The following briefly summarize some of our statistical analysis findings:

Comparisons of NSQD Data with Historical NURP Data

Table 2 compares data obtained from the EPA's NURP summary report (EPA 1983) and NSQD data. Lead concentrations, as expected, have dropped by an order of magnitude over the last 20 years, likely associated with reduced use of unleaded gasoline. Sediment and heavy metal concentrations appear to have declined across all land uses, while nutrient concentrations are similar between the two data sets.

Table 2. Comparison of Median NURP and NSQD Reported Concentrations

	Overall		Residential		Commercial		Open Space	
	NSQD	NURP	NSQD	NURP	NSQD	NURP	NSQD	NURP
Area (acres)	56	69	57	58	39	28	74	3,775
BOD_5 (mg/L)	8.6	9	9	10	12	9.3		
COD (mg/L)	53	65	55	73	63	57	21	40
TSS (mg/L)	58	100	48	101	43	69	51	70
Pb, total (µg/L)	16	144	12	144	18	104	5	30
Cu, total (µg/L)	16	34	12	33	17	29		
Zn, total (µg/L)	116	160	73	135	150	226	39	195
Nitrogen, Total Kjeldalh (mg/L)	1.4	1.5	1.4	1.9	1.6	1.18	0.6	0.97
NO_2+NO_3 (mg/L)	0.6	0.68	0.6	0.74	0.6	0.57	0.6	0.54
Phos., total (mg/L)	0.27	0.33	0.3	0.38	0.22	0.20	0.25	0.12
Phos., filtered (mg/L)	0.12	0.12	0.17	0.14	0.11	0.08	0.08	0.03

As part of their MS4 phase 1 applications, Denver and Milwaukee both returned to some of their earlier sampled monitoring stations used during the local NURP projects. In the time between the early 1980s (NURP) and the early 1990s (MS4), they did not detect any significant differences, except for large decreases in lead concentrations. Suspended solids, copper, lead, and zinc concentrations at the Wood Center NURP monitoring site in Milwaukee average site concentrations remained the same, except for lead, which decreased from about 450 down to about 110 µg/L. Similar comparisons were made in the Denver Metropolitan area by the Urban Drainage and Flood Control District. Although there were apparent differences in the averages of the event concentrations between the sampling dates, they concluded that the differences were all within the normal range of stormwater quality variations, except for lead, which decreased by about a factor of four.

The differences between the median NURP and NSQD observations for several of the constituents are likely due to the random nature of stormwater quality data, and not from significant trends, except for lead. However, the areas represented are different in the databases. The NSQD is much more representative of a broader range of land uses, while almost all of the NURP data was obtained from residential areas. Also, the geographical distributions of the monitoring programs are slightly different. NURP has more northern data, while NSQD has more southern data.

Land Use and Seasonal Variations

Statistical analyses found significant differences for land use categories for all pollutants (Figure 1). This is notable because National Urban Runoff Program (NURP) findings showed no significant differences in urban runoff concentrations as a function of common urban land uses (EPA 1983), likely because they had few data from non-residential areas.

Freeway locations generally had the highest median values, except for phosphorus, nitrates, fecal coliforms, and zinc, while industrial and institutional sites had the highest reported zinc concentrations. Total Kjeldahl Nitrogen (TKN), copper, lead, and zinc observations are lowest for open space areas, as for most constituents.

Seasonal variations were not as important as were geographical variations, except that the bacteria values were lowest during the winter season and highest during the summer and fall (a similar conclusion was obtained during the NURP data evaluations).

Relationships of common pollutants such as suspended solids, phosphorus, fecal coliforms, and total zinc concentrations for different rain depths show little variation, implying there is no strong "first flush" effect at stormwater outfall locations (Figure 2). To explore this further, a more rigorous analysis was conducted using paired first-flush and total storm composite data.

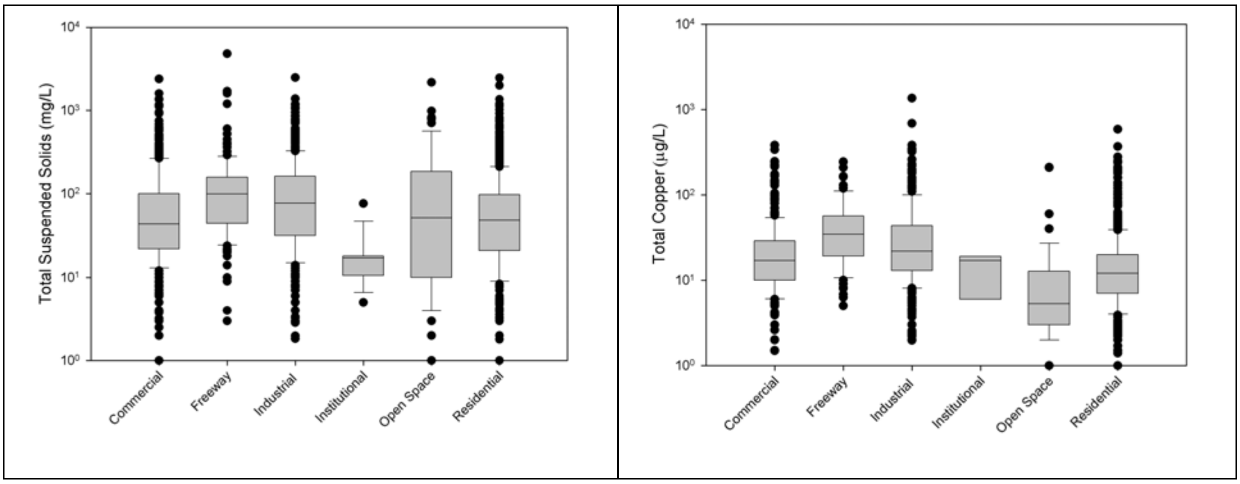

Figure 1. Example plots showing variations in constituent concentrations between land uses.

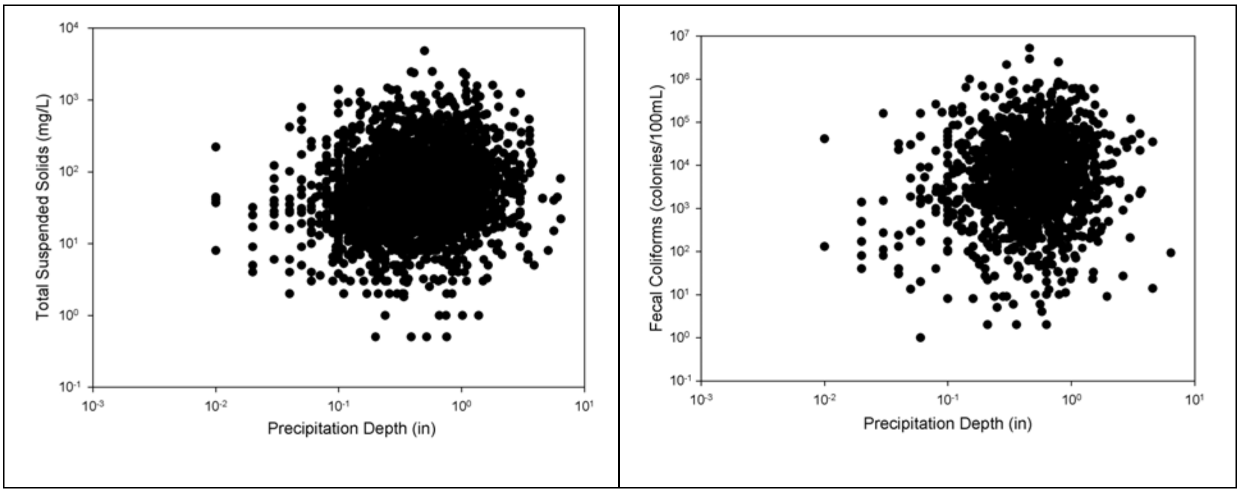

Figure 2. Example scatterplots of residential area TSS and fecal coliform observations showing no relationship with rain depth.

Median concentrations of the first-flush data set was larger than for the flow-weighted composite sample data set for only about half of the evaluated cases. Where the differences were statistically significant, the ratios of the first flush median concentrations to the composite median concentrations were rarely larger than 2.0. About 70% of the constituents in the commercial land use category, about 60% of the constituents in the residential, institutional and the mixed (mostly commercial and residential) land use categories, and about 45% of the constituents in the industrial land use category, had first flushes. In contrast, no constituents were found to have first flushes in the open space category. COD, BOD_5, TDS, TKN, and Zn had first flushes in all areas (except for the open space category). In contrast, turbidity, pH, fecal coliforms, fecal strep., total N, dissolved and ortho-P showed no statistically significant first-flushes in any category.

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