ANALYSIS OF URBAN STORM-WATER RUNOFF CHARACTERISTICS OF FOUR BASINS IN THE BALTIMORE METROPOLITAN AREA, MARYLAND

By Gary T. Fisher and Brian G. Katz

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CONVERSION OF MEASUREMENT UNITS

The following factors may be used to convert the inch-pound units published in this report to the International System (SI) of metric units.

To convert from	Multiply by	To obtain
	Length	
inch (in)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
pound (lb)	0.4536	kilogram (kg)
	Miscellaneous	
pound per acre (lb/acre)	0.000112	kilogram per square meter (kg/m^2)
pound per acre per inch of runoff {(lb/acre)/in}	4.415	milligram per liter (mg/L)

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ABSTRACT

Event-mean concentrations of eight constituents exceed selected water-quality criteria most of the time in a study of urban storm-water runoff in the Jones Falls watershed in Baltimore, Maryland. There are statistically significant (greater than 0.95 level) differences among three small high-density residential catchment sites (10.5 to 16.9 acres) for event-mean concentrations of total Kjeldahl nitrogen, total phosphorus, total copper, total lead, and total zinc. There are no significant differences among the small catchment sites for total suspended solids, chemical oxygen demand, or total organic carbon. At a main-stem site near the mouth (59.0 mi^2), urban storm-water runoff contributes more than 60 percent of the total annual load of total Kjeldahl nitrogen, total phosphorus, and total organic carbon, more than 70 percent of chemical oxygen demand, and more than 80 percent of total suspended solids, total lead, and total zinc. Inadvertent detention storage is being provided in one of the small catchments and affects water quantity and quality. Evidence suggests that accumulated trash on the paved surfaces of the catchment may be the source of this detention.

Data have been collected, verified, and entered into the U.S. Geological Survey data base for 65 station-storms sampled during 36 separate storms over a 16-month period.

INTRODUCTION

As mandated by the 1972 Federal Water Pollution Control Act and the 1977 revisions to this act, the quality of the Nation's water is to be suitable for aquatic life and contact recreation by 1985. Under this mandate, the Baltimore Regional Planning Council made a "208" planning study for the Baltimore region, which includes the Jones Falls watershed. In 1978, it collected some water-quality and quantity data on storm-water runoff from small watersheds having varied land uses (agricultural to high-density residential) and from wet- and dry-weather sampling of the main stem of Jones Falls and selected tributaries (Baltimore Regional Planning Council, written commun., 1980). The major water-quality problem identified in Jones Falls by that study was the presence of high contaminant loadings of metals, bacteria, and nutrients, which are released into Baltimore Harbor. The "208" study concluded that the major contributors to degradation of the water quality of Jones Falls and Baltimore Harbor are (1) urban storm-water runoff, (2) legal and illegal industrial or commercial discharges, and (3) permitted overflows and unknown connections from industrial and domestic sanitary sewers. However, in a national review of the "208" program, it was concluded by Shelley and Driscoll (1979) that the program generally was inadequate in providing an understanding of urban storm-water runoff quality. To gain a better understanding of urban runoff, the U.S. Environmental Protection Agency (USEPA) began the Nationwide Urban Runoff Program (NURP). This program established 28 projects to collect and analyze a national data base specifically devoted to urban hydrologic data. The U.S. Geological Survey has coordinated its own urban hydrology activities with NURP and has participated directly in 12 of the studies through its cooperative program.

Purpose and Scope

This report describes the analysis and interpretation of data collected over a 2-year period at four sites in an urban watershed of Baltimore, Md. The Jones Falls Urban Runoff Project, one of 28 NURP projects, was a cooperative effort of the Baltimore Regional Planning Council, Baltimore City, Baltimore County, and the U.S. Geological Survey to determine the quantity and quality of urban runoff. The Jones Falls project was one of the most comprehensive studies of urban hydrology for a city of Baltimore's size. It was also the only one of the NURP studies to investigate highly urbanized, inner-city areas.

Specific objectives have been to determine the impact of urban storm-water runoff on water quality and to study the influence of storm (rainfall and runoff) and basin characteristics on storm-water quality. For purposes of this report, the impact of urban storm-water runoff is evaluated relative to water-quality criteria that reflect the suitability of water for man's use (economic or aesthetic). The study of the influence of storm and basin characteristics is important to formulating models of the urban hydrologic system to aid in the management of water-quality problems.

The collection, analysis, and interpretation of urban storm-water runoff data have many unique elements. Two reports have presented methodologies applicable to the collection and analysis of urban data (Alley, 1977; Kibler, 1982). Methodologies similar to those in the reports were established for NURP. Deviations from the general NURP methodology necessary to meet local needs and conditions are discussed or referenced. Particular emphasis is placed on quality assurance in this report because the credibility and validity of conclusions depend upon it.

Acknowledgments

The cooperation of the Baltimore Regional Planning Council, Baltimore City, and Baltimore County is gratefully acknowledged. The authors would like to express their appreciation to the many U.S. Geological Survey employees who assisted in the project under very difficult field conditions, most notably Robert James, Bernard Helinsky, and John Hornlein for the installation of equipment in sewers. In particular, the significant contribution of George Noah is acknowledged for his diligence and dedication in equipment maintenance and storm sampling.

PROJECT DESCRIPTION

Study Area

The Jones Falls watershed, part of the Patapsco River basin, encompasses 59 mi^2 of Baltimore City and rural sections of Baltimore County (fig. 1). The entire watershed is considered to be heavily urbanized, with 54 percent of the total area developed to some extent. The southernmost part, 16 mi^2, is the most heavily urbanized, with about 84 percent in urban uses. About 46 percent of the land south of Lake Roland (fig. 1) is classified as low-, medium-, and high-density residential. Streets and alleys constitute 21 percent of the total land area in this section.

The study area is located within two physiographic provinces -- the Piedmont Plateau and the Atlantic Coastal Plain. The southern part, within the Atlantic Coastal Plain, is characterized by gently rolling, dissected uplands. The Piedmont Plateau in the northern part is characterized by higher elevations, gently rolling hills, and deep, narrow stream valleys.

The climate generally is one of warm summers and mild winters. The coldest period is usually in late January and early February and the warmest is in the last half of July and early August. Monthly precipitation is distributed fairly uniformly throughout the year, and the average yearly precipitation is 42 in. Long-duration storms occur predominantly during the cold season (December through March). Average precipitation intensities, however, are highest in June, July, August, and September (0.08 to 0.13 in/hr), whereas the lower intensity storms usually occur in December through April (0.03 to 0.05 in/hr).

During cold-weather months, prevailing winds are from the west to northwest. Southerly winds predominate during warm months. The average annual wind speed is about 10 mi/hr, with the highest frequency of strong winds between late winter and early spring.

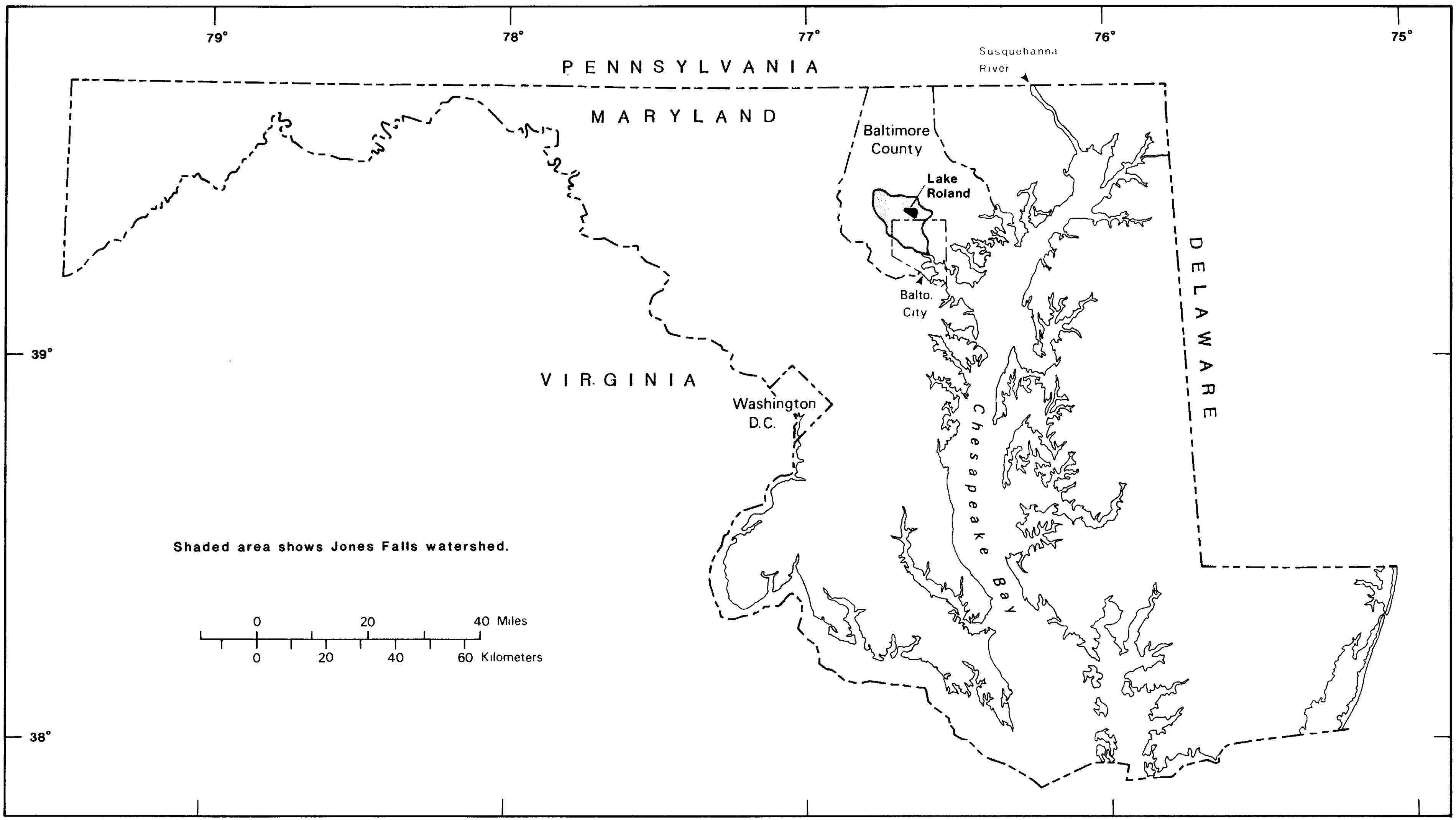


Figure 1. -- Location of Jones Falls watershed, Maryland.

Data Collection

Rainfall, runoff, and water-quality data were collected at four watershed sites (fig. 2) described in table 1. The data consist of rainfall and runoff at 1-minute intervals for the small watershed sites (Hampden, Reservoir Hill, and Bolton Hill) and streamflow at 5-minute intervals for the Biddle Street site. Water-quality data were collected as either discrete or flow-weighted-composite samples. In addition, a network of eight supplemental rain gages was maintained in the watershed to better define watershed rainfall and to help estimate missing data at the monitoring sites. Continuous rainfall data were collected at 5-minute intervals at the supplemental rain gage sites. Also, the other cooperating agencies operated four runoff data-collection sites and five atmospheric deposition stations (fig. 2). They also conducted special studies of street dust and dirt, sanitary overflows, and sources of microbiological pollution. The Baltimore Regional Planning Council can be contacted for information on the cooperators' work. This report presents only the analysis of data collected by the U.S. Geological Survey.

Data were collected, verified, and entered into the U.S. Geological Survey Water Data Storage and Retrieval (WATSTORE) system for 65 station-storms sampled during 36 separate storms. A station-storm refers to an event at a single station, whereas a storm encompasses the entire study area. Table 2 indicates the storms for which data were collected.

Table 3 lists the water-quality constituents for which analyses were made. Only 8 of the 16 constituents were selected for detailed data analysis. The eight constituents were chosen because they are representative of the types of potential contaminants of most interest in the study: total suspended solids was a measure of sediment, which is itself of concern but also is a medium for constituent transport; total Kjeldahl nitrogen and total phosphorus are important nutrients; total organic carbon and chemical oxygen demand are measures of organic pollution; and total copper, total lead, and total zinc are potentially toxic metals.

Water-quality data also were collected during base-flow conditions at the Biddle Street site every 2 weeks throughout the data-collection period, when possible. In this study, base flow was assumed to exist when at least 2 days had passed since the end of rainfall. This assumption is reasonable for the study of urban storm-water runoff because ground-water discharge from the urban area to the stream is negligible. Data for 29 base-flow samples were entered into WATSTORE. Base-flow sampling included a microbiological sample and measurement of pH, specific conductance, dissolved oxygen, and temperature, as well as analysis for the constituents listed in table 3.

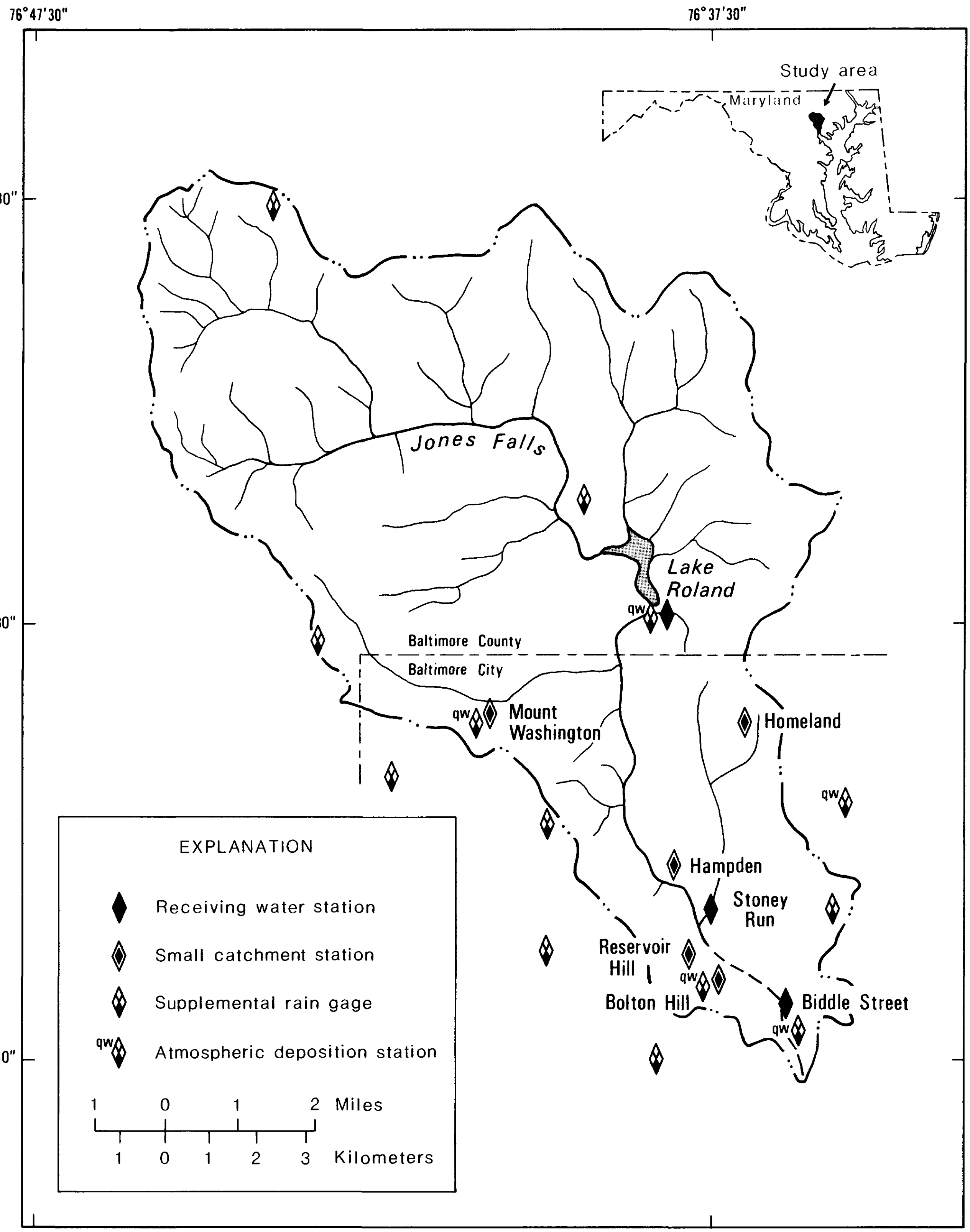


Figure 2. -- Location of sites for monitoring small catchments, receiving waters, and wetfall/dryfall, and supplemental rain gage network.

Table 1. -- Characteristics of drainage basins

Basin Characteristics[1/]	Hampden	Reservoir Hill	Bolton Hill	Biddle Street
Site ID	01589460	01589470	01589475	01589480
Latitude/ Longitude	39°19'42" 76°37'52"	39°18'48" 76°37'52"	39°18'29" 76°37'31"	39°18'12" 76°36'43"
Total drainage area (acres)	16.91	10.48	14.15	37,760
Impervious area (percentage of drainage area)	72	76	61	34
Effective impervious area (percentage of drainage area)	72	76	61	33
Average basin slope (ft/mi)	206	169	185	456
Main conveyance slope (ft/mi)	188	97	86	22
Population density (persons/mi^2)	35,800	47,300	17,800	3,640
Street density (lane miles/mi^2)	112	128	98	2/
Percentage of drainage area for each land use				
Residential[3/]	84	100	100	44
Commercial	16	0	0	4
Other	0	0	0	[4/]52
Percentage of area drained by storm sewers	100	100	100	3/
Percentage of streets with curb and gutter drainage	100	100	100	3/

Notes:

1/ Basin characteristics were determined using procedures specified for the Nationwide Urban Runoff Program, which were generally based upon the National Handbook of Recommended Methods for Water-Data Acquisition (U.S. Geological Survey, 1977).
2/ A particular basin characteristic which was not determined for Biddle Street.
3/ Residential land use is all high density (more than eight dwelling units per acre) for Hampden, Reservoir Hill, and Bolton Hill.
4/ "Other" land use percentages for Biddle Street include: industrial (2 percent), institutional (4), cemetery/recreational (6), woodland (23), agricultural (12), brush/grass (3), miscellaneous (2).

Table 2. -- Inventory of storm data[1/]

STORM ID#	BEGIN DATE	END DATE	HAMPDEN	RESERVOIR HILL	BOLTON HILL	BIDDLE STREET
1	020881	020981				X
2	030481	030581		X	X	X
3	033081	033181				X
4	040581	040681				X
5	042881	042981				X
6	050181	050181			X	
7	051581	051581	X	X	X	
8	061081	061081				X
9	072081	072081			X	
10	072581	072581	X	X	X	
11	072681	072681	X	X	X	
12	072881	072881		X	X	
13	072881	072881		X	X	
14	080681	080681		X		
15	080881	080881		X		
16	081181	081181	X			
17	090881	090881	X			
18	091581	091681	X		X	
19	091781	091881	X			X
20	092281	092281	X			
21	092781	092781	X		X	X
22	100181	100281			X	X
23	100681	100681			X	
24	101881	101881	X	X	X	X
25	102381	102481	X	X	X	X
26	110581	110681			X	
27	120181	120281		X	X	X
28	121481	[2/] 121581	X		X	X
29	013082	020182				X
30	020982	021082				X
31	021682	021882				X
32	030682	030782	X	X		
33	031682	031782	X	X		
34	032582	032682		X		
35	040382	040382	X			X
36	042682	[2/] 042682	X			X

Notes:

1/ Storm data consist of streamflow and water-quality data for the Biddle Street site (receiving waters) and rainfall, runoff, and water-quality data for the other three sites (small catchments).

2/ Flow was sustained above base flow at Biddle Street until 121981 and 042982 for storms #28 and #36, respectively.

Table 3.--Selected chemical constituents[1/]

CONSTITUENT	WATSTORE AND STORET CODE
Total Kjeldahl nitrogen[2/]	00625
Ammonia - N	00610
Total phosphorus[2/]	00665
Total orthophosphorus - P	70507
Total organic carbon[2/]	00680
Total inorganic carbon	00685
Suspended solids[2/]	00530
Dissolved solids	70300
Turbidity	00076
Chemical oxygen demand[2/]	00335 or 00340
Cadmium	01027
Chromium	01034
Copper[2/]	01042
Iron	01045
Lead[2/]	01051
Zinc[2/]	01092

Notes:

1/ Some additional analyses are not being reported, because of questionable data quality.

2/ Detailed analyses are for these constituents.

Tables 4 and 5a to 5d define and summarize, respectively, the rainfall and runoff characteristics of the sampled storms. Most of these characteristics were derived from 1-minute rainfall/runoff data at the small catchments and 5-minute streamflow at Biddle Street. The supplemental rain gage data were used to derive rainfall characteristics for the basin above Biddle Street and to estimate missing data at the small catchments.

In the data-collection program, state-of-the-art instrumentation and data-management techniques were used. Contrary to expectations, it was found that advanced instrumentation cannot be counted on to work consistently under adverse field conditions, especially when several complex systems are interfaced. Experiences with these systems have been documented by Fisher and Katz (1982).

Basic data for the Jones Falls study have been published in the Water Resources Data for Maryland and Delaware reports for Water Years 1981 and 1982 (U.S. Geological Survey, 1982 and 1983). Also, a concurrent related study was made. Katz and Fisher (1983) present the results of a comparison of methods for flow measurement in storm sewers. These results helped in obtaining stage-discharge relationships at the small catchment sites. For information on unpublished data or the related study, the authors should be contacted.

QUALITY ASSURANCE AND DATA MANAGEMENT

The water-quality and quantity data collected during this study were interpreted to provide a basis for water-resources management decisions. To insure that the large volume of data are valid and reliable, a good quality-assurance program was needed in the field, office, and laboratory. Basic quality assurance included those procedures common to any water-quality study: proper record keeping, careful sample collection and handling, and a documented laboratory quality-assurance/quality-control program. The basic quality-assurance program is described in the project work plan (Katz and Fisher, 1982). Data management, which is an additional element of quality assurance, is discussed in a report on instrumentation and data management by Fisher and Katz (1982).

Complete quality-assurance records have been maintained throughout the project and are available for inspection. These include rainfall/runoff data verification as well as laboratory quality assurance and equipment maintenance and calibration records.

Table 4. -- Definitions of selected storm characteristics

YEAR	Calendar year of storm, for example, 1981.
BDATE	Beginning date of rainfall, month and day.
T2DATE	Ending date of rainfall, month and day.
BTIME	Beginning time of rainfall, hours and minutes.
T2	Ending time of rainfall, hours and minutes.
DURRNF	Duration of rainfall, in minutes.
TRAINA	Average total rainfall for the basin, in inches.
MAXR1	Maximum 1-minute rainfall rate, in inches per hour.
MAXR5	Maximum 5-minute rainfall rate, in inches per hour.
MAXR15	Maximum 15-minute rainfall rate, in inches per hour.
MAX1H	Maximum 1-hour rainfall rate, in inches per hour.
NDRD02	Number of dry hours since storm with 0.2 in. or more rainfall.
NDR001	Number of dry hours since storm with 0.01 in. or more rainfall.
DERNPD	Rainfall accumulation, in inches, during the 24 hours preceding beginning time of sampled storm (BTIME).
DERNP3	Rainfall accumulation, in inches, during the 72 hours preceding beginning time of sampled storm (BTIME).
DERNP7	Rainfall accumulation, in inches, during the 168 hours preceding beginning time of sampled storm (BTIME).
T3DATE	Beginning date of runoff, month and day.
T3	Beginning time of runoff, hours and minutes. For small catchments, T3 = the time of first observable runoff; for Jones Falls, T3 = the time when the discharge first exceeds 25 percent above the base flow (BFLOW).
EDATE	Ending date of runoff, month and day.
ETIME	Ending time of runoff, hours and minutes. For small catchments, ETIME= the first point on the recession limb of the storm hydrograph where the stage drops to 0.05 ft after the cessation of rainfall; for Jones Falls, ETIME = the point on the recession limb of the storm hydrograph, where the discharge drops to 25 percent above the base flow.
DURSTO	Total duration of runoff, in minutes.
Q	Total runoff for storm hydrograph, in inches.
TOTRUN	Total runoff, in inches, using criteria established for the Nationwide Urban Runoff Program (see text p.20 and 21).
PEAKQ	Peak discharge of event, in cubic feet per second (ft^3/s).
T5DATE	Date of peak discharge, month and day.
T5	Time of peak discharge, hours and minutes.
TIMBPK	Time before peak, in minutes. Total elapsed time from the beginning of rainfall (BTIME), to the time of the occurrence of the peak discharge (T5).
BFLOW	Base flow, in cubic feet per second. For the small catchments, base flow is zero; for Jones Falls, base flow is the mean daily discharge of the day prior to the beginning date of rainfall.
N	The number of discrete or composite samples analyzed.

Table 5.a. -- Characteristics of storms

Characteristics 1/		Storm identification						
		7	10	11	16	17	18	19
YEAR		1981	1981	1981	1981	1981	1981	1981
BDATE	(mo-d)	05-15	07-25	07-26	08-11	09-08	09-15	09-17
BTIME	(hr,min)	1343	0442	1838	1941	1409	1659	1915
T2DATE	(mo-d)	05-15	07-25	07-26	08-11	09-08	09-16	09-18
T2	(hr,min)	1919	0511	2126	2134	1608	0715	0501
DURRNF	(min)	336	29	168	113	119	856	586
TRAINA	(in.)	1.40	0.13	0.05	0.42	0.39	1.51	0.42
MAXR1	(in/hr)	13.20	0.60	0.60	1.20	3.00	22.2	1.20
MAXR5	(in/hr)	5.64	0.24	0.12	0.84	1.32	4.44	0.36
MAXR15	(in/hr)	2.40	0.12	0.04	0.56	1.20	1.80	0.28
MAX1H	(in/hr)	0.75	-	0.01	0.35	0.32	0.80	0.12
NDRD02	(hrs)	74	705	747	335	198	369	13
NDRD001	(hrs)	74	65	38	44	198	369	13
DERNPD	(in.)	0.00	0.00	0.00	0.00	0.00	0.00	0.21
DERNP3	(in.)	0.00	0.04	0.07	0.04	0.00	0.00	1.52
DERNP7	(in.)	1.13	0.15	0.22	0.22	0.00	0.00	1.52
T3DATE	(mo-d)	05-15	07-25	07-26	08-11	09-08	09-15	09-17
T3	(hr,min)	1343	0451	1838	1949	1413	1700	1915
EDATE	(mo-d)	05-15	07-25	07-26	08-11	09-08	09-16	09-18
ETIME	(hr,min)	1906	0636	2136	2239	1705	0206	0617
DURSTO	(min)	323	105	178	170	172	546	662
Q	(in.)	1.01	0.02	0.01	0.10	0.13	0.77	0.17
TOTRUN	(in.)	0.55	0.01	0.01	0.01	0.10	0.22	0.03
PEAKQ	(ft^3/s)	67	1.6	0.17	2.9	42	67	1.6
T5DATE	(mo-d)	05-15	07-25	07-26	08-11	09-08	09-15	09-17
T5	(hr,min)	1448	0453	2050	1951	1423	1704	1935
TIMBPK	(min)	65	11	132	2	14	5	20
BFLOW	(ft^3/s)	0	0	0	0	0	0	0
N 2/	(no.)	10	4	6	11	11	10	10

Note:

1/ See table 4 for definitions of storm characteristics.
2/ "C" indicates composite rather than discrete (no notation) water samples.

sampled at Hampden

number (from table 1)

20	21	24	25	27	28	32	33	35	36
1981	1981	1981	1981	1981	1981	1982	1982	1982	1982
09-22	09-27	10-18	10-23	12-01	12-14	03-07	03-16	04-03	04-26
1901	1900	1710	0753	1057	1338	0713	1349	0457	0510
09-22	09-27	10-18	10-23	12-02	12-15	03-07	03-16	04-03	04-26
1909	2023	1953	2336	0054	0059	1637	2136	0916	1326
8	83	163	943	837	681	564	467	259	496
0.15	0.19	0.31	0.53	0.87	1.10	0.55	0.75	0.45	1.06
1.80	4.20	1.80	0.60	1.20	1.20	0.60	1.20	1.80	1.20
1.32	2.16	0.84	0.24	0.72	0.36	0.24	0.60	0.60	0.60
-	1.16	0.56	0.16	0.48	0.20	0.20	0.48	0.32	0.48
-	0.29	0.28	0.12	0.25	0.15	0.15	0.23	0.22	0.31
110	231	500	101	607	303	374	205	58	199
89	105	296	101	607	151	343	73	58	199
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.57	0.00
2.30	0.18	0.00	0.00	0.00	0.11	0.00	0.22	0.57	0.00
09-22	09-27	10-18	10-23	12-01	12-14	03-07	03-16	04-03	04-26
1925	1900	1758	0907	1140	1410	0823	1450	0530	0724
09-22	09-27	10-18	10-24	12-02	12-14	03-07	03-16	04-03	04-26
2114	2143	2235	0415	0041	2250	1310	2130	1550	1335
109	163	277	1148	781	520	287	400	620	371
0.03	0.06	0.08	0.29	0.34	0.44	0.19	0.27	0.18	0.28
0.02	0.01	0.07	0.26	0.33	0.42	0.06	0.24	0.18	0.27
2.5	2.5	2.6	1.2	2.7	1.3	1.5	2.9	3.0	2.4
09-22	09-27	10-18	10-23	12-01	12-14	03-07	03-16	04-03	04-26
1940	1902	1804	1408	2200	1842	0828	1937	0737	1016
39	2	54	375	663	304	75	348	160	306
0	0	0	0	0	0	0	0	0	0
8	7	9	2C	1C	1C	1C	1C	1C	4C

Table 5.b. -- Characteristics of storms

Characteristics[1/]		Storm identification					
		2	7	10	11	12	13
YEAR		1981	1981	1981	1981	1981	1981
BDATE	(mo-d)	03-04	05-15	07-25	07-26	07-28	07-28
BTIME	(hr,min)	2213	1430	0442	1924	1124	1901
T2DATE	(mo-d)	03-05	05-15	07-25	07-26	07-28	07-28
T2	(hr,min)	1410	1943	0511	2115	1354	2040
DURRNF	(min)	957	313	29	111	150	99
TRAINA	(in.)	0.71	0.82	0.05	0.03	0.10	1.02
MAXR1	(in/hr)	0.60	4.20	0.60	0.60	0.60	4.80
MAXR5	(in/hr)	0.24	2.76	0.24	0.12	0.24	3.72
MAXR15	(in/hr)	0.16	1.40	0.12	0.04	0.08	2.28
MAX1H	(in/hr)	0.13	0.36	-	0.01	0.05	0.93
NDRD02	(hrs)	219	75	705	747	784	791
NDRD001	(hrs)	100	75	65	38	37	6
DERNPD	(in.)	0.00	0.00	0.00	0.00	0.00	0.07
DERNP3	(in.)	0.03	0.00	0.04	0.07	0.04	0.11
DERNP7	(in.)	0.07	1.13	0.15	0.22	0.15	0.22
T3DATE	(mo-d)	03-04	05-15	07-25	07-26	07-28	07-28
T3	(hr,min)	2214	1430	0442	1955	1124	1905
EDATE	(mo-d)	03-05	05-15	07-25	07-26	07-28	07-28
ETIME	(hr,min)	1412	2104	0652	2216	1421	2203
DURSTO	(min)	958	394	130	141	177	178
Q	(in.)	0.68	0.38	0.03	0.01	0.09	0.72
TOTRUN	(in.)	0.21	0.27	0.03	0.01	0.09	0.69
PEAKQ	(ft^3/s)	4.1	14	0.43	0.08	1.0	19
T5DATE	(mo-d)	03-05	05-15	07-25	07-26	07-28	07-28
T5	(hr,min)	0416	1940	0509	2047	1204	1954
TIMBPK	(min)	363	310	27	83	40	53
BFLOW	(ft^3/s)	0	0	0	0	0	0
N[2/]	(no.)	4	10	10	6	8	11

Note:

1/ See table 4 for definitions of storm characteristics.
2/ "C" indicates composite rather than discrete (no notation) water samples.

sampled at Reservoir Hill

number (from table 1)

14	15	16	32	33	34
1981	1981	1981	1982	1982	1982
08-06	08-08	08-11	03-07	03-16	03-26
1106	0456	1941	0715	1416	0019
08-06	08-08	08-11	03-07	03-16	03-26
1350	0839	2134	1631	2145	0351
164	223	113	556	449	212
0.07	0.14	0.42	0.59	0.85	0.10
0.60	1.80	1.20	1.20	1.20	1.20
0.12	0.84	0.84	0.36	0.60	0.24
0.04	0.28	0.56	0.28	0.52	0.12
0.03	0.08	0.35	0.17	0.26	0.06
208	245	335	374	205	214
208	35	44	343	73	114
0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.07	0.04	0.00	0.00	0.00
0.00	0.07	0.22	0.00	0.22	0.08
08-06	08-08	08-11	03-07	03-16	03-26
1106	0457	1941	0732	1415	0209
08-06	08-08	08-11	03-07	03-16	03-26
1652	1054	2357	1423	2155	0350
346	357	256	411	460	101
0.03	0.05	0.20	0.17	0.53	0.05
0.03	0.02	0.05	0.15	0.53	0.05
0.15	0.69	25	0.58	2.0	0.81
08-06	08-08	08-11	03-07	03-16	03-26
1251	0511	1950	1149	1946	0226
105	15	9	274	330	127
0	0	0	0	0	0
9	8	11	8	1C	6

Table 5.c. -- Characteristics of storms

Characteristics[1/]		Storm identification 2	6	7	9	10	11	12	13
YEAR		1981	1981	1981	1981	1981	1981	1981	1981
BDATE	(mo-d)	03-04	05-01	05-15	07-20	07-25	07-26	07-28	07-28
BTIME	(hr,min)	2148	0839	1345	1903	0442	1843	1145	1901
T2DATE	(mo-d)	03-05	05-01	05-15	07-20	07-25	07-26	07-28	07-28
T2	(hr,min)	1318	2259	1944	1950	0511	1930	1354	2040
DURRNF	(min)	930	860	359	47	29	47	129	99
TRAINA	(in.)	0.62	1.11	0.84	0.24	0.06	0.02	0.22	0.94
MAXR1	(in/hr)	1.20	1.20	7.20	4.20	0.60	0.60	0.60	3.60
MAXR5	(in/hr)	0.36	0.36	3.48	1.56	0.24	0.12	0.24	3.24
MAXR15	(in/hr)	0.16	0.28	1.48	0.68	0.12	0.04	0.08	2.04
MAX1H	(in/hr)	0.11	0.17	0.37	-	-	-	0.05	0.85
NDRD02	(hrs)	219	58	75	388	705	747	784	791
NDR001	(hrs)	100	23	75	388	65	38	37	6
DERNPD	(in.)	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.07
DERNP3	(in.)	0.03	0.57	0.00	0.00	0.04	0.07	0.04	0.11
DERNP7	(in.)	0.07	0.57	1.13	0.00	0.15	0.22	0.15	0.22
T3DATE	(mo-d)	03-04	05-01	05-15	07-20	07-25	07-26	07-28	07-28
T3	(hr,min)	2148	0945	1441	1903	0442	1852	1124	1903
EDATE	(mo-d)	03-05	05-01	05-15	07-20	07-25	07-26	07-28	07-28
ETIME	(hr,min)	1335	2303	2045	2015	0740	2035	1400	2159
DURSTO	(min)	947	798	364	72	178	103	156	176
Q	(in.)	0.30	0.34	0.76	0.23	0.03	0.00	0.12	0.59
TOTRUN	(in.)	0.22	0.13	0.73	0.21	0.02	0.00	0.10	0.40
PEAKQ	(ft^3/s)	1.4	1.6	46	34	0.99	0.05	9.3	32
T5DATE	(mo-d)	03-05	05-01	05-15	07-20	07-25	07-26	07-28	07-28
T5	(hr,min)	0500	1527	1938	1909	0512	1905	1200	1917
TIMBPK	(min)	432	408	353	6	30	22	15	16
BFLOW	(ft^3/s)	0	0	0	0	0	0	0	0
N [2/]	(no.)	6	8	10	9	10	5	9	10

Note:

1/ See table 4 for definitions of storm characteristics.
2/ "C" indicates composite rather than discrete (no notation) water samples.

storms sampled at Bolton Hill

number (from table 1)

13	18	21	22	23	24	25	26	27	28
1981	1981	1981	1981	1981	1981	1981	1981	1981	1981
07-28	09-15	09-27	10-01	10-06	10-18	10-23	11-05	12-01	12-14
1901	1646	1940	2136	1029	1801	0806	2223	0850	1320
07-28	09-16	09-27	10-02	10-06	10-18	10-23	11-06	12-02	12-14
2040	0721	2139	0053	1046	2039	2258	0229	0056	2318
99	875	119	197	17	158	892	246	966	598
0.94	2.39	0.70	0.31	0.08	0.28	0.58	0.44	0.85	1.09
3.60	3.60	10.20	2.40	1.20	1.20	1.20	1.20	1.20	0.60
3.24	2.64	5.04	1.44	0.60	0.48	0.36	0.72	0.48	0.24
2.04	2.08	2.72	0.64	0.24	0.36	0.24	0.56	0.32	0.20
0.85	1.33	0.68	0.19	-	0.22	0.13	0.34	0.22	0.17
791	369	231	97	202	500	101	218	607	303
6	369	105	97	105	296	101	218	607	151
0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.22	0.00	0.18	0.32	0.25	0.00	0.28	0.00	0.00	0.11
07-28	09-15	09-27	10-01	10-06	10-18	10-23	11-05	12-01	12-14
1903	1704	1940	2136	1029	1801	1640	2223	1106	1420
07-28	09-16	09-27	10-02	10-06	10-18	10-23	11-06	12-02	12-14
2159	0117	2226	0239	1201	2129	2230	0401	0220	2324
176	493	166	303	92	208	350	338	914	544
0.59	2.26	0.50	0.25	0.05	0.21	0.48	0.39	0.12	0.23
0.40	1.54	0.49	0.14	0.04	0.19	0.25	0.33	0.07	0.23
32	44	44	18	4.8	4.3	4.6	5.5	0.58	0.70
07-28	09-15	09-27	10-01	10-06	10-18	10-23	11-06	12-01	12-14
1917	1736	2023	2142	1035	1845	1420	0126	1311	1843
16	50	43	6	6	44	374	183	261	323
0	0	0	0	0	0	0	0	0	0
10	10	4	7	3	9	2C	5	6	7

Table 5.d. -- Characteristics of storms

Characteristics[1/]		Storm identification							
		1	2	3	4	5	8	19	21
YEAR		1981	1981	1981	1981	1981	1981	1981	1981
BDATE	(mo-d)	02-08	03-04	03-30	04-05	04-28	06-10	09-17	09-27
BTIME	(hr,min)	1055	2140	0845	1720	1610	0255	1915	2010
T2DATE	(mo-d)	02-08	03-05	03-30	04-05	04-28	06-10	09-18	09-27
T2	(hr,min)	1510	1415	1600	2030	2200	0710	1425	2200
DURRNF	(min)	255	995	435	190	350	255	1150	110
TRAINA	(in.)	0.35	0.71	0.35	0.21	0.53	0.60	0.74	0.32
MAXR1[2/]	(in/hr)	-	-	-	-	-	-	-	-
MAXR5	(in/hr)	0.42	0.42	0.42	0.42	1.27	0.85	0.42	2.55
MAXR15	(in/hr)	0.14	0.14	0.14	0.28	0.85	0.42	0.28	1.13
MAX1H	(in/hr)	0.11	0.14	0.11	0.11	0.32	0.25	0.21	0.28
NDRD02	(hrs)	144	219	595	95	343	97	13	231
NDRD001	(hrs)	144	100	331	95	115	16	13	105
DERNPD	(in.)	0.00	0.00	0.00	0.00	0.00	0.04	0.21	0.00
DERNP3	(in.)	0.00	0.00	0.00	0.00	0.00	0.04	1.52	0.00
DERNP7	(in.)	0.74	0.04	0.00	0.63	0.04	1.17	1.52	0.18
T3DATE	(mo-d)	02-08	03-05	03-30	04-05	04-28	06-10	09-17	09-27
T3	(hr,min)	1130	0140	0845	1740	1730	0325	2030	2010
EDATE	(mo-d)	02-09	03-06	03-31	04-06	04-29	06-10	09-18	09-27
ETIME	(hr,min)	1055	0205	1320	1320	0255	2400	2350	2335
DURSTO	(min)	1405	1465	1715	1180	565	1235	1640	205
Q[3/]	(in.)	0.03	0.07	0.03	0.02	0.05	0.05	0.05	0.00
TOTRUN[3/]	(in.)	0.03	0.07	0.03	0.02	0.05	0.05	0.05	0.00
PEAKQ[3/]	(ft^3/s)	150	220	180	190	1700	460	250	720
T5DATE	(mo-d)	02-08	03-05	03-30	04-05	04-28	06-10	09-18	09-27
T5	(hr,min)	1435	0525	1615	1810	1755	0655	0615	2045
TIMBPK	(min)	220	465	450	50	105	240	660	35
BFLOW	(ft^3/s)	73	46	23	47	58	46	49	39
N[4/]	(no.)	5	1	3	7	7	9	13	10

Notes:

1/ See table 4 for definitions of storm characteristics.
2/ Rainfall data were collected at 5-minute intervals for Biddle Street, so 1-minute intensities are not available.
3/ Base flow has been subtracted from Q, TOTRUN, and PEAK, to yield the volume of water that represents only storm-water runoff.
4/ "C" indicates composite rather than discrete (no notation) water samples.

sampled at Biddle Street

number (from table 1)

22	24	27	28	29	30	31	32	35	36
1981	1981	1981	1981	1982	1982	1982	1982	1982	1982
10-01	10-18	12-01	12-14	01-30	02-09	02-17	03-06	04-03	04-26
2130	1755	0915	1350	1115	1140	0120	1645	0510	0610
10-02	10-19	12-01	12-18	02-02	02-09	02-17	03-07	04-03	04-27
0100	0315	2355	1325	2350	1830	1215	1930	1645	2105
210	560	880	5735	5075	410	655	1605	695	2335
0.25	0.28	0.74	1.52	1.10	0.39	0.07	0.86	0.64	1.74
-	-	-	-	-	-	-	-	-	-
0.85	0.85	0.42	0.42	0.42	0.42	0.42	0.42	0.42	0.42
0.42	0.42	0.28	0.28	0.42	0.14	0.14	0.14	0.28	0.42
0.14	0.25	0.21	0.18	0.28	0.07	0.04	0.14	0.21	0.25
97	500	607	303	233	145	175	354	58	199
97	296	607	151	19	145	82	330	58	199
0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.57	0.00
0.32	0.00	0.00	0.11	0.15	1.34	0.07	0.00	0.57	0.00
10-01	10-18	12-01	12-14	01-30	02-09	02-17	03-06	04-03	04-26
2130	1755	0915	1350	1150	1140	0120	1645	0520	0610
10-02	10-19	12-04	12-19	02-02	02-10	02-18	03-09	04-05	04-29
2040	1715	0035	0655	1440	0610	0655	1810	1350	1420
1390	1400	3800	6785	4490	1110	1775	4405	3390	4810
0.06	0.03	0.11	0.28	0.09	0.03	0.05	0.13	0.11	0.29
0.06	0.03	0.11	0.28	0.09	0.03	0.05	0.13	0.11	0.29
410	300	510	470	210	100	1300	370	560	1700
10-01	10-18	12-01	12-14	01-31	02-09	02-17	03-07	04-03	04-26
2205	1905	2255	2250	0035	1340	1305	1210	0805	1120
35	70	820	540	800	120	705	1165	175	310
25	29	22	22	32	59	55	41	38	41
12	11	5	17	2	1C	1C	11	9	1C

Nitrate and dissolved-solids data reported by the laboratory were not used in this report. This decision is based upon a relatively frequent violation of quality-assurance criteria for one or both constituents. It is suspected that random contamination of sample bottles from rinsing with nitric acid followed by improper rinsing with distilled water may have caused the problem for nitrate.

Once the basic data sets were assembled and verified, the U.S. Geological Survey Urban Hydrology Studies Data Management System (Doyle and Lorens, 1982) was used to further manipulate the data. The Data Management System was developed to store, update, and retrieve data collected in urban storm-water studies. The system allows for the assembly of a data base by merging data from the WATSTORE Daily Values, Unit Values, and Water-Quality Files and through the input of related basin and storm characteristics. It is based on the data management aspect of the Statistical Analysis System (SAS) described by Barr and others (1979). User programs built into the Data Management System allow for the production of data tables, computation of water-quality loads for storms, and interfacing with urban storm-water models. In addition, any of the capabilities of SAS can be utilized.

A water-quality loads program in the Data Management System was used to estimate storm loads and loading rates for water-quality constituents. The program merges continuous discharge data with discrete water-quality concentrations data. Concentrations between sample points are estimated by linear interpolation. The concentrations before the first sample and after the last sample are assumed to be those at the first and last samples, respectively. The total load for a storm is estimated by summing the product of concentration and discharge throughout the hydrograph.

SPECIAL METHODS OF DATA ANALYSIS

The Event-Mean Concentration Concept

At the onset of NURP, a technique was sought to enable the comparison of water-quality constituent loadings between different storms at different locations. Total washoff alone cannot be used for comparison since large watersheds will generally yield more mass of a particular constituent than similar small watersheds, given similar storm characteristics. As a better indicator of watershed differences, total washoff per unit area has been used and works well for long-term comparisons, such as pounds per acre per year of a particular constituent. However, for comparisons of loadings between storms, whose individual characteristics can vary significantly, another method of comparison was needed. Dividing the loading rate in washoff per unit area by the volume of storm runoff normalizes the loading for any storm at any location. Typical units used are pounds per acre per inch of runoff. Runoff volume, like precipitation, is usually expressed as a depth of water, such as inches, distributed uniformly over the drainage area. It is a relative unit of measurement, where drainage area must also be known to obtain an absolute volume. Pounds per acre per inch (or pounds per acre-inch) is actually a concentration, since acre-inch is a unit of absolute volume. This concentration, expressed in milligrams per liter, can be obtained by multiplying pounds per acre per inch of runoff by 4.415. For NURP and related studies, it was known as Event-Mean Concentration (EMC). EMC is simply a flow-weighted average concentration for a storm -- that is, total constituent washoff divided by total storm-runoff volume.

Runoff Event Duration in Normally Dry Storm Sewers

NURP established criteria to ensure that consistent data were collected and reported by its many projects. These criteria were established by joint agreement of the U.S. Geological Survey and the U.S. Environmental Protection Agency in a technical coordination plan.

Definition of the ending point of runoff in storm sewers that are normally dry posed a particular problem. Many storm sewers are never completely dry but have a trickle flow sustained by ground-water infiltration into the sewer-pipe joints. In most cases this flow is at or below measurable levels. The true ending point of storm runoff cannot easily be identified because flow does not completely stop after rainfall. Prior to NURP, the ending point of runoff was usually assigned using subjective criteria. To circumvent this problem, consistent criteria were established for the NURP and related U.S. Geological Survey studies.

Figure 3 shows example runoff hydrographs produced by frontal and convective storms in a small urban watershed (drainage area on the order of tens of acres or less). While the beginning of runoff is clearly defined, the ending is not. Of course, in theory, monitoring of the hydrograph could continue indefinitely until flow ceases, but this is often impractical. Under the technical coordination plan, it was decided to define the end of runoff as the point at which the flow rate equalled 10 percent of the peak flow rate (shown in fig. 3). This point was based on the experience of prior studies. When used in the Baltimore study it was found to yield an acceptable representation of the runoff hydrograph and the constituent loads for most, but not all, storms. For convective storms (fig. 3), characterized by intense bursts of rainfall early in the storm, the NURP criteria generally led to an overestimation of constituent loads and an underestimation of total runoff volumes, as illustrated by figures 4 and 5.

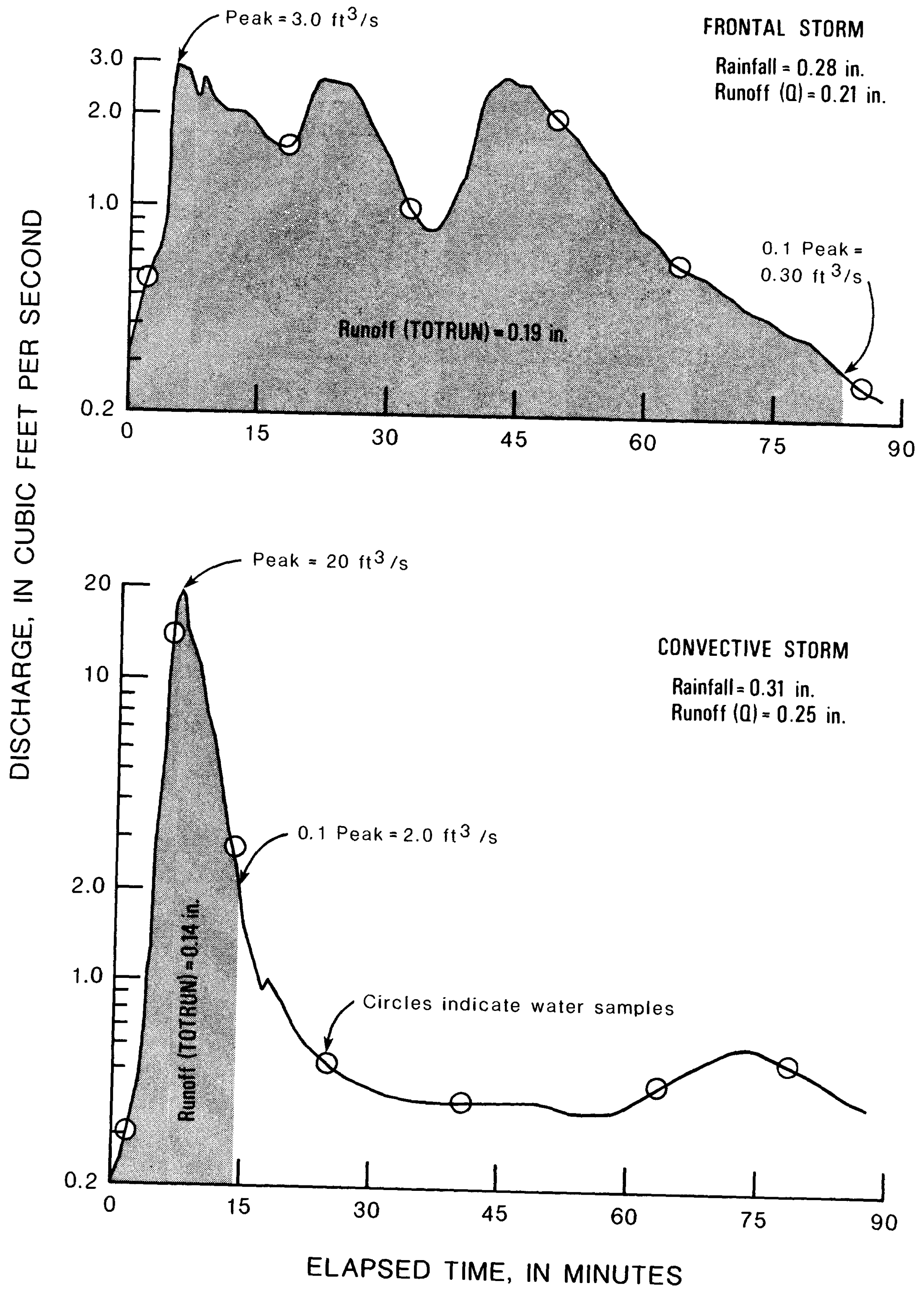
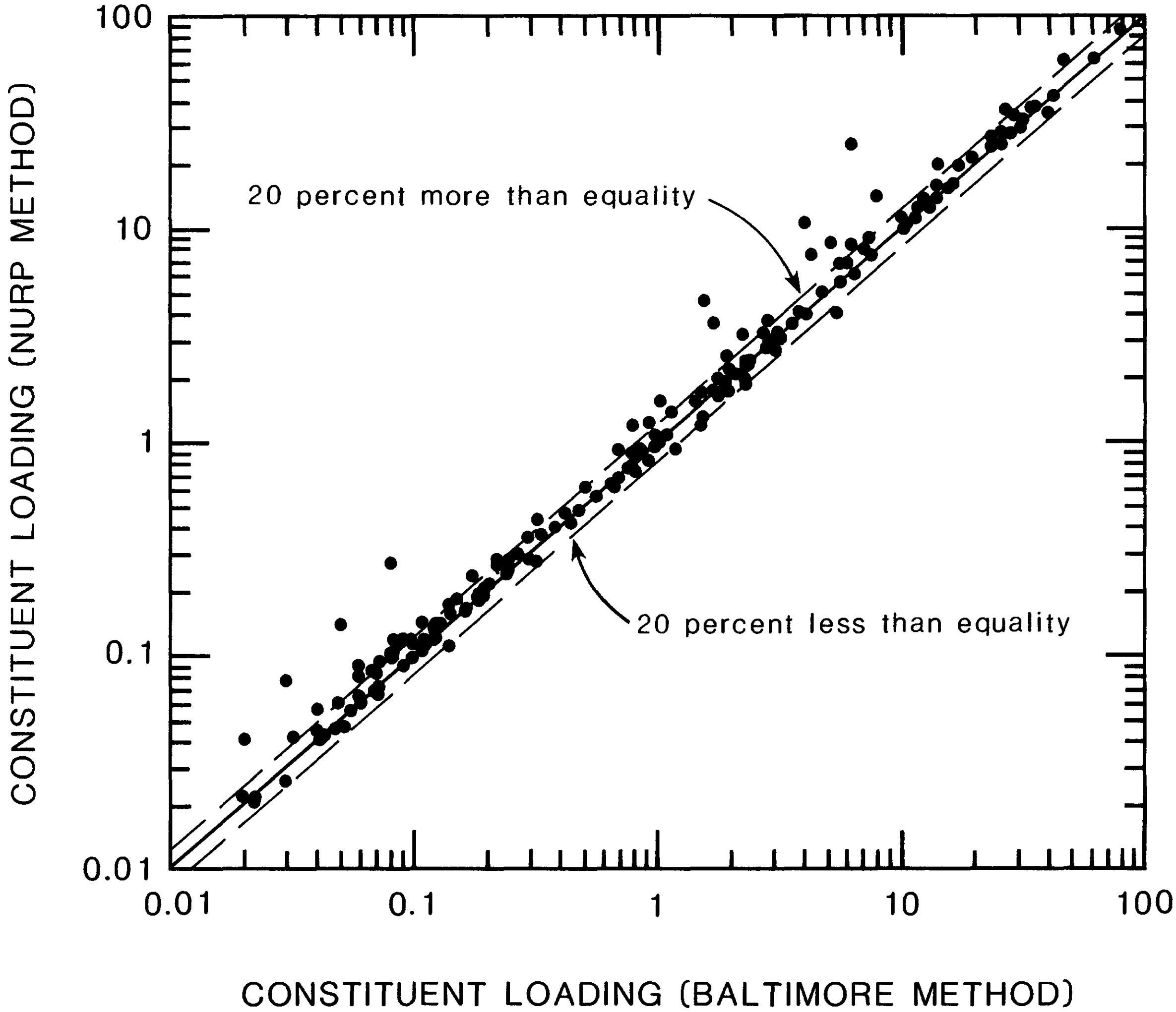


Figure 3. -- Typical hydrographs produced from frontal and convective storms in a typical small urban watershed.



Note: Units are in pounds per acre per inch of runoff.

Figure 4. -- Comparison of constituent loadings using Baltimore project method and Nationwide Urban Runoff Program method at three small catchments.

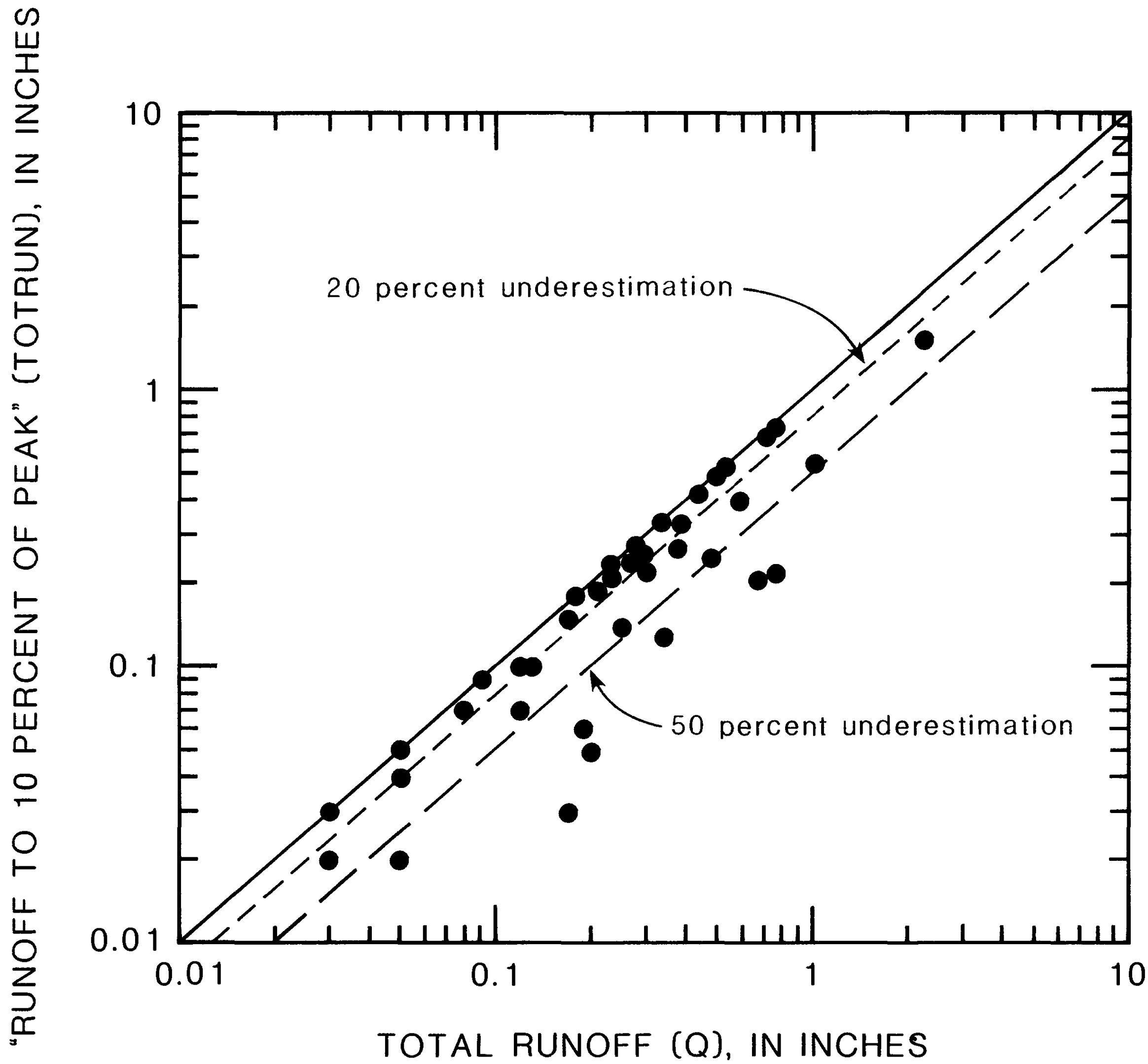


Figure 5. -- Comparison of total runoff (Q) and "runoff to ten percent of peak" (TOTRUN) at three small catchments.

The overestimation of constituent loads occurs because load computations are biased by samples which occur early in a storm, before the 10 percent of peak cutoff. These samples tend to have higher constituent concentrations. In the computation of loads, these samples are given more weight because their concentrations are applied to a larger percentage of the runoff volume than if the entire hydrograph is considered (weighting factor is "x" volume / TOTRUN opposed to "x" volume / Q). The underestimation of total runoff is inherent in the criteria since only part of the hydrograph is used for computations. Fortunately, the rainfall/runoff process is fairly well understood and total runoff can be estimated from total rainfall. The reliability of this estimate will depend on the method chosen and can range from poor to excellent. Constituent loading rates, on the other hand, are not as well understood. The understanding of loading mechanisms is in fact one of the objectives of current urban hydrology studies. Overestimation of loads could lead to implementation of overly conservative and costly control measures. Therefore, it is important to obtain the best possible estimate of constituent loading rates.

Because of these discrepancies, the U.S. Geological Survey study in Baltimore adopted a criterion different from that of NURP to define the end of storm runoff in the small catchments. This criterion makes use of a longer recorded hydrograph to determine both the total runoff volume and the constituent loads. The recorded hydrograph begins with the first detectable flow and ends when the flow recedes to the smallest measurable stage, which is about 0.05 ft with the instrumentation used. Since the stage often fluctuates around this level for some time because of ground-water infiltration or watershed storage, the ending is defined as the first occurrence of a 0.05-ft stage after rainfall ceases. For most storms, using the new definition yields constituent loads that are only slightly different from those obtained using the original criterion, as figure 4 shows. However, for intense convective storms, the new definition yields a noticeably lower estimate of constituent loads than the original criterion.

QUALITY OF RUNOFF FROM SMALL CATCHMENTS

Water-Quality Statistics

Tables 6 and 7 list descriptive statistics for both instantaneous and event-mean constituent concentrations (EMC's). Table 8 compares these concentrations to selected water-quality criteria. These criteria have been selected from the literature for comparison only because definitive water-quality standards do not generally exist for the constituents considered. Both instantaneous and event-mean concentrations must be considered in assessing water quality. Aquatic organisms can be affected by either a one-time exposure to a high concentration (acute) or by a prolonged lower concentration (chronic). EMC's are more indicative of long-term conditions since high instantaneous

Table 6. -- Descriptive statistics for instantaneous concentrations observed at three small catchments

Site	Constituent	N	Mean (mg/L)	Standard Deviation (mg/L)	Percentiles (mg/L) 10	25	50(median)	75	90
Hampden	Total suspended solids	89	70.5	110	8.00	14.5	32.0	75.5	190
	Total Kjeldahl nitrogen	78	8.89	8.48	1.70	2.88	6.25	11.4	20.3
	Total phosphorus	89	1.09	1.60	.220	.330	.540	.975	2.50
	Chemical oxygen demand	88	151	159	22.0	40.0	110	198	321
	Total organic carbon	88	33.1	31.4	4.90	11.3	22.5	46.3	72.2
	Total copper	89	.0717	.0538	.020	.040	.060	.080	.130
	Total lead	89	.236	.342	1/ .020	.050	.100	.255	.680
	Total zinc	89	.355	.360	.070	.115	.230	.445	.930
Reservoir Hill	Total suspended solids	89	122	186	10.0	18.5	46.0	125	392
	Total Kjeldahl nitrogen	89	11.9	10.7	2.50	5.10	8.50	15.5	26.0
	Total phosphorus	89	4.08	9.96	.560	.790	1.70	3.65	8.60
	Chemical oxygen demand	89	217	270	40.0	65.0	110	250	460
	Total organic carbon	89	48.6	55.8	6.00	12.5	25.0	66.0	130
	Total copper	89	.0478	.0491	1/ .010	.020	.030	.060	.090
	Total lead	89	.399	.690	.030	.060	.150	.370	1.00
	Total zinc	89	.491	.640	.100	.160	.280	.625	1.20
Bolton Hill	Total suspended solids	123	73.1	161	6.00	12.0	22.0	52.0	138
	Total Kjeldahl nitrogen	119	6.06	5.12	1.20	2.60	5.00	7.70	12.0
	Total phosphorus	129	.894	1.49	.190	.255	.400	.725	2.40
	Chemical oxygen demand	127	142	188	21.0	36.0	79.0	200	334
	Total organic carbon	128	28.5	41.9	2.00	4.50	11.0	41.0	76.3
	Total copper	127	.109	.0820	.040	.050	.080	.140	.234
	Total lead	127	1.21	4.94	.040	.080	.150	.540	1.76
	Total zinc	127	.834	2.55	.110	.170	.250	.560	.968

Note:

1/ Lower detection limit.

Table 7. -- Descriptive statistics for event-mean concentrations observed at three small catchments

Site	Constituent	N	Mean (mg/L)	Standard Deviation (mg/L)	Percentiles (mg/L)				
					10	25	50(median)	75	90
Hampden	Total suspended solids	17	77.6	63.3	12.1	35.3	60.7	114	206
	Total Kjeldahl nitrogen	16	7.16	5.40	2.92	3.71	6.39	7.34	14.7
	Total phosphorus	17	.663	.420	.193	.332	.619	1.01	1.24
	Chemical oxygen demand	17	102	70.9	15.0	45.5	96.3	137	187
	Total organic carbon	17	22.4	16.1	3.83	13.0	17.4	24.8	54.0
	Total copper	17	.0589	.0318	.0218	.0300	.0499	.0827	.112
	Total lead	17	.247	.169	.055	.114	.200	.373	.513
	Total zinc	17	.332	.177	.112	.195	.280	.461	.649
Reservoir Hill	Total suspended solids	12	136	96.4	25.3	42.8	127	180	318
	Total Kjeldahl nitrogen	12	11.0	5.42	3.99	8.20	10.0	13.3	21.8
	Total phosphorus	12	3.60	2.36	1.20	1.81	3.05	4.59	8.43
	Chemical oxygen demand	12	190	155	45.5	91.8	115	275	508
	Total organic carbon	12	40.3	33.8	6.79	14.6	36.0	53.5	109
	Total copper	12	.0442	.0314	.0125	.0224	.0338	.0619	.107
	Total lead	12	.395	.363	.043	.120	.292	.608	1.13
	Total zinc	12	.514	.468	.095	.262	.422	.546	1.54
Bolton Hill	Total suspended solids	16	92.4	122	11.7	27.9	59.9	114	263
	Total Kjeldahl nitrogen	16	5.92	3.25	1.44	3.60	5.84	8.06	10.8
	Total phosphorus	17	1.02	1.05	.259	.371	.556	1.14	3.46
	Chemical oxygen demand	17	196	195	30.8	54.4	122	307	595
	Total organic carbon	17	25.3	29.0	3.80	4.85	11.7	39.7	78.4
	Total copper	17	.105	.0615	.0402	.0547	.0763	.167	.201
	Total lead	17	2.59	5.07	.092	.184	.362	1.66	10.7
	Total zinc	17	1.58	3.07	.171	.226	.428	1.02	6.34

Table 8. -- Comparison of observed data to selected water-quality criteria for three small catchments.

Constituent	Criteria[1/] (mg/L)	Percentage exceeding criteria: Hampden	Reservoir Hill	Bolton Hill
		Instantaneous Concentrations		
Total suspended solids	[2/]30	53	65	43
Total Kjeldahl nitrogen	[3/] 0.074	100	100	100
Total phosphorus	[3/] 0.069	99	100	98
Total organic carbon	[4/]10	78	81	54
Total copper	[5/] 0.022	88	70	100
Total lead	[5/] 0.17	39	48	49
Total zinc	[5/] 0.32	40	47	44
		Event-Mean Concentrations		
Total suspended solids	[2/]30	78	86	73
Total Kjeldahl nitrogen	[3/] 0.074	100	100	100
Total phosphorus	[3/] 0.069	93	100	100
Total organic carbon	[4/]10	80	84	46
Total copper	[6/] 0.0056	100	100	100
Total lead	[6/] 0.0038	100	100	100
Total zinc	[6/] 0.047	100	93	100

Notes:

1/ No criteria have been established for total Kjeldahl nitrogen, total phosphorus, chemical oxygen demand, or total organic carbon; the listed values have been selected from the cited literature for comparison, except for chemical oxygen demand, for which no comparisons were found.

2/ USEPA, 1976; secondary sewage effluent limitation, mean for 30 days of consecutive sampling.

3/ Sylvester, 1961; mean concentration for three streams draining forested watersheds.

4/ Malcolm and Durum, 1976; typical concentration for non-polluted U.S. streams under normal flow conditions.

5/ USEPA, 1980; acute exposure limit for fresh-water aquatic life assuming hardness of 100 mg/L as $CaCO_3$.

6/ USEPA, 1980; chronic exposure limit for fresh-water aquatic life assuming hardness of 100 mg/L as $CaCO_3$.

concentrations, while important, may result from a transient condition or contamination of water samples. Thus, only EMC's are subjected to further detailed analysis. As table 8 shows, the criteria considered are exceeded for most storm-flow observations, particularly the EMC's. Suspended solids EMC's exceed limits for secondary sewage effluent for most observations. EMC's for nutrients, total Kjeldahl nitrogen and total phosphorus exceed concentrations observed in forest watersheds most of the time. Also, total phosphorus exceeds 0.04 mg/L for all samples, a general criterion proposed by Lee, Jones, and Rast (1981) for classifying lakes as eutrophic. Most EMC's for total organic carbon, an indicator of general organic contamination, are higher than those considered typical for non-polluted streams in the United States. Almost all EMC's for metals exceed long-term exposure limits for fresh-water aquatic life. Urban runoff is considered to be be a primary source of some metals in receiving waters.

In general, table 8 shows that urban storm-water runoff, in all cases, is significantly degraded with respect to the water-quality criteria considered. A thorough evaluation of the problem involves identification of significant inputs, principal factors influencing the inputs, and relative and absolute contributions of each input. The first step in this assessment is to compare the three small catchments, which are the source areas.

Figures 6 and 7 show the distribution of EMC's observed for the three small catchments. A visual comparison between plots reveals that the ranges of observations for the three sites generally have the same magnitudes. The only clear differences are that total phosphorus values tend to be higher at Reservoir Hill and total copper and total lead tend to be higher at Bolton Hill. Total zinc values are slightly higher at Bolton Hill and total Kjeldahl nitrogen are slightly higher at Reservoir Hill.

To further assess differences between the small catchments, an analysis of variance was performed. For this analysis to be valid, the data set tested must be normally distributed. A Shapiro-Wilk test for normality (SAS-PROC UNIVARIATE; Barr and others, 1979) was used for both linear and log-transformed data. Generally, a higher probability of normal distribution was indicated for linear data, although some constituents at some sites produced better results for log-transformed data. A normal distribution was found to be likely for both linear and log-transformed data. Therefore, analysis of variance was performed for both linear and log-transformed data. In addition, a nonparametric analysis of variance (Kruskal-Wallis) was made. Nonparametric procedures are independent of distribution. All analyses of variance were made using the General Linear Model (GLM) procedure (Barr and others, 1979). Results of all alternative analyses indicate that total Kjeldahl nitrogen and total phosphorus EMC's at Reservoir Hill are

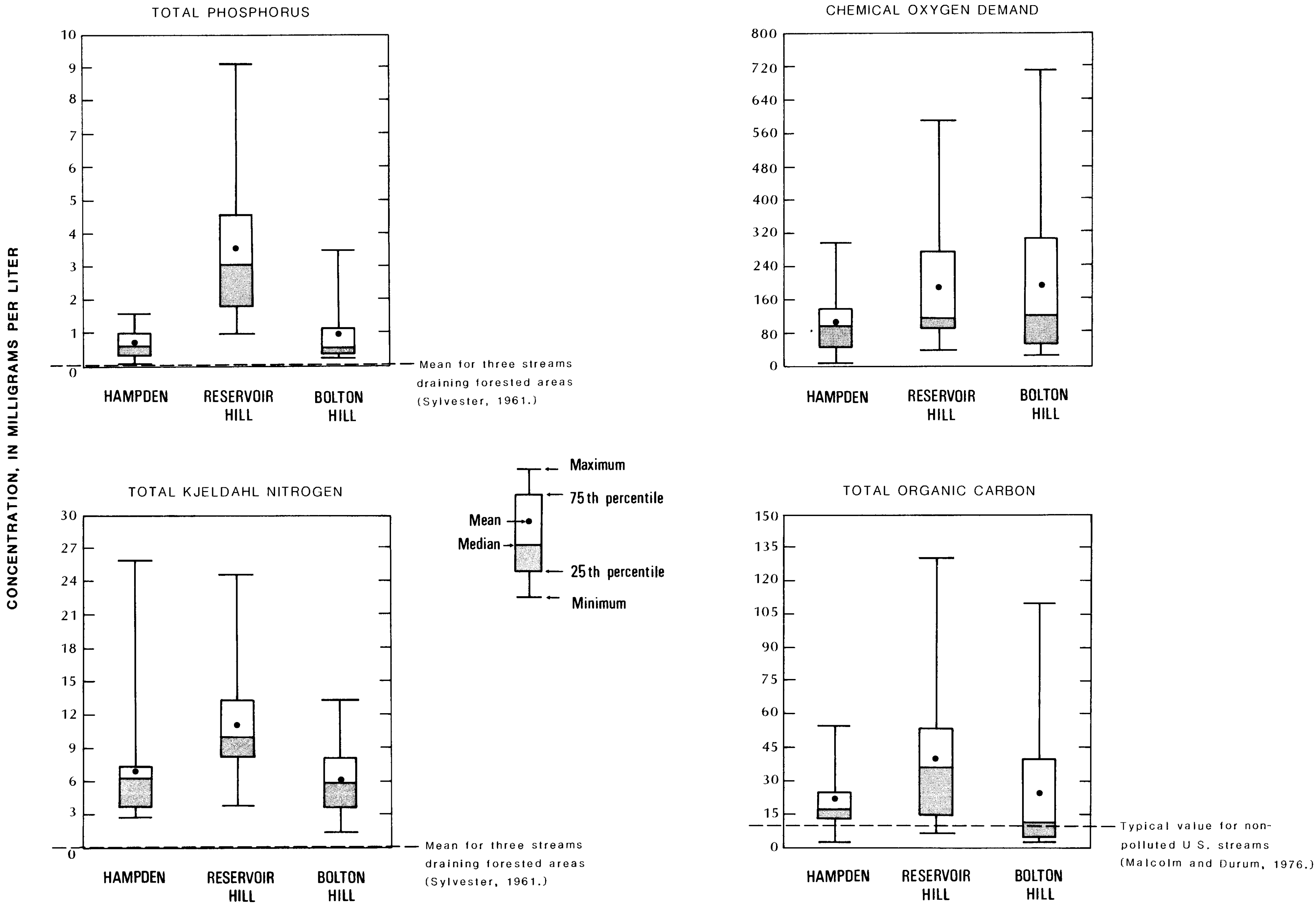


Figure 6. -- Comparison of event-mean concentrations of total Kjeldahl nitrogen, total phosphorus, chemical oxygen demand, and total organic carbon for three small catchments.

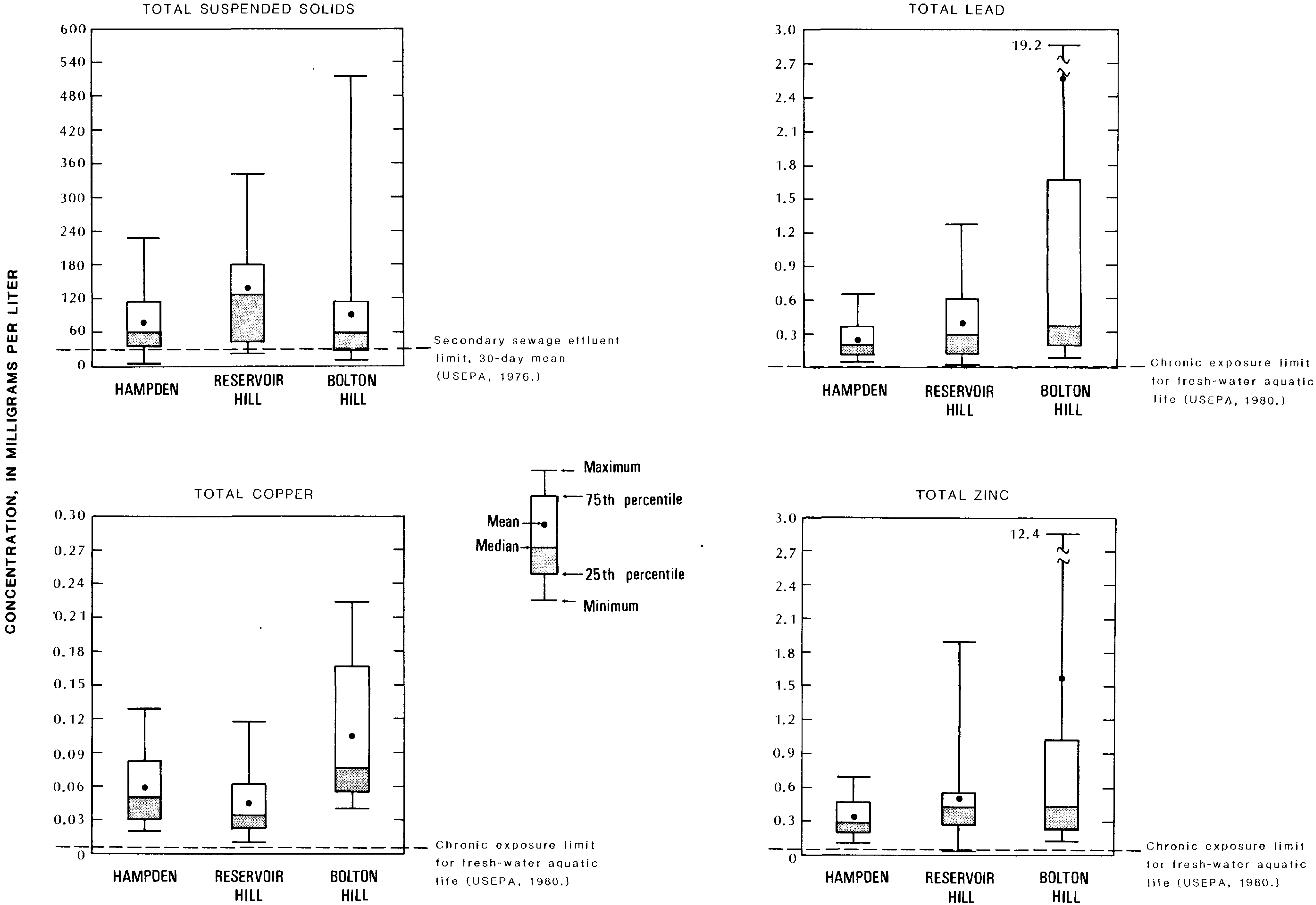


Figure 7.-- Comparison of event-mean concentrations of total suspended solids, total copper, total lead, and total zinc for three small catchments .

significantly different (0.99 significance level) from those at Hampden and Bolton Hill, with the phosphorus differences being highly significant. Total copper EMC's are significantly higher (0.99 level) at Bolton Hill than at the other two sites. There is a lesser degree of significance (greater than 0.95 probability level) for the difference in lead and zinc EMC's between Hampden and the other two sites. No other significant differences between constituent EMC's for the small catchment sites were found.

Factors Influencing Water Quality

Storm Characteristics

An axiom accepted at the onset of the project was that storm characteristics play a key role in influencing the water quality of urban storm-water runoff. The relationships between storm characteristics and water quality must be determined to develop a pollution-control strategy. For example, if peak discharge is the principal factor affecting water quality, then techniques to control the peak can be used, such as storm-water management ponds. Correlation analysis was used to search for possible relationships between EMC's and storm characteristics. Twelve storm characteristics were investigated. To simplify interpretation of the results, the characteristics were grouped into five classes of influencing factors. These were volume, duration, intensity, accumulation, and timing factors. Table 9 indicates the grouping of the characteristics. Accumulation refers to material on the land surface and is directly related to the time period since the previous rainfall. It is inversely related to the antecedent rainfall (with greater antecedent rainfall, less material accumulates on the land surface), which is used in this analysis as a measure of accumulation.

Correlation analysis between selected water-quality constituents and storm characteristics was used to identify relationships with significant correlation coefficients (greater than 0.50 with a significance level of 0.95 or greater). Tables 10 to 12 list correlation matrices for event-mean concentrations versus the grouped storm characteristics from table 9. Correlation analysis for grouped characteristics was done as multiple correlation analysis (Chow, 1964) using the SAS procedure SYSREG to compute multiple correlation coefficients (SYSREG computes a R^2 value; the correlation coefficient is the square root of R^2; the sign of R was obtained from simple correlation analysis with individual characteristics using SAS-PROC CORR). As with the analysis of variance between sites, calculations were made for both linear and log-transform data. The sign of the correlation coefficient indicates whether the relationship is directly (+) or inversely (-) proportional. Grouped storm characteristics that are more significant in influencing the observed EMC's are indicated by the higher correlation coefficients.

Table 9. -- Grouping of storm characteristics

Group	Storm Characteristic	Description
Volume	TRAINA	Total rainfall
	Q	Total runoff
Duration	DURRNF	Duration of rainfall
	DURSTO	Duration of runoff
Intensity	MAXR5	Max. 5-min rainfall intensity
	MAXR15	Max. 15-min rainfall intensity
	MAX1H	Max. 1-hour rainfall intensity
	PEAKQ	Peak discharge
Accumulation	DERNPD	Rainfall previous 24 hours
	DERNP3	Rainfall previous 72 hours
	DERNP7	Rainfall previous 168 hours
Timing	TIMBPK	Time to peak discharge

Table 10. -- Significant correlation coefficients for grouped storm characteristics versus event-mean constituent concentrations at Hampden[1/]

Constituent	Grouped storm characteristics				
	Volume	Duration	Intensity	Accumulation	Timing
Linear data					
Total suspended solids			0.92		
Total Kjeldahl nitrogen			0.97		
Total phosphorus					-0.60
Chemical oxygen demand					-0.51
Total organic carbon					
Total copper			0.80		-0.68
Total lead					-0.51
Total zinc					-0.52
Log-transform data					
Total suspended solids			0.87		
Total Kjeldahl nitrogen			0.88		
Total phosphorus					-0.54
Chemical oxygen demand					-0.57
Total organic carbon		-0.63			-0.53
Total copper					-0.74
Total lead					-0.62
Total zinc					-0.58

Note:

1/ Correlations are significant at the 0.95 or greater level.

Table 11. -- Significant correlation coefficients for grouped storm characteristics versus event-mean constituent concentrations at Reservoir Hill[1/]

Constituent	Grouped storm characteristics				
	Volume	Duration	Intensity	Accumulation	Timing
		Linear data			
Total suspended solids				-0.87	0.60
Total Kjeldahl nitrogen					
Total phosphorus		0.82			0.69
Chemical oxygen demand					
Total organic carbon					
Total copper					
Total lead					
Total zinc					
		Log-transform data			
Total suspended solids					0.72
Total Kjeldahl nitrogen					
Total phosphorus		0.81			0.73
Chemical oxygen demand	-0.89		-0.92		
Total organic carbon	-0.89				
Total copper					
Total lead					
Total zinc					

Note:

1/ Correlations are significant at the 0.95 or greater level.

Table 12. -- Significant correlation coefficients for grouped storm characteristics versus event-mean constituent concentrations at Bolton Hill[1/]

Constituent	Grouped storm characteristics				
	Volume	Duration	Intensity	Accumulation	Timing
		Linear data			
Total suspended solids			0.94		
Total Kjeldahl nitrogen					-0.66
Total phosphorus					-0.55
Chemical oxygen demand	0.77		0.88		
Total organic carbon					
Total copper		-0.68			-0.66
Total lead			0.84		
Total zinc					
		Log-transform data			
Total suspended solids	0.74	-0.77			
Total Kjeldahl nitrogen				0.79	
Total phosphorus					
Chemical oxygen demand					
Total organic carbon					
Total copper		-0.77			-0.58
Total lead					
Total zinc					

Note:

1/ Correlations are significant at the 0.95 or greater level.

In evaluating the correlations, certain results are expected: EMC's should increase with intensity and accumulation factors and decrease with volume and duration. Accumulation makes material available for washoff and intensity provides the energy required to transport it. EMC's decrease with increased volume and duration as the supply of available material in the watershed is exhausted and concentrations become diluted. It is expected that EMC's will decrease as timing increases. Longer times to peak are generally associated with frontal storms, which usually have lower rainfall intensities and peak discharges.

An investigation of tables 10 to 12 reveals that the storm characteristics that are significantly related to water quality vary considerably among the small catchments. Unfortunately, this suggests that a single strategy to control storm-water-quality problems may not work. For example, since intensities are found to be a significant factor at Bolton Hill, reduction of peak discharge using detention storage may reduce EMC's of total lead there, but not at the other two sites. However, it must be understood that correlation is an exploratory technique and does not necessarily determine cause and effect relationships. The development of strategies to control urban runoff will require the application of both simple techniques, such as correlation, and more sophisticated techniques, such as computer modeling. It will also require investigation of a large number of catchments, since any one may contain anomalies which could bias interpretation of the data. It is expected that this work will be done by NURP, using data from all 28 studies to formulate national or regional strategies to control urban runoff pollution.

Detention Storage in Reservoir Hill

The possible anomalous conditions mentioned in the last paragraph are evident in the Reservoir Hill catchment. The relationships found for EMC's versus total suspended solids and total phosphorus are opposite those which would normally be expected. For total suspended solids, EMC's decrease as more material accumulates and increase with longer times to peak. EMC's of total phosphorus also increase with timing and increase with longer storm durations. In addition, EMC's of chemical oxygen demand decrease as intensity factors increase, another anomaly. (An anomalous condition also exists in Bolton Hill where EMC's of total suspended solids and chemical oxygen demand increase with volume factors. This is not believed to be related to the effects discussed below, because there is no apparent detention storage in the catchment. Considerable sand-sized sediment buildup has been observed upstream of the flow-measurement flume, and is probably related to the anomaly.) The relationship with intensity and timing factors suggests that detention storage may be occurring since detention affects both peak discharge and time to peak. However, there are no detention structures (such as ponds) in the catchment. A further investigation of this phenomenon is desirable because the storage must be accounted for in any water-quality management strategy and could possibly have beneficial effects. If detention storage is actually occurring, then there should be noticeable effects on the storm characteristics related to the quantity of runoff as well as its quality.

Simple regression was used to study the relationship of TIMBPK, the time from beginning of rainfall to the peak discharge, to DURRNF, the duration of rainfall, and also some other storm characteristics relationships (table 13). The analysis indicates that Reservoir Hill peaks further into a storm than either Hampden or Bolton Hill. That is, the response time is longer. However, conventional hydrologic design analysis would determine that the response time of Reservoir Hill is shortest, based on watershed factors such as drainage area, slopes, and shape. This suggests that there is detention storage occurring in the catchment.

Alleys in Baltimore serve as primary conveyances of storm water to the sewer system. Piles of trash located in the alley waterways would significantly affect their hydraulic efficiency, with the result being detention storage. The piles could actually function as small dams, with water ponding behind them. This ponding has been observed in the field during storms. A likely scenario is that the trash piles break up with longer or larger storms. This breakup could account for the anomalies observed in the relationships between total suspended solids and total phosphorus EMC's and storm characteristics, where EMC's increased with longer storm durations and increased volumes at Reservoir Hill. If trash is providing detention storage, then there should be an inverse relationship between antecedent rainfall versus runoff duration and time to peak. Antecedent rainfall would help to break up the trash piles and reduce detention effects. Correlation analysis indicates significant inverse relationships, with correlation coefficients of -0.65 and -0.58 between 3-day antecedent rainfall versus runoff duration and time to peak, respectively.

Although analysis of water-quality and quantity data supports the theory that detention storage is occurring and affects both types of data, more work is needed to validate it. This is because the theory is based on a retrospective look at the data and the study was not specifically designed to look for detention storage effects. A definitive scientific assertion must be based on additional data. The importance of identifying the existence of detention storage effects is in management of water quality. For example, if the trash piles are acting as filters for contaminants being washed off by smaller storms, removal of the piles at strategic times, such as in late winter before larger spring storms occur, might improve water quality.

Table 13. -- Summary of bivariate regression equations between selected storm characteristics for three small catchments (All equations are significant at the 0.95 or greater level.)

$$Q = B\ (TRAINA)^A$$

Site	A	B	R^2
Hampden	1.42	0.439	0.95
Reservoir Hill	1.05	0.551	0.91
Bolton Hill	1.11	0.564	0.81

$$PEAKQ = B\ (MAXR15)^A$$

Site	A	B	R^2
Hampden	1.32	10.7	0.79
Reservoir Hill	1.24	9.06	0.74
Bolton Hill	1.35	16.6	0.70

$$DURSTO = B\ (DURRNF)^A$$

Site	A	B	R^2
Hampden	0.949	0.374	0.29
Reservoir Hill	0.612	5.94	0.31
Bolton Hill	0.821	1.35	0.56

$$TIMBPK = B\ (DURRNF)^A$$

Site	A	B	R^2
Hampden	1.11	0.0977	0.34
Reservoir Hill	0.986	0.454	0.53
Bolton Hill	0.992	0.301	0.58

Basin Characteristics

Significant differences were found between sites for event-mean concentrations of four constituents. Total phosphorus and total Kjeldahl nitrogen were higher at Reservoir Hill, and total lead and total copper were higher at Bolton Hill. While the exact sources of these high concentrations are not known, certain land use/land treatment factors are likely contributors.

At Reservoir Hill and Bolton Hill, extensive rehabilitation of 100-year-old housing is taking place with Bolton Hill being much further along. Rehabilitation techniques include removal of old paint, which tends to be lead-based in these neighborhoods, and acid cleaning of building facades. Either process could release metals to the street surface. In addition, rain gutters and downspouts in Bolton Hill are usually made of copper, and may be a source of copper. While significantly higher levels of copper were not detected at Reservoir Hill, EMC's were high compared to selected water-quality criteria (table 8). It is possible that differences do not yet exist, but may with continued renovation. Also, existing differences may be masked by the effects of the detention storage previously discussed.

The higher EMC's observed for the two nutrients at Reservoir Hill may be attributed to the general level of untidiness which predominates in the neighborhood. Although rehabilitating, it is still mostly an area of tenant housing with absentee landlords. There are many stray animals and some rat infestation, which may contribute to the nutrients through their feces. The streets are generally littered and unswept, and the alleys tend to be choked with piles of trash, both organic and inorganic.

QUALITY OF RUNOFF AT JONES FALLS NEAR MOUTH

Water-Quality Statistics

Tables 14 and 15 list descriptive statistics for both instantaneous and event-mean concentrations for the eight selected constituents at the Biddle Street site (main-stem Jones Falls). Total copper concentrations in base flow were always at or below detection, and are not included for base flow or in any comparisons with storm flow. Table 16 compares observed data with selected water-quality criteria. These criteria have been selected from the literature for comparison only because definitive water-quality standards do not generally exist for the constituents considered. As for the small catchments, the criteria considered are exceeded most of the time during storm flow. Base-flow concentrations of the nutrients exceed the criteria all of the time. Other constituents exceed the criteria during base flow less often, with the exception of lead, which never exceeded

Table 14. -- Descriptive statistics for instantaneous concentrations for Biddle Street base flow and storm flow

Constituent	N	Mean (mg/L)	Standard Deviation (mg/L)	Percentiles (mg/L)				
				10	25	50(median)	75	90
Base flow 1/,2/								
Total suspended solids	29	24.3	29.3	2.00	6.50	17.0	28.0	72.0
Total Kjeldahl nitrogen	26	3.04	1.77	.985	1.88	2.95	3.45	5.03
Total phosphorus	29	.504	.221	.270	.365	.510	.590	.810
Chemical oxygen demand	28	36.4	23.2	11.5	20.3	30.0	46.5	82.2
Total organic carbon	29	8.26	3.98	3.00	6.00	8.00	10.0	13.0
Total lead	28	.026	.015	3/.020	3/.020	3/.020	.024	.061
Total zinc	27	.023	.014	3/.005	.010	.020	.030	.040
Storm flow								
Total suspended solids	164	184	345	8.00	24.00	90.0	220	379
Total Kjeldahl nitrogen	141	10.9	11.6	2.20	5.25	7.80	11.5	21.0
Total phosphorus	162	1.31	1.63	.083	.430	.895	1.64	2.65
Chemical oxygen demand	129	135	125	32.0	51.0	110	176	260
Total organic carbon	163	19.7	18.9	3.60	7.40	14.0	28.0	40.8
Total copper	134	.058	.058	3/.010	.018	.040	.080	.120
Total lead	157	.165	.212	3/.020	3/.020	.090	.210	.470
Total zinc	133	.243	.247	.030	.060	.170	.325	.616

Note:

1/ Base-flow instantaneous concentrations are actually flow-weighted composites representing a one-day period, and are included here for comparison with storm-flow concentrations.
2/ Concentrations of copper in base flow were always at or below detection limits.
3/ Lower detection limit.

Table 15. -- Descriptive statistics for event mean concentrations observed for Biddle Street base flow and storm flow

Constituent	N	Mean (mg/L)	Standard Deviation (mg/L)	Percentiles (mg/L) 10	25	50(median)	75	90
Base flow[1]								
Total suspended solids	29	24.3	29.3	2.00	6.50	17.0	28.0	72.0
Total Kjeldahl nitrogen	26	3.04	1.77	.985	1.88	2.95	3.45	5.03
Total phosphorus	29	.504	.221	.270	.365	.510	.590	.810
Chemical oxygen demand	28	36.4	23.2	11.5	20.3	30.0	46.5	82.2
Total organic carbon	29	8.26	3.98	3.00	6.00	8.00	10.0	13.0
Total lead	28	.026	.015	[2].020	[2].020	[2].020	.024	.061
Total zinc	27	.023	.014	[2].005	.010	.020	.030	.040
Storm flow								
Total suspended solids	16	199	175	45.7	87.4	148	305	483
Total Kjeldahl nitrogen	16	8.78	5.04	2.08	5.85	7.92	11.7	17.4
Total phosphorus	16	1.29	1.02	.433	.543	.733	2.22	3.13
Chemical oxygen demand	16	155	222	31.5	48.7	82.8	173	478
Total organic carbon	16	18.8	10.5	6.85	10.2	14.8	31.7	33.1
Total copper	15	.0487	.0344	.0183	.0221	.0403	.0499	.121
Total lead	15	.162	.134	.047	.061	.121	.219	.417
Total zinc	15	.185	.164	.046	.068	.110	.271	.492

Notes:

1/ Concentrations of copper in base flow were always at or below detection limits.
2/ Lower detection limit.

Table 16. -- Comparison of observed data to selected water-quality criteria at Biddle Street

Constituent	Criteria 1/ (mg/L)	Percentage of observations exceeding criteria: Base flow	Storm flow
		Instantaneous Concentrations	
Total suspended solids	2/ 30	25	73
Total Kjeldahl nitrogen	3/ 0.074	100	100
Total phosphorus	3/ 0.069	100	93
Total organic carbon	4/ 10	25	65
Total copper	5/ 0.022	7/ -	70
Total lead	5/ 0.17	0	33
Total zinc	5/ 0.32	0	26
		Event-Mean Concentrations	
Total suspended solids	2/ 30	25	100
Total Kjeldahl nitrogen	3/ 0.074	100	100
Total phosphorus	3/ 0.069	100	100
Total organic carbon	4/ 10	25	75
Total copper	6/ 0.0056	7/ -	100
Total lead	6/ 0.0038	100	100
Total zinc	6/ 0.047	7	89

Notes:

1/ No criteria have been established for total Kjeldahl nitrogen, total phosphorus, chemical oxygen demand, or total organic carbon; the listed values have been selected from the cited literature for comparison, except for chemical oxygen demand, for which no comparisons were found.

2/ USEPA, 1976; secondary sewage effluent limitation, mean for 30 days of consecutive sampling.

3/ Sylvester, 1961; mean concentration for three streams draining forested watersheds.

4/ Malcolm and Durum, 1976; typical concentration for non-polluted U.S. streams under normal flow conditions.

5/ USEPA, 1980; acute exposure limit for fresh-water aquatic life assuming hardness of 100 mg/L as $CaCO_3$.

6/ USEPA, 1980; chronic exposure limit for fresh-water aquatic life assuming hardness of 100 mg/L as $CaCO_3$.

7/ Concentrations of copper in base flow were always at or below detection limits.

instantaneous criteria but always exceeded event-mean criteria. In general, an investigation of table 16 reveals that urban storm-water runoff quality is significantly degraded, and base flow is somewhat degraded, with respect to the criteria considered.

An analysis of variance was made to determine if the differences observed are significant between storm flow and base flow. The same procedures were used as for comparisons between the small catchments. Based on a Shapiro-Wilk test statistic, a normal distribution of the data was found to be likely for both linear and log-transform data, so analyses of variance were made for both cases. A Kruskal-Wallis nonparametric procedure was also used. All aforementioned analyses indicated that base-flow and storm-flow data are significantly different for all selected constituents.

Impact of Storm Water on Quality of Jones Falls

To assess the impact of storm-water runoff on water quality, the relative portion of total annual load contributed by storm water is estimated. Two independent approaches to load estimation are used. First, a semi-quantitative procedure is used to estimate annual loads of selected constituents in storm water as a percentage of total annual load. The relative mean concentrations in base flow and storm flow are weighted by the percentages of total annual flow as base flow and storm flow, respectively. These percentages were estimated by using the average of 29 base-flow sampling discharges as the mean base flow for 2 years of continuous streamflow record. In the second approach, daily loads are estimated using a one- or two-parameter regression equation. Either daily-mean flow or daily-mean flow and 3-day antecedent precipitation are the independent variables. Separate equations are used for base flow and storm flow. Criteria for assigning storm flow or base flow are the same as for defining the beginning and ending of a sampled storm. The sum of daily loads as base flow and storm flow produces estimates of total annual load and the relative contributions of storm flow and base flow.

It is important to note that the simplified regression model selected will generally not produce the most accurate results. The addition of independent variables will most likely increase the correlation coefficient and decrease the magnitude of error terms for the regression model. However, the model would become increasingly harder to use. The independent variables selected, daily-mean flow and antecedent precipitation, are easy to determine from existing long-term data networks.

The semi-quantitative approach is illustrated in table 17. The results indicate that about 60 percent of the total annual loads of total Kjeldahl nitrogen, total phosphorus, and total organic carbon are

Table 17. -- Semi-quantitative approach to estimating contribution of storm water to annual constituent loads at Biddle Street

General equation:

$$\text{PERCENT} = \frac{C_s\,(Q_s)}{C_s(Q_s) + C_b(Q_b)} \times 100$$

where: PERCENT = percentage of mean annual constituent load contributed by storm water.

C_s, C_b = flow-weighted mean annual constituent concentration in storm flow and base flow, respectively, in milligrams per liter.

Q_s, Q_b = percentage of mean annual flow as storm flow and base flow, respectively (39 and 61 percent, based on 2 years of record; mean base flow = average flow for 29 base flow samples).

Constituent	C_s	C_b	Percent
Total suspended solids	199	24.3	84
Total Kjeldahl nitrogen	8.78	3.04	65
Total phosphorus	1.29	0.504	62
Chemical oxygen demand	155	36.4	73
Total organic carbon	18.8	8.26	59
Total lead	0.162	0.026	80
Total zinc	0.185	0.023	84

contributed by storm water. More than 70 percent of chemical oxygen demand and more than 80 percent of the loads of total suspended solids and metals are delivered by storm water. The regression approach gave similar percentages, although they were about 7 to 12 percent higher. Table 18 summarizes the regression equations derived, and table 19 compares the results of the two approaches. Table 19 also includes estimates of the total annual load and the storm-flow annual load in pounds per acre for calendar year 1981. The error associated with these estimates is a function of both the uncertainty in the regression equation and the input variables. The errors in predicting daily loads are estimated to range from about 150 to 500 percent of the mean daily loads of the seven constituents, with errors for base flow towards the lower end of the range. The errors in estimating annual loads are not known, although they are probably less than the daily errors. This is because the cumulative positive and negative errors of the daily predictions should cancel each other to some degree. Also, the daily error estimates are based on the maximum expected error in the daily discharge. This site was a short-term station established solely for this project. Because of difficult physical conditions at the site and the short period of record, uncertainties persist in the data. The daily discharge records are rated poor (Water Resources Data, Maryland and Delaware, Water Year 1982), which signifies that the daily means may be more than 15 percent in error.

Even though the annual load estimates (table 19) are only very approximate, they were compared with annual loads contributed by the Susquehanna River, the single largest input of fresh water to the Chesapeake Bay. The Susquehanna River enters the Bay about 30 mi upstream of Baltimore Harbor (fig. 1) and its watershed is approximately 35 percent agricultural, 60 percent forested, and 5 percent urban. Susquehanna River loads of total Kjeldahl nitrogen, total phosphorus, and total organic carbon for April 1980 through March 1981 (Lang, 1982) were compared with those for calendar year 1981 from Jones Falls. Regional rainfall was about the same for both time periods. Results indicate that the loads in pounds per acre per year were about 10, 9, and 3 times greater from the Jones Falls watershed for the three constituents, respectively. The annual loads (total pounds) of total Kjeldahl nitrogen and total phosphorus from Jones Falls are about 2 percent of those from the Susquehanna. Annual loads of total organic carbon are about one percent of those from the Susquehanna.

Table 18. -- Summary of regression equations for estimating daily loads for seven selected constituents at Biddle Street (All equations are significant at the 0.95 or greater level.)

General form of equation:

$$LOAD = A(Q_d) + B(P3) + C$$

where: LOAD = daily constituent load, in pounds;

Q_d = mean daily discharge, in cubic feet per second;

P3 = rainfall accumulation, in inches, during the three previous calendar days;

A,B,C = regression coefficients.

Constituent	Base flow					Storm flow 1/				
	A	B	C	R^2	SEE 2/	A	B	C	R^2	SEE 2/
Total suspended solids	89.9	5050	106	0.39	95	2150	0	-123,000	0.58	106
Total Kjeldahl nitrogen	8.99	0	251	0.24	49	55	0	-2,000	0.86	44
Total phosphorus	3.69	0	-38.0	0.55	51	9.76	0	-529	0.55	110
Chemical oxygen demand	102	0	3070	0.25	45	488	0	38,200	0.20	118
Total organic carbon	47.7	0	-176	0.55	43	118	0	-4,340	0.70	70
Total lead	0.108	0	1.15	0.26	57	0.505	0	23.8	0.57	59
Total zinc	0.0848	1.36	1.19	0.24	71	0.798	0	14.8	0.69	52

Notes:

1/ Any flow which exceeds 125 percent of previous base flow is designated as storm flow.

2/ Standard error of estimate as a percentage of the mean.

Table 19. -- Estimates of storm-water contribution to annual loads of seven selected constituents at Biddle Street using two approaches

Constituent	Percentage of annual load contributed by storm water		Estimate of annual load by regression approach (pounds per acre)	
	Semi-quantitative approach	Regression approach	Storm flow	Total
Total suspended solids	84	93	488	523
Total Kjeldahl nitrogen	65	77	14.7	19.2
Total phosphorus	62	74	2.27	3.06
Chemical oxygen demand	73	83	259	311
Total organic carbon	59	71	31.5	44.0
Total lead	80	87	0.234	0.274
Total zinc	84	90	0.316	0.352

CONCLUSIONS

1. Storm-water-runoff quality from the three small catchments is significantly degraded with respect to water-quality criteria. No significant differences exist among the sites for event-mean concentrations (EMC's) of total suspended solids and total organic carbon. EMC's of total Kjeldahl nitrogen and total phosphorus are significantly higher at Reservoir Hill than the other two sites. Total lead and total zinc EMC's are significantly higher at Reservoir Hill and Bolton Hill than at Hampden. Total copper EMC's are significantly higher at Bolton Hill than the other two sites.

2. Storm-water runoff contributes a significant percentage of the total annual loads of seven constituents to Jones Falls. More than 60 percent of total Kjeldahl nitrogen, total phosphorus, and total organic carbon, more than 70 percent of chemical oxygen demand, and more than 80 percent of total suspended solids, total lead, and total zinc are delivered by storm water. The water quality of both storm flow and base flow is significantly degraded when compared to accepted water-quality standards and criteria.

3. There are significant relationships between some storm characteristics and EMC's. However, no generalities can be made concerning the relationships between EMC's and storm characteristics. For any given constituent, there is no uniform relationship among sites.

4. The data indicate that detention storage is occurring in the Reservoir Hill watershed. This is believed to be caused by the presence of piles of trash in the alley waterways and is likely causing significantly higher loads of total phosphorus and total Kjeldahl nitrogen. Additional work is suggested to confirm this theory.

5. The influence of basin characteristics upon water quality could not be quantified. Therefore, the results of this study should only be transferred to watersheds that are very similar to those studied here. Results from the three small catchment sites were too variable to justify extensive extrapolation of the data and results.

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