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ANALYSIS AND CHARACTERIZATION OF URBAN STORM-WATER RUNOFF FOR SELECTED BASINS IN THE BALTIMORE, MARYLAND, METROPOLITAN AREA-- A PROJECT PLAN

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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 International System (SI) of metric units.

To convert from	Multiply by	To obtain
inch (in.)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
gallon (gal)	3.785	liter (L)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)

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ABSTRACT

The Jones Falls Urban Runoff Project (JFURP), one of 28 study locations in the Nationwide Urban Runoff Program (NURP) of the Environmental Protection Agency, is a cooperative effort by the State of Maryland Regional Planning Council (RPC), Baltimore City, Baltimore County, and the U.S. Geological Survey (USGS). The JFURP study will concentrate on determining the characteristics of storm-water runoff at five representative urban watersheds (less than 20 acres) and its impact on three receiving waters within the Jones Falls drainage basin. Drainage areas for the receiving water sites range in size from 3 to 59 square miles.

By agreement between RPC and USGS, each agency will operate four sites. Equipment for the three USGS small catchment sites was designed to fit hydrologic response conditions expected at each site and to perform automatically with backup capability. The site, on Jones Falls near its mouth, is equipped with the USGS Urban Hydrology Monitoring System, which has automatic sampling capability. An effort has been made to have storm sampling at all sites compatible with other NURP studies, while also directly addressing the specific hydrologic conditions in the Baltimore area. Water samples collected during dry-weather conditions and storms are being analyzed for 31 chemical, physical, and biological parameters at varying frequencies.

Other programs in the JFURP study include: (1) Monitoring variations in base-flow characteristics, (2) identifying sources of contamination to the receiving waters, (3) atmospheric deposition sampling, (4) street-surface sampling, (5) priority-pollutant sampling, (6) quality assurance and control, (7) microbiological sampling, and (8) evaluating control measures in reducing contamination from urban nonpoint sources.

A data management system designed by the USGS's Urban Hydrology Studies Program will be used to relate quantity and quality characteristics of storm-water runoff to watershed characteristics. Findings from study watersheds will be extrapolated to unsampled watersheds in the metropolitan area by regression equations and selected models.

INTRODUCTION

The Baltimore metropolitan area, one of the Nation's oldest urban areas, was chosen as one of 28 locations to participate in the Nationwide Urban Runoff Program (NURP) of EPA. The major goals of the program are to assess effects of urban runoff on the quality of receiving waters and to evaluate methods for controlling urban non-point source pollution.

The Baltimore NURP study, which concentrates on the Jones Falls watershed (fig. 1), is a cooperative effort by the Regional Planning Council, Baltimore City Department of Public Works, Baltimore County Department of Public Works, and the U.S. Geological Survey. The Jones Falls watershed (fig. 1), one of four drainage basins that intersect the Baltimore metropolitan area and part of the Patapsco River Basin of central Maryland, is composed of highly urbanized sections of Baltimore City and the more rural, agricultural, and developing areas of Baltimore County. In the southern one-third of the watershed, the Jones Falls drains areas typical of the following land uses: all densities of residential, commercial, industrial, institutional, as well as undeveloped areas. Baltimore is distinctive in being the first large city in the United States to construct a separate sewer system for sanitary and storm-water flows. About 90 percent of the population of the city used the sanitary sewer system by 1920. There are, however, numerous industrial waste connections and sanitary sewer overflows that discharge directly into the urbanized part of the Jones Falls and directly contribute to its generally poor water quality.

The Jones Falls ultimately discharges into Baltimore harbor, the water quality of which has been severely degraded in past years. A major urban revitalization and renewal program, which is using the harbor as a focal point, is stressing the cleanup of degraded and(or) abandoned neighborhoods and commercial sections throughout the Jones Falls watershed. One of the major goals of this program is to improve the quality of the harbor for water-related recreation.

Previous Studies

As mandated by amendments to the 1972 Federal Water Pollution Control Act and the 1977 revisions to this act, the Nation's waters are to be cleaned up or be adequately protected by 1985. Under this mandate, the Regional Planning Council was given the authority by the State of Maryland to make a "208" planning study for the Baltimore Region, which included the Jones Falls watershed. In 1978, some water-quality and quantity data were collected for storm-water runoff from small watersheds having various land uses (agricultural-rural to high-density residential) and from wet- and dry-weather sampling of the main stem of Jones Falls and selected tributaries (Regional Planning Council, written commun., 1980). The major water-quality problem identified by this study was the presence of high contaminant loadings of metals, bacteria, and nutrients in Jones Falls, 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-commercial discharges, and (3) permitted overflows and unknown connections from industrial and domestic sanitary sewers.

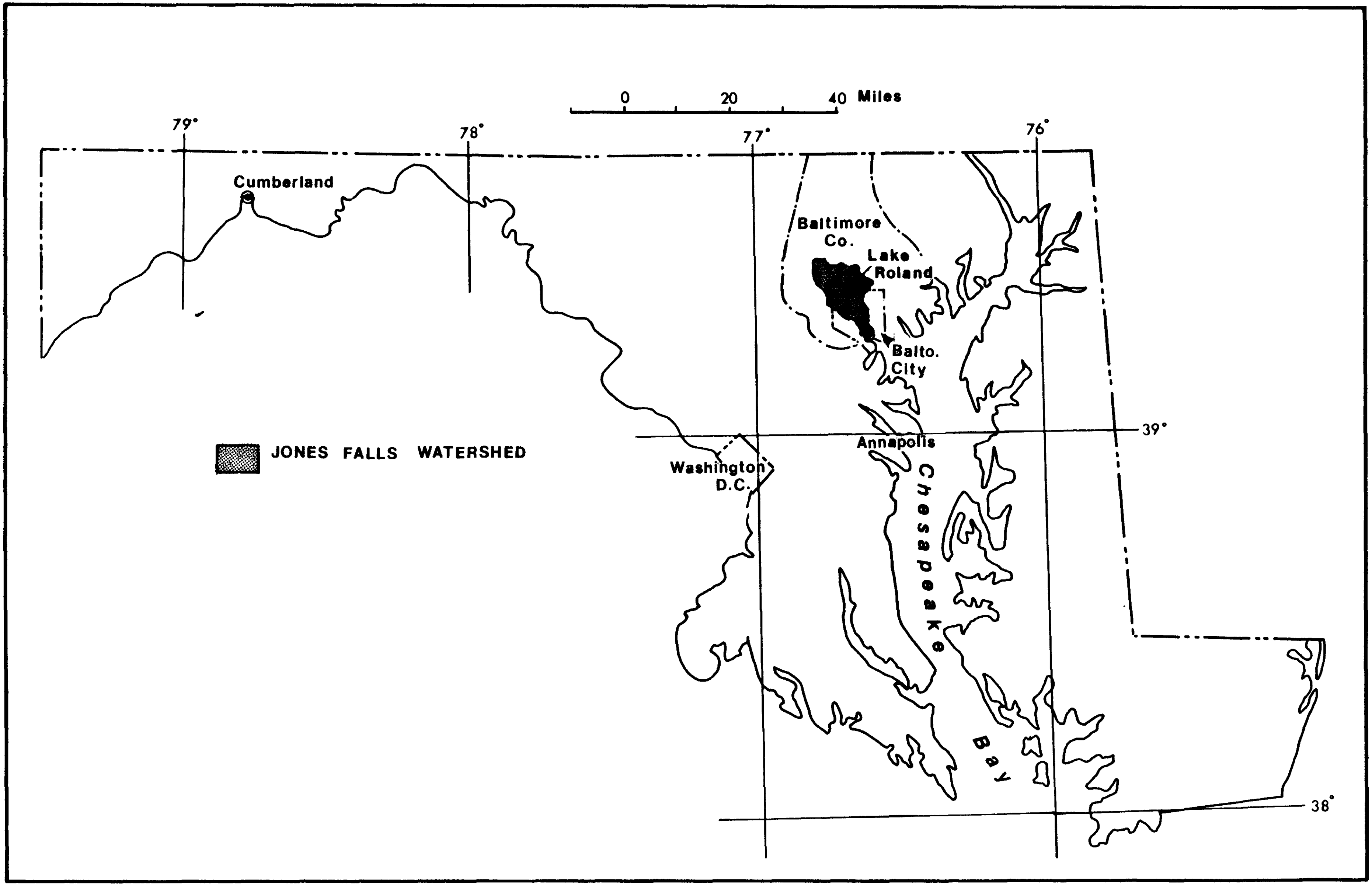

Figure 1. Location of Jones Falls watershed, Maryland.

In a related study, Olivieri and others (1977) found high levels of both pathogenic and indicator organisms in storm-water runoff in Baltimore City. The presence of pathogens in the runoff was found not to be related to season, amount of rainfall, period of antecedent rainfall, or stream discharge. Furthermore, there was either a poor or nonexistent correlation between indicator organisms and pathogens in storm-water runoff.

Description of Study Area

The Jones Falls watershed, part of the Patapsco River basin, encompasses 59 mi^2 in the Baltimore area 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 total land area in this section.

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

The Coastal Plain province is made up of unconsolidated layers of sand, silt, clay, and gravel overlying metacrystalline rocks. The eastern part of the study area in the Piedmont province is characterized mostly by metamorphic rocks such as gneiss, schist, and marble, and some granitic and gabbroic rocks. The western part contains slightly metamorphosed limestone, sandstone, and shale.

The climate is generally one of warm summers and mild winters. The coldest period is usually in late January and early February and the warmest in the last half of July and early August. Monthly precipitation is distributed fairly uniformly throughout the year, and the average yearly precipitation is 45 in. Long-duration storms occur predominantly during the cold season (December through March). However, average precipitation intensities are highest in June, July, August, and September (0.08 - 0.13 in./hr), whereas the lower intensity storms usually occur in December through April (0.03 - 0.05 in./hr).

During cold weather months, prevailing winds are from the west to northwest. Warm weather winds are usually evenly distributed with regard to magnitude and frequency, although southerly winds predominate during warm months. The average annual wind speed is about 10 mi/hr, with the highest frequency of winds between late winter and early spring.

OBJECTIVES

The objectives of the Jones Falls Urban Runoff Project (JFURP) reflect an integration of local problems and the goals of the Nationwide Urban Runoff Program. Specifically, these include (1) identifying sources and magnitude of contamination, (2) assessing non-point source impact on the receiving waters (Jones Falls and Baltimore harbor), (3) identifying contaminant transport in stream water, (4) assessing effectiveness of control measures in reducing contamination by urban non-point sources, and (5) calibrating computer modeling methods for estimating and predicting storms and seasonal and annual loadings of critical water-quality constituents and to apply these methods to unsampled watersheds in the Baltimore area.

APPROACH

Site Selection

To study urban runoff successfully in a city the size of Baltimore, careful site selection and realistic planning are necessary. Because it is impossible to observe all urban streams for all water-quality constituents and discharge, sites must be chosen that are representative of the major land uses (residential, commercial, industrial) in Baltimore.

Observation sites were selected in the spring of 1980, after numerous meetings and conversations with State, city, and county engineers and planners, and extensive field reconnaissance. The following criteria were used to select small catchments (subbasins less than 25 acres) of different land-use character (residential, commercial, industrial):

1. The site located so that flow observation and representative water-quality sampling are feasible.

2. The contributing catchment area yields sufficient runoff for sampling.

3. Catchment runoff has a single drainage channel--one point of sampling.

4. The runoff at the site is not affected by illegal sanitary connections, broken pipes with exfiltration, or point discharges of any type.

5. The site has minimal vandalism potential.

6. Land-use type represents a predominant land use in the Jones Falls watershed and the greater Baltimore area.

7. The catchment is large enough so that specific land use can be detailed and activities observed.

8. The site has average physiographic characteristics; for example, topography, street slopes, etc.

9. The catchment in which the site is located is slated for major change(s) in management practices so that its (their) effect can be observed and evaluated.

It was nearly impossible to find small homogeneous catchments in Baltimore City that perfectly met all the above criteria. Although it was highly desirable, a sufficiently large catchment could not be found with manageable point-discharge contributions and clearly defined flow patterns and basin boundaries in the downtown, commercial section. Trade-offs were made between criteria based on the relative impact each criteria would have on the potential success of the project in meeting the stated objectives. Criteria 1 to 3 were considered to be essential. Criteria 4 to 9 affect to a greater or lesser degree the quality, quantity, and transfer value of the results.

Sites were chosen to observe receiving waters (perenially flowing streams that also receive storm-water runoff from catchments and other small drainage areas) during wet and dry weather in the urbanized part of the Jones Falls watershed. The following criteria were used to select sites for receiving water observation:

1. The site located so that it is representative of stream conditions in the drainage area and so that changing conditions can be characterized seasonally and annually.

2. The site is relatively easily accessible to sampling crews, yet have low vandalism potential.

3. Accurate flow measurements and continuous observation of stage is feasible.

4. Site is representative of major land uses and activities in the drainage basin.

5. Site is far enough downstream from major inputs to allow proper mixing distance.

6. Drainage area and demographic and physiographic characteristics are known.

The three receiving-water sites that were chosen (table 2) meet all the above criteria. The main-stem site on Jones Falls near the harbor, hereafter referred to as Biddle Street site, will give valuable information as to the types, magnitude, and characteristics of contaminant loadings to the Baltimore harbor from virtually the entire Jones Falls watershed. Stony Run is a major tributary to Jones Falls, and land use in its basin is characteristic of medium- to high-density residential.

The third receiving water site, Lake Roland (fig. 1), was chosen for two main reasons. First, the potential value of the lake as a means for water-quality management, such as a detention pond, will be explored. Second, because most of the watershed above Lake Roland is rural, data from storms and base flow at Lake Roland should provide a control for comparison with urban-influenced stream water collected at the downstream site on Jones Falls.

Table 1 summarizes the characteristics of each of the five small catchment sites selected. The physical characteristics of the drainage basins for the receiving-water sites are summarized in table 2. The locations of the five small catchment sites and the three receiving-water sites are shown in figure 2. There are five automatic wetfall/dryfall sampling sites around Baltimore (fig. 2). In addition to the tipping-bucket rain gages at each of these sites, there will be eight (supplemental) rain gages at other various locations in the metropolitan area (fig. 2). As part of a mutual agreement between the Regional Planning Council and the USGS, each agency will maintain and operate four storm-water monitoring sites. The USGS stations include the Biddle Street site and three small catchment sites: Bolton Hill, Reservoir Hill, and Hampden (fig. 2). The following sections of the report regarding instrumentation, data collection, laboratory analysis, quality assurance, and data management and analysis refer to these four USGS stations.

Instrumentation

The philosophy in designing the instrumentation systems has been to make them completely automatic and to incorporate fail-safe systems wherever possible. Both of these design features are essential to completing the sampling program successfully. Particular emphasis has also been placed on (1) the hydrologic response characteristics of each site, and (2) obtaining data in a form suitable for automatic data processing. The selected instrumentation requires a minimum of manpower for operation and attendance during storms.

Table 1.--Characteristics of small catchments being sampled in the JFURP study

[Data on drainage area, general land use, dwelling units, and population from Regional Planning Council, written commun., 1981]

Site name and downstream order No.	Sampling site		Drainage area		General land use and topography	Dwelling units per acre	Population in catchment
	Latitude	Longitude	acre	mi^2			
Bolton Hill 01589475	30°18'29"	76°37'31"	14.0	0.0219	95 percent high-density residential; 5 percent parkland. Pervious-impervious area not determined. 100 percent of streets with curbs and gutters. Mean slope is 3.18 percent.	9	415
Hampden 01589460	39°19'42"	76°37'52"	17.0	0.0265	72 percent high-density residential; 28 percent commercial. Pervious-impervious area not determined. 100 percent of streets with curbs and gutters.	19	681
Reservoir Hill 01589470	39°18'48"	76°37'52"	10.4	0.0163	100 percent high-density residential. 90 percent impervious area. 100 percent of streets with curbs and gutters.	13	577
Homeland 01589462	39°21'18"	76°37'08"	23.0	0.0359	100 percent low-density residential. Pervious-impervious area not determined. 100 percent of streets with curbs and gutters.	½ to 2	204
Mt. Washington 01589455	39°21'41"	76°40'43"	16.6	0.0259	84 percent medium-density residential; 16 percent parkland. Pervious-impervious area not determined.	3 to 8	195

Table 2.--Characteristics of drainage basins for receiving-water sites being sampled in the JFURP study

[Data on general land use of basin from Regional Planning Council, written commun., 1981]

Site name and downstream order No.	Sampling site		Drainage area		General land use of basin
	Latitude	Longitude	acre	mi^2	
Biddle Street (Jones Falls near mouth) 01589480	39°18'12"	76°36'43"	33,978	53	44 percent residential. 13 percent commercial, industrial, and semi-public. 4 percent institutional. 12 percent agricultural. 23 percent woodlands. 4 percent vacant land.
Lake Roland 01589452	39°22'41"	76°38'36"	22,142	35	36 percent residential. 8 percent commercial, industrial, and semi-public. 4 percent institutional. 19 percent agricultural. 30 percent woodlands. 3 percent vacant and open space.
Stony Run 01589465	39°19'28"	76°37'34"	2,047	3.2	72 percent residential. 8 percent institutional. 11 percent commerical, industrial, and semi-public. 6 percent agricultural. 4 percent vacant and open space. 5 percent woodlands.

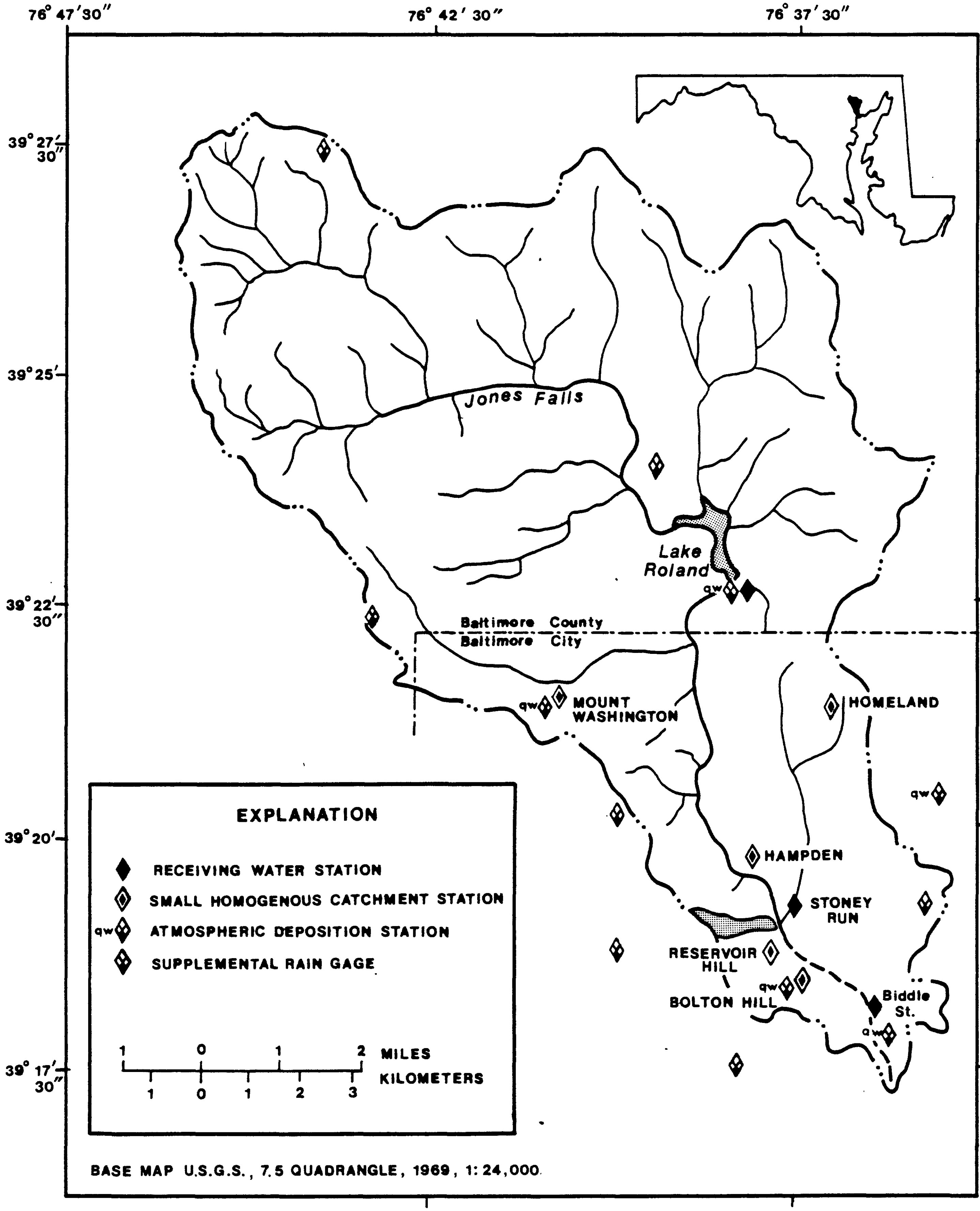

Figure 2. Location of JFURP supplemental raingage network, and sites for monitoring small catchments, receiving waters, and wetfall/dryfall.

Urban Hydrology Monitoring System

The Urban Hydrology Monitoring System (UHMS) has been developed by the U.S. Geological Survey specifically for studies of urban-runoff quality and quantity. This system will be used at the Biddle Street site. The UHMS is versatile in that it can be programmed to the user's specific need. It provides a continuous record of discharge on a paper-tape digital recorder and automatically collects water samples during storms in a programmed sequence. The system is shown schematically in figure 3 and is described below:

A. System Control Unit (SCU) - processes data and controls sampler.

1. Scans input data at 5-minute intervals.

2. Labels each data scan with time and date.

3. Makes decisions for automatic sampler control based on input-stage data and computed discharge. Provides signals to automatic sampler to take water samples.

4. Formats all data and sampler status information for output to the digital recorder.

B. Sampler - collects and stores water samples during storms.

1. Collects 5-gallon flow-weighted composite sample or twenty-four 3-liter discrete samples.

2. Maintains temperature of water sample at 4°C in a companion chest-type freezer.

C. Servo-manometer bubbler gage (with potentiometer tap) - senses stream or pipeflow stage and provides input to the SCU and a digital recorder (item D below).

D. Digital recorder - records stage on a punched paper tape at a 5-minute interval.

E. Digital recorder (modified for digital input) - records output from the SCU.

In the event of main (110 VAC) power failure, all electrically operated devices have automatic battery backup. In addition, if the SCU or its recorder fails, a duplicate record of stage is available (item D above). The servo-manometer bubbler gage uses pressurized gas and is not dependent on electrical power.

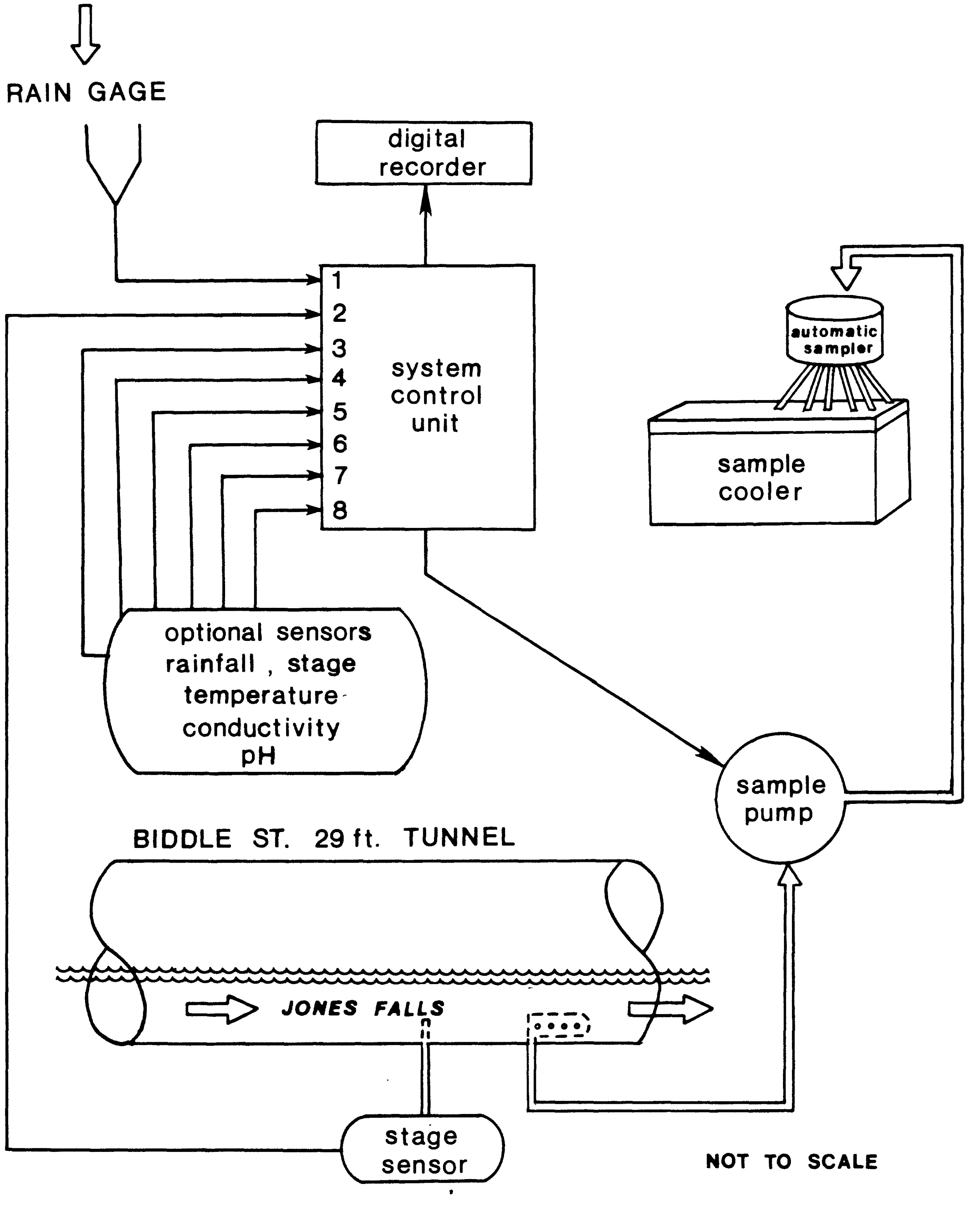

Figure 3. Urban hydrology monitoring system being used at the Biddle street site on Jones Falls (modified from U.S. Geological Survey and U.S. Enviromental Protection Agency, 1980).

Small Catchment Monitoring System

The purpose of the Small Catchment Monitoring System (SCMS) is to collect data on the quantity of rainfall and the quantity and quality of storm-water runoff from a small catchment. This system provides a record of rainfall and runoff during storms and automatically collects water samples at pre-selected intervals of flow and(or) time. The system is shown schematically in figure 4 and is described below:

A. Tipping-bucket rain gage - activates data-acquisition system and provides measurement of rainfall quantity.

1. First tip of bucket corresponds to beginning of storm and activates data-acquisition system.
2. Bucket tips provide momentary contact closure for each 0.01 in. of precipitation.
3. Rainfall accumulator totalizes bucket tips and outputs an analog voltage proportional to cumulative rainfall.

B. Actuator - turns on flowmeter.

1. Sensor for actuator is set in a cup, which collects rainfall. When depth of rainfall reaches a point of runoff, the device will turn on the flowmeter, which, in turn, controls the samplers.
2. Generally, the actuator is set to respond to 0.03 in. of rainfall.

C. Flowmeter - provides record of flow during storms and signals automatic sampler to collect samples.

1. Flowmeter remains dormant until activated by actuator.
2. Stage is sensed by bubbler gage and electronically converted to flow by a programmed rating curve.
3. Flow is recorded on a 4-in.-wide strip chart at a speed of two or four in./hr.
4. Analog voltage output proportional to flow is provided by an interface between the flowmeter and the digital recorder.
5. Sampling initiation signals (12 VDC pulse) are provided to samplers at specified interval of flow. Sampler signal is converted to a contact closure starting the primary sampler by an interface between the flowmeter and sampler. When either sampler begins a sampling cycle, an event mark is made on the strip chart.

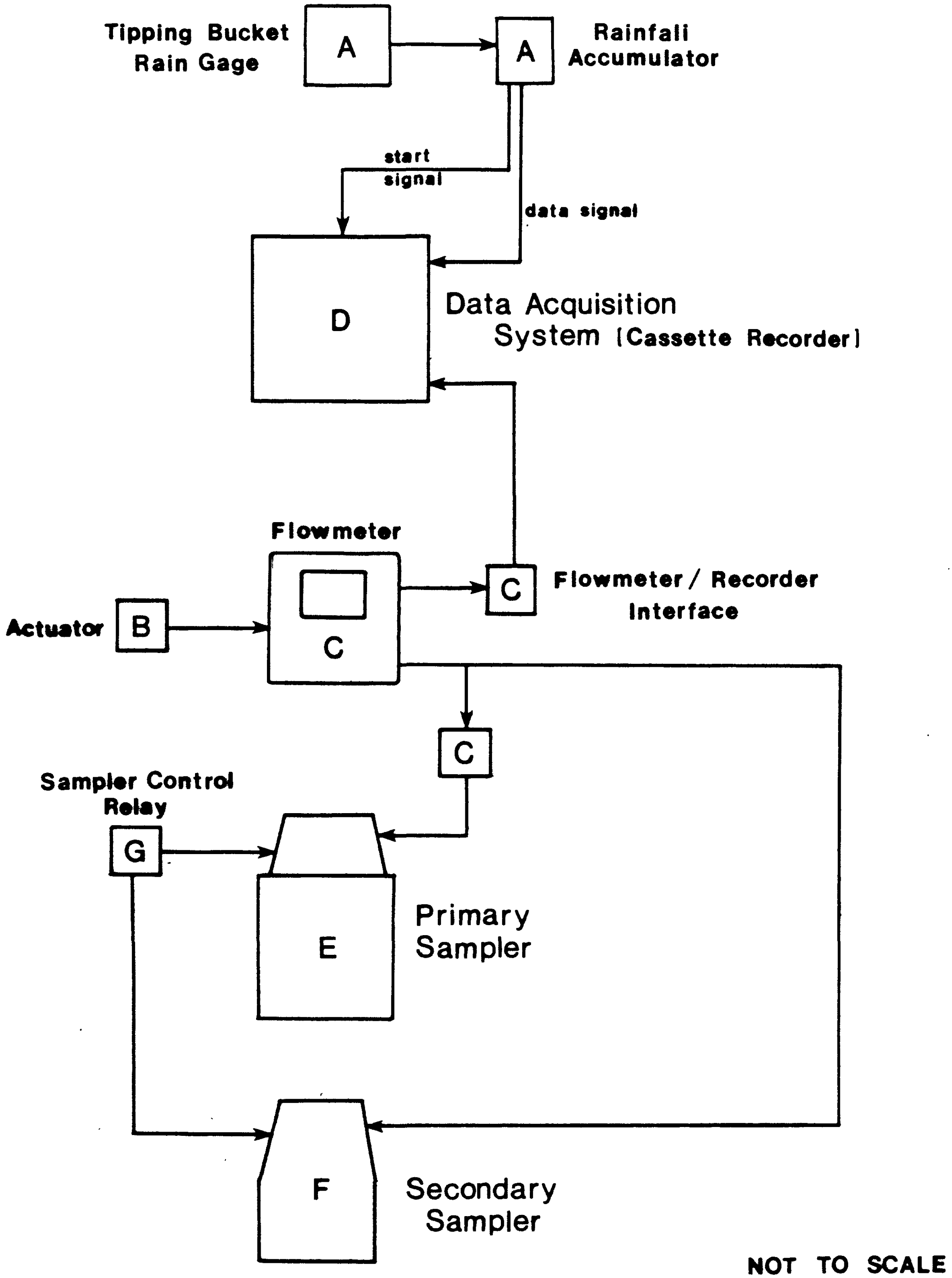

Figure 4. Monitoring system being used at small-catchment sites.
(refer to text for explanations of letters A - G)

D. Data-acquisition system - does analog/digital conversion and stores data on cassette tape.

1. Unit remains dormant until activated by first tip of tipping-bucket rain gage. Internal clock runs continuously.

2. Time and date are recorded with flow and rainfall data, and an event mark is made when the primary sampler begins its sampling cycle.

E. Sampler (primary) - collects and stores discrete or composite water samples automatically during storms.

1. Up to 24 discrete water samples are collected with a volume of up to 1 liter, or a single composite 5-gal sample when signals are received from the flowmeter.

2. An event mark is sent to the data-acquisition system (cassette recorder) and to the flowmeter strip chart when the sampler begins its sampling cycle.

3. Water samples are maintained at 4°C by an associated 110-120 VAC-powered refrigerator unit.

F. Sampler (secondary) - backup system to collect and store discrete or composite water samples during storms.

1. Sampler is activated by a sampler control relay (item G below) during power failure or when primary sampler has filled a complete rack of bottles.

2. Up to 24 discrete water samples are collected with a volume of up to 1 liter, or a single 5-gal sample when signals are received from the flowmeter.

3. An event mark is sent to the flowmeter strip chart when the unit takes a water sample.

4. Sampler is not refrigerated; however, ice placed in base will chill samples to about 4°C.

G. Sampler Control Relay - switches to secondary sampler in the event of a main power failure because primary sampler will not run on battery power. If main power is re-established during storm, secondary sampler continues to operate.

In the event of main (110 VAC) power failure, automatic backup capability has been designed into the SCMS. Every device in the system, except the primary sampler and the interface between flowmeter and the cassette recorder (fig. 4), will automatically switch to battery power if main power is disconnected. The sampler control relay will switch to the secondary sampler, which will run on battery power. The flowmeter strip chart will provide a flow record and event marks when samples are taken.

Other backup capabilities exist in the event of equipment failures. There is independent recording of flow rate and primary sampler event marks on both the strip chart and cassette tape. Also, the precipitation gaging network of 12 sites, described in the section "Atmospheric Data Collection" and shown in figure 2, allows any missing rainfall records to be synthesized by interpolation techniques.

Data Collection

Preliminary Water Sampling of Jones Falls at Biddle Street Site

To quantify the variability of flow and chemical constituents due to depth, width, and diurnal cycles at the Biddle Street site, an intensive program of dry-weather and storm-event sampling is proposed. This information will be helpful in determining whether samples taken at one location in the channel cross-section are representative of the water quality over the width and depth of the channel at that location.

The following sampling procedure is being used during a period of base flow and during a moderate rainstorm to test for instream variability of flow and chemical constituents. A line perpendicular to streamflow (sampling bridge, fig. 5) is established at the approximate location of the sampler intake. At approximately 2-ft intervals in the channel cross-section, water depth and velocity are measured by wading rod and current meter. At the midpoint of each interval, a 1-liter water sample is taken at 20 percent and 80 percent of the total depth, resulting in a total of six samples. Water samples will be taken simultaneously by an automatic water sampler.

Before taking the first stream-water sample, 1 liter of distilled water is drawn through the sampler to flush the tubing. After flushing, a 1-liter sample of distilled water is pulled through the sampler tube, and this sample is used for background measurements. After the final stream-water sample is taken, another 1-liter sample of distilled water is passed through the sampler and used to measure any contamination from sample to sample.

Dissolved oxygen, temperature, specific conductance, and pH will be measured in the stream water at each sampling point by a four-parameter meter.

To identify any diurnal cycles in Jones Falls, the entire sampling program, including measuring stream velocity, collecting water samples, and measuring field parameters, is repeated every 4 hours over a 24-hour period. The second and fifth set of samples are collected as duplicates, and the results will be used as a check on automatic sampling methods. After each 12-hour shift, the samples are packed in ice and delivered to the laboratory for analysis.

If chemical constituents have little or no cross-sectional variability across the stream, as one would intuitively expect from preliminary observations of a well-mixed channel, then representative water samples can be taken from a single point in the stream channel. Also, water samples taken over a period of time during storms or base-flow conditions could be composited to characterize the average water quality of the stream during that period.

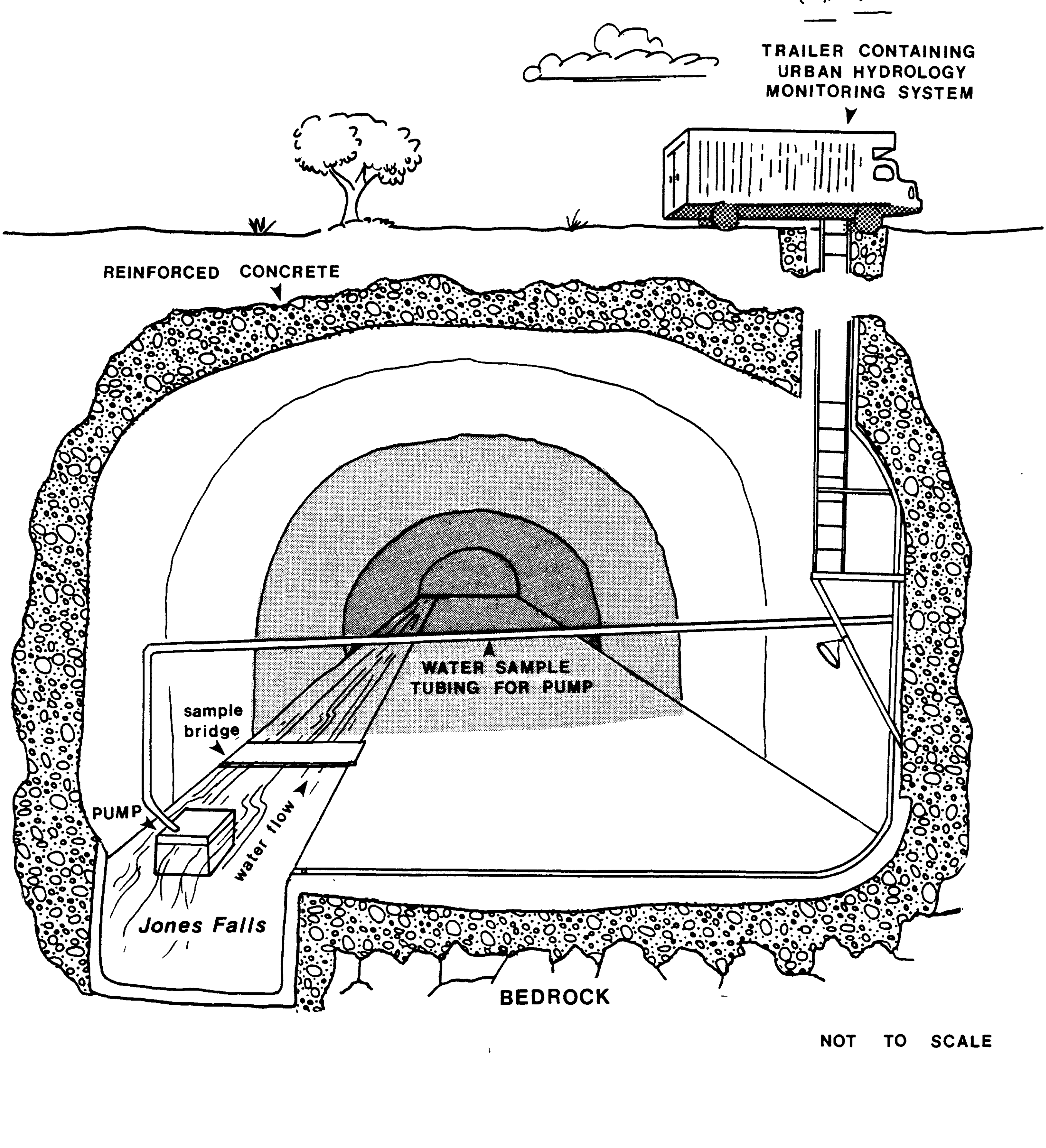

Figure 5. Three-dimentional view of Jones Falls at Biddle street site showing location of water-sampling equipment.

Dry-Weather (Base-Flow) Water Sampling of Jones Falls at Biddle Street Site

Biweekly sampling will be used to quantify base-flow variations in water quality of Jones Falls seasonally. The information gained will be useful in relating seasonal changes in stage, discharge, and selected water-quality and microbiological constituents and for calculating constituent loads to the harbor during dry-weather periods. Fluctuations in the concentration of selected constituents during base-flow conditions will also be compared with data collected during storms.

The following program will be used to collect samples on a biweekly basis. Samples will be taken on Tuesdays, except when precipitation is sufficient to increase the stage by 0.05 ft above the stage measured before precipitation. On precipitation, dry-weather (base-flow) sampling will be delayed until the stage returns to the value before precipitation. The intake of the tube from an automatic sampler will be placed at approximately mid-depth of water in the stream. The sampler will be programmed to withdraw a 1-liter water sample every 4 hours over a 20-hour period (1900 hours 1 day to 1500 hours the following day) to be composited in a 20-liter container.

Dissolved oxygen, temperature, specific conductance, and pH will be measured by a four-parameter meter. These field parameters will be measured only once just before the last aliquot is taken for the composite sample. The composite sample will be packed in ice and delivered to the laboratory for analysis.

To determine whether there is cross-contamination from one aliquot to another in the composite sample, a distilled water blank will be taken through the sampler intakes after the composite sample is collected, once during each 13-week seasonal period. Every other composite sample will be split by the laboratory, and a replicate sample will be analyzed. During a 1-year period, the biweekly sampling program will generate a total of 43 samples--13 replicate samples, 4 blanks, and 26 composite samples. A summary of the biweekly sampling schedule is given in table 3.

Table 3.--Proposed schedule for dry-weather (base-flow) sampling of Jones Falls at Biddle Street site during each season

	WINTER							SPRING						SUMMER							FALL						TOTAL
Week	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	
Number of total samples	2	1	3	1	2	1	2	1	2	1	3	1	2	1	2	1	3	1	2	1	2	1	3	1	2	1	43
Quality control samples	1	0	2	0	1	0	1	0	1	0	2	0	1	0	1	0	2	0	1	0	1	0	2	0	1	0	17

Storm Sampling

To insure consistency among the different urban-runoff projects throughout the country, selected characteristics of storms have been defined. At receiving-water sites, the start of storm runoff is defined as the time when discharge reaches a point 25 percent above base-flow discharge. The end of storm runoff is defined as the time when the discharge recedes below this same level. The duration of storm runoff will be the interval between these two times. For the small catchment sites, where the storm sewers are dry before a storm, the duration of runoff begins when discharge begins and ends when discharge recedes to 10 percent of the peak discharge. The duration of the precipitation is to begin at the start of rainfall [wet snowfall (0.01 in.)] and is to end when the last precipitation is followed by 6 or more hours without additional rainfall.

Other climatologic and hydrologic factors that may affect the quality of storm-water runoff will be recorded. Table 4 contains a list of characteristics that will be recorded for each storm.

Automatic water samples will be used to collect sequential discrete samples for selected storms. However, project resources dictate that 10 discrete samples only will be analyzed in every other sampled storm (table 5). At selected times, a distilled water blank that has been drawn through the automatic sampler after the storm will also be analyzed. These 11 water samples will be chilled, maintained at $4^{o}C$, and delivered to the laboratory. For every other sampled storm, a flow-weighted composite water sample will be prepared, chilled, maintained at $4^{o}C$, and delivered to the laboratory. In addition, once during each season (13-week period), for storms numbered 2, 6, 10, and 14 (table 5), the flow-weighted composite sample will be split by the laboratory into two separate samples. These two samples, along with a sample of distilled water drawn through the automatic sampler, will be analyzed.

The flow-weighted composite sample can be useful for calculating loads for selected constituents during storms. To obtain a representative water sample that is a composite of a storm, flow-proportional aliquot volumes are obtained from each sample and combined into a single sample. The volume of each aliquot, V_i, taken from each discrete sample is calculated by the relationship:

$$V_i = \frac{q_i \, t_i}{\Sigma q_i \, t_i} * V_t$$

where

q_i = instantaneous flow at the time of the "i^{th}" sample;

t_i = sum of half the time since the last sample and half the time until the next sample; and

V_t = total volume of the desired composite sample.

Table 4.--Selected characteristics related to storms for determination in the national urban studies program

1. Total precipitation, average for the basin, in inches.
2. Maximum 5-minute rainfall rate, in inches/hour.
3. Maximum 15-minute rainfall rate, in inches/hour.
4. Maximum 1-hour rainfall rate, in inches/hour.
5. Number of dry hours before storm, counting backward to storm, with precipitation greater than 0.2 inches.
6. Depth of precipitation accumulated during previous 24 hours, in inches.
7. Depth of precipitation accumulated during previous 72 hours, in inches.
8. Depth of precipitation accumulated during previous 168 hours, in inches.
9. Total runoff, in inches, over the basin.
10. Peak discharge, in cubic feet per second.
11. Base flow before storm, in cubic feet per second.
12. Duration of storm runoff, in minutes.
13. Duration of precipitation, in minutes.
14. Time from beginning of precipitation to hydrograph peak, in minutes.

Table 5.-- Proposed schedule for storm sampling at small catchment sites and at Biddle Street site on Jones Falls

	WINTER				SPRING				SUMMER				FALL				TOTAL
Small Catchment Sites																	
Storm number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
Total number of samples	11	3	11	1	11	3	11	1	11	3	11	1	11	3	11	1	104
Quality control samples	1	2	1	0	1	2	1	0	1	2	1	0	1	2	1	0	16
Jones Falls at Biddle Street Site																	
Total number of samples	1	3	1	2	1	3	1	2	1	3	1	2	1	3	1	2	28
Quality control samples	0	2	0	1	0	2	0	1	0	2	0	1	0	2	0	1	12

Atmospheric Data Collection

Rainfall data will be obtained from three sources: the National Weather Service (NWS) network, the small catchment monitors, and the supplemental rain-gage network. Locations of the collection sites in the NWS network and in the Baltimore NURP study are shown in figures 2 and 6. Specific locations of all sites where rainfall data are being collected are listed in appendix I.

Records will be kept from the NWS gages as backup to the JFURP gages and as a check for quality assurance. Hourly precipitation records for the Baltimore, Baltimore-Washington-International Airport, and Parkton, Md., gages and daily records for the other NWS gages are published monthly and received by the USGS District office in Towson, Md. The daily precipitation at the Custom House gage (fig. 6) is reported daily in the local newspapers.

The small catchment monitors collect data at 1-minute intervals on magnetic tape by a tipping-bucket rain gage and associated equipment. The gages have a resolution of 0.01 in. of rainfall. This high resolution of data is needed for detailed modeling of the small catchments.

The supplemental rain gages have three main functions: (1) To provide back-up to the small catchment gages if one or more is disabled, (2) to provide a better measurement of total watershed rainfall and its areal and temporal distribution, and (3) to provide a synoptic record of rainfall in the adjacent (Gwynns Falls) watershed for possible future modeling studies. The eight gages collect data at 5-minute intervals. All eight are float-type gages and record on punched paper tape with a resolution of 0.03 in. of rainfall and a capacity of 10 in. of rainfall. A typical gage is illustrated in figure 7.

Atmospheric Deposition

Atmospheric deposition, defined as precipitation (wetfall) and dry deposition (dryfall), may account for a large proportion of chemical loads measured in storm-water runoff from small urban catchments. Knowledge of collecting and analyzing this type of data, however, is scant. In the Baltimore study, the main objective for collecting atmospheric deposition data is for an indication of the magnitude of local or regional atmospheric sources, rather than an accurate quantification of constituent loading over the entire watershed. To observe variations in atmospheric deposition throughout the urbanized area, five automatic wetfall/dryfall collectors have been placed at various locations (fig. 2). The Regional Planning Council is maintaining the collectors and submitting the wetfall/dryfall samples for analysis by Martel Laboratory Services, Inc., the contract laboratory. The strategy to be used for collecting atmospheric deposition samples is: (1) Wetfall samples are collected immediately after a major storm and delivered to the laboratory within 18 hours after the end of the storm, and (2) dry deposition samples are collected the first Tuesday of every other month. If dry deposition rates prove to be high, then a more frequent collection schedule will be used (once per month). The wetfall/dryfall data will be reviewed and interpreted as the project proceeds. If a review shows that certain constituent loads in wetfall/dryfall are insignificant when compared to runoff loads, then certain constituents may be deleted from an analysis schedule.

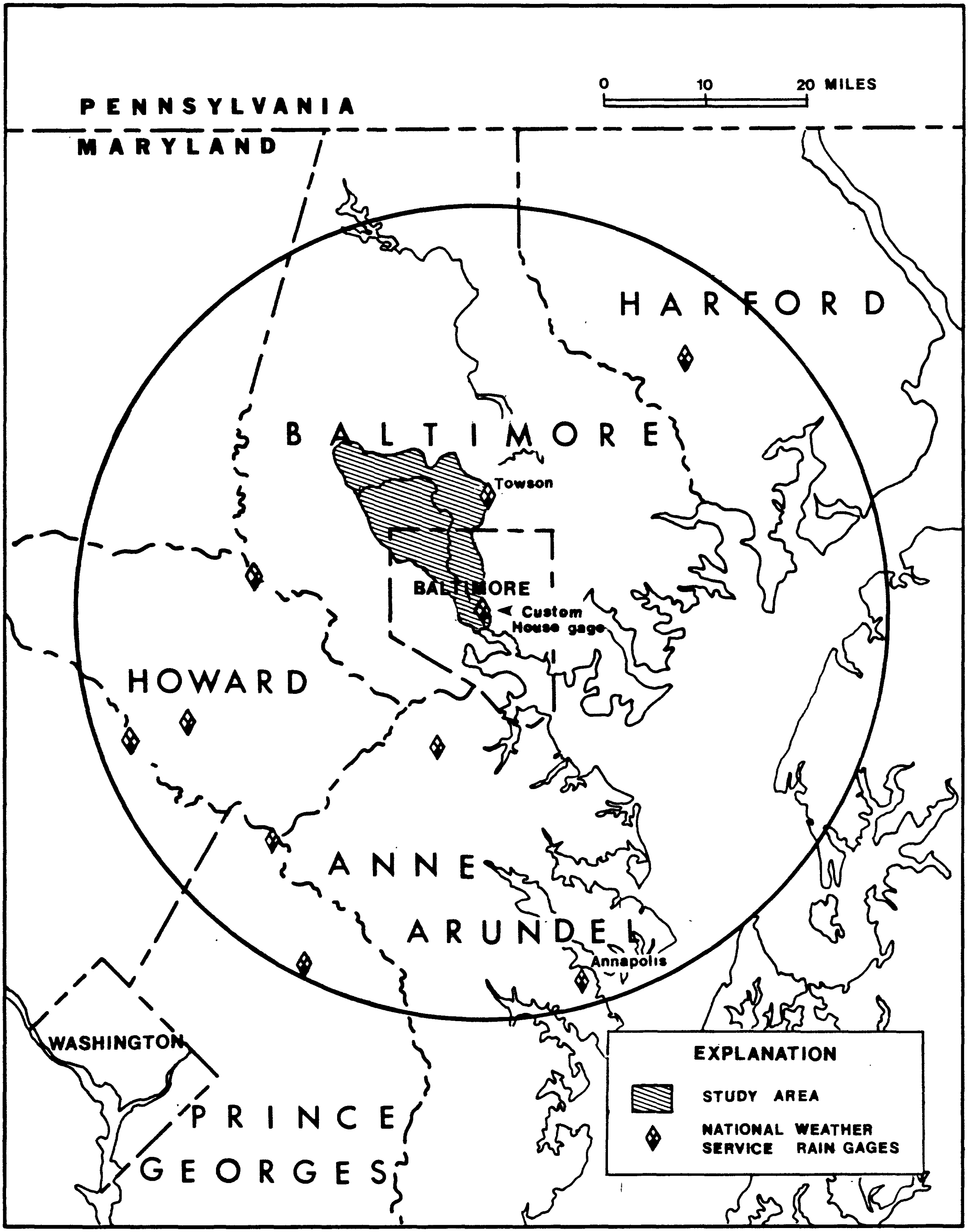

Figure 6. Location of sites in a 25-mile radius of Baltimore where meteorological data are being collected by the National Weather Service.

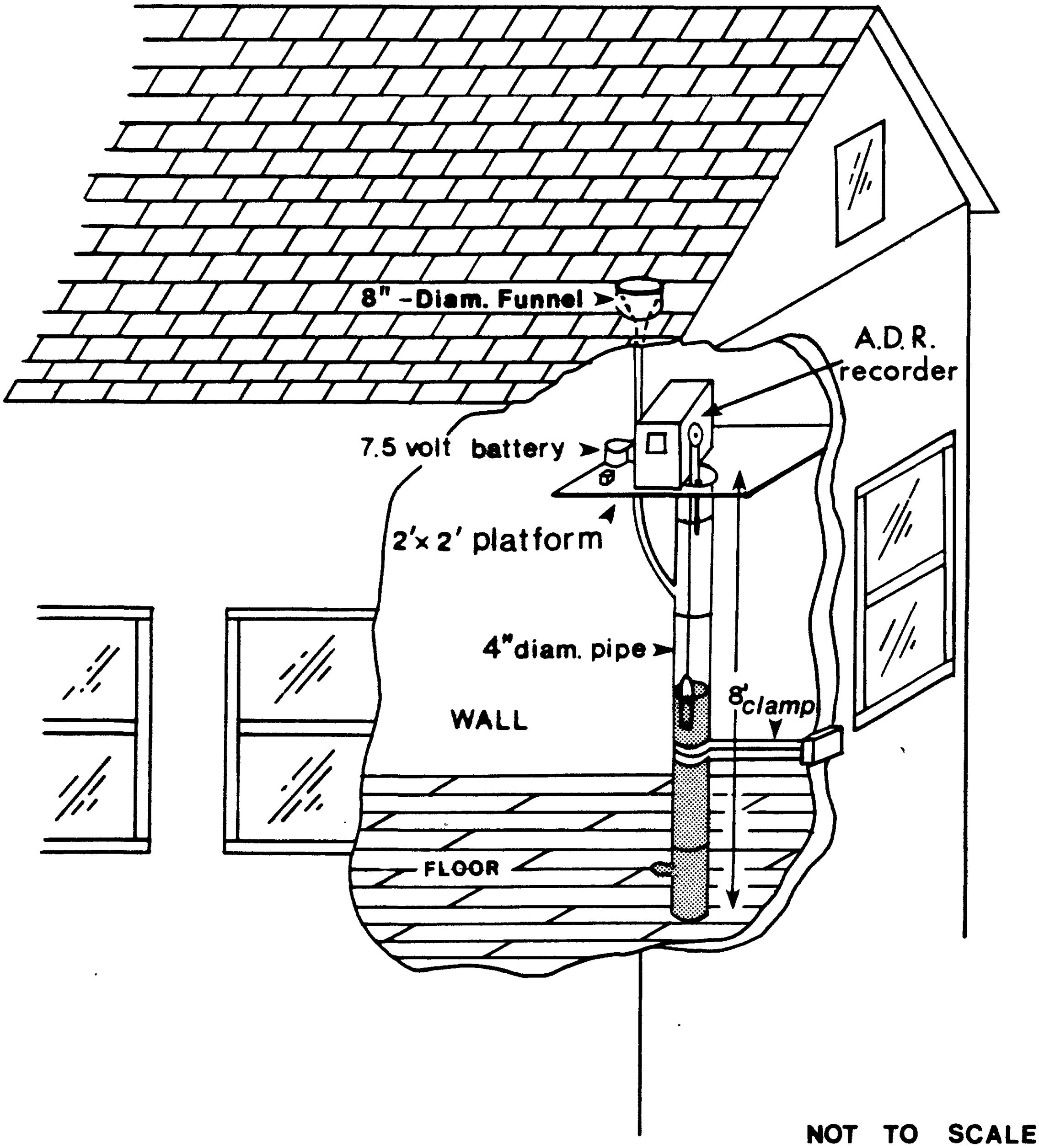

Figure 7. Diagram of a typical gage installation in the supplemental raingage network.

Street-Surface Sampling

To determine accumulation rates of dust and dirt (related to automotive sources), street surfaces will be sampled by the Regional Planning Council. The sampling procedures and plan of operations will be similar to those done by Pitt (1979). Some modifications will be made to take into account local conditions and weather patterns. After collection, street dust and dirt samples will be sent to the Baltimore County Soils Testing Laboratory for particle-size analysis. These data will be reviewed, and acceptable data for particle-size distributions will be stored in the WATSTORE water-quality files.

Measurement of Discharge by Various Techniques

One of the keys to obtaining reliable values for contaminant loads in storm water from urban drainage areas is accurate measurement of discharge in storm sewers and open channels. Palmer-Bowlus flumes have been chosen to obtain stage-discharge ratings of storm sewers at the three USGS small catchment sites. This particular flume was chosen because of its effectiveness and accuracy (Grant, 1979). Its other advantages include (1) ease of installation, (2) relatively low cost, and (3) minimal restriction to flow. Rating curves, which are usually provided by the manufacturer, will be verified by tracer-dilution techniques. Ratings at Biddle Street site will be made by conventional current-meter measurements at or near base-flow and tracer-dilution techniques during storms.

In channels where mixing is good and where current meters cannot be readily used, such as in storm sewers or tunnels during storms, tracer-dilution techniques have been shown to be able to measure discharge accurately (Cobb and Bailey, 1965). Tracer-dilution gaging involves the metered addition of a tracer solution of a constant and known concentration to the stream water or storm water in a sewer pipe where discharge is to be measured. Water samples are withdrawn from a point downstream and are analyzed for the tracer used. Measuring discharge by this technique involves determining the degree of dilution (by use of a mass-balance equation) of an added tracer solution by the water flowing in a pipe or stream.

A combination of two tracers will be used to measure discharge throughout the range of flow for a hydrograph. The discharge determined from the two tracer methods will be used to verify the accuracy of the technique and as a check for losses of either tracer between the points of injection and sampling. Rhodamine-WT and lithium ion (added as lithium chloride) are the two tracers selected for use based on the following criteria:

1. The fluorescence of Rhodamine-WT and the concentration of lithium can be determined to extremely low levels.
2. Both tracers are highly soluble and mix well in the stream and storm water.
3. Both tracers are environmentally harmless at the low concentrations resulting from the injection.
4. Both tracers are normally non-detectable, or present in extremely low concentrations in storm water above the injection point.
5. The presence of small amounts of Rhodamine-WT, lithium, or added chloride will not interfere with determining other chemical or biological constituents.

A generalized outline of the field procedure for measuring discharge by tracer-dilution techniques follows:

1. The solution containing the two tracers will be injected at a constant rate.

2. Water samples upstream from the injection point will be taken throughout the flow hydrograph to monitor any changes in background concentration of either tracer.

3. Water samples will be taken at a point downstream from the point where the tracers are added by automatic water sampler.

4. Twenty to thirty mL of sample will be transferred to glass vials and stored overnight in a dark place and will be analyzed for fluorescence the next day. The remaining water in each sample will be sent to a contract laboratory for lithium analysis by atomic absorption or emission spectroscopy.

5. The dilution ratio of the dye and lithium will be measured in the water samples. Standards for calibration will be prepared with small amounts of the injected solution containing the two tracers and the storm water or stream water. A precise dilution of the injection solution will also be analyzed along with the water samples and the background sample (blank).

6. Discharge will then be calculated by the dilution ratios of the two tracers, according to the following relationship:

$$Q = 3.53 \times 10^{-5}\, q\, \frac{c_1}{c_2}$$

where

Q = discharge being measured (ft^3/s);

q = injection rate of the solution containing the tracers (mL/s);

c_1 = concentration of Rhodamine-WT or lithium in the injected solution; and

c_2 = concentration of the Rhodamine-WT or lithium measured in water at the downstream point.

Priority Pollutant Sampling

The priority pollutants are a group of toxic chemicals or classes of chemicals listed in Section 307 of the Clean Water Act of 1977. There are nine major groups of priority pollutants, and, in total, there are 129 compounds or classes of compounds. To determine which priority pollutants are found in urban storm-water runoff, EPA is providing grants to selected NURP projects for initial sampling and laboratory analyses.

For sampling, the priority pollutants have been grouped into five categories based on the methods used for preservation, extraction, analysis, and storage (Versar, Inc., 1980). These categories include cyanides, metals, extractable organic chemicals (acids, base/neutrals and pesticides), total phenolics, and volatile organic acids (table 6). Selected samples of storm-water runoff will be taken according to published procedures for sampling (Versar, Inc., 1980).

A laboratory selected by and under contract to EPA will analyze selected storm samples for priority pollutants. This laboratory is required to follow EPA's quality-assurance protocols. In addition, a tracking procedure for all samples, from collection through laboratory analysis, has been developed. This procedure will assure that samples are delivered and received on time and analyzed within certain time constraints.

The strategy for priority pollutant sampling follows:

1. The first set of samples will be taken at the Lake Roland and Biddle Street sites with a specially equipped automatic water sampler. Samples will be collected and composited throughout a storm hydrograph. The composite sample will be chilled during and after sampling and transported to the field office as soon as possible after the end of the storm. At the field office, the sample will be split into pre-selected aliquot sizes and preserved, as necessary, for shipping to the laboratory.

2. If the first set of samples yield significant amounts of priority pollutants, the two stations (Lake Roland and Biddle Street sites will be sampled again, along with two major tributaries to Jones Falls [(Stony Run and Western Run (fig. 2)]. Sample collection and handling will be the same as described above.

3. If significant concentrations are found in the tributary stream waters, sampling will be continued to the small catchment sites. Because of budgetary restrictions, this phase of observation may concentrate on specific compounds rather than the entire list of priority pollutants.

4. Samples from the Lake Roland and Biddle Street sites will be taken through a cycle of four seasons during large storms. The first significant spring runoff is especially important because of the buildup of particulate matter during the winter.

5. Additional sampling will depend on the preliminary results. Wetfall/dryfall, dry-weather (base-flow) or sediment samples may be taken at a later date.

Table 6.--Categories of priority pollutants to be sampled and analyzed

Sampling category	Class name	Number of elements or compounds
Metals	Metals	13
Cyanides	Cyanides	1
Total phenolics	Phenols	1
Volatile organic chemicals	Purgeables	31
Extractable organic chemicals	Acids	11
	Base/Neutrals	46
	Pesticides	25

Laboratory Analyses

All water samples collected during base-flow conditions and storms will be analyzed by Martel Laboratory Services, Inc., within 15 mi from all sites. A local laboratory was chosen to minimize the shipping and handling times. Delays in shipping samples may have detrimental effects on a water sample.

Table 7 summarizes the generalized laboratory analysis schedules designed for various types of water samples collected. These schedules were designed on the basis of data needs with respect to local objectives, the National program objectives, and laboratory costs.

Water samples collected during the preliminary study of the instream variability of Jones Falls will be analyzed for the constituents listed in schedule A (table 7). Generally, samples of water and blanks collected during the biweekly study and during storms will be analyzed for the list of constituents in schedule B (table 7). For special cases, once every 13 weeks, blanks and replicate samples of water collected during the dry-weather (biweekly) study and storms will be analyzed for the constituents listed in schedules B and C (table 7).

Wetfall and dryfall samples will be analyzed for the chemical constituents listed in table 7, schedules B and D. Dry-deposition samples will be prepared for laboratory analysis according to procedures outlined in USGS Quality of Water Branch Technical Memorandum No. 81.07. The constituents analyzed for wetfall/dryfall samples are identical to those in storm-water runoff, with the exception of chemical oxygen demand to be deleted from the dry-deposition analysis.

The chemical constituents listed in table 7 will be analyzed by the laboratory by procedures described in "Methods for Chemical Analysis of Water and Wastes" (U.S. EPA, 1977), and in Skougstad and others (1979).

In addition to analysis of water samples for inorganic and organic chemical constituents, water samples will be analyzed for total coliform, fecal coliform, and fecal streptococci by The Johns Hopkins University. The analyses are being done as part of a sub-project titled "Microbiological Quality of an Urban Stream."

Total coliforms will be determined by the multiple tube-dilution procedure with lactose broth presumptive test and confirmation of positive tubes with brilliant green lactose broth with 2 percent bile, according to Standard Methods (1975). Fecal coliforms will be determined by confirmation of positive lactose broth presumptive tubes on EC medium incubated at 44.5 $^{\circ}$C, based on procedures in Standard Methods (1975). Fecal streptococci will be determined by plate counts on KF streptococcus agar, according to Standard Methods (1975).

Table 7.--Laboratory schedules for water-quality constituents in runoff, base-flow, and atmospheric samples collected during JFURP study

Schedule A	Schedule B	Schedule C	Schedule D
Total Nitrogen	Total Kjeldahl Nitrogen	Dissolved Kjeldahl Nitrogen	pH
Total Phosphorus	Total Ammonia	Dissolved Ammonia	Specific Conductance
Turbidity	Nitrate-Nitrite	Dissolved Nitrate-Nitrite	Total Sulfate
Total Organic Carbon	Total Phosphorus	Dissolved Total Phosphorus	
Total Copper	Total Ortho Phosphorus	Dissolved Alkalinity	
Total Lead	Total Organic Carbon	Biochemical Oxygen Demand	
Total Iron	Total Inorganic Carbon		
	Turbidity		
	Dissolved Solids		
	Total Suspended Solids		
	Cadmium		
	Chromium		
	Copper		
	Iron		
	Lead		
	Zinc		
	Chemical Oxygen Demand		

Quality-Assurance Program

The water-quantity and quality data produced in this study will be interpreted to provide a basis for management decisions and further action. To insure that the large volume of data generated are valid and reliable, a good quality-assurance program is needed in the field for collecting samples and maintained through the laboratory for analysis.

Field Quality Assurance

A major part of the quality-assurance program in the field consists of routine standardized checks and calibration of all equipment. A general schedule of equipment service and calibration is listed in table 8. Briefly, servicing, checking, and calibrating the equipment is done before and immediately after a storm. If no storm occurs within 1 week, the equipment at the field stations will be serviced, checked, and calibrated each Tuesday and Friday of every week. Records will list all checked items (appendix II). A detailed step-by-step procedure for checking, servicing, and calibrating equipment will be prepared as a field-procedures manual.

Another vital part of field quality assurance is to evaluate whether a water sample being drawn from the fixed location of the intake for the automatic sampler is representative of conditions throughout the stream. A procedure has been described in the section on "Preliminary Water Sampling" for evaluating instream variability of flow and chemical constituents at the Biddle Street site during storms and dry-weather sampling. Similar procedures will be followed for evaluating instream variability of flow and chemical constituents in sewer pipes during selected storms.

The final part of maintaining good quality assurance in the field involves preserving and delivering of water samples to the laboratory. As described previously, all water samples will be chilled and maintained at 4°C immediately after collection. Flow-weighted composite samples, when prepared manually, will be immediately chilled at 4°C. All discrete and composite samples will be labeled to indicate the location, date, time, and sequence of sample. Field sheets and laboratory-analysis-request forms will be completed at the field office immediately after storm samples are collected. The chilled samples will then be delivered to the laboratory, where they will be entered in the laboratory's log book and assigned a code number. The person receiving the sample will write the code number and his signature on the analysis-request form. Examples of the field data sheet and analysis request form are included as appendices III and IV, respectively.

Table 8.--General schedule of equipment service and calibration

Equipment	Frequency				
	Twice a week	Weekly	Biweekly	Following storms	Less frequent
Service:					
Supplemental rain gages			X		
Flow meters	X				
Samplers	X			X	
Data loggers	X				
Batteries	X				
Tipping-bucket rain gages					X
Servo-manometer			X		
System control unit				X	
Tubing, cables, and connections	X			X	
Calibration:					
Supplemental rain gages			X		
Flow meters		X			
Samplers		X			
Data loggers		X			
Tipping-bucket rain gages					X
Servo-manometer			X		X
System control unit		X			

Laboratory Quality Assurance

In evaluating data reported by the laboratory, both accuracy and precision are of concern. One of the main goals of laboratory quality assurance is to identify and eliminate systematic errors. These errors, which are biased and not random, may result from technician error, equipment malfunction, or a variety of other causes.

Quality assurance (QA) by the U.S. Geological Survey will consist of two parts.

The first part, concerning the precision of a particular analytical method, consists of analyzing replicate samples. Fifteen percent of all samples submitted to the laboratory will be replicates (tables 4 and 5). The laboratory also analyzes one replicate sample of their own per batch of 10 or more samples. Sample-acceptability criteria for replicate analyses will be based on a statistical analysis of historical data. When replicate analyses are found to be unacceptable, the replicate samples are rerun, and the method is reviewed by the laboratory manager.

The second part involves evaluating the accuracy of an analysis. This is done by analyzing blanks, standards, and spiked samples. Ten percent of all samples submitted to the laboratory will consist of blanks collected by drawing distilled water through the automated samplers after a storm and after selected biweekly base-flow events (tables 4 and 5). In addition to these field blanks, the laboratory maintains an internal quality-assurance program. This program consists in part in analyzing one blank, one midpoint standard, and one spiked sample per batches of 10 or more samples. If there are less than 10 samples in a batch, only the standards are run. In any case, standards, blanks, replicates, and spikes are analyzed at least weekly on each constituent (standards and spikes are not available for all constituents). Entries are made in QA log books for standard and spike accuracy. Reference type samples (such as EPA and USGS round-robin standards) are also part of this system.

Laboratory standards and spikes are evaluated to be acceptable based on a statistical analysis of past acceptable data. When a standard is rated as not acceptable, the entire batch is to be rerun, and the method is reviewed by the laboratory manager.

Spiked samples of storm water will also be submitted to the laboratory four times per year. These samples will be collected in large containers, preserved for their appropriate constituents according to Beetem and others (1980), and sent to the USGS National Water Quality Laboratory for spiking with selected constituents. The contract laboratory and a USGS laboratory will analyze on triplicate samples of the storm water before and after spiking. A report summarizing the quality-assurance data generated by Martel Laboratory will be prepared semi-annually. This report is forwarded to the Quality Assurance Coordinator (USGS, Quality of Water Branch, Reston, Va.) for review.

Data Management and Analysis

In the JFURP study, the following types of samples will be analyzed for water quality: biweekly base flow (receiving-water sites), storm-water runoff, wetfall/dryfall, and quality control. The water-quality data received from Martel Laboratory Services, Inc. are not reported in a format compatible for direct entry into the water-quality files of the U.S. Geological Survey WATSTORE system. As a result, a laboratory form was prepared (see appendix V), which will expedite the entry of water-quality data from the laboratory into WATSTORE and maintain the turnaround time for the laboratory at 2 to 3 weeks.

After the laboratory data forms are received, the forms containing quality-assurance data (field-sample blanks, spikes, and replicates) are pulled out and kept in a separate file. If there seems to be no obvious problems with the analytical data, additional water-quality data collected in the field, microbiological data, stage, and other selected parameters are entered on this coding form. If replicate analyses are done and no obvious problems are observed, these analyses are averaged, and the resulting values are entered on a new form with the additional field and microbiological data. Data from these forms are then keypunched and the data entered into WATSTORE. Retrievals of these data are checked against the original forms for accuracy. Any errors and inconsistencies are corrected, and the appropriate values are re-entered into WATSTORE. Once each month, all water-quality data are transferred from WATSTORE to EPA's STORET system. If data records are corrected after a transfer from WATSTORE to STORET, a correction is made in WATSTORE and is automatically transferred to STORET the next month. Figure 8 shows a flow chart of the data-management processes used in the JFURP study.

Water-quality and quantity data from the JFURP study will be stored in the following WATSTORE files: daily values, unit values, and water quality. At present, data from all three files cannot be retrieved and combined simultaneously for use in computations such as contaminant loadings for storms and in rainfall/runoff-quality models. However, an intermediate system for manipulating quantity and quality data has been developed and documented by the U.S. Geological Survey (fig. 8). This system is based on the data management feature of the Statistical Analysis System (SAS) described by Barr and others (1979). Data in this system will be retrieved, reviewed, and verified by project personnel by standard review procedures. Any errors and inconsistencies will be corrected and removed from both the WATSTORE and intermediate data files.

Applicable data from WATSTORE will be transferred to the intermediate file (user's file) for use in constituent load calculations during storms and dry-weather periods, preparation of tables, graphical plotting, statistical analyses (such as correlations, analyses of variance, and regression), and modeling applications. More specifically, the types of data analysis that will be done include:

1. Calculate loads for major constituents of interest in storm-water runoff schedules B and C in table 7) from small catchments and to the harbor from the Jones Falls watershed.

2. Compute long-term average seasonal and annual loads for the small catchments and dry-weather loads for Jones Falls watershed.

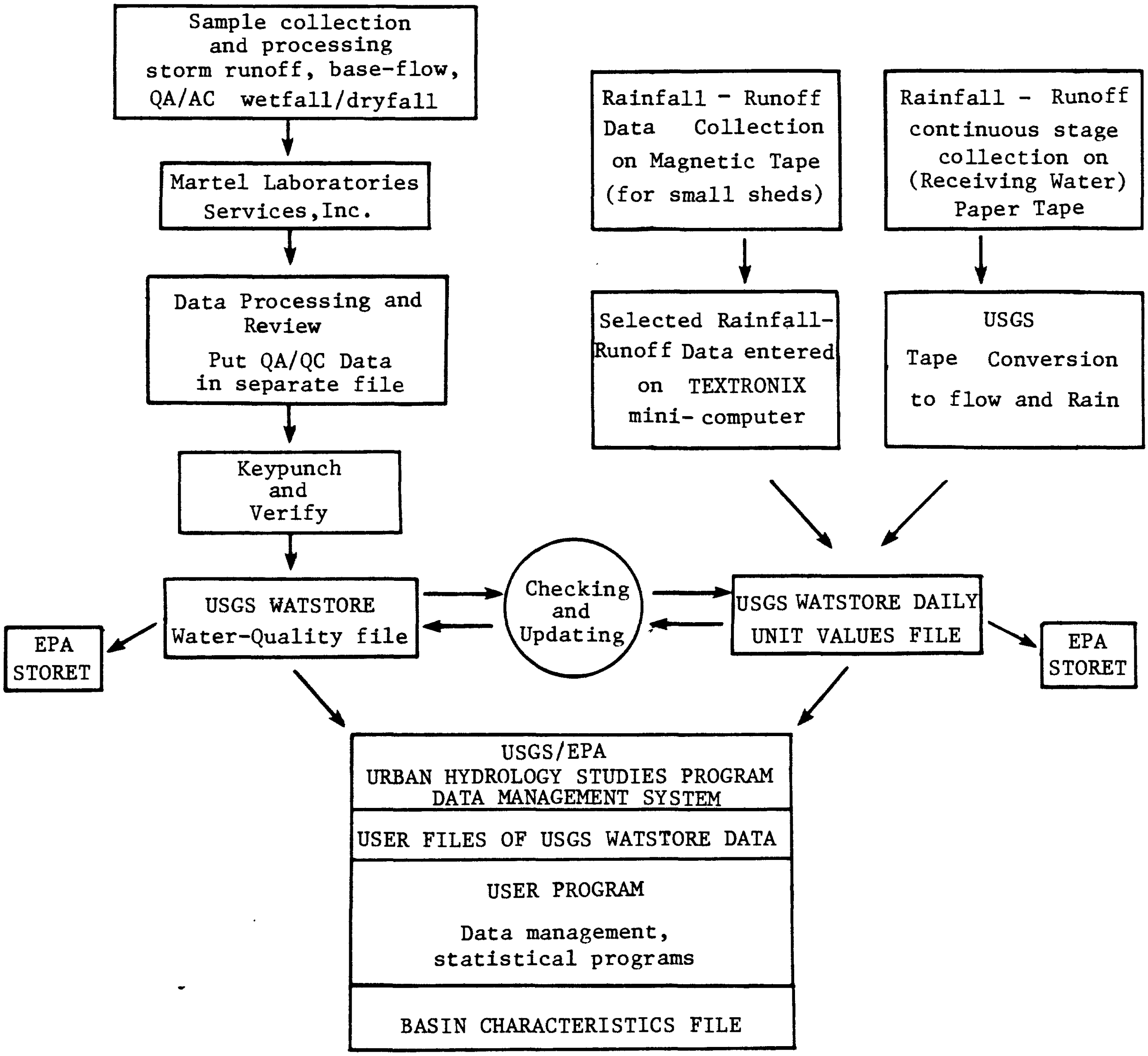

Figure 8. Flow chart of data management processes for the JFURP study.

3. Use regression equations to predict the relationship of concentrations of chemical and microbiological constituents with flow and time. Equations with relatively low standard errors ($\pm$ 20 percent or less) will be used to estimate concentrations and loads of constituents during periods when only flow and rainfall data are collected.

4. Compare the variability in hydrologic characteristics such as total runoff, time to hydrograph peak, and base flow before a storm (table 9). Attempts will be made to relate selected hydrologic parameters (table 9) with catchment parameters (table 9) such as land use, percentage pervious-impervious areas, and others by regression equations.

5. Determine if any relationships exist between mean (flow-weighted) concentrations or loads of constituents in storm water and selected hydrologic characteristics of small catchments such as total rainfall, number of dry days before storm, and wetfall load of individual constituent since previously sampled storm. If correlations exist, develop regression equations to predict loads (seasonal and storm) for selected constituents based on precipitation records and other hydrologic characteristics of the catchments.

6. Determine if any relationships exist between physical, chemical, and microbiological characteristics in storm water or in water sampled during baseflow conditions. Regression equations will be used to estimate concentrations of certain unanalyzed chemical constituents from field parameters or other more frequently analyzed chemical constituents.

7. Simulate the rainfall/runoff-quality processes in the small catchments and in Jones Falls watershed by use of models such as the USGS rainfall/runoff model by Dawdy and others (1978), EPA's SWMM, USCE's STORM, and the USGS DR_3M-Qual (W. M. Alley, written commun., 1981).

More specifically, after selecting and calibrating one of these models, verification runs will be made, and attempts will be made to predict average constituent loads from unsampled small catchments and other urbanized watersheds based on known hydrologic, environmental, and catchment characteristics. Models will also be used to calculate loads for constituents where rainfall/runoff data are present, but no water-quality analyses are available.

Reports and Other Products

The large amount of data collected will be presented at selected scientific and technical meetings and summarized in a variety of reports. These reports will include open-file publications, water-resources investigations, and articles in professional journals.

Schedule

The schedule for project activities is presented in figure 9, including the planned ending date for data collection (mid-1982) and the timing of interim and final reports.

Table 9.--List of watershed or catchment, hydrologic, and environmental characteristics to be used in correlation and regression analysis and in modeling applications

CHARACTERISTICS OF WATERSHED OR CATCHMENT

1. Total drainage area, in square miles.

2. Contributing drainage area, in square miles. (Total area less area draining into impoundments with no outlet.)

3. Impervious area, in percentage of drainage area.

4. Effective impervious area, in percentage of drainage area. Include only impervious surfaces connected directly to a sewer pipe or principal conveyance.

5. Average catchment slope, in feet per mile, determined from an average of terrain slopes at 50 or more equispaced points with best available topographic map.

6. Main conveyance slope, in feet per mile, measured at points 10 and 85 percent of the distance from the gaging station to the divide.

7. Permeability of the A horizon of the soil profile, in inches per hour.

8. Available water capacity as an average of the A, B, and C soil horizons, in inches of water per inch of soil.

9. Soil-water pH of the "A" horizon.

10. Hydrologic soil group (A, B, C, or D), according to SCS methodology.

11. Population density, per square mile.

12. Street density, in lane miles per square mile.

13. Land use of the basins as a percentage of total drainage area, including:

    a. Rural and pasture
    b. Agricultural
    c. Low-density residential
    d. Medium-density residential
    e. High-density residential
    f. Commercial
    g. Industrial
    h. Under construction (bare surface)
    i. Idle or vacant land
    j. Wetland
    k. Parkland

Table 9.--List of watershed or catchment, hydrologic, and environmental characteristics to be used in correlation and regression analysis and in modeling applications--Continued

CHARACTERISTICS OF WATERSHED OR CATCHMENT--Continued

14. Detention storage, in acre-feet of storage.

15. Percentage of watershed or catchment upstream from detention storage.

16. Percentage of area drained by a storm-sewer system.

17. Percentage of streets with curb and gutter drainage.

18. Percentage of streets with ditch and swale drainage.

HYDROLOGIC CHARACTERISTICS

1. Total precipitation, average for the basin, in inches.

2. Maximum 5-minute rainfall rate, in inches/hour.

3. Maximum 15-minute rainfall rate, in inches/hour.

4. Maximum 1-hour rainfall rate, in inches/hour.

5. Number of dry hours before storm, counting backward to storm having more than 0.2 inches of precipitation.

6. Depth of precipitation accumulated during previous 24 hours, in inches.

7. Depth of precipitation accumulated during previous 72 hours, in inches.

8. Depth of precipitation accumulated during previous 168 hours, in inches.

9. Total runoff, in inches, over the basin.

10. Peak discharge, in cubic feet per second.

11. Base flow before storm, in cubic feet per second.

12. Duration of storm runoff used to calculate load, in minutes.

13. Duration of precipitation, in minutes.

14. Time from beginning of precipitation to hydrograph peak, in minutes.

15. Time since last street cleaning, in days.

16. Storm-runoff loads of individual constituents, in pounds/acre.

17. Dry-deposition load of individual constituents since previous storm, in pounds/acre.

18. Wetfall load of individual constituents, in pounds/acre.

Table 9.--List of watershed or catchment, hydrologic, and environmental characteristics to be used in correlation and regression analysis and in modeling applications--Continued

ENVIRONMENTAL CHARACTERISTICS

1. Methods and average frequency of street sweeping, in days.
2. Estimated annual fertilizer load applied to watershed, in pounds per acre of nitrogen and phosphorus.
3. Average time interval between sewer flushing, in days.
4. Average time interval between catchment cleaning, in days.
5. Estimated average daily vehicle traffic, in vehicle miles per day.
6. Grading and agricultural ordinances in effect.
7. Refuse-collection practice.
8. Solid-waste-disposal areas in watershed.
9. Flood-retarding features.
10. Leaf-disposal practice in watershed.
11. Identify major sediment source(s), such as construction activities in watershed.
12. Street pavement and condition.
13. Deicing chemicals.

PROJECT TIME LINE

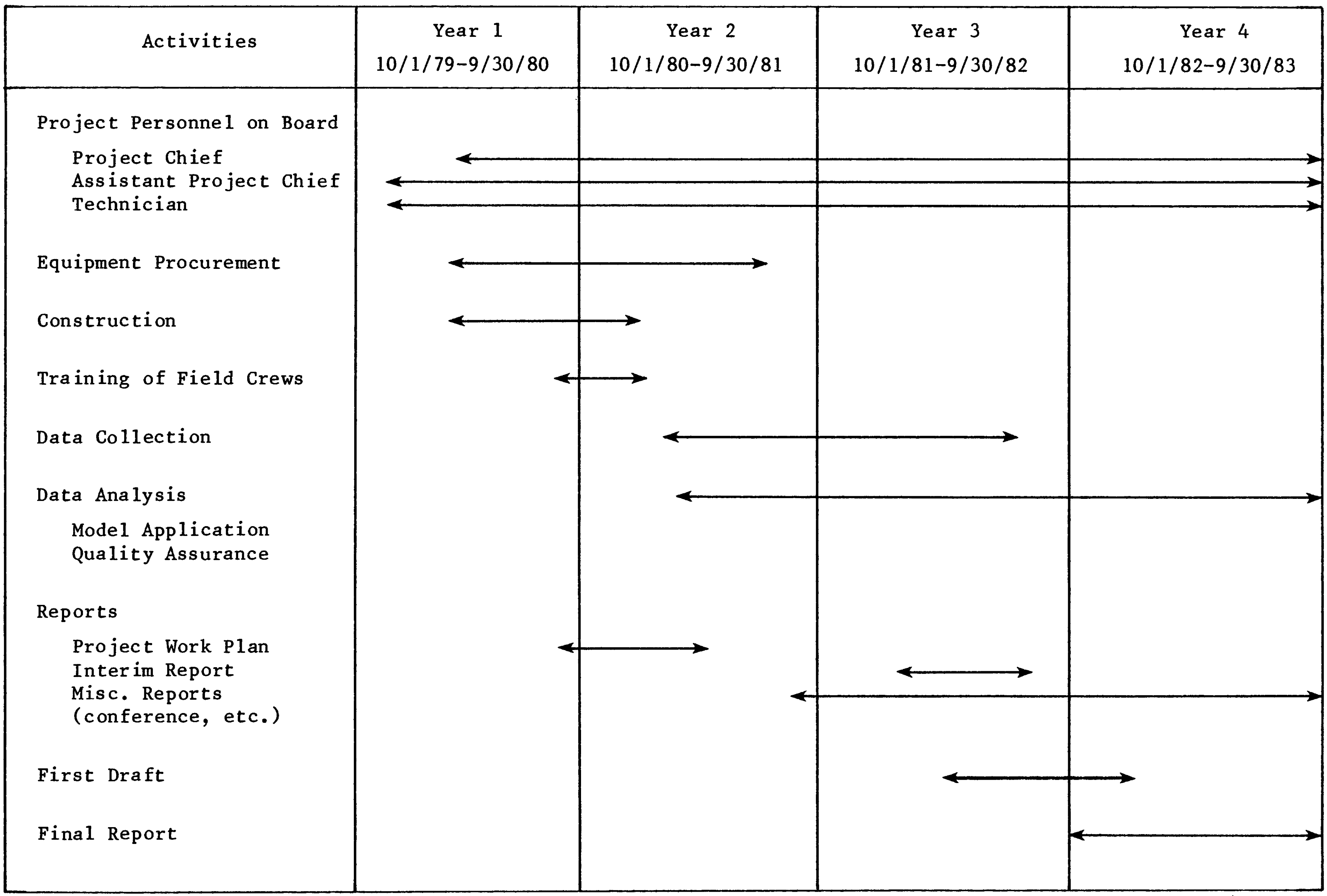

Figure 9.--Schedule for JFURP activities.

SUMMARY

The Jones Falls Urban Runoff Project (JFURP), one of 28 study locations in EPA's Nationwide Urban Runoff Program (NURP), is a cooperative effort by the Regional Planning Council (State of Maryland), Baltimore City, Baltimore County, and the U.S. Geological Survey. The JFURP study will concentrate on determining characteristics of storm-water runoff from small urban catchments and runoff impact on receiving waters. Other studies include base-flow characteristics and sources of contamination of receiving waters and control measures in reducing contamination from urban non-point sources. Five small urban catchments (each less than 25 acres) were chosen as representative of residential land use in the Baltimore area. Each will be sampled at one location near the drainage outlet. In addition, three sites in the urbanized part of the watershed were chosen to monitor receiving waters during wet and dry weather. The drainage area for these sites range in size from 3 to 59 mi^2. The Biddle Street site on Jones Falls (1 mi upstream from mouth) will provide information on contaminant loadings to Baltimore harbor from virtually the entire watershed. As part of an agreement between the Regional Planning Council and the USGS, each agency will operate four sites. The USGS will operate the Biddle Street site and three small catchment sites (Bolton Hill, Reservoir Hill, and Hampden).

Instrumentation was designed to (1) fit the hydrologic conditions expected at each site, and (2) perform completely automatically and with backup capability in case of power failure. Each small catchment site is equipped with two automatic water samplers, a tipping-bucket rain gage, a flowmeter, and a 10-channel magnetic tape recorder. The Biddle Street site is equipped with the Urban Hydrology Monitoring System (UHMS), which consists of a system control unit, an automatic water sampler and cooler, digital recorders, and a servo-manometer bubbler gage.

Two programs have been developed to investigate variations of selected water-quality constituents at the Biddle Street site during base-flow and moderate-storm conditions. The first program will observe changes in water quality at points in a cross-section over 24 hours. The second is designed to quantify base-flow variations in water quality of Jones Falls seasonally. Selected chemical and microbiological parameters in both programs will be analyzed by the contract laboratories.

Storm sampling at all sites has been designed to be compatible with other NURP studies and also geared to specific hydrologic conditions in the Baltimore area. Discrete and flow-weighted composite water samples will be collected during storms at all sites according to a designed schedule. Samples will be analyzed by Martel Laboratory Services, Inc., for as many as 28 chemical constituents at varying frequencies. Selected microbiological constituents will be analyzed by The Johns Hopkins University. Rainfall and runoff quantity will be continuously recorded during storms. In addition, rainfall samples collected at five atmospheric deposition sites will be analyzed for a list of selected constituents. Eight supplemental sites will continuously record rainfall at 5-minute intervals.

In addition to sampling during dry-weather periods and storms, several other studies will be made. Dry deposition (dry fallout) will be collected by automatic samplers and analyzed for a selected list of constituents. Street surfaces will be sampled to determine accumulation rates of dust and dirt. Selected samples of receiving waters will be analyzed for EPA's list of priority pollutants. Discharge of water in storm sewers will be measured by tracer-dilution techniques and compared with other flow-measurement techniques.

Rigorous quality assurance will insure that the large volume of data collected in the field and reported by the laboratory are valid and reliable. A field manual will be used to insure consistent collection of accurate field data. Quality assurance in the laboratory involves analysis of blanks, standards, and spiked samples, according to a regular schedule.

All quantity and quality data from storms, dry-weather (base-flow) sampling, atmospheric deposition (wetfall/dryfall), and street-surface sampling will be reviewed, and all pertinent data are to be entered into the appropriate WATSTORE file. Data will then be transferred to the Urban Hydrology Data Management System developed by the Geological Survey for use in statistical analyses and model applications. Data analysis will concentrate on (1) defining the relationship between land use of small urban watersheds and the quantity and quality of stormwater runoff from these basins, (2) calculations of contaminant loadings from the entire watershed to Baltimore harbor during wet and dry periods, and (3) extrapolating findings from study watersheds to unsampled watersheds in the metropolitan area by regression equations and selected models. Data collection by USGS will probably continue into the middle part of 1982. The large amount of data generated will be presented at various scientific and technical meetings and summarized in a variety of reports.

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APPENDICES

APPENDIX I

LOCATIONS OF RAINFALL GAGES

A. National Weather Service (nearby gages)

1. Baltimore Custom House
2. BWI Airport
3. Clarksville
4. Woodstock
5. Westminster
6. Towson
7. Parkton

B. Small Catchments

1. Bolton Hill, Park Ave. & Mosher St., Baltimore City
2. Reservoir Hill, 700 Newington Ave., Baltimore City
3. Hampden, 34th & Elm Sts., Baltimore City
4. Mt. Washington, 2700 Cross County Blvd., Baltimore City
5. Homeland, 204 Enfield Rd., Baltimore City

C. Supplemental Rain Gages (1-5 Baltimore City, 6-9 Baltimore County, 10-11 Receiving-Water Sites)

1. Company No. 14, 1908 Hollins St.
2. Company No. 33, 1749 Gorsuch Ave.
3. Company No. 20, 3130 W. North Ave.
4. Company No. 40, 5200 Liberty Hgts. Ave.
5. Company No. 29, 4312 Park Hgts. Ave.
6. Chestnut Ridge VFD, 12020 Greenspring Ave.
7. Pikesville Company No. 2, 1212 Reisterstown Rd.
8. Brooklandville Company No. 14, 10017 Falls Rd.
9. Towson, USGS District Office, 8600 LaSalle Rd.
10. Lake Roland, at dam, Lakeside Drive.
11. Jones Falls near mouth, Fallsway and I-83

JONES FALLS URBAN RUNOFF PROJECT
SMALL WATERSHED MONITORING SITES
SERVICE SCHEDULE

SITE: ____________________ SITE NUMBER: ____________________

		WHEN: Twice/Week	WHEN: After Storms	WHEN: After Use	DATE: / BY:						
GENERAL CHECK		X									
SUPPLIES CHECK		X									
TIME CHECK	TELEPHONE	X									
	CLOCK										
	RESET										
FLOW METER PANEL DESSICANT	CHECKED	X									
	REPLACED										
FLOW METER SIDE DESSICANT	CHECKED	X									
	REPLACED										
ISCO SAMPLER PANEL DESSICANT	CHECKED	X									
	REPLACED										
REFRIDGERATOR TEMP. (°C)		X									
ISCO BATTERY VOLTAGE		X	X								
PEN CHECK		X		X							
CHART SUPPLY (roll diameter, in.)				X							
CLEAN TAPE HEAD				X							
MINILOGGER BATTERY VOLTAGE		X		X							
RAIN GAGE CHECK (monthly)											
MANHOLE	CHECK	X	X								
	PROBLEMS										
	PURGE		X								

JONES FALLS URBAN RUNOFF PROJECT
BIDDLE STREET MONITORING SITE
SERVICE SCHEDULE

SITE NUMBER : 589480

DATE									
SERVICED BY :									
GENERAL CHECK									
SUPPLIES CHECK									
TIME CHECK	TELEPHONE								
	CLOCK								
	RESET								
STAGE CHECK	MANOMETER								
	SCU								
	RESET								
SCU PAPER TAPE SUPPLY (days on 5 min. cycle)									
SCU BATTERY VOLTAGE									
SAMPLER BATTERY VOLTAGE									
REFRIGERATOR TEMP. (°C)									
ISCO SAMPLER PANEL DESSICANT	CHECKED								
	REPLACED								
PLUMBING AND SWIRL TANK CHECK	CHECKED								
	PROBLEMS								
BACKUP SAMPLE LINE CLEANED									
MANHOLE	CHECK								
	PROBLEMS								
RAIN GAGE CHECK (MONTHLY)									

JFURP FIELD DATA RECORD

Page ____ of ____

Station ______________________ Date ______________________

Sampler ID ______________________ Weather ______________________

	Time	Sample ID	Flow	DO	°C	Cond.	pH	(Other)
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
21								
22								
23								
24								

Signature: ____

Comments:

REQUEST FOR CHEMICAL ANALYSIS
JONES FALLS URBAN RUNOFF PROJECT

Parameter	REPLICATE I Individual Analysis	REPLICATE I Group Analysis	REPLICATE II Individual Analysis	REPLICATE II Group Analysis
Total Kjeldahl Nitrogen				
Ammonia				
Nitrate-Nitrite Nitrogen				
Total Phosphorus				
Total Ortho Phosphorus				
Total Organic Carbon				
Total Inorganic Carbon				
Turbidity				
Dissolved Solids				
Suspended Solids				
Cadmium				
Chromium				
Copper				
Iron				
Lead				
Zinc				
COD				
Fats, Oils, & Grease				
pH				
Conductivity				
Dissolved Kjeldahl Nitrogen				
Dissolved Ammonia				
Dissolved Nitrate-Nitrite				
Dissolved Total Phosphorus				
Dissolved Alkalinity				
BOD				

DATE: ____________ SAMPLE I. D. NUMBER: ____________

TIME: ____________ TOTAL NUMBER OF SAMPLES: ____________

COLLECTED BY: ____________

DELIVERED TO: ____________

SPECIAL INSTRUCTIONS: ____________

Appendix V

LABORATORY WATER QUALITY ANALYSIS FORM

Sample Identification on Bottle: ______________________ Lab Invoice Number: ____________________

Date and Time Received by Laboratory: _________________ Date Reported by Laboratory: ___________

Remarks: ____

____

Type	Station identification number	Date of collection Y M D (Begin)	Date of collection Y M D (End)	Time of measurement
☐	☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐	☐☐☐☐☐☐	☐☐☐☐☐☐	☐☐☐☐
1	2 … 9 … 16	17 Begin 22	23 End 28	29 … 32

Parameter (units)	Parameter code	Value	Exp.	Rmk.	Parameter (units)	Parameter code	Value	Exp.	Rmk.
BEGIN TIME (Composite) (hrs)	☐☐☐☐☐	☐☐☐☐	☐☐	☐	END TIME (Composite) (hrs)	☐☐☐☐☐	☐☐☐☐	☐☐	☐
STAGE (Ft.)	☐☐☐☐☐	☐☐☐☐	☐☐	☐	FLOW (cfs)	☐☐☐☐☐	☐☐☐☐	☐☐	☐
FIELD PH	☐☐☐☐☐	☐☐☐☐	☐☐	☐	FIELD TEMP. (°C)	☐☐☐☐☐	☐☐☐☐	☐☐	☐
FIELD SPEC. COND. (uhmos/cm)	☐☐☐☐☐	☐☐☐☐	☐☐	☐	FIELD D. O. (mg/L)	☐☐☐☐☐	☐☐☐☐	☐☐	☐
TOTAL KJELDAHL N (mg/L)	☐☐☐☐☐	☐☐☐☐	☐☐	☐	NITRATE-NITRITE - N (mg/L)	☐☐☐☐☐	☐☐☐☐	☐☐	☐
AMMONIA - N (mg/L)	☐☐☐☐☐	☐☐☐☐	☐☐	☐	TOTAL NITROGEN - N (mg/L)	☐☐☐☐☐	☐☐☐☐	☐☐	☐
TOTAL PHOS. (as P) (mg/L)	☐☐☐☐☐	☐☐☐☐	☐☐	☐	TOTAL ORTHO PHOS. (as P) (mg/L)	☐☐☐☐☐	☐☐☐☐	☐☐	☐
TOTAL ORG. CARBON (mg/L)	☐☐☐☐☐	☐☐☐☐	☐☐	☐	TOTAL INORG. CARBON (mg/L)	☐☐☐☐☐	☐☐☐☐	☐☐	☐
DISS. ORG. CARBON (mg/L)	☐☐☐☐☐	☐☐☐☐	☐☐	☐	SUSPENDED SOLIDS (mg/L)	☐☐☐☐☐	☐☐☐☐	☐☐	☐
TURBIDITY (NTU)	☐☐☐☐☐	☐☐☐☐	☐☐	☐	DISSOLVED SOLIDS (mg/L)	☐☐☐☐☐	☐☐☐☐	☐☐	☐

Appendix V--(Continued)

Type	Station identification number	Date of collection Begin (Y M D)	Date of collection End (M D)	Time of measurement
1	2 ... 9 ... 16	17 ... 22	23 ... 28	29 ... 32

Parameter	Units	Parameter code	Value	Exp.	Rmk.
CHEMICAL OXYGEN DEMAND	(mg/L)				
FATS, OIL, GREASES	(mg/L)				
CADMIUM	(ug/L)				
COPPER	(ug/L)				
CHROMIUM	(ug/L)				
IRON	(ug/L)				
LEAD	(ug/L)				
ZINC	(ug/L)				
DISSOLVED KJELDAHL N. as (N)	(mg/L)				
DISSOLVED $NO_3 - NO_2$ - (N)	(mg/L)				
DISSOLVED AMMONIA - N	(mg/L)				
DISSOLVED ALKALINITY	(mg/L)				
BOD 5 DAY	(mg/L)				
SULFATE	(mg/L)				
DISSOLVED TOTAL PHOS.	(mg/L)				
TOTAL VOLUME (ADS)	(m/l)				
ANALYZING AGENCY					
WEATHER CODE					

Reviewed by ____________________ Date ____________