Research Progress Report

Findings from the

NATIONAL STORMWATER QUALITY DATABASE (NSQD)

Photo courtesy of Roger Bannerman.

Robert Pitt, Alex Maestre, and Renee Morquecho
Dept. of Civil and Environmental Engineering
University of Alabama
Tuscaloosa, AL 35487

and

Ted Brown, Tom Schueler, Karen Cappiella, Paul Sturm,
and Chris Swann
Center for Watershed Protection
Ellicott City, MD 21043

January 2004

Introduction

The University of Alabama and the Center for Watershed Protection have collected and evaluated stormwater data from a representative number of National Pollutant Discharge Elimination System (NPDES) municipal separate storm sewer system (MS4) stormwater permit holders. This project fills an important need for nationally summarized and accessible data from the existing U.S. EPA's NPDES stormwater permit program. The data from this project will be useful for both developing pollutant loading assessments and water quality evaluations associated with compliance monitoring activities, and determining the need for runoff monitoring as part of future stormwater permits.

The initial version of this database, the National Stormwater Quality Database (NSQD Version 1.0), is currently being completed. To our knowledge, it is the largest urban stormwater database ever developed. This memorandum provides a brief summary of the more notable findings to date, presents preliminary recommendations for application of data findings, and identifies remaining research gaps. A more complete presentation of current findings is provided in Pitt *et al. (2003)* and at the research web site (http://www.eng.ua.edu/~rpitt/Research/ms4/mainms4.shtml). A final report will be produced by the fall of 2004.

Data Collection and Analysis to Date

As of September 2003, data from 3,770 separate storm events from 66 agencies and municipalities from 17 states were collected and entered into NSQD. Figure 1 shows the locations of these municipalities on a national map. The original scope of the project focused on southeastern and Chesapeake Bay locations, but we were able to substantially increase the geographical coverage due to excellent cooperation and interest from many agencies. The database has good representation from most regions of the country, although it contains few municipalities from the Midwestern states of Ohio, Michigan, Illinois, and Indiana. Other regions where data are lacking include the northern west-central states of Montana, Wyoming, North and South Dakota and the New England states of Maine, Vermont, and New Hampshire. This is due to the absence of Phase I communities (where cities are generally small, or where larger cities have combined sewer systems). We also obtained additional information after our cut off date that is not included in our work thus far, in order to allow time for the necessary quality control.

The NSQD database includes 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 pollutant measurements (concentrations, grouped in categories). In addition, more detailed site, sampling, and analysis information has been collected for most sampling sites and is included as supplemental information. Most municipalities sampled the conventional stormwater pollutants, while a few also included organic toxicants. The most serious gap is the lack of runoff volume data, although all sites have included rain data.

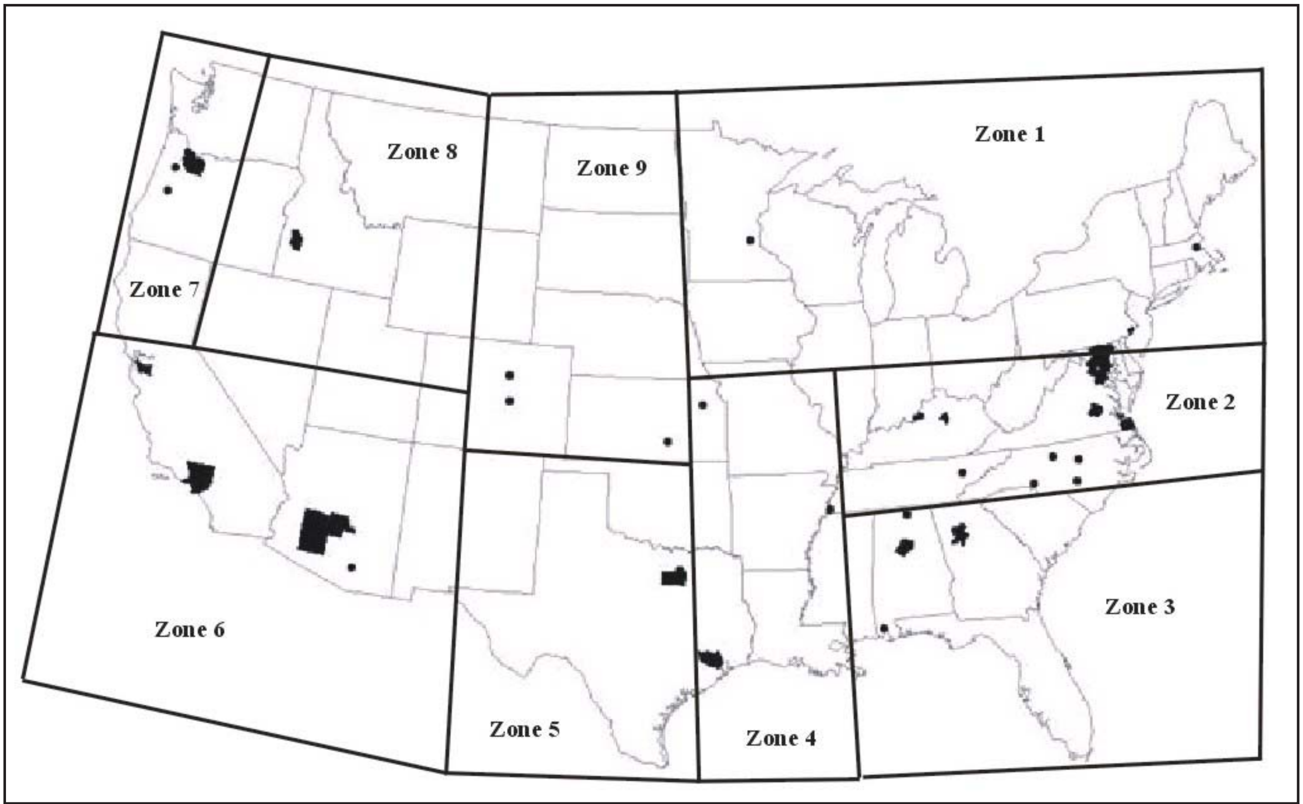

Figure 1. Communities where data have been obtained and entered in NSQD. (EPA Rain Zones are indicated)

Early Findings from the NSQD

Our initial conclusions about the NPDES Phase I stormwater data should be considered preliminary and may change slightly with additional data and analyses. This report presents only the most basic and robust analyses.

A total of 3,770 individual events are included in the database. Tables 1 and 2 show the distribution of runoff samples for five major land uses by season and by EPA rainfall zone (Figure 1). Mixed land uses (not shown in Tables 1 and 2) account for the remaining events. Most common pollutants were detected for almost all monitored events. However, filtered heavy metal observations, and especially organic analyses, have many fewer detected values.

Most of the available data are from residential, industrial, and commercial land uses from EPA rain zones 2 through 7. Therefore, most of the multivariate statistical analysis efforts will focus on this subset of data, although basic analyses will be conducted on the complete data set.

Table 3 summarizes the median values and event mean concentrations (EMCs) for common urban runoff parameters. Pitt *et al.* (2003) provides a more detailed presentation of the data, along with coefficients of variation (COV). In general, COV values are less than 2.0 for the majority of pollutants across all major land uses. The COV values are substantially reduced when significant subsets of the data are identified.

Photo courtesy of the Harford County Department of Public Works, Water Resources Engineering, 2003

Table 1. Numbers of Events for Different Seasons and Land Uses					
	Residential	Industrial	Commercial	Freeways	Open Space
Winter	280	142	122	103	28
Spring	277	135	125	45	15
Summer	223	113	109	2	15
Fall	295	134	147	35	16
Total	1075	524	503	185	74

Table 2. Numbers of Events for Different Geographic Regions and Land Uses					
EPA Rain Zone	Residential	Industrial	Commercial	Freeways	Open Space
1	25	13	3	0	1
2	686	239	304	3	36
3	58	46	24	0	0
4	91	63	58	0	13
5	98	47	22	0	22
6	45	74	37	154	2
7	58	33	46	28	0
8	7	0	0	0	0
9	7	9	9	0	0
	1075	524	503	185	74

Table 3. Median Values and EMCs for Selected Parameters in the NSDQ, Version 1.0						
Parameter	Overall	Residential	Commercial	Industrial	Freeways	Open Space
Area (acres)	56	57.3	38.8	39	1.6	73.5
% Imperv.	54.3	37	83	75	80	2
Precip. Depth (in)	0.47	0.46	0.39	0.49	0.54	0.48
TSS (mg/L)	58	48	43	77	99	51
BOD5 (mg/L)	8.6	9	11.9	9	8	4.2
COD (mg/L)	53	55	63	60	100	21
Fecal Coliform (mpn/100 mL)	5081	7750	4500	2500	1700	3100
NH3 (mg/L)	0.44	0.31	0.5	0.5	1.07	0.3
N02+NO3 (mg/L)	0.6	0.6	0.6	0.7	0.3	0.6
Nitrogen, Total Kjeldahl (mg/L)	1.4	1.4	1.6	1.4	2	0.6
Phos., filtered (mg/L)	0.12	0.17	0.11	0.11	0.2	0.08
Phos., total (mg/L)	0.27	0.3	0.22	0.26	0.25	0.25
Cd, total (ug/L)	1	0.5	0.9	2	1	0.5
Cd, filtered (ug/L)	0.5	ND	0.3	0.6	0.68	ND
Cu, total (ug/L)	16	12	17	22	35	5.3
Cu, filtered (ug/L)	8	7	7.6	8	10.9	ND
Pb, total (ug/L)	16	12	18	25	25	5
Pb, filtered (ug/L)	3	3	5	5	1.8	ND
Ni, total (ug/l)	8	5.4	7	16	9	ND
Ni, filtered (ug/L)	4	2	3	5	4	ND
Zn, total (ug/L)	116	73	150	210	200	39
Zn, filtered (ug/L)	52	33	59	112	51	ND
ND = not detected, or insufficient data to present as a median value.						

1. Notable observations for different major land use categories include the following:

    - Preliminary statistical analyses found significant differences among land use categories for all pollutants (Figure 2). 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).

    - Freeway locations generally had the highest median values, except for phosphorus, nitrates, fecal coliforms, and zinc.

    - The industrial sites had the highest reported zinc concentrations.

    - The Total Kjeldahl Nitrogen (TKN), copper, lead, and zinc observations are lowest for open space areas.

2. Comparison of select NURP (1983) and NSQD data (Table 4) reveals the following interesting observations:

    - Lead concentrations, as expected, have dropped by an order of magnitude over the last 20 years, largely assumed to be the result of instituting unleaded gasoline regulations.

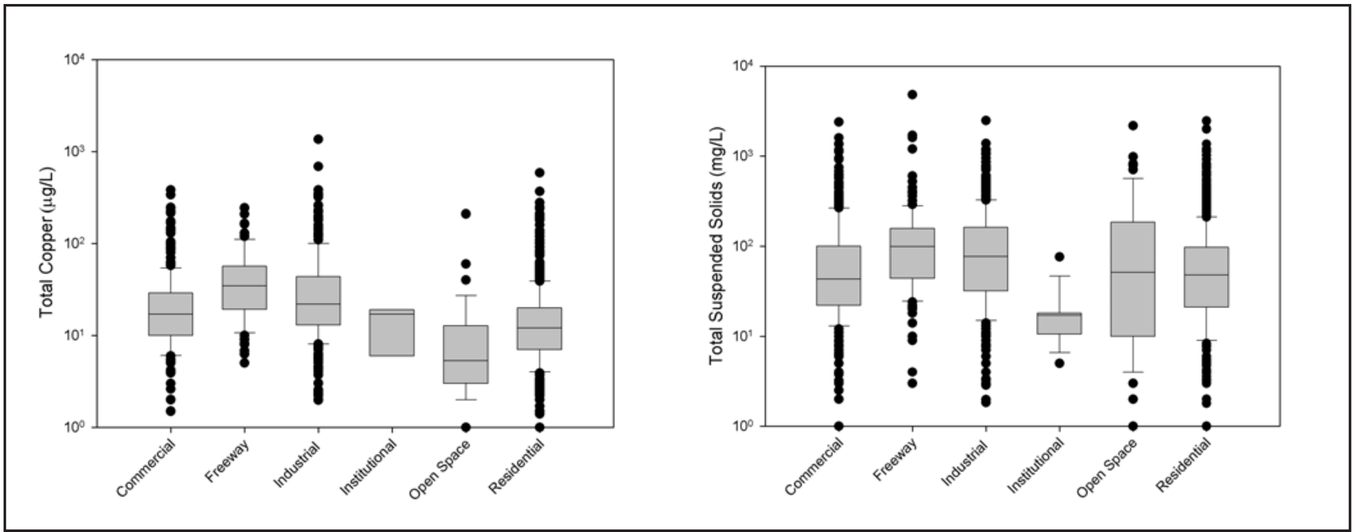

Figure 2. Example plots showing variations in pollutant concentrations between land uses.

Table 4. Comparison of NURP and NSQD Data								
	Overall		Residential		Commercial		Open Space	
Parameter	NSQD Median	NURP Median	NSQD Median	NURP Median	NSQD Median	NURP Median	NSQD Median	NURP Median
Area (Acres)	56	68.5	57.3	57.5	38.8	27.5	73.5	3,775
BOD5 (mg/L)	8.6	9	9	10	11.9	9.3	NA	NA
COD (mg/L)	53	65	55	73	63	57	21	40
TSS (mg/L)	58	100	48	101	43	69	51	70
Pb, total (ug/L)	16	144	12	144	18	104	5	30
Cu, total (ug/L)	16	34	12	33	17	29	NA	NA
Zn, total (ug/L)	116	160	73	135	150	226	39	195
Nitrogen, Total Kjeldahl (mg/L)	1.4	1.5	1.4	1.9	1.6	1.18	0.6	0.97
N02+NO3 (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

- Sediment and heavy metal concentrations appear to have declined across all land uses. Further analysis is required to determine whether the decline is statistically significant. Reasons for the decline may be related to sample collection locations.

- Nutrient concentrations are relatively similar between the two data sets.

3. Table 5 summarizes selected PAH and pesticide data. These pollutants were only monitored for a few hundred storm events, so only an overall summary is included. The percentage of samples with observable concentrations of these constituents ranged from 15 to 35% (common for these pollutants), suggesting the importance of selecting appropriate analytical techniques with sufficiently low method detection limits (MDLs)[1].

4. A preliminary review of seasonal variations for residential data revealed few apparent seasonal trends, except that bacteria values appear to be lowest during the winter season and highest during the summer and fall (a similar finding was reported during the NURP data evaluations) (Figure 3).

5. Residential area data were also analyzed across the different EPA rain zones for the country (Figure 4). The wettest areas of the country (Southeast and Northwest) may have the lowest EMCs for some stormwater pollutants. This may be due to the reduced inter-event times for pollutant buildup and greater runoff for dilution.

Table 5. Summary of Selected Organic Information

	Methylene - chloride (ug/L)	Bis (2-ethylhexyl) phthalate (ug/L)	Di-n-butyl phthalate (ug/L)	Fluor-anthene (ug/L)	Phen-anthrene (ug/L)	Pyrene (ug/L)	Diazinon (ug/L)	2, 4-D (ug/L)
Number of observations	251	250	93	259	233	249	79	101
% of samples above detection	36	30	16	19	13	14	22	35
Median of detected values	**11.2**	**9.5**	**0.8**	**6**	**3.95**	**5.2**	**0.06**	**3**
Coefficient of variation	0.77	1.13	1.03	1.31	1.00	1.24	1.9	0.86

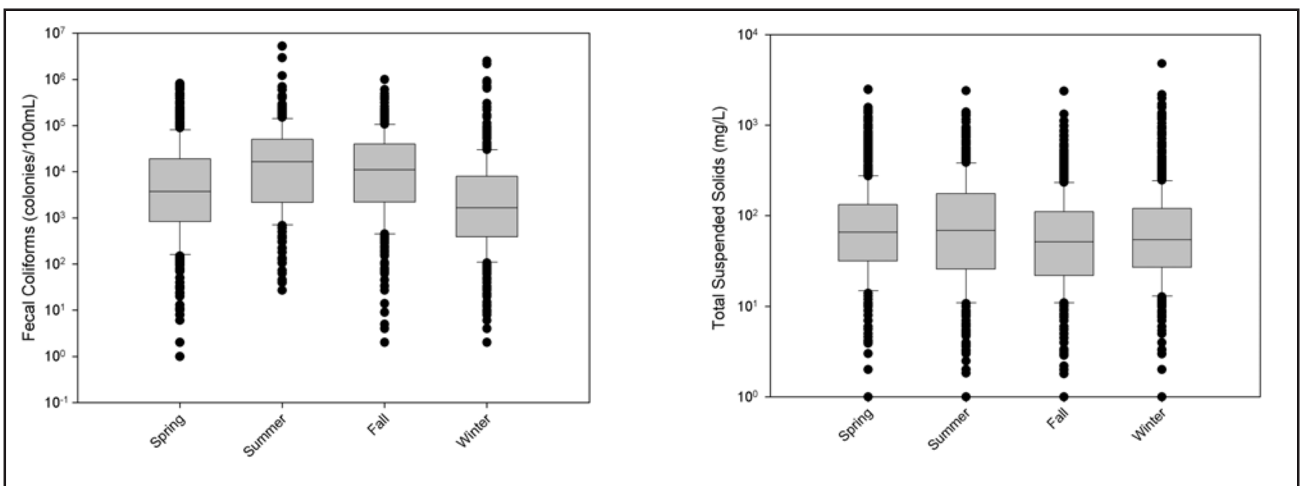

Figure 3. Plots of seasonal variations of residential TSS and fecal coliform observations.

[1] There are many important factors that must be considered when selecting an analytical method (availability, cost, detection limit, repeatability, safety and disposal problems, comparisons with historical data, etc.), but the detection limit is likely most important when ensuring the suitability of the data. Analytical methods with detection limits larger than a criterion value are of little use when determining accurate exceedence frequencies (Burton and Pitt 2001).

6. Analysis of scatter plots of common pollutants such as suspended solids, phosphorus, fecal coliforms, and total zinc concentrations for different rain depths show little variation when all of the data are combined, implying there is no strong "first flush[2]" effect at stormwater outfall locations (Figure 5). To explore this further, a more rigorous analysis was conducted using paired first flush and total storm composite data from Region 4 communities (Maestre *et al.*, in press).

   Results of this analysis indicated that the median concentrations of the first flush data set were 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. First flushes were experienced by approximately 70% of the constituents in the commercial land use category, approximately 60% of the constituents in the residential, institutional and the mixed (mostly commercial and residential) land use categories, and approximately 45% of the constituents in the industrial land use category. 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. The conflict with TKN and total N implies that there may be some other factors involved in the identification of first flushes besides land use.

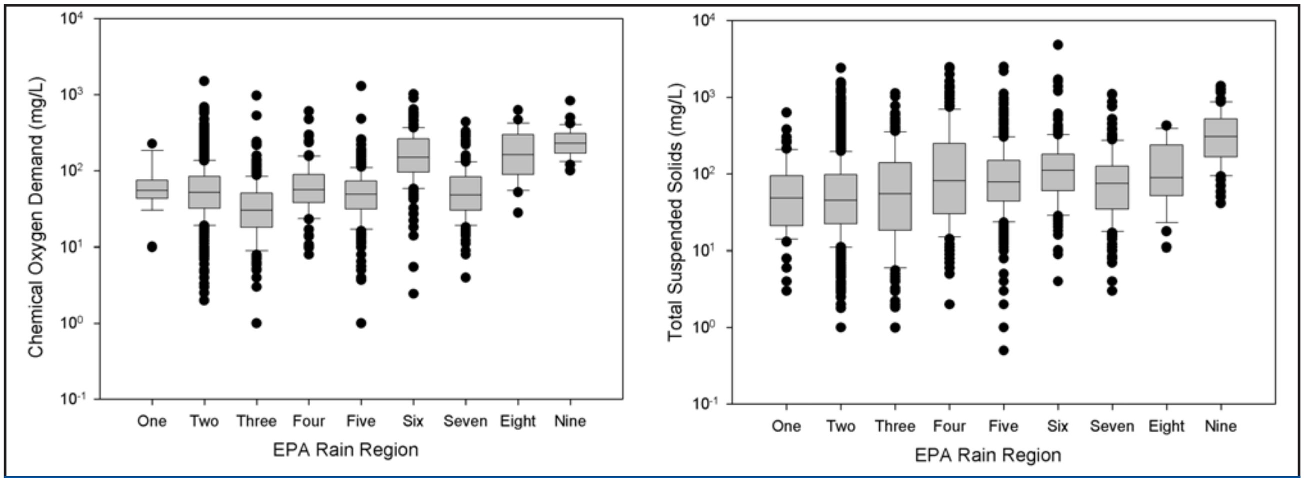

Figure 4. Plots of residential TSS and COD observations for different EPA Rain Zones.

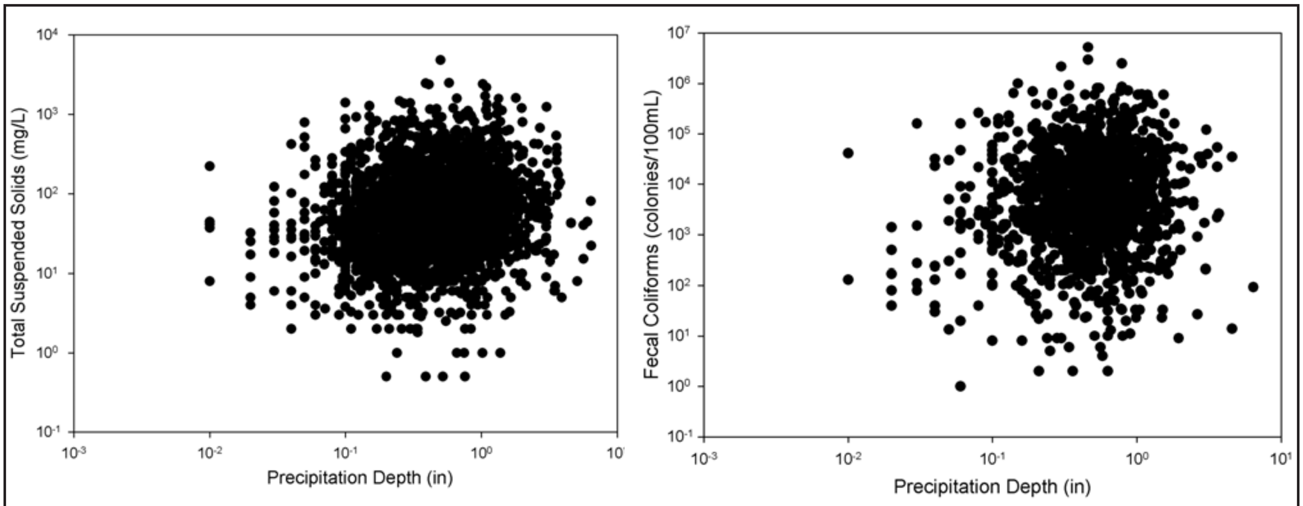

Figure 5. Example scatterplots of TSS and fecal coliform observations showing no relationship with rain depth.

[2] *First flush refers to an assumed elevated load of pollutants discharged in the first part of a runoff event.*

Conclusions

The current information contained in the NSQD indicates the value that a completed database (containing most of the NPDES Phase I stormwater data) can provide. The excellent U.S. national coverage, along with the broad representation of land uses, seasons, and other factors, makes this information highly valuable for numerous basic stormwater management needs. Important conclusions drawn from the analyses to date include the following:

- Expanding the current NSQD with additional available Phase I NPDES data sets would allow more statistically significant findings about the effect of land use, climate, drainage area, and seasonal factors on pollutant concentrations. The enhanced database would give watershed and stormwater managers greater confidence to develop regional pollutant loading calculations and permit requirements.

- Communities that have not initiated a stormwater monitoring program (such as the Phase II NPDES communities) may not require general characterization monitoring (this is not required as part of the Phase II regulations), if they can identify a regional Phase I community that has compiled extensive monitoring data as part of their required NPDES stormwater permit.

- Monitoring with no specific objective, except for general characterization of runoff, is not likely to provide any additional value beyond the data and information contained in an expanded NSQD. After a sufficient amount of data have been collected by a Phase I community for representative land uses and other conditions, outfall characterization monitoring resources could be effectively redirected to other specific data collection and evaluation needs such as the following:

  – Receiving water monitoring to understand beneficial use impairments and develop assimilative capacity calculations (i.e., TMDLs).

  – Source area monitoring to identify critical pollutant sources within a specific drainage area.

  – Treatability tests to verify performance of stormwater controls (both structural and nonstructural) for local conditions.

  – Trend monitoring to determine long-term system response to both adverse conditions and mitigation measures.

- Having statistically significant data sets at regional, seasonal, and land use levels enables modelers to use the information for more sensitive calibration of models that may be used for pollutant load allocations. Similarly, appropriate discretization of the data would assist stormwater engineers in the design of better performing treatment practices that address specific rainfall/runoff conditions.

- Where additional monitoring is warranted, the NSQD can be useful when selecting analytical methods and associated MDLs. MDL objectives should generally be about 0.25, or less, of the median value for sample sets having typical concentration variations (COV values ranging from 0.5 to 1.25). Table 6 lists the typical median stormwater runoff constituent concentrations and the associated calculated MDL goals for a typical stormwater monitoring project. Using analytical methods with these detection limits will at least result in relatively few “non-detected” values.

- The initial investigation of the first flush effect indicated that this effect did not occur for all land uses and pollutants, but is more likely for the more heavily developed land uses and for selected constituents. This suggests that it can be important to capture and treat more than just the initial portion of runoff from a site and that stormwater water quality criteria should account for this observation.

· It is important that NPDES monitoring efforts properly report basic catchment information. Of particular note is the general lack of catchment data such as land use, impervious cover and runoff volume. The lack of this information limits the analysis that can be conducted with the NSQD to provide more insight into the key factors that affect pollutant concentrations and loadings. For example, the current database has insufficient information to fully explore the relationship between catchment imperviousness or slope and stormwater EMCs.

Table 6. Example MDL Objectives for a Stormwater Characterization Project

Constituent	Units	Typical COV category[1]	Typical Median Conc.	Estimated MDL Goal
turbidity	NTU	low	5	4
COD	mg/L	medium	50	12
suspended solids	mg/L	medium	50	12
nitrates	mg/L	low	0.6	0.4
chromium	µg/L	medium	7	1.5
copper	µg/L	medium	15	3.5
lead	µg/L	medium	15	3.5
nickel	µg/L	medium	10	2.3
zinc	µg/L	medium	100	23
1,3-dichlorobenzene	µg/L	medium	10	2
benzo(a) anthracene	µg/L	medium	30	8
bis(2-ethylhexyl) phthalate	µg/L	medium	10	2.3
butyl benzyl phthalate	µg/L	medium	15	3
fluoranthene	µg/L	medium	6	1.4
pentachlorophenol	µg/L	medium	10	2
pyrene	µg/L	medium	5	1
lindane and chlordane	µg/L	medium	1	0.2

[1] *COV Value*	*Multiplier for MDL*
<0.5 (low)	*0.8*
0.5 to 1.25 (medium)	*0.23*
>1.25 (high)	*0.12*

from: Burton and Pitt 2001

Future Direction

The remaining six months of this grant project will be devoted to more rigorous statistical analyses that have implications for the way stormwater program managers and regulators structure Phase I and Phase II NPDES MS4 permits. The database is currently available to the public for download and analysis at the following web site: http://www.eng.ua.edu/~rpitt/Research/ms4/mainms4.shtml. In addition to the statistical analyses, community profiles are being developed for each jurisdiction in the database summarizing the station locations, sampling and analytical methods, sampling and analytical obstacles, and other information.

Even with the substantial size and coverage of the existing NSQD database, it is clear that additional data gathering and analysis would offer more widespread application. In particular, there is a need to fill in data gaps from the Midwest, New England, and northern west central states, as well as for some land uses, such as freeways. There is also a need to promote the database and to encourage future monitoring efforts that can be easily appended to the existing database and will help developing more statistically robust findings about urban runoff characteristics.

References

Burton, G.A. Jr., and R. Pitt, *Stormwater Effects Handbook: A Tool Box for Watershed Managers, Scientists, and Engineers*. CRC Press, Inc., Boca Raton, FL. 911 pgs. 2002.

Maestre, A., Pitt, R. E., and R. Morquecho. "Nonparametric statistical tests comparing first flush with composite samples from the NPDES Phase 1 municipal stormwater monitoring data." *Stormwater and Urban Water Systems Modeling*. In: *Models and Applications to Urban Water Systems,* Vol. 12 (edited by W. James). CHI. Guelph, Ontario, forthcoming 2004.

Pitt, R. Maestre A., Morquecho R. "The National Stormwater Quality Database (NSQD, version 1.0)" Water Environment Federation Technical Exposition and Conference, Los Angeles. October, 2003.

U.S. Environmental Protection Agency, Dec. *Results of the Nationwide Urban Runoff Program*. Water Planning Division, PB 84-185552, Washington, D.C. 1983.

prepared by:

CENTER FOR WATERSHED PROTECTION

http://www.cwp.org