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EVALUATION OF NPDES PHASE 1 MUNICIPAL STORMWATER MONITORING DATA

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Abstract

The University of Alabama and the Center for Watershed Protection were awarded an EPA Office of Water 104(b)3 grant in 2001 to collect and evaluate stormwater data from a representative number of NPDES MS4 municipal stormwater permit holders. The data is being collected and reviewed to both describe the characteristics of this data and to provide guidance to permit writers for future sampling needs.

There have been serious concerns about the reliability and utility of Phase 1 stormwater NPDES monitoring data, mainly due to the wide variety of experimental designs, sampling procedures, and analytical techniques used. On the other hand, the cumulative value of the monitoring data collected over almost a ten year period from more than 200 municipalities from throughout the country has a great potential value in characterizing the quality of stormwater runoff and comparing it against historical benchmarks. This project is creating a national database of Phase 1 stormwater monitoring data, providing a scientific analysis of the data, and providing recommendations for improving the quality and management value of future NPDES monitoring efforts.

Each data set will receive quality assurance/quality control review, based on reasonableness of data, extreme values, relationships among parameters, sampling methods, and a review of the analytical methods. The statistical analyses will be conducted at several levels. Probability plots will be used to identify range, randomness and normality. Clustering and principal components analysis will also be utilized to characterize significant factors affecting the data. The master data set will also be evaluated to develop descriptive statistics, such as measures of central tendency and standard errors. We will test for regional and climatic differences, the influence of land use, the effect of storm size and season, among other factors.

This paper describes our data collected to date and presents some preliminary data summaries, including comparisons with other stormwater data sets. An example site description is also presented. We have been collecting much data to date, and would like to encourage any other communities having wet weather outfall data collected as part of their NPDES permit program to contact us so we can include as much data as possible in our final effort.

Project Description and Background

The importance of this project is based on the scarcity of summarized and accessible data from the existing NPDES stormwater permit program. As an example, the 1983 NURP data base is still used as the primary source for stormwater data in the US., although substantial stormwater data has been collected nationwide since that time.

This project is collecting stormwater runoff data from existing NPDES permit applications and permit monitoring reports; we are conducting QA/QC evaluations of these data; and statistical analyses and summaries of these data. The final information will be published on the Internet (such as on an EPA OW-OWM site and on the Center for Watershed Protection's SMRC site).

The phase 1 NPDES communities included areas where:

- A stormwater discharge from a municipal separate storm sewer system serving a population of 250,000 or more (large system), or
- A stormwater discharge from a municipal separate storm sewer system serving a population of 100,000 or more, but less than 250,000 (medium system)

More than 200 municipalities, plus numerous additional special districts and governmental agencies were included in this program. Part 2 of the NPDES discharge permit application specified that sampling was needed and that the following was to be included in the application:

- Proposed monitoring program for representative data collection during the term of the permit.
- Quantitative data from 5 to 10 representative locations,
- Estimates of the annual pollutant load and event mean concentration (EMC) of system discharges,
- Proposed schedule to provide estimates of seasonal pollutant loads and the EMC for certain detected constituents during the term of the permit.

The permit applications were due in 1992 and 1993. For Part 2 of the application, municipalities were to submit grab (for certain pollutants) and flow-weighted sampling data from selected sites (5 to 10 outfalls) for 3 representative storm events at least 1 month apart. In addition, the municipalities must have also developed programs for future sampling activities that specified sampling locations, frequency, pollutants to be analyzed, and sampling equipment. Numerous constituents were to be analyzed, including typical conventional pollutants (TSS, TDS, COD, BOD_5, oil and grease, fecal coliforms, fecal strep., pH, Cl, TKN, NO_3, TP, and PO_4), plus many heavy metals (including total forms of arsenic, chromium, copper, lead, mercury, and zinc, plus others), and numerous listed organic toxicants (including PAHs, pesticides, and PCBs). Therefore, there has been a substantial amount of data that has been collected during the past 7 or 8 years from throughout the country. Most of these data are currently not readily available.

Description of Data Collection Efforts to Date

As of mid-October, 2002, data from 32 municipalities and 9 states have been collected and entered into our database. These are listed in Table 1. Most of these are located in the Chesapeake Bay region and in the southeast, the initially targeted areas for our project. However, some additional data has been gathered at this time from other areas (such as Minneapolis, MN). Table 2 lists the 17 additional states where municipalities have been contacted and that are preparing data submittals. Figure 1 shows the locations of these municipalities on a national map. We anticipate excellent national coverage with our database, although we may have few represented municipalities from the western northern tier states (where cities are generally small, and few were included in the Phase 1 program).

Table 1. Municipalities whose Data has been Entered into Database

ALABAMA	MARYLAND	MINNESOTA	VIRGINIA
Jefferson County	Anne Arundel County	Minneapolis	Arlington County
	Baltimore		Chesapeake
GEORGIA	Baltimore County	**NORTH CAROLINA**	Chesterfield County
Atlanta	Carroll County	Greensboro	Fairfax County
Cobb County	Harford County		Hampton
DeKalb County	Howard County	**PENNSYLVANIA**	Henrico County
Fulton County	Montgomery County	Philadelphia	Newport News
Gwinnette County	Prince George's County		Norfolk
	Charles County	**TENNESSEE**	Portsmouth
KENTUCKY		Knoxville	Virginia Beach
Louisville		Memphis	
Lexington			

Table 2. States Where Other Communities are Still Preparing Data for Submittal

Arizona	**California**	**Colorado**	**Hawaii**	**Idaho**
Indiana	**Iowa**	**Kansas**	**Louisiana**	**Massachusetts**
Michigan	**Mississippi**	**Missouri**	**Nevada**	**Ohio**
Texas	**Utah**			

We also have a number of additional municipalities to contact and discuss data availability. However, some of the municipalities that we have contacted (and some where we actually received data) have data that could not be used for various reasons. One of the most common reasons for rejecting the data for our database was that the samples were collected from receiving waters. We are only collecting data from well-described outfall locations. These can be open channels in completely developed areas, but are more commonly conventional outfall pipes. The other major problem is that the sampling locations and/or the drainage areas were not described. We are using data with some missing information for now, with the intention of obtaining the needed information later during interviews. However, there will likely still be some minor data gaps that we will not be able to fill. In addition, the list of constituents being monitored has varied for different locations. Most all areas evaluated the common stormwater constituents, but few have included organic toxicants. The most serious gap is the common lack of runoff volume data, although all sites have included rain data. Finally, if we collect all the data we have asked for, our current project resources will not permit us to fully utilize them, as it requires a great deal of time to enter and review this information.

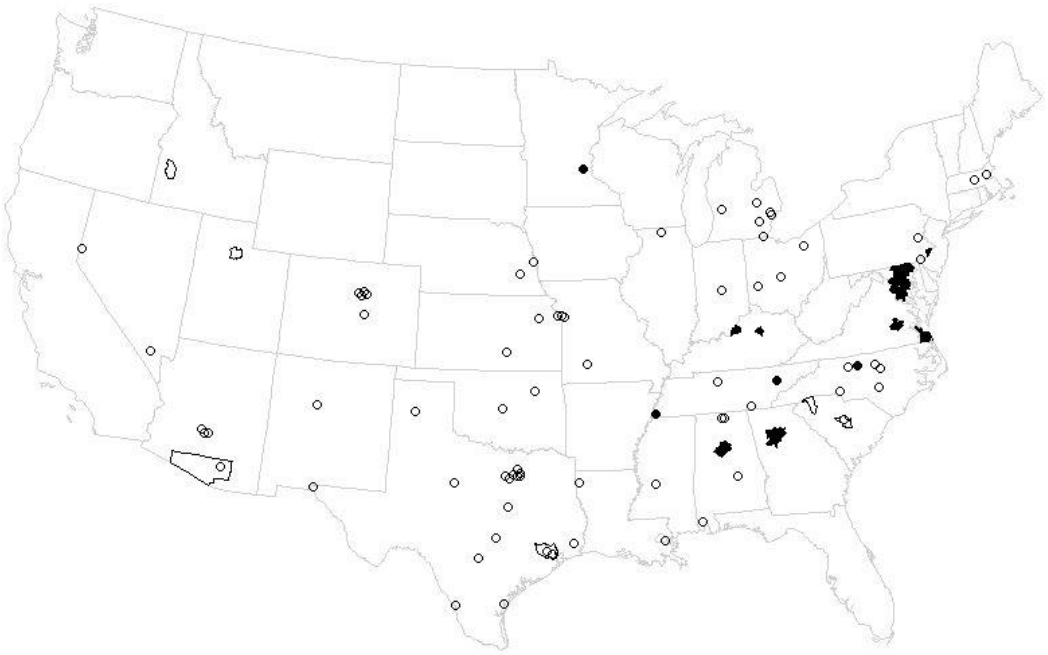

Figure 1. Data has been obtained and entered in our database for the communities shown in black. The other communities shown have been contacted and we are waiting their information (plus Southern California and Hawaiian communities).

Preliminary Results and Conclusions

The assembled data has been entered into a database which contains site descriptions (state, municipality, land use components, and EPA rain zone), sampling information (date, season, rain depth, runoff depth), and constituent measurements (concentrations, grouped in categories). In addition, more detailed site, sampling, and analysis information has been collected for each sampling site and included as supplemental information.

The following is an example of the supplemental description information assembled for the Clayton County, Georgia, sampling locations. The initial part shows information for the four sampling locations in the county from supplied data, followed by more detailed data for one of the sites. This example shows the aerial photographs and maps we have collected from various sources to complement the site data supplied by the county.

Site Description Example for Clayton County, Georgia

Clayton County participates with the Atlanta Region Storm Water Management Task Force in a regional stormwater sampling program.

South Ridge Industrial Park

This area is 100% industrial and is located off Sullivan Road in the north eastern corner of the county. This industrial park is near Hartsfield International Airport and is representative of the development in this area. Many of the businesses are cargo warehouse facilities. The sampling point is at the discharge of a 48 in. coated metal corrugated pipe which passes under a driveway from Southridge Parkway. The small stream is

a tributary of Sullivan reek and flows intermittently during wet periods draining a basin of approximately 18 acres.

The Southridge site was sampled between May 1995 and March 2000. Two sigma 800SL automatic samplers with integral flow meters were used by Clayton County for their sampling program. Tipping-bucket rain gauges interfaced with the sampling units were also used. This equipment was placed in the field when a storm event was anticipated and set to begin sampling when 0.1 in of rain had fallen and the flow level in the pipe increased by 0.5 in. The sampler was programmed for time discrete samples, collecting a 250 mL sample aliquot every ten minutes for a four hour period. One dry-weather grab sample was also acquired during each dry season (May through October) and wet season (November through April).

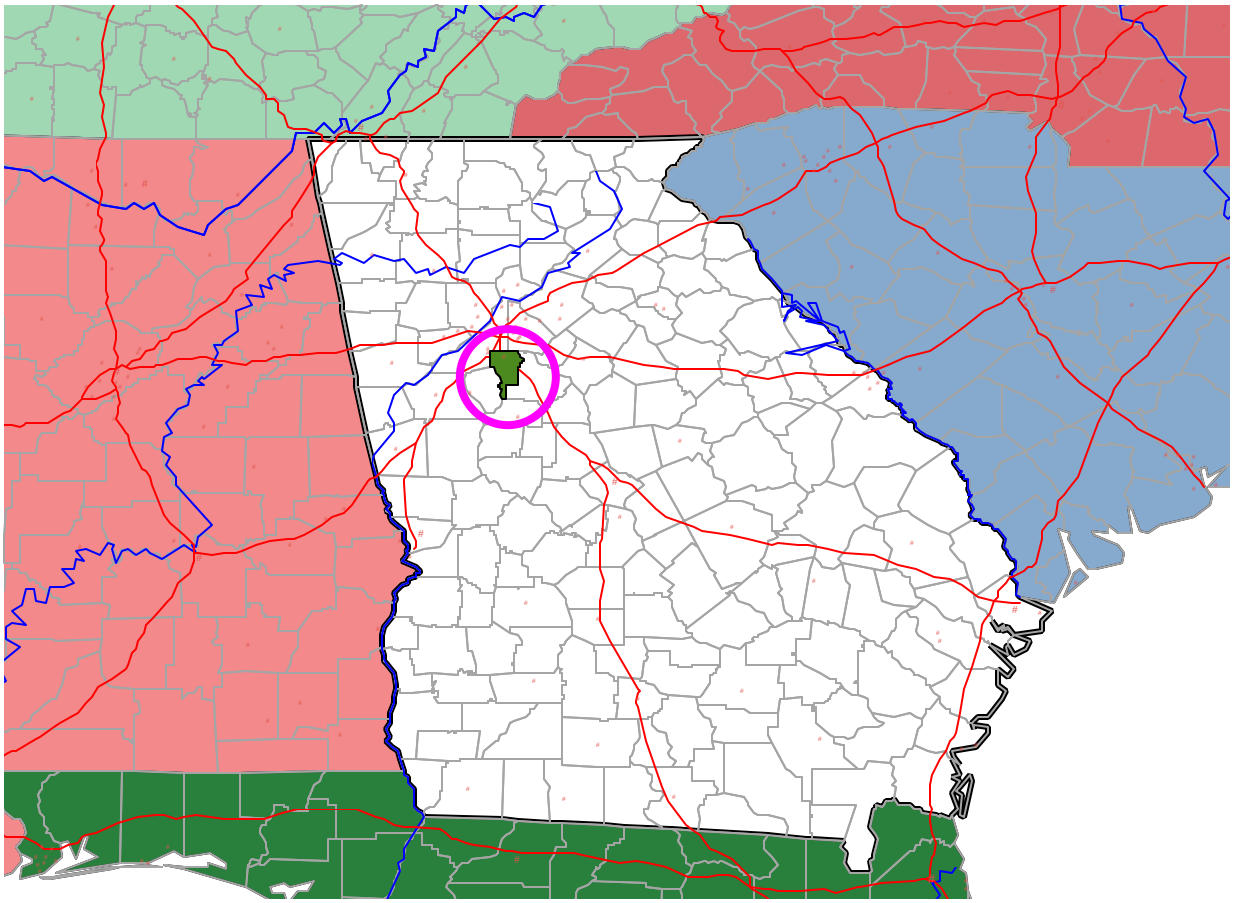

Figure 2. Location map showing Clayton County in Georgia.

Table 3. Land Use for each Drainage Area

	Tara Road	South Ridge	Lee Mill Road	North Bridge
Residential	100	0	0	X[1]
Commercial	0	0	0	0
Industrial	0	100	100	X
Construction	0	0	0	0
Undeveloped	0	0	0	0
Area (Acres)	125	18	--	--

[1] North Bridge was reported to contain both residential and industrial areas, but the breakdown and total area was not supplied. We will obtain this information during follow-up interviews.

Table 4. Constituents Analyzed and Numbers of Samples

Constituent	Tara Road	Southridge	Lee's Mill	Northbridge
Precipitation	21	21	3	3
Runoff	15	15	3	3
pH			3	3
Temperature			3	3
TDS	22	22	3	3
TSS	22	22	3	3
BOD5	22	22	3	3
COD	22	22	3	3
Fecal Coliform	16	15	3	3
NO2+NO3	22	21	3	3
TKN	22	22	3	3
P Dissolved	22	22	3	3
P Total	22	22	3	3
Cadmium	22	22	3	3
Copper	22	22	3	3
Lead	22	22	3	3
Zinc	22	22	3	3

Lee's Mill and Northbridge are the current sampling locations. The Tara Road and Southridge sampling programs have ended.

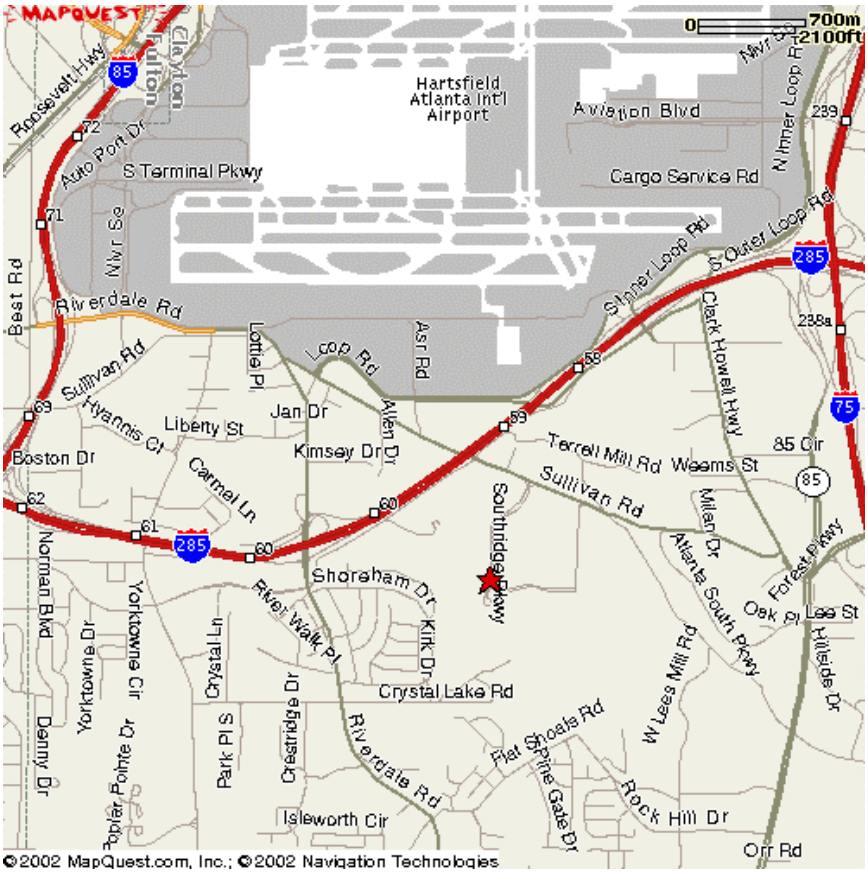

Figure 3. Street map showing sampling station location (from MapQuest.com).

Figure 4. Aerial photograph showing same area as street map (from GlobeXplorer).

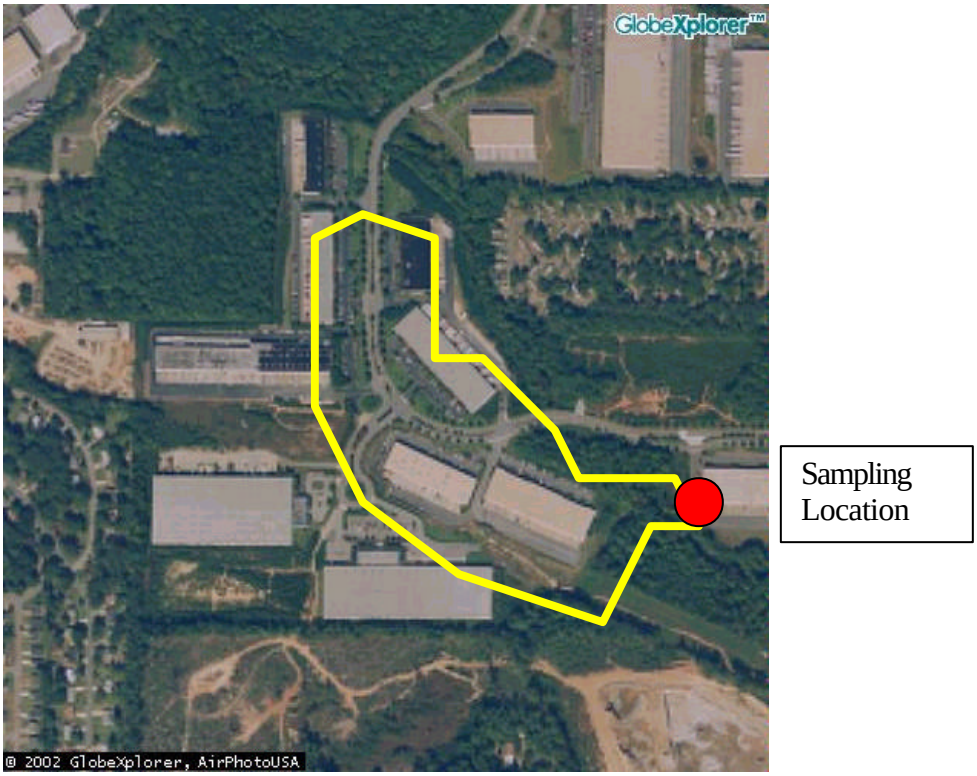

Figure 5. Enlarged aerial photograph showing 18 acre drainage area (from GlobeXplorer).

Figure 6. Higher resolution aerial photograph showing sampling area (from GlobeXplorer).

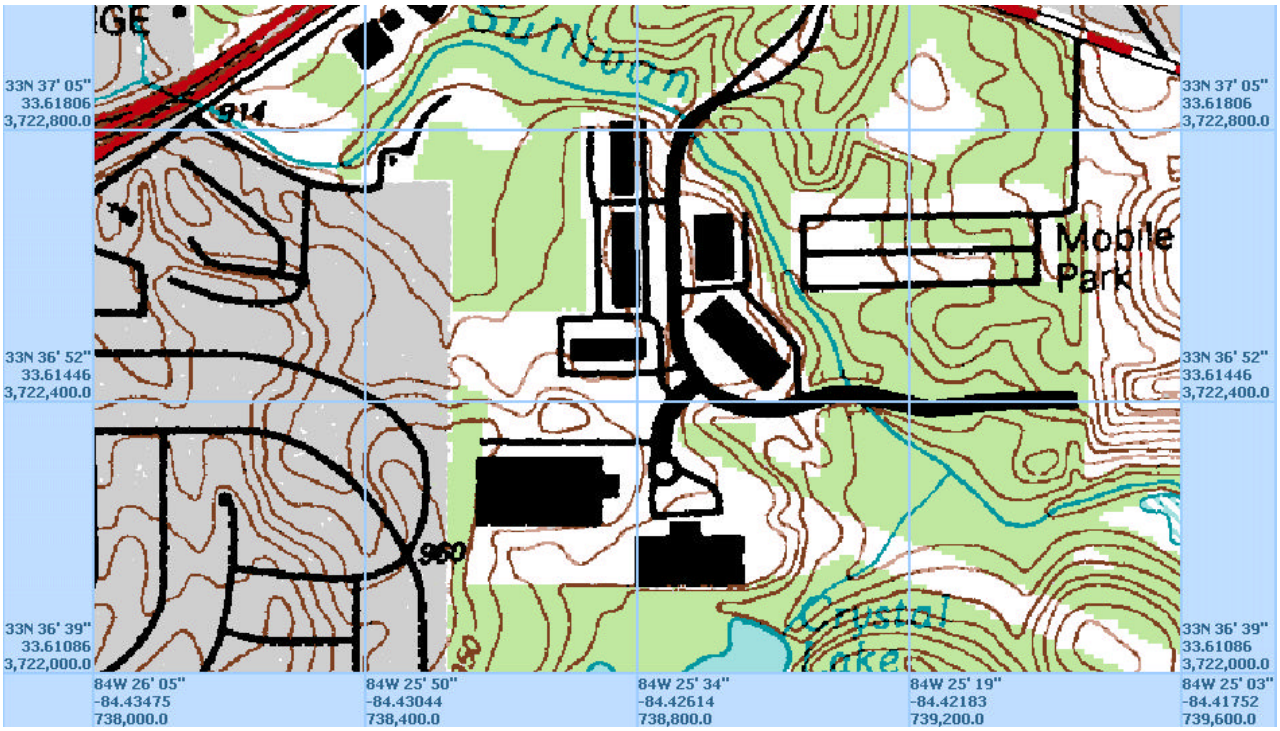

Figure 7. Topographic map showing sampling area.

Preliminary Summary of Phase 1 Stormwater Data

Table 5 is a summary of the Phase 1 data we have collected and entered into our database as of late summer 2002. This data is mostly from the Chesapeake Bay and southeastern areas of the US, as those were the areas where the data collection effort was initiated. The data was separated into four major land use categories (residential, commercial, industrial, and open space). Only data for constituents having at least 10 observations in each land use category are presented. This table includes the number of sample observations greater than the detection limit, the median, and the coefficient of variation (for data above the detection limits) for each land use category and constituent. Samples from about 800 residential area storms, 250 commercial area storms, 175 industrial area storms, and 25 open space area storms, are included on this table.

These data are only from our initial block of data and are not representative of expected national conditions, or other sampling situations. However, the large number of observations can give us an indication of the overall use of this information. We have not attempted to conduct any statistical tests with this preliminary data yet, as final quality control checks have not been completed, and we do not yet have a critical mass of data representing the expected complete database. However, it is interesting to compare this preliminary data with prior stormwater observations.

Historical Data on Stormwater Characteristics

Table 6 contains a summary of the Nationwide Urban Runoff Program (NURP) stormwater data collected from about 1979 through 1982 (EPA, 1983). The NURP data is the most comprehensive stormwater data available from throughout the nation, but was almost solely represented by medium density residential area runoff, with much less data from other areas (such as shopping centers, light industrial areas, and open space). A comparison between this older (1977-1983) NURP data and the more recent Phase 1 data (1993 to 2001) collected so far is shown in Table 6.

The preliminary Phase 1 NPDES stormwater data presented above contains no major surprises. The medians are all seen to be within ± 50% of the older NURP data, with the notable (and expected) exception for lead. The more recent lead data is about 1/10 of the older NURP data in residential areas and about 1/5 for commercial areas. The relatively large COV values indicate typically large ranges of the data for both data sets. We will explore factors that may explain some of this large variation later in the project when additional data is collected that better represents national conditions. The first comprehensive statistical analyses are scheduled to be preformed early in 2003.

Planned Data Analyses

Statistical analyses will be conducted at several levels. First, probability plots will be used to identify range, randomness, and normality. Clustering and principal components analyses (PCA) will also be utilized to characterize expected factors influencing sample variability. The master data set will also be evaluated to develop descriptive statistics, such as measures of central tendency and standard errors. The runoff data will then be evaluated to determine what factors have a strong influence on event mean concentrations, including sampling methods. We will test for regional and climatic differences, the influence of land use, and the effect of storm size, among other factors.

Table 5. Preliminary Data Summary of Municipal Stormwater Data (mostly from Chesapeake Bay area and Southeast)

	Residential			Commercial			Industrial			Open Space		
	NUMBER OF SAMPLES[1]	MEDIAN	COV[2]	NUMBER OF SAMPLES	MEDIAN	COV	NUMBER OF SAMPLES	MEDIAN	COV	NUMBER OF SAMPLES	MEDIAN	COV
Precipitation Depth (in)	74	0.52	1.0	231	0.38	1.0	166	0.50	1.9	21	0.16	0.6
Conductivity (µS/cm @25ºC)										18	166	1.2
Hardness (mg/L CaCO3)	85	32.0	1.9				22	48.0	1.2			
Oil and Grease (mg/L)	156	4.26	4.5	78	6.00	1.5	64	5.85	1.3			
pH	129	7.70	1.0	22	7.22	0.6	27	6.98	0.9			
TDS (mg/L)	587	73.0	2.4	183	71.0	2.5	119	54.0	5.2			
TSS (mg/L)	816	47.5	1.1	25	90.0	1.5	173	44.0	1.3	26	154	1.6
BOD_5 (mg/L)	778	8.00	1.5	249	12.0	1.0	161	15.0	2.0	26	8.13	1.2
COD (mg/L)	58	48.0	3.7	182	90.0	1.0	12	53.5	1.4			
Fecal Coliform (colonies/100 mL)	211	12,900	2.6	73	1,640	5.1	76	965	2.6	13	1,980	2.4
Fecal Streptococcus (colonies/100 mL)	67	12,800	2.3	28	379	2.3	25	25.0	1.7			
Ammonia (mg/L)	425	0.26	0.9	168	0.39	1.2	93	0.29	1.2			
NO_2+NO_3 (mg/L)	83	0.56	1.3	247	0.57	1.0	165	0.62	1.2	26	1.12	1.3
Nitrogen, Total (mg/L)	83	1.90	0.7									
Nitrogen, Total Kjeldahl (mg/L)	81	1.32	4.6	247	1.59	0.8	159	1.16	1.0	24	2.36	1.3
Phosphorous, Dissolved (mg/L)	489	0.13	2.1	147	0.20	2.9	97	0.12	1.7			
Phosphorous, Total (mg/L)	87	0.27	1.3	251	0.30	1.6	166	0.25	0.9	26	0.36	3.4

Table 5. Preliminary Data Summary of Municipal Stormwater Data (mostly from Chesapeake Bay area and Southeast) (cont.)

	Residential			Commercial			Industrial			Open Space		
	NUMBER OF SAMPLES[1]	MEDIAN	COV[2]	NUMBER OF SAMPLES	MEDIAN	COV	NUMBER OF SAMPLES	MEDIAN	COV	NUMBER OF SAMPLES	MEDIAN	COV
Arsenic, Total (µg/L)	79	3.00	4.9	19	3.00	0.3	22	2.25	0.3			
Beryllium, Total (µg/L)	29	0.40	2.9									
Cadmium, Total (µg/L)	26	0.50	1.6	87	1.00	1.3	51	0.40	1.1			
Chromium, Total (µg/L)	95	4.00	1.5	44	5.50	1.8	21	3.10	1.0			
Copper, Total (µg/L)	432	15.0	1.6	146	18.8	1.2	123	9.50	0.9	18	31.4	1.1
Copper, Dissolved (µg/L)	34	7.25	1.3	17	8.00	0.5	38	7.00	1.6			
Cyanide, Total (µg/L)	19	5.00	1.3				13	11.0	1.5			
Lead, Total (µg/L)	419	13.0	1.8	123	21.0	1.7	91	8.00	1.2			
Lead, Dissolved (µg/L)	16	2.75	0.9				24	4.50	0.9			
Mercury, Total (µg/L)	16	0.20	1.9									
Nickel, Total (µg/L)	74	7.15	0.9				13	9.00	0.6			
Selenium, Total (µg/L)	15	2.00	0.5									
Silver, Total (µg/L)	13	1.00	2.1									
Zinc, Total (µg/L)	548	76.0	1.8	15	170	1.3	142	130	1.3	26	99.9	1.1
Zinc, Dissolved (µg/L)	46	28.0	0.5	21	139	0.6	55	53.0	1.9			

[1] only samples above the reported detection limit and only constituents having at least 10 observations were used for this summary.
[2] COV = coefficient of variation = standard deviation/mean

Table 6. Comparison of NURP Data and Preliminary Phase 1 Data Collection

mg/L, except for metals that are µg/L		Residential		Commercial		Open Space	
Constituent	Data Source	median	COV	median	COV	median	COV
BOD_5	NURP	10	0.41	9.3	0.31	n/a	n/a
	Phase 1	8	1.5	12	1	8.1	1.2
COD	NURP	73	0.55	57	0.39	40	0.48
	Phase 1	48	3.7	90	1	n/a	n/a
TSS	NURP	101	0.96	69	0.85	70	2.92
	Phase 1	48	1.1	90	1.5	154	1.6
TKN	NURP	1.9	0.73	1.2	0.43	0.97	1
	Phase 1	1.32	4.6	1.59	0.8	2.36	1.3
NO_2+NO_3	NURP	0.74	0.83	0.57	0.48	0.54	0.91
	Phase 1	0.56	1.3	0.57	1	1.12	1.3
P	NURP	0.38	0.69	0.2	0.67	0.12	1.66
	Phase 1	0.27	1.3	0.3	1.6	0.36	3.4
P, filtered	NURP	0.14	0.46	0.08	0.71	0.026	2.11
	Phase 1	0.13	2.1	0.2	2.9	n/a	n/a
Pb	NURP	144	0.75	104	0.68	30	1.52
	Phase 1	13	1.8	21	1.7	n/a	n/a
Cu	NURP	33	0.99	29	0.81	n/a	n/a
	Phase 1	15	1.6	18.8	1.2	31.4	1.1
Zn	NURP	135	0.84	226	1.07	195	0.66
	Phase 1	76	1.8	170	1.3	100	1.1

Initial exploratory data analyses will be prepared that represent data relationships and groupings, arranged by parameter sets (solids, common parameters, bacteria, nutrients, heavy metals, and organics). This analysis will consist mainly of probability plots and grouped box plots, plus error analyses:

- simple statistical summaries of data (such as presented in Table 5, but expanded as more constituents become available, plus tables of selected probability values)
- probability plots and grouped box and whisker plots examining residential, commercial, industrial, and open space data, separated by season, and EPA rainfall zone.
- associated nonparametric comparison tests to quantify differences between all categories of data.

More complex correlation analyses and model building will also be conducted, including:

- simple correlation analyses (mainly Pearson correlation matrices and associated scatter plots),
- complex correlation analyses (mainly cluster and principal component analyses), and
- model building (based on factorial analyses of the most important factors)

The goal of these analyses will be to provide guidance to stormwater managers and regulators. Especially important will be the use of this data as an updated benchmark for comparison with locally collected data. In addition, this data may be useful for preliminary calculations when using the "simple method" for predicting mass discharges for unmonitored areas. This data can also be used as guidance when designing local stormwater monitoring programs (Burton and Pitt, 2001), especially when determining the needed sampling effort based on expected variations.

As we are still collecting information for the database, we would like to encourage all local and state agencies who have Phase 1 municipal stormwater data, that have not previously been sent to us, to please contact us so we can arrange to have your data included in our analyses.

References

Burton, G.A. Jr., and R. Pitt, August 2001. *Stormwater Effects Handbook: A Tool Box for Watershed Managers, Scientists, and Engineers*. CRC Press, Inc., Boca Raton, FL. 911 pgs.

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Acknowledgements

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508 Compliance

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Figure 1. Data has been obtained and entered in our database for the communities shown in black. The other communities shown have been contacted and we are waiting their information (plus Southern California and Hawaiian communities).
Figure 1 shows the locations of these municipalities on a national map.

Figure 2. Location map showing Clayton County in Georgia.

Table 3. Land Use for each Drainage Area
Table showing the land use breakdowns for each Clayton County sampling area.

Table 4. Constituents Analyzed and Numbers of Samples
Sampling effort and constituents analyzed for each Clayton County sampling location. 3 to 22 storms have been sampled at each location. The new sampling locations will eventually have more samples.

Figure 3. Street map showing sampling station location (from MapQuest.com).
Sampling location south of Hartsfield Atlanta International Airport.

Figure 4. Aerial photograph showing same area as street map (from GlobeXplorer).
Large warehouses are clearly shown on the map for the surrounding area.

Figure 5. Enlarged aerial photograph showing 18 acre drainage area (from GlobeXplorer).
The sampled drainage area contains 4 large warehouses and surrounding area.

Figure 6. Higher resolution aerial photograph showing sampling area (from GlobeXplorer).

Figure 7. Topographic map showing sampling area.
The location of Sullivan Creek and small lakes are shown, along with the site topography.

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