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Non-Point Source Sampling in the Hampton Roads Area

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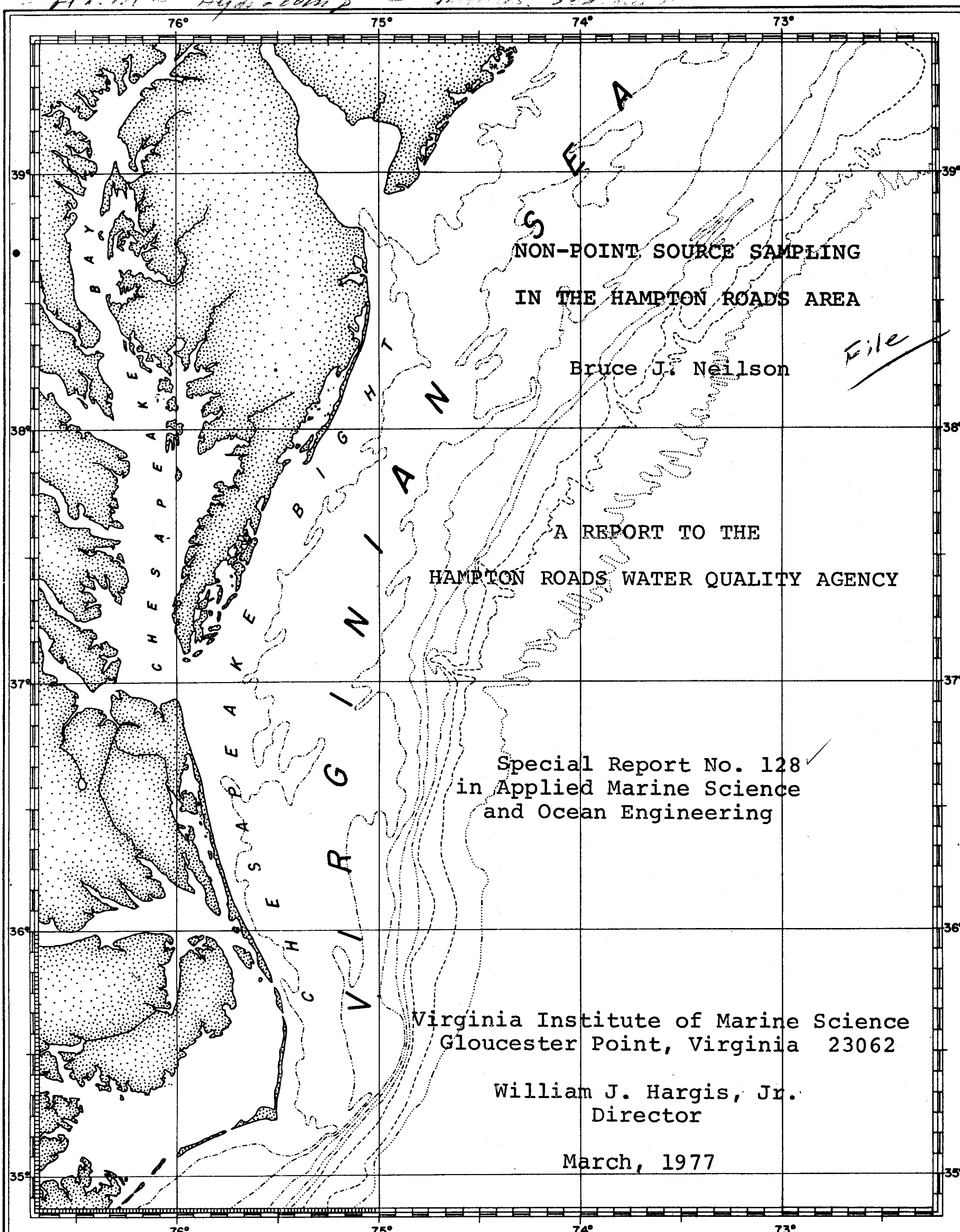

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A REPORT TO THE

HAMPTON ROADS WATER QUALITY AGENCY

Special Report No. 128
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TABLE OF CONTENTS

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Chapter 1.

Introduction

The Hampton Roads Section 208 Studies include several diverse efforts. One of these is predicting the likely non-point source loadings to the estuaries within the study area for selected periods in the future. Since limited information is available concerning the quantity and quality of runoff from various land uses and types, especially for the Coastal Plains environment, a field sampling program was initiated to collect data for use in the mathematical modelling program.

Twenty-five sites, listed in Table 1, were selected for sampling. Thirteen of these sites, classified as land use specific, included low and high density residential areas, commercial and light industrial activities, agriculture, pastureland, forest, open space and marshes. Four sites were located on waterways which drained a combination of land uses. The remaining eight sites included such special land uses as construction, land fill, sludge disposal, feed lots, commercial airport, large parking lots, coal loading and creosoting. The sites were selected by Malcom Pirnie Engineers, Inc., the contractor for Task Package 5, and physical planners from the Peninsula and Southeastern Virginia Planning Districts. The sites were located in three general areas as shown in Figure 1: a) the Hampton-Newport News area, with sites as far North on the Peninsula as Patrick Henry

Table 1. Site Locations and Land Use

Site Number	City or County	Name	Land Use
1	Newport News	Rollingwood Apts.	Residential
2	Newport News	Lucas Creek	Combination
3	Newport News	Patrick Henry Int'l.	Commercial Airport
4	Newport News	Yoder's Farm	Sludge Disposal
5	Newport News	Yoder's Farm	Pasture Land
6	Newport News	Beaconsdale	Residential
7	Newport News	Government Ditch	Combination
8	Hampton	Coliseum Mall	Parking Lot
9	Hampton	Copeland Ind. Park	Open Space
10	Newport News	East End	Residential
11	Newport News	Downtown	Commercial
12	Newport News	C&O Coal Piers	Coal Loading
13	Virginia Beach	Thalia Creek	Combination
15	Virginia Beach	Centerville Tpk.	Land Fill
16	Chesapeake	Norfolk Highlands	Residential
17	Virginia Beach	Pocaty Creek	Marsh
18	Norfolk	Norfolk Ind. Park	Light Industry
20	Portsmouth	Creosoting Plant	Special
21	Norfolk	Colony Point Apts.	Residential
23	Suffolk	Shingle Creek	Combination
24	Isle of Wight	Indika	Forest
25	Isle of Wight	Route 17	Agricultural
26	Newport News	Christopher Newport College	Institutional
27	Virginia Beach	Quail Run	Construction
28	Suffolk	Presson Farms	Special-feed lot

NOTE: Sites 14, 19 and 22 were eliminated due to changes in land use.

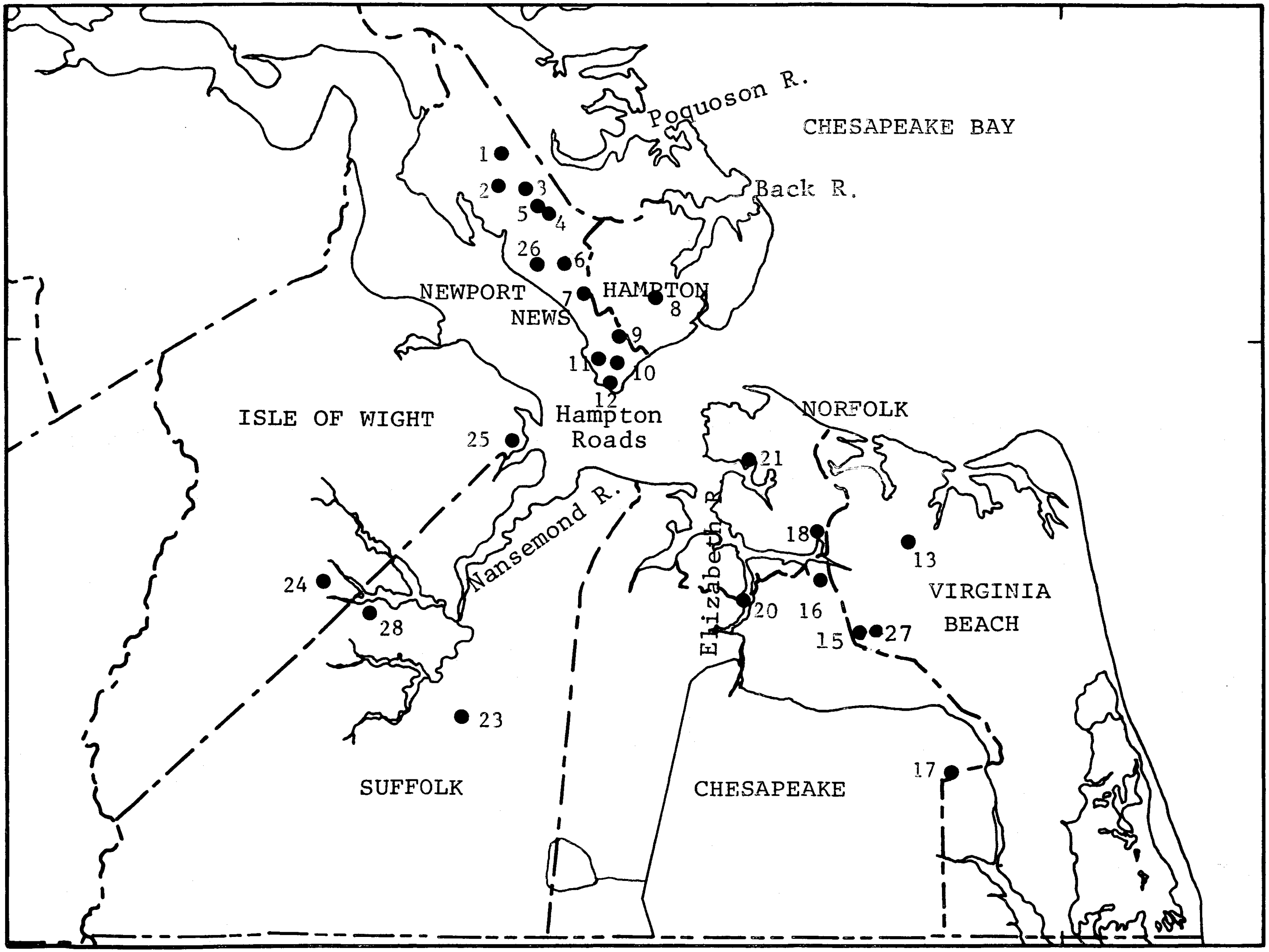

Figure 1. Sampling locations for stormwater runoff studies.

International Airport and as far South on the Peninsula as the C & O coal piers at Newport News Point; b) the Norfolk metropolitan area, with most sites located in the densely populated sections, but with several outlying sites ranging as far south as Fentress airfield; and c) the Isle of Wight-Suffolk area.

Each of the twenty-five sites was to be sampled during two rain events. A rain event was defined as "a rainfall having an intensity of 0.05 inches or more per hour, a duration of at least two hours and an antecedent dry period of 72 hours." Since the amount and intensity of rain necessary to create a reasonable amount of runoff varies with soil type, topography, drainage area and land use, the above definition was used only as a guideline rather than an absolute criterion. Highly impervious areas (e.g. shopping center parking lots) required only a few hundredths of an inch of rain to produce runoff. At the other extreme, one small, flat, open area with sandy soil required nearly two inches of rain to generate even a small volume of short-lived runoff.

In mid-February, 1976, the Virginia Institute of Marine Science was asked to undertake the field sampling. At that time the plans were to begin sampling immediately and complete the program before summer. The first samples were collected on March 16. Unfortunately, the spring of 1976 was one of the driest on record, so that only about one-half the program was completed by June 1. In general, each site was sampled once in the spring and once in the fall, with the final samples of the study collected on October 17. The rainfall records for three weather stations in the study area (the Daily Press Building in Newport News, the Norfolk International Regional Airport and Lake Kilby in Suffolk), as well as times of successful and unsuccessful field efforts, are given in Figure 2. It may be noted that on many occasions rain lasted for several days. Thus, it was imperative to occupy the stations and conduct the sampling program during the initial rainfall in each series; usually this was achieved. Eighteen successful rain events were needed to complete the entire program. On at least seven other occasions, technicians and scientists monitored stations when there was either no rainfall or insufficient rainfall. In addition, for virtually all successful events, the effort was not successful at all sites. This was due to high spatial variability in rainfall during thundershower periods (for example, an inch of rain at one site, but no rain at a site only a mile away); variations in the amount of paved and impervious surfaces throughout the drainage basin (for example, parking lots versus open, grassy fields); and difficulties encountered in occupying numerous, widely separated sites on short notice.

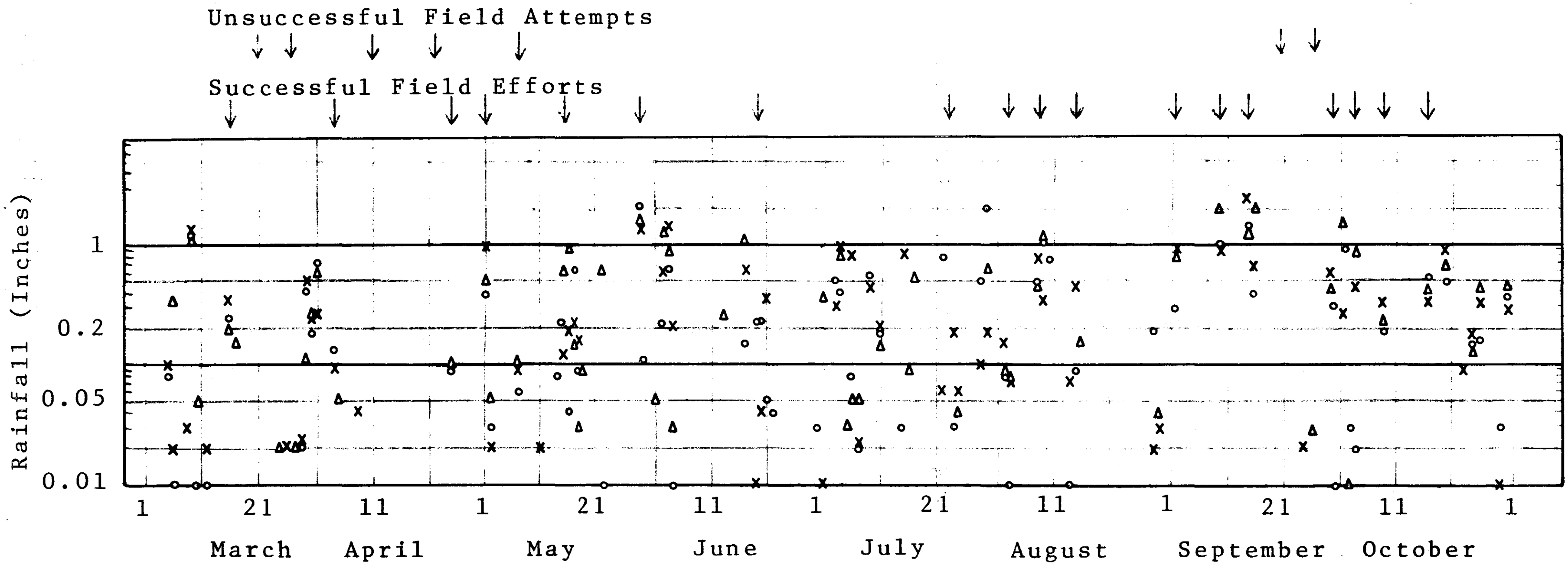

Figure 2. Rainfall record during 1976 for Norfolk (o - Norfolk Int'l Airport), Suffolk (x - Lake Kilby), and Newport News (▵ - Daily Press Building).

Chapter 2.

Materials and Methods

A considerable amount of data is required for the modelling effort. Drainage areas, population projections, land use and other factors were included as other Task Packages. The major components of information to be developed in the Task Package 3 non-point source sampling program were the rainfall record and time variation of runoff quantity and quality for each rain event. The results of these studies will be used in Task Package 5 to generate future non-point source loads.

Rainfall Records

For most site events, the cumulative rainfall was read and recorded at fifteen minute intervals using portable rain gages. These gages could be read to the nearest hundredth of an inch. Gages were normally adjacent to the water sampling station, although sometimes overhanging trees required that it be located a small distance away. For a few events in late September and October, automatic recording rain gages were used where the safety of the instrument was assured. These gages record rainfall in hundredth of an inch increments and were normally set to record for a seven day period.

Runoff Quantity

The quantity of runoff was measured by a variety of techniques, depending on the conditions at the site. V-notched weirs, floats and current meters were used.

A small ducted current meter was used to measure flows where the water depth was sufficient to allow the meter to be submerged. The diameter of the duct is 3½ inches and the thresh-hold current is around 1.5 cm/sec. Each time the impeller makes a revolution, a signal is sent to a remote counter. Current speed is calculated from the number of counts per unit of time. This meter is a precision instrument, which caused some problems due to suspended sediment load and other material which either lodged on the impeller or was caught between the impeller blade and the duct wall.

When possible, V-notched weirs were used. In this instance, only the depth of water upstream of the weir was recorded. Flow was calculated using empirical relationships. However, the applicability of this equation is doubtful when there is a small drop in water elevation as the water passes over the weir. A minimum drop of 20 to 30 cm is recommended to insure that the flow is not attached to the weir. For many sites, this type of elevation difference did not exist. A weir sufficiently elevated to meet this requirement would have impounded the water and thereby drastically altered the flow record. It also was difficult to completely block the flow of water with a temporary weir. In areas with soggy soil, alternate channels developed which bypassed the weir.

Many of the sites were located in ditches that were normally dry. Water flow for these cases was usually too shallow to permit the use of current meters and elevation differences were insufficient to allow installation of weirs. Current speed in such instances was measured by timing the passage of small floats. These measurements were repeated three times and the average used to estimate the speed. When possible, small flumes were installed in the ditches to create a section with constant cross-section and slope to improve the accuracy of the measurements.

The water flow is known directly from weir measurements, but must be calculated with current measurements. The profile of the ditch at the point of measurement was determined and cross-sectional area calculated for the given water depth. The product of area and speed gives flow. When the channel geometry changed as a result of erosion or sedimentation, new profiles were made.

Runoff Quality

Water quality samples were taken when either flow began in a previously dry ditch or when water elevation and/or current speed changed significantly in an already flowing waterway. Two samples were taken every fifteen minutes for five hours. The first sample was collected in a sterile bottle and returned to the laboratory for fecal coliform determinations. The second sample was taken in a 2-liter plastic bottle and returned to the laboratory for processing. These samples were composited in the pattern indicated in

Table 2 with proportions from each original sample determined by the magnitude of flow. The resulting composites were split for the various determinations listed in Table 3. In addition, a duplicate coliform sample and a duplicate composite for each site event were sent to the Hampton Roads Sanitation District for analysis, as part of a quality control program. Analytical techniques were those given in Standard Methods and recommended by the EPA.

Samples were composited primarily for budgetary considerations. Laboratory analyses are expensive, especially those which require monitoring and treatment over a long period, for example, the 30-day BOD test. Costs for performing the necessary analyses on a single water sample are in excess of $100 at commercial rates. With twenty samples for each of two rain events at twenty five sites, the total number of samples is 1,000. The compositing scheme was developed to reduce the laboratory expenses while maintaining a sound data base. Since the initial runoff is often "dirty", there are fewer samples per composite at the start of the sampling period.

Bacterial levels were monitored since the receiving waters for much of the runoff are shellfish growing areas. Nitrogen and phosphorus were measured because the mathematical models of the estuaries simulate the uptake and release of nutrients by phytoplankton as part of the dissolved oxygen regime. BOD and suspended solids are typical water quality measures which appear in most NPDES permits. Comparisons of point and non-point sources of pollutants are facilitated if

TABLE 2. COMPOSITING METHOD

Composite Number	Original Sample Number	Time of Sample
1	1	0
2	2	015
	3	030
3	4	045
	5	100
4	6	115
	7	130
	8	145
5	9	200
	10	215
	11	230
	12	245
6	13	300
	14	315
	15	330
	16	345
7	17	400
	18	415
	19	430
	20	445

TABLE 3. Water Quality Analyses

Bacteria	
Fecal coliforms	SM 908 Multiple Tube Fermentation Technic for Members of the Coliform Group 908C - Fecal coliform MPN Procedure
Biochemical Oxygen Demand	
30-Day, 20°C, Carbonaceous BOD	SM 507 Biochemical Oxygen Demand EPA #310 - BOD Modified: Nitrification inhibited with pyridine
Nitrogen	
Ammonia-N	SM 418C Nitrogen (Ammonia)-Phenate Method EPA #610 Automated Colorimetric Phenate Method
Nitrate-N	SM 419C - Nitrate-Nitrogen - Cadmium Reduction Method
Nitrite-N	SM 420 - Nitrite-Nitrogen EPA #630 - Automated Cadmium Reduction Method for Nitrate-Nitrite Nitrogen
Total Kjeldahl Nitrogen	SM 421 Organic Nitrogen EPA #625 - Total Kjeldahl Nitrogen
Phosphorus	
Total Phosphorus	SM 425 Phosphate - Total Filtrable and non-filtrable phosphate 425C III - Persulfate Digestion Method EPA #665 - Total Phosphorus
Residue	
Total Suspended Solids	SM 208D - Total Non-filtrable Residue Dried at 103-105°C (Total Suspended Matter) EPA #530 - Total Non-Filtrable Residue
Settleable Solids	SM 208F - Settleable Matter EPA # 50086 Settleable Matter.

SM = Standard Methods for the Examination of Water and Wastewater, 14th Edition, 1975, APHA-AWWA-WPCF

EPA = Methods for Chemical Analysis of Water and Wastes, 1974 U. S. EPA, National Environmental Research Center, Cincinnati, Ohio at least a few measures of effluent quality are similar for all water discharges. Since the land uses which were monitored varied greatly, there is no simple means to relate 5-day BOD measurements to ultimate oxygen demands. Also, since samples were analyzed for Total Kjeldahl Nitrogen, a measure of the nitrogenous BOD was already available. For those reasons, the BOD samples were treated with pyridine to inhibit nitrification and were held for 30 days to determine the long-term oxygen demand. Triplicates from each composite were monitored with dissolved oxygen levels measured by oxygen probe. Samples were reaerated when the DO concentration fell below 4 mg/l. When the oxygen consumption was low, DO levels were read on the following days: 1, 2, 3, 4, 5, 10, 15, 20, 25 and 30. When BOD values were high, samples were followed more closely and reaerated as often as required. Thus, the ultimate oxygen demand was measured rather than being calculated by using "typical values". In fact, the time series allows the decay rate to be calculated directly. Both decay rate and the ratio of 5-day to ultimate oxygen demand is available for each type of runoff.

Chapter 3.

Results and Conclusions

The end product of the field study is a series of rainfall records, hydrographs and pollutographs for a variety of rain events, locations and land uses. The rainfall measurements were made every fifteen minutes from the beginning of the rainfall until five hours after runoff began. The hydrograph is simply a record of the quantity of runoff which occurred, with flow measurements made every fifteen minutes from the beginning of runoff. The pollutograph is the five hour record of the amount of pollutants which was carried by the resulting runoff. Since samples were composited, the time interval between measurements was not equal, but shorter at the initiation of runoff than near the end of the five hour period. With the exception of one site, two rain events were monitored at each of the twenty five sites.

The data from the 50 site events will be studied and used to calibrate "STORM", a mathematical model for predicting runoff quantity and quality. The calibrated model then can be run to determine the runoff from a specific rain event and for a particular watershed. This model will be used to estimate non-point source loads during the time of intensive surveys in the rivers and also for future land use conditions. These efforts will be described in later reports to the Hampton Roads Water Quality Agency from the concerned contractors. The data from the 50 site events cannot be summarized in any simple fashion since a large number of land uses, soil types, and rainfall intensities were sampled. However, a few points need comment.

From a bacteriological point of view, the quality of the runoff is almost universally poor. Typical values for all stations would be several thousand fecal coliforms per 100 mls of water. In other words, by itself, the runoff does not meet drinking water standards without treatment and is unsuitable for contact recreation as well. That coliform levels are high in runoff from feedlots and pastureland is not surprising, but that levels are quite similar for residential areas and other land uses was unexpected.

Runoff quantity was often quite small. This was due, in great part, to the dryer-than-average conditions during 1976. Monthly rainfall in 1976 for the Norfolk Airport, the Daily Press Building in Newport News, Lake Kilby in Suffolk and the VIMS campus at Gloucester Point are given in Table 4, along with the 1871 to 1975 monthly means for the Norfolk station. The rainfall for 1976 was only about 75% of the mean annual rainfall for the area. Another factor which reduced the amount of runoff is the general lack of topographic relief. Although some parts of the study area are hilly, for much of the area, especially the Norfolk-Virginia Beach region, the terrain is flat. The highest point in this area, Mount Trashmore, is a man-made hill and the highest naturally occurring point is only about 10 meters above sea level. Runoff may not reach a water-

TABLE 4. MONTHLY RAINFALL RECORDS
(inches of rain)

	Norfolk (1871-1975) Mean	Norfolk 1976	Newport News 1976	Suffolk 1976	VIMS 1976
J	3.26	2.51	5.16	3.86	3.70
F	3.36	1.50	1.68	1.82	2.01
M	3.73	2.21	2.18	2.57	2.24
A	3.20	0.99	0.72	0.38	0.07
M	3.64	3.74	4.55	3.17	3.86
J	4.05	1.59	3.48	3.17	2.23
J	5.79	5.19	2.71	4.11	2.71
A	5.43	2.62	1.96	1.89	1.54
S	3.86	3.51	6.54	5.10	5.41
O	3.12	2.90	5.26	3.05	5.48
N	2.56	2.38	2.03	2.63	1.71
D	3.22	3.22	---	3.49	2.91
Yearly Total	45.22	32.36		35.24	33.87

way for a few hours after flow begins and current speeds tend to be small. Where the soil is sandy, a large portion of the rain will percolate into the ground.

Since velocities are not great, the amount of material suspended and carried with the flow is smaller than would be found in more hilly terrain. A review of the runoff data indicates that TKN and Total Phosphorus values were reasonably constant during rain events. Maximum concentrations were two or three times the minimum concentration for about two-thirds of the site events. In other words, although the concentrations of pollutants varied during a rain event, rarely were there order of magnitude variations in the concentrations. On the other hand, flow rates did vary over an order of magnitude or more. Therefore, the mass emission rates (mass per unit time = flow x concentration) also vary by an order of magnitude or more.

Reliability of Results

Few measurements of runoff quantity and quality have been made for the land uses included in this study and the special characteristics of the coastal plain. The gentle topography and highly pervious soils preclude the use of information gathered in other environments. Therefore, the program was designed to collect necessary data rather than rely on literature values.

The field studies include three basic measurements: rainfall, runoff quantity and runoff quality. The estimated accuracy of rainfall measurements is $\pm$ 0.01" as a result of errors inherent in collecting the rainfall and reading the gage. For the small drainage areas (less than 20 acres) the readings taken at the flow measurement site should be typical of the entire area. It is unlikely that the rainfall record differed appreciably within drainage basins of that size. For the few large sites (greater than 150 acres) there could be significant variations in rainfall within the drainage basin, especially with thundershowers.

Unless one had attempted to measure runoff flows, one might assume that quantity of runoff could be measured easily and extremely accurately. In practice, this proved to be a very difficult measurement to make. At one site the variation in depth of water ranged from a few centimeters under normal conditions to several meters at maximum flow. Shallow flows (less than 5 cm), debris and downstream obstructions all made velocity measurements difficult. Changes in channel geometry, some of which occur during the rain event, render flow calculations even more difficult.

Since a wide range of land uses was sampled, runoff quality varied over several orders of magnitude from site to site. For example, fecal coliform levels ranged from less than 2 to greater than two billion per 100 mls, and BOD concentrations ranged from near zero to around 10,000 mg/l.

As a consequence, it was difficult to anticipate the ranges for laboratory tests. A more important source of error is the suspended sediment-contaminant relationship. In general, a large portion of the nitrogen, phosphorus and bacteria will be associated with particulate matter in the water. Variations in suspended solids concentration, can cause variance in the results of chemical analyses, as can differing analytical methods which have greater or lesser ability to include these particulate-bound fractions. Total phosphorus results, in particular are highly susceptible to variation due to very brief (a few seconds) periods of settling.

It also must be noted that it was a rare occasion when samples were returned to the laboratory during normal working hours, although immediate processing was required. Undoubtedly some error was introduced during compositing, filtering, labeling bottles and other processing steps. Samples were split for quality control purposes and sent to HRSD laboratories for analysis. The data from that program, along with other information, were used to evaluate the water quality chemistry.

The information gathered during the field program will be used to calibrate a mathematical model of stormwater runoff. Sampling a small watershed with a single land use provides reliable data for that drainage basin, but some error will be introduced as this information is applied to larger, and perhaps more diverse, areas. Larger, multi-use basins include natural diversity but acquiring data over large areas (e.g., rainfall records) is difficult and/or expensive. Therefore, no matter how the field program is designed, some amount of error will enter as the results are extended to the entire study area.

Finally, it will be necessary to select the hydrographic conditions in the estuaries and the hypothetical rainfall records to be used as test conditions. In the Hampton Roads area, tidal flows dominate the circulation patterns. No concept comparable to the "seven-day, ten-year low flow" for freeflowing rivers has been developed for estuaries. Both hydrographic and meteorological conditions must be chosen using sound engineering judgement.

The only alternative to a field program was to use literature values from studies in non-coastal areas, with different air quality, vegetation, soil types and topography. Although the measurement and prediction of stormwater runoff is difficult and susceptible to error at all stages, the results of the field program are believed to be significantly more accurate than those which would have been generated using "typical values". These data also are available for scientists and engineers to use in the future as they attempt to expand our understanding of stormwater runoff processes.