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Intensive hydrographical and water quality survey of the Chincoteague/Sinepuxent/Assawoman Bay Systems : Volume III. Non-point source pollution studies in the Chincoteague Bay System

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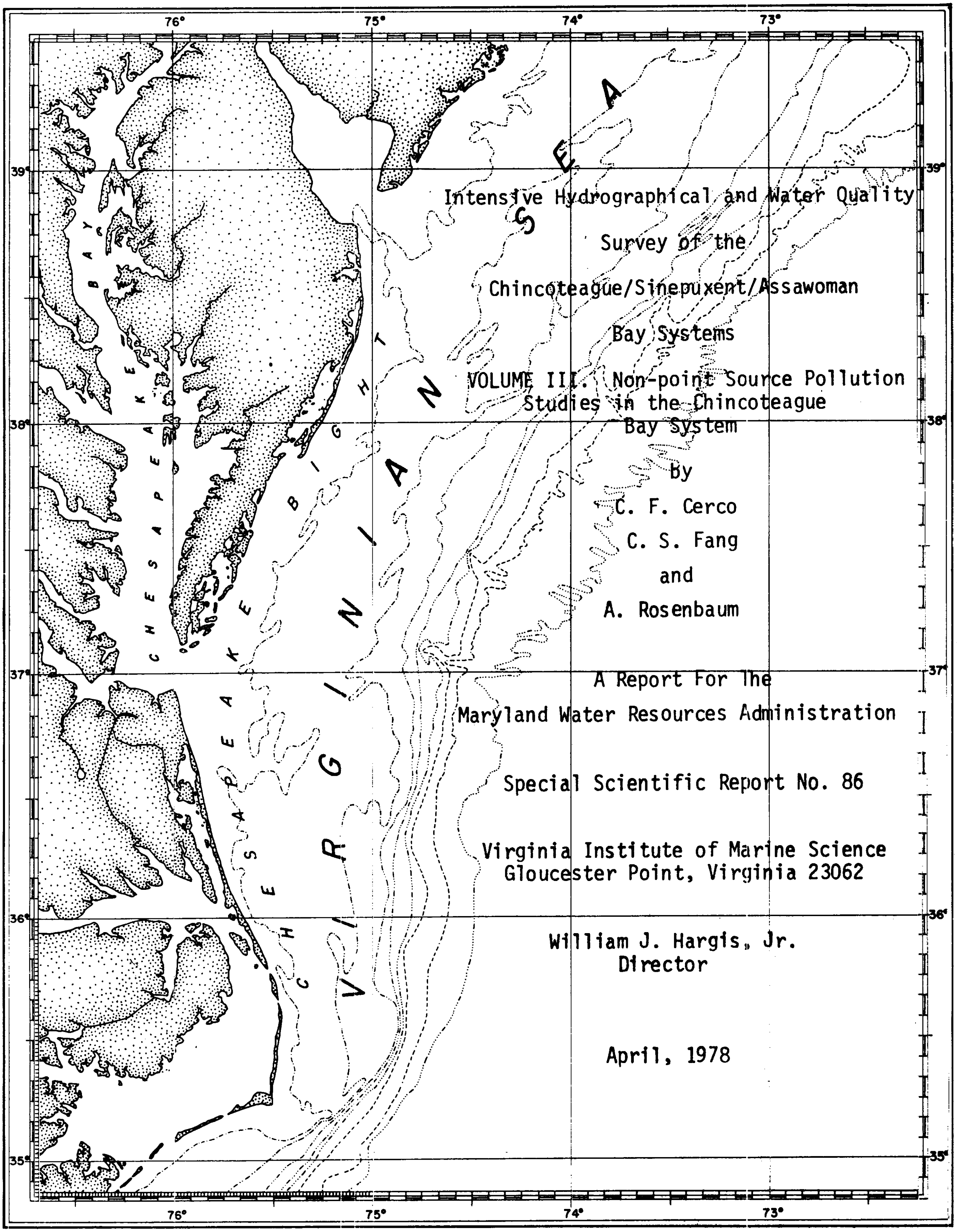

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A Report For The

Maryland Water Resources Administration

Special Scientific Report No. 86

Virginia Institute of Marine Science
Gloucester Point, Virginia 23062

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WATER RESOURCES ADMINISTRATION REVIEW NOTICE

This is one of a continuing series of technical reports prepared by an outside consultant under contract to the Water Resources Administration to aid the Administration in its decision-making functions.

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ACKNOWLEDGEMENTS

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ABSTRACT

NON-POINT SOURCE POLLUTION IN THE CHINCOTEAGUE BASIN

Based on field data collected from ten sample sites encompassing seven land uses, the U. S. Army Corps of Engineer's STORM model has been calibrated and applied to the watershed of the Chincoteague Bay System located on the eastern shores of Delaware, Maryland, and Virginia. Current and projected year 2000 non-point source pollution loads have been calculated and current loads have been compared with point source discharges and storm-generated marsh nutrient exports. Point sources are responsible for larger quantities of ammonia and phosphorous while non-point sources contribute greater amounts of nitrate and coliforms. Rough equivalence is noted in the contributions of organic nitrogen and BOD_5. A single storm on the local marshes, however, can produce nutrient export of the same order of magnitude as the monthly average point or non-point source loads from the remainder of the basin.

KEYWORDS: water pollution; runoff; models; estuaries; Chincoteague Bay; non-point source pollution

BACKGROUND AND PURPOSE OF STUDY

Located on the DelMarVa peninsula, the area collectively referred to as the Chincoteague Bay System includes the drainage basins of Sinepuxent, Newport, Isle of Wight, and Assawoman Bays and of the St. Martin River as well as Chincoteague Bay. The entire basin measures roughly 45 miles from north to south and 10 miles from east to west and has a land area of approximately 250 square miles.

The economic base of the region is largely dependent upon the adjacent coastal waters and upon the wise management of resources within them. Charged with this management task, the Water Resources Administration of the Maryland Department of Natural Resources has undertaken to complete a Basin Water Quality Management Plan for the area under the authority of Section 303(e) of the Federal Water Pollution Control Act Amendments of 1972 (PL92-500).

One phase of this plan is an assessment of non-point source pollution within the system. The following report details the results of a study conducted by the Virginia Institute of Marine Science to provide the Water Resources Administration with the information necessary to make that assessment.

SUMMARY AND CONCLUSIONS

This report details the preparation, execution, and results of a study to model and predict non-point source pollution in the Chincoteague Basin. Topics included are the selection and formulation of a runoff model, the collection of field data, the synthesis of data and calibration of the model, and the application of the model.

The calibrated STORM model utilized herein has been shown to predict pollutant runoff from small watersheds generally within factor-of-two accuracy. This order of accuracy compares favorably with the results of a similar study (6) conducted in coastal Virginia and is most satisfactory in a basin-wide planning study of this nature. Long-range predictions of runoff over the entire Chincoteague Basin will possess a superior order of accuracy as the spatial and temporal errors involved in formulating predictions for small sample watersheds during a single event will tend to cancel as larger land areas and longer time periods are considered.

A summary of the results of this study is presented under the following headings:

The STORM Model

Sampling Methodology

Non-Point Source Modelling in the Coastal Zone

Current and Projected Sources of Pollution in the Chincoteague Basin

A. The STORM Model

Runoff volume and pollutant mass predictions in this study have been made primarily through use of the U. S. Army Corps of Engineers' STORM Model (4). The model has been found easy to implement, flexible in its data requirements and output, and inexpensive to utilize (An annual simulation of the Chincoteague Basin including quantity and quality computations for seven land uses consumed less than 60 seconds of CPU time on an IBM 370/158 system at a cost of approximately $10).

The STORM model is especially suitable for estimations of the long-term pollutant runoff produced by large land areas. Its applicability to extended simulations of large basins renders it difficult to calibrate with short-term data from small sub-basins, however. Particular difficulty is encountered in setting initial conditions, through the parameter LDATE, of depression storage and pollutant accumulation. In a long-term simulation, the effect of initial conditions becomes negligible after one or two simulated rain events. In a calibration which simulates only one rain event, however, the initial conditions are critical and affect the values of the derived calibration parameters used in subsequent model simulations. The problem of specifying initial conditions is not unique to the STORM model, however, and can be partially overcome by conducting replicate field surveys for each land use and averaging the resultant calibration parameters so that errors caused by imprecise estimation of initial conditions will tend to cancel each other.

B. Sampling Methodology

A sampling methodology has been developed by VIMS which starts with the selection of small watersheds (on the order of 10-100 acres) occupied by single land uses typical of the region to be modelled. Runoff from these small watersheds is sampled during several rain events and the field data and calibration values obtained are later employed to estimate the pollution runoff from larger watersheds encompassing similar land uses.

For a period of five hours after initiation, runoff from the data collection sites is sampled at fifteen-minute intervals and analyzed for organic nitrogen, ammonia, nitrate & nitrite nitrogen, total phosphorous, ortho-phosphorous, BOD_5, TOC, total coliforms and fecal coliforms. Various methods of flow quantification including the use of a V-notch weir, volumetric measurements, and simultaneous measurement of flow velocity and cross-section have been utilized.

The concept of sampling for only five hours is justified by the fact that most of the pollutant runoff occurs during this period - the so-called "first flush" effect. This rapid rise and decline in pollutant washoff is illustrated both in the sample pollutographs (Figs. B1-B5) and in the model predictions (Figs. 17-21). Thus sampling only the "first flush" maximizes the information obtained while maintaining reasonable expenditures of time, manpower, and laboratory resources.

Of the flow quantification techniques, simultaneous measurement of flow velocity and cross-section proved the most satisfactory. Although it is labor-intensive, this method is simple, reliable, and provides data well within the limits of accuracy imposed by other aspects of non-point source pollution modelling.

C. Non-Point Source Modelling in the Coastal Zone

Modelling of non-point source pollution in the coastal zone presents several unique problems not encountered in the modelling of upland watersheds. Coastal watersheds tend to be relatively flat, to be indistinct due to absence of topographic relief, and to possess numerous poorly defined outlets. This combination of factors renders application of the concept of overland and open-channel hydrographs, utilized in the study of typical watersheds, difficult and often meaningless. An alternative conception in which the large, topographically defined study basin (in this case the Chincoteague Basin) is arbitrarily divided into sub-basins is recommended.

In the alternate conceptualization, sub-basin boundaries are drawn in any convenient, rational fashion, as along minor divides or so as to enclose an open waterway. The coefficient method of runoff prediction (in which runoff is considered to be a constant fraction of rainfall once depression storage is satisfied) is then applied. This method maintains desired spatial detail in runoff predictions while reducing the number of small watersheds and tributaries which must be considered.

A second source of difficulty is encountered in evaluating the effect of the marshes which surround the open waters of the Chincoteague Basin as non-point pollution sources. It is known the marshes contribute both background and storm-induced quantities of nutrients and organic matter which would be considered pollutants if they originated from an alternate source. In this study, nutrient import-export from a selected marsh was sampled on five occasions for a complete tidal cycle. Although the information collected was insufficient to construct a detailed predictive model of marsh nutrient dynamics, a regression model has been formulated which provides an order-of-magnitude estimation of the storm-induced export from a Chincoteague marsh.

Marshy streams and embayments also affect the temporal distribution of upland pollutants transversing these regions on their way to major receiving waters; the marshes may be envisioned as dampers which slow and alter the flow patterns of pollutants passing through them. A similar damping effect occurs in tidal creeks and bays during periods of rising tide when the direction of pollutant run-off may be temporarily reversed by the tidal currents causing pollutants to be stored for release later on the ebb tide. These effects provide additional support for the use of the coefficient method of runoff prediction since any additional information gained through utilization of overland and open-channel hydrographs or other flow routing schemes would be negated by the unknown effects of marsh hydrology. Thus, until additional investigations into coastal hydrology are performed, the coefficient method of runoff prediction provides runoff estimations as useful as more sophisticated methods.

D. Current and Projected Sources of Pollution in the Chincoteague Basin

1. Comparison of Current Point and Non-Point Source Loads - A comparison has been provided in this report between monthly point source and upland non-point source loadings in sub-basins containing point sources. In each sub-basin, the point sources were found to contribute significantly larger amounts of organic nitrogen, ammonia, phosphosous and BOD_5 to the Chincoteague Bay system while the non-point sources contribute larger quantities of nitrate and coliforms. Even when compared with the non-point runoff from the entire Chincoteague watershed, the point sources still contribute greater amounts of ammonia and phosphorous. In comparing the basinwide amounts of other pollutants contributed by point and upland non-point sources, a rough equivalence is found in the amounts of organic nitrogen and BOD_5 while non-point sources are found to contribute significantly larger quantities of nitrate and coliforms.

2. Comparison of Current and Projected Non-Point Source Loads - Non-point source pollution in the Chincoteague Basin can be expected to increase as the region is developed and to gain in significance as present point sources are reduced or eliminated under the NPDES. Based on projections provided herein, the volume of stormwater runoff will increase 29% by the year 2000 with an increase in associated pollutant mass of 25% to 49%. The largest increase will occur in ammonia runoff while the smallest increases will be in organic nitrogen, nitrate, and coliforms. Runoff of BOD_5, a significant pollution measure, will increase by 33%.

3. Comparison of Runoff from Upland and Wetlands Areas - A simple model has been developed to predict the storm generated washoff of nutrients and organic matter from wetlands. The model shows that a single half-inch storm can produce organic nitrogen, phosphorous, and BOD_5* washoff from the Chincoteague marshes of the same order of magnitude as the monthly non-point source runoff from the remaining upland portions of the basin. Thus the marshes are seen as significant sources of "pollution" and a great deal of additional study is warranted to accurately quantify this effect.

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*Computed as a fraction of TOC

CHAPTER I. INTRODUCTION

In the management of water resources, increasing attention is being devoted to the effect of non-point sources of pollution. As opposed to point sources (e.g. municipal and industrial wastefalls) which enter a water body at a specific point and are easily traced to their origin, non-point sources (typically stormwater runoff) may be distributed along the entire shoreline of a water course and originate throughout a watershed or land-use region.

Non-point sources also differ from point sources in that they are sporadic in their nature; while individual point sources may be considered relatively constant in quantity and quality, storm dependent non-point loads originating from a region will vary widely in amount and constituency depending on the intensity and duration of the storm, antecedent weather conditions, the accumulation rate of pollutants on the watershed, and a host of other factors.

Point sources of pollution are relatively easy to control and under the National Pollutant Discharge Elimination System present sources will be significantly reduced or eliminated. Conversely, non-point sources are difficult both to control and regulate. Structural devices, changes in land use, or land use regulation (or a combination of the three) exist as possibilities for reducing these sources. Non-point pollution loads must first be quantified, however, and a methodology established for predicting future loads and the effects of control techniques before a non-point pollution abatement program can be implemented. This report details the efforts of the Virginia Institute of Marine Science (VIMS) to provide the Maryland Department of Natural Resources (DNR) with the quantifications and methodology needed to assess the current and future non-point source pollution loadings in the Chincoteague Bay Drainage Basin. Topics which are covered include:

Components of the Hydrologic Cycle Related to Non-Point Source Pollution,

Selection and Analysis of a Runoff Model,

Metholology and Results of Field Studies,

Model Calibration Procedures,

Quantification of Current Non-Point Source Pollutant Loads, and

Estimation of Year 2000 Non-Point Source Pollutant Loads

A. The Hydrologic Cycle and Non-Point Source Pollution

Non-point pollution loads may originate from a variety of sources. Among these are septic tank seepage, erosion of stream banks and tidal flushing of marshes as well as stormwater runoff. Except in special cases, however, stormwater runoff is the most significant of these potential sources.

This storm-generated component of pollution is intimately linked with the hydrologic cycle. That is, the cycling of moisture from the atmosphere to the surface of the earth and back again. Some understanding at this cycle is necessary before the most important non-point source of pollution can be analyzed. Therefore, the following brief review is provided. For additional information, the reader is referred to one of the standard texts on the subject (1,2, for example).

A simplified hydrologic system may be thought to consist of the following components:

atmospheric moisture
precipitation
interception
depression storage
infiltration
runoff
evaporation
transpiration

The hydrologic cycle (illustrated in Fig. 1) is initiated when meteorological conditions cause atmospheric moisture to condense and fall as precipitation. (For simplicity, rain is the only form of precipitation considered.) Before striking the earth, however, a portion of the precipitation is intercepted and stored on foliage, buildings, etc. Once it strikes the earth, an additional fraction of the rainfall is stored in various sized depressions on the ground surface. Interception, depression storage, and other processes which remove precipitation before infiltration and runoff can occur are often grouped under the term "initial abstraction" or else referred to collectively, as in this report, as just "depression storage".

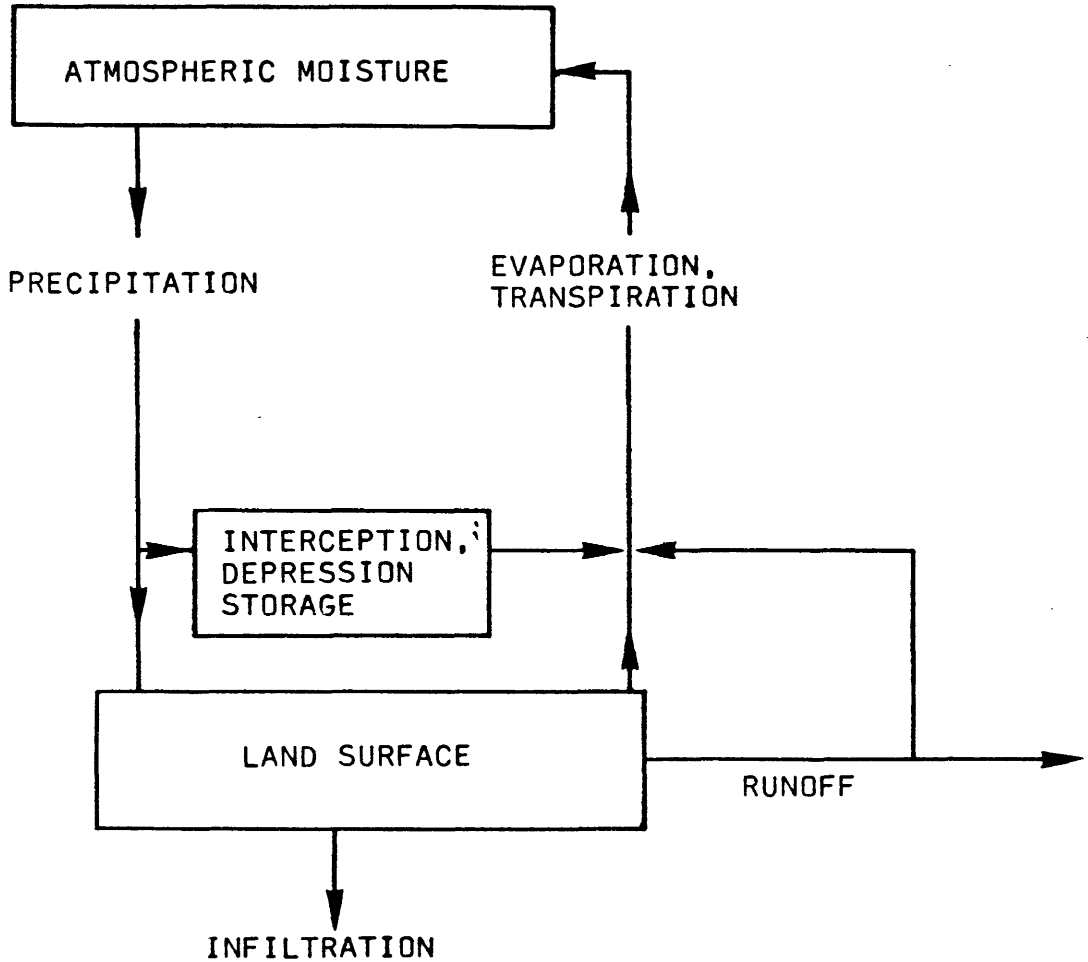


Figure 1. The Hydrologic Cycle

As interception and depression storage are satisfied, the remaining fraction of the rainfall infiltrates the soil or else runs off, following the local topography, to the nearest water-course. A portion of the infiltration also finds its way, through seepage, to adjacent water courses. An additional fraction may go to replenishing groundwater storage.

The cycle is completed when evaporation and transpiration return to the atmosphere moisture borne to the earth as precipitation. Evaporation is the physical process, dependent on humidity, temperature, and wind, by which water vapor is removed from depressions and open water courses. Transpiration is the biologically mediated process through which moisture, absorbed from the soil by the root systems of plants is returned to the atmosphere. Together, these processes are referred to as "evapotranspiration" or, occasionally, as just "evaporation".

It is the precipitation induced runoff to adjacent waterways which is the primary agent of non-point source pollution. As the stormwater runs off, it erodes the ground surface, picking up sediment and washing away pollutants which have accumulated there. Common pollutants include sediment from construction sites, fertilizer and pesticide residue from agricultural acreage, and coliforms, refuse, and chlorides from urban and other developed sites. Heavy metals, oil and grease, and a variety of additional, site-specific, pollutants may also be found.

CHAPTER II. SELECTION AND ANALYSIS OF A RUNOFF MODEL

Estimations of the quantity and distribution of non-point source pollutants originating from a study area can be obtained through exceedingly complex and precise calculations or they may be performed "on the back of an envelope". Detailed calculations would be expected to represent the real system more accurately, and to produce superior results, although this is not always so, especially if data necessary for the calculations is unavailable or lacks sufficient accuracy. Calculations which are too simplistic to produce sufficiently reliable results are also of little use. In performing a study of non-point source pollution, the engineer must judiciously select a model (that is a simplified, mathematical representation of a prototype system) which is simultaneously commensurate with the desired accuracy of the results, the availability and accuracy of the data, and the time and resources allotted to the study.

In the planning phase of this study, it was decided to use the Environmental Protection Agency's Stormwater Management Model (SWMM) (3) to perform the calculations necessary to estimate non-point source pollution originating in the Chincoteague drainage basin and Ocean City. The model proved to be difficult to implement, however, to require a wealth of unavailable data, and to provide results in detail unnecessary in a basinwide planning study. Instead, an alternate selection of the U. S. Army Corps of Engineers' Storage, Treatment, Overflow, Runoff Model (STORM) (4) was made. STORM is readily implemented and provides results of sufficient accuracy based on data available to this study. A comparison of the relevant features of STORM and SWMM upon which the model selection was based is given in Table I.

STORM computes the runoff-borne loads and concentrations of six basic water quality parameters,

suspended solids,
settleable solids,
biochemical oxygen demand (BOD),
total nitrogen,
total phosphorous, and
total coliforms,

and offers the option of estimating runoff volume via the coefficient method, the Soil Conservation Service method or an input hydrograph. In its computations, the model will consider the interaction of up to seven stormwater elements:

rainfall - snowmelt,
runoff,
dry weather flow,
pollution accumulation and washoff,
soil erosion,
runoff treatment, and
runoff storage.

Not all of the options and elements incorporated in STORM are suitable or necessary in this study, however. For the Chincoteague Bay System project, the coefficient method is used to compute the rainfall produced washoff of five-day biochemical oxygen demand (BOD_5), total nitrogen, total phosphorous, and total coliforms only. The applicable features of the STORM model used in the computation of these parameters are described in the following paragraphs.

Table I. Comparison of STORM and SWMM Models

STORM	SWMM
Easy to implement computer program of 4400 lines	Difficult to implement, 10,000 line program
Input data readily available	Major effort is necessary to collect required data
Model output is consistent with quality of data and nature of analysis	Model is oversophisticated. To achieve results consistent with model analysis, extreme detail is required in data collection, etc.
Simulates many events consecutively	Simulates only one event
Does not consider flood routing, the effect of treatment on runoff quality or the impact on receiving waters	Includes all these processes, but they are unnessary for this study.
Models BOD, suspended and settleable solids, nitrogen, phosphorous and coliforms.	Models all these as well as COD and oil and grease
Useful as a planning tool for large areas including non-urban catchments.	Useful primarily for a detailed study of a limited area. Emphasizes urban catchments.

A. Computation of the Quantity of Runoff

The coefficient method of computing runoff volume assumes that a certain fraction of rainfall will runoff in each hour of each rainfall event. The fraction of rainfall which does not runoff is assumed to go into depression storage or to infiltrate the soil, recharging the groundwater or contributing to the base flow of adjacent water courses. Although the coefficient method is only a rough representation of the actual hydrologic process, it is a useful approximation for small watersheds undergoing storms of short duration such as were sampled during this study.

The coefficient method uses the following equation for computation of runoff volume during each hourly time interval:

$$r = C\,(P - D) \qquad \text{where} \qquad (1)$$

r = runoff (in inches)

C = composite runoff coefficient

P = rainfall (in inches)

D = available depression storage (in inches)

It is the runoff coefficient, C, which determines the fraction of the rainfall which runs off. This parameter will vary among watersheds of different soil types, land use, and topography and even within a watershed it will vary according to season, land use, and the degree of perviousness of the land surface. Pervious surfaces, e.g. open, grassy fields, allow a large proportion of the incident rainfall to infiltrate the ground surface and therefore have relatively low runoff coefficients ($C_{per} \approx 0.15$). Impervious surfaces, e.g. pavement, allow little infiltration and have relatively high runoff coefficients ($C_{imp} \approx 0.9$).

Average annual runoff coefficients for the pervious and impervious areas of the watershed are specified and weighted according to the total fraction of the basin which is pervious and impervious in order to obtain a single composite runoff coefficient according to the following equation:

$$C = \sum_{i=1}^{n} F_i \{C_{per} f_{per_i} + C_{imp} f_{imp_i}\} \quad \text{where} \qquad (2)$$

n is the number of land uses in the watershed
F_i is the fraction of the watershed under land use i
C_{per} is the runoff coefficient of the pervious areas
C_{imp} is the runoff coefficient of the impervious areas
f_{per_i} is the fraction of land use i which is pervious
f_{imp_i} is the fraction of land use i which is impervious

Note that while this method allows the fraction of pervious and impervious areas to vary among land uses, the runoff coefficients must be constant for each land use throughout the watershed. In order to accomodate land uses with differing values of C_{per} and C_{imp}, separate computations of runoff must be made for each land use and the results summed to obtain runoff for the entire watershed.

The composite runoff coefficient is used for every rainfall event regardless of rainfall intensity, antecedent moisture, or seasonal variability. Before the coefficient is applied, however, depression storage must be satisfied. Depression storage represents the capacity of the watershed to retain rainfall in depressions and on foilage and is a function both of antecedent rainfall and evaporation. Depression storage is computed by the model on a continuous basis according to the following relationship:

$$D = D_o + N_D k, \quad D \leq D_{max} \qquad \text{where} \qquad (3)$$

D_o is available depression storage at the end of the preceeding rain event

N_D is the number of dry days since the preceeding rain event

k is the pan evaporation rate, in inches/day

D_{max} is the maximum depression storage

The pan evaporation rate is a physical measurement of evaporation from a large tank and is usually reported for one or more weather stations within a region. It is considered to be an approximation of the local rate of evapotranspiration.

In order to initialize the value of D, the program requires as input the number of days since the last major precipitation. Available depression storage is considered to be zero at the completion of this event and initial depression storage at the beginning of the model run is calculated according to equation (3). This method requires discretion on the part of the modeller in determining what is a "major" rainstorm and allows for no remaining depression storage at the end of that event. In addition, land uses within a watershed which have different values of depression storage require separate runoff computations.

B. Computation of the Quality of Runoff

The mass of pollutant washoff in any rainfall event is considered by the STORM model to be a function of both the runoff volume and of the mass of pollutants which have accumulated on the ground surface. Pollutants may accumulate on the land in many ways including litter and sidewalk sweepings, erosion and debris from construction, animal droppings, over-fertilization of fields and fallout of particulate matter from the air.

Two methods of specifying pollutant accumulation are available in STORM - the dust and dirt method and the daily pollutant accumulation method. The dust and dirt method assumes that all pollutants are associated with dust and dirt accumulation in the streets. The method, originally developed for use in the City of Chicago, is suited primarily for urbanized areas. For non-urbanized areas or regions in which pollutants come from sources other than streets, the daily pollution accumulation method is recommended and is utilized throughout this study.

In the daily accumulation method, pollutants are assumed to accumulate according to the relationship:

$$P_i = P_{io} + a_i N_D \quad \text{where} \qquad (4)$$

P_i is the amount of pollutant i accumulated on the watershed

P_{io} is the amount of pollutant i remaining after the preceeding rain event

a_i is the daily rate of accumulation of pollutant i

N_D is the number of dry days since the preceeding rain event

For watersheds encompassing land uses with differing accumulation rates, STORM computes the daily pollutant accumulation for each land use separately.

STORM initializes the pollutants accumulated on the watershed in a similar fashion to the initialization of depression storage. The number of days since the last major rainfall is input and accumulated pollutants are assumed to be completely washed off at that time. Pollutants accumulated from that date until the beginning of the model run are calculated according to equation (4).

The expression used to compute the hourly rate at which pollutants are washed off the watershed is:

$$M_i = P_i \; (1 - e^{-Kr}) \quad \text{where} \qquad (5)$$

M_i is the mass of pollutant i washed off

P_i is the amount of pollutant i accumulated

r is the runoff rate (inches/hr)

K is a washoff decay coefficient.

Equation (5) is based on the assumption that the rate of pollutant washoff decreases exponentially as the storm continues. The rate of washoff is initially high when runoff begins and a large accumulation is available. As the accumulation washes away, and less soluble fractions remain, the rate of pollutant washoff decreases. The STORM model also considers that a certain proportion of the accumulated solids will become unavailable with the passage of time due to compacting and other processes. Equation (5) must therefore be modified to reflect only the available proportion of accumulated pollutants.

The complete expressions used by STORM to calculate the hourly rate of washoff, M, of the suspended solids (SUS), settleable solids (SET), biochemical oxygen demand (BOD), nitrogen (NIT), phosphorous (P), and coliforms (COL) are as follows:

$$M_{SUS} = A_{SUS} P_{SUS} EXPT \qquad \text{where} \tag{6}$$

A_{SUS} is the availability of suspended solids

$$= 0.057 + 1.4r^{1.1}, \text{ and} \tag{7}$$

$$EXPT = 1 - e^{-Kr} \tag{8}$$

$$M_{SET} = A_{SET} P_{SET} EXPT \qquad \text{where} \tag{9}$$

A_{SET} is the availability of settleable solids

$$= 0.028 + r^{1.8} \tag{10}$$

$$M_{BOD} = P_{BOD}EXPT + 0.1\ M_{SUS} + 0.02\ M_{SET} \qquad (11)$$

$$M_{NIT} = P_{NIT}EXPT + 0.05\ M_{SUS} + 0.01\ M_{SET} \qquad (12)$$

$$M_P = P_PEXPT + .005\ M_{SUS} + .001\ M_{SET} \qquad (13)$$

$$M_{COL} = P_{COL}EXPT \qquad (14)$$

Note that equations (11), (12), and (13) indicate a certain portion of the available solids are considered to be BOD, nitrogen, or phosphorous related materials and contribute to these pollutant loads.

CHAPTER III. STORMWATER RUNOFF SURVEYS

A. The Purpose of Field Studies

It is entirely possible to conduct a non-point source pollution study while collecting no field data. Instead of measurements and field surveys, the scientist could rely on land use and topographical maps, meteorological records, and published pollutant loading rates as a basis for his analyses. If only preliminary results are necessary or if estimates must be obtained hurriedly for large areas, this method can provide satisfactory results.

If optimum accuracy is required or if the region to be studied represents unique conditions different from those for which data for estimating loading rates are published, however, field surveys and in-situ data collection become necessary.

The Chincoteague Basin qualifies for field studies on both these bases. Desired outputs from the investigation include an estimation of the typical monthly non-point source pollution load of the basin, a prediction of pollutant loading from a design storm event and loading data suitable for the calibration of a time-varying water quality model of the bay. Predictions meeting the spatial and temporal detail necessary to provide these results cannot be made based on published loading rates alone which usually give only average, annual estimates of the pollution load.

Topography and land use also render the results of studies of other dissimilar watersheds less useful. The Chincoteague Basin is very flat (the slope of the watershed averages $\leq 0.5\%$), has a high proportion of sandy permeable soil, and few well-defined, permanent waterways to channel runoff. Therefore the volume of runoff might differ from that expected based on data from other watersheds. Clearly, some sort of field studies are needed to sample and quantify both the temporal variability of runoff and the effect of local topography on non-point pollution loads.

The alternate extreme to collecting no field data would be to sample each pollutant source in the watershed under all possible storm conditions so that the total regional pollutant load in any situation would be known from exact measurements. This method is unfeasible and, in any event, would be of small practicality under conditions of changing land use.

A middle course, used in this study, is to sample several sub-basins in the watershed, thought to be typical in topography and land use, under a variety of storm conditions. Based on the field measurements, a mathematical relationship (or model) may be derived relating the runoff volume and pollutant load of the sample watersheds to land use, storm conditions, and other parameters. (Such a model is STORM, outlined in Chapter II). Using the model, the results of the field studies of sample sub-basins may then be extended to non-sampled sub-basins of similar land use and topography, and pollution loads resulting from a range of storm conditions may be predicted. The mathematical model - supplemented, perhaps, by literature values of certain parameters - also allows the scientist to estimate the pollution loads resulting from projected, non-existent land uses by substituting revised parameters, based on the projected use, for corresponding parameters, based on the current use, in the model. The predictive mathematical model is thus a valuable tool in estimating pollutant loads from both current and projected land uses.

B. Site Selection

Selection of sample sites and collection of field data is a laborious and often frustrating process. Potential sites thought to be representative in the parameters upon which the model will be based are first selected from maps of the study area. On-site inspections follow to verify that the selected sites are indeed suitable and, if a prospective site is privately owned, permission is sought of the landlord to collect data on his property. If a selected site is unsuitable or if the owner is uncooperative, alternative sites must be investigated.

Once a site is selected, it is surveyed to ascertain a suitable means of flow measurement and channel dimensions and other parameters are recorded. Measures of area and percent imperviousness may also be taken. If the site requires a permanent equipment installation (e.g. a V-notch weir) this is next set up. Only after these and other preliminary processes are completed, can the actual collection of field data begin.

C. Descriptions of Sample Sites

In this study, a total of ten sub-basins, three urban and seven rural, were selected in Worcester County, Maryland and sampled under storm conditions by Virginia Institute of Marine Science (VIMS) and Maryland Department of Natural Resources (DNR) field teams. The location of the sites are shown in Fig. 2 and a description of each site follows:

Sample Site One - Site one is located in a roadside ditch draining approximately 72 acres of farmland planted in a cover crop. Flow was quantified by constructing a rectangular plywood flume of known cross-section in the ditch. Measurements of runoff depth, obtained with a staff gauge, and of velocity, obtained with a current meter or by noting the time a floating particle took to travel a known distance, provided an estimation of the flow rate by using the relationship

$$Q = uA(h) \qquad \text{where} \qquad (15)$$

Q is the flow rate (in ft^3/sec)
u is the velocity (in feet/sec)
h is the depth
A is the channel cross section (in ft^2) as a function of depth

Figure 3 shows sites one and two in detail as reproduced from a 1:24000 U.S.G.S. topographic map.

Sample Site Two - Site two is located in a ditch draining approximately 29 acres of cropland adjacent to Site One. Flow was quantified with a device known as a V-notch weir.

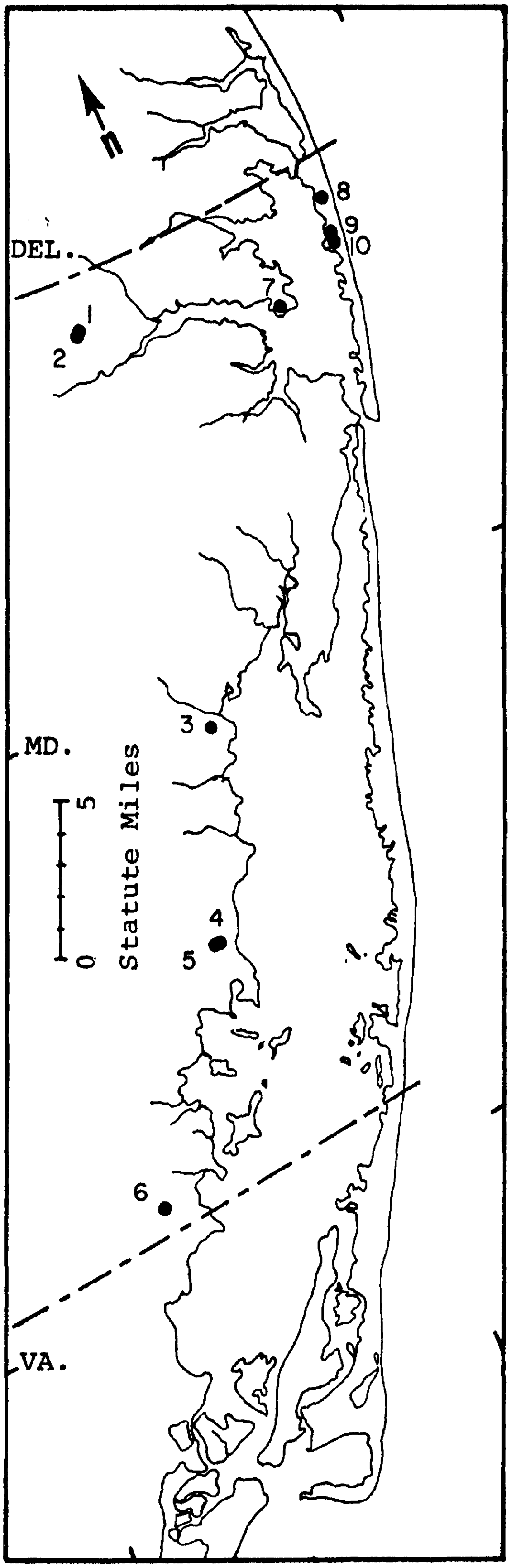


Figure 2. Sample Site Locations

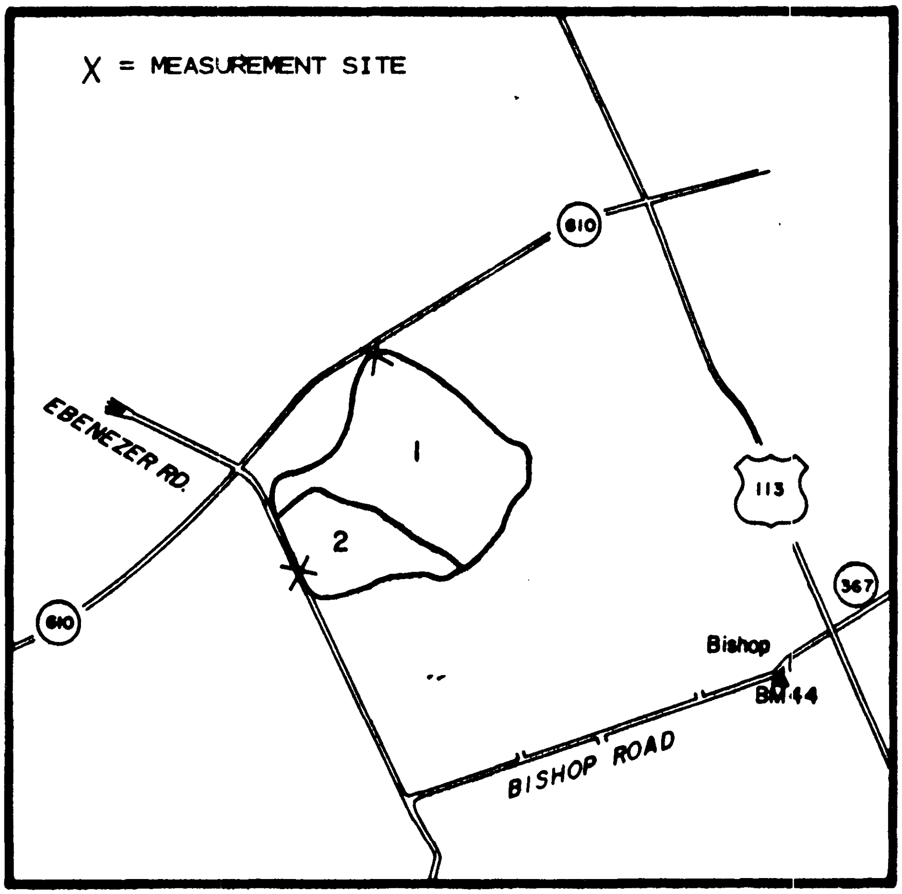


Figure 3. Sample Sites One and Two.
(U.S.G.S. Selbyville Quadrangle)

The V-notch weir (Fig. 4) consists of a vertical plate, mounted perpendicular to the channel axis, which forces all flow through a sharp-edged, V-shaped crest with a notch angle commonly of 90°. Such weirs are frequently used for flow measurement since the flow through the breach may be related to the depth of water behind the weir according to the relationship

$$Q = 2.5\ (H-h)^{2.5} \qquad \text{where} \qquad (16)$$

Q is flow (in cfs)

H is the total water depth (ft)

h is the height of the bottom of the breach (ft)

Thus a simple measure of the depth of water in the channel, H, and knowledge of the breach height, h, provides a way of calculating the flow rate with no additional measurements or devices necessary. Properly used, it is an ideal field measurement technique.

<u>Sample Site Three</u> - Site three is located at the natural outlet of a swampy, lowland wooded area of 262 acres in extent. Standing water was frequently observed in the area and rainfall sometimes added to this standing water rather than producing runoff. When runoff occurred, it was quantified by measurements of runoff depth and velocity in the outlet. The flow rate was then calculated via Eq. (15). Figure (5) shows site three as reproduced from a topographical map.

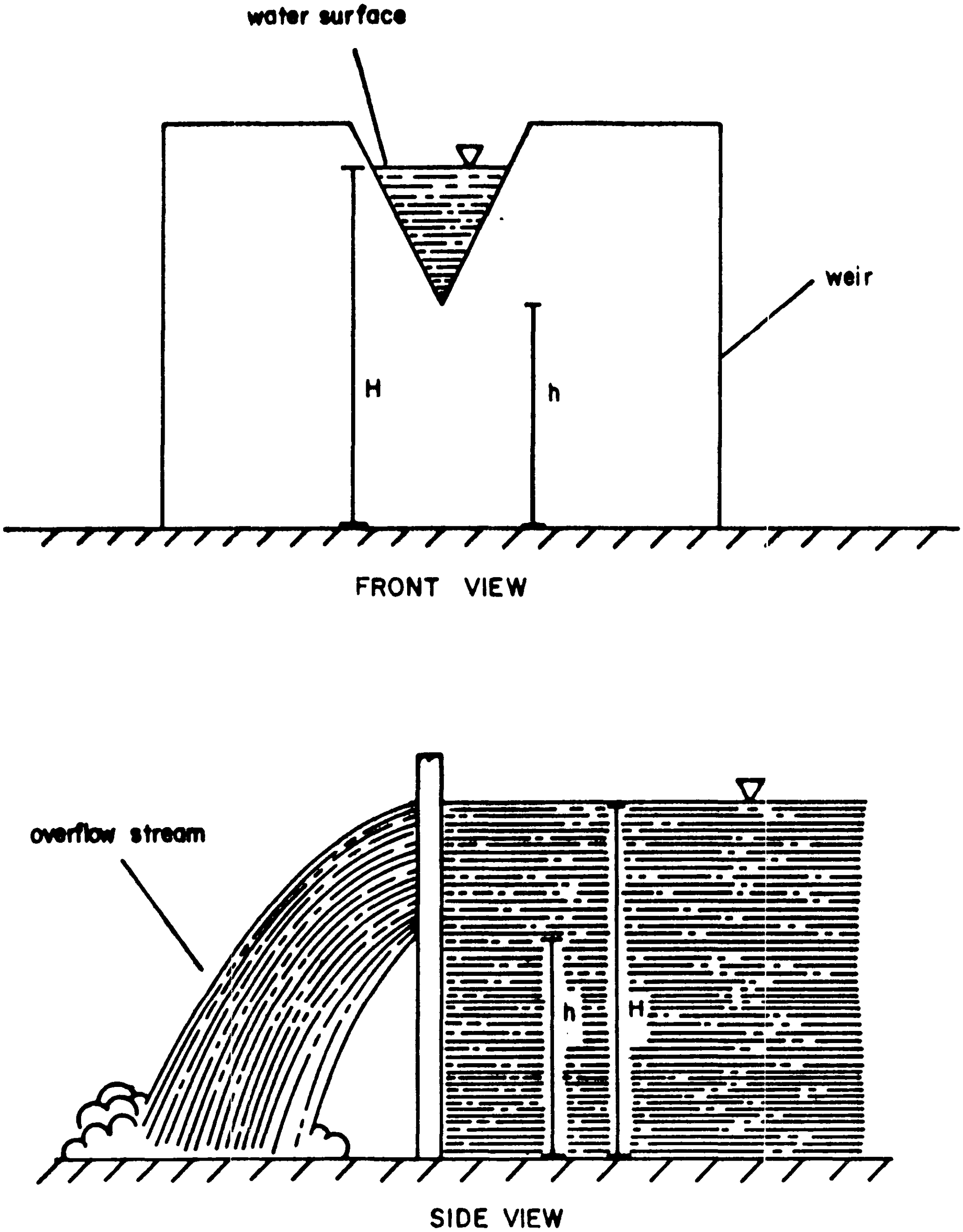


Figure 4. The V-Notch Weir

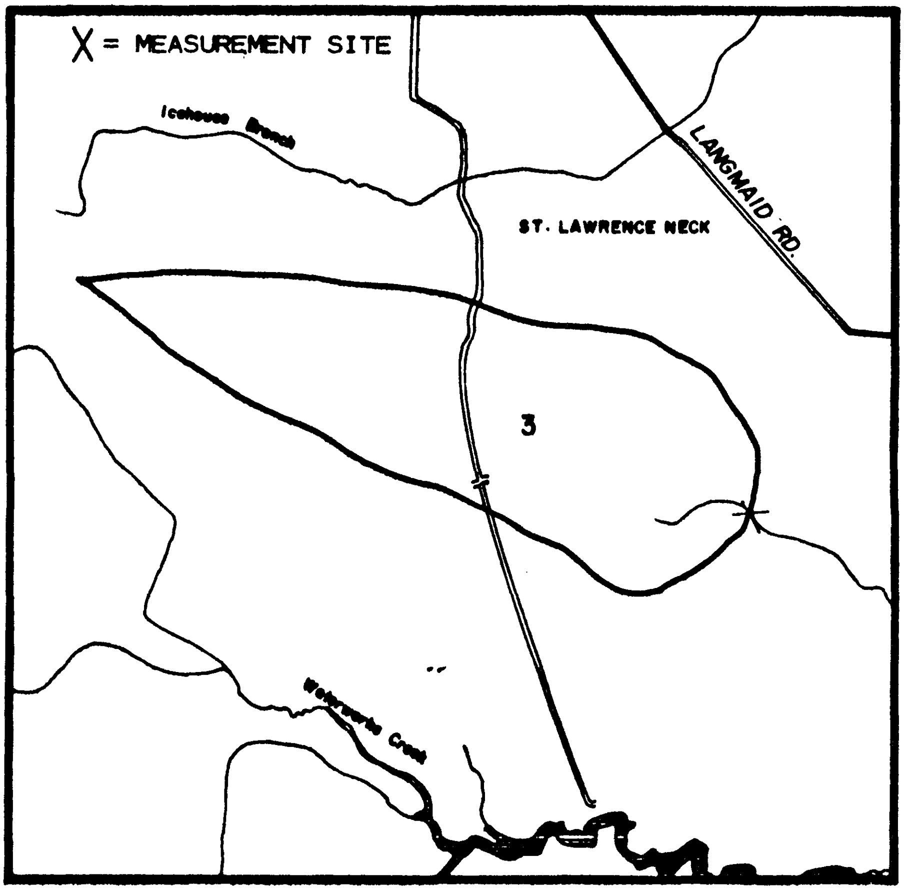


Figure 5. Sample Site Three.
(U.S.G.S. Public Landing Quadrangle)

<u>Sample Site Four</u> - Site four, shown in Figure 6 along with adjacent site five, is located in a roadside ditch draining approximately 117 acres of cropland, a chicken feeding operation, and some lowland forest. This site was selected to provide information on the nature of runoff from the chicken feeding operations that are common in Worcester County. Flow was quantified by measurements of runoff depth and velocity in the outlet.

<u>Sample Site Five</u> - Site five is located in a ditch draining approximately 79 acres of cropland. The site is located in the same ditch but upstream of sample site four and the chicken feeding operation. Comparison of the pollutant concentration in runoff from sites four and five allows the incremental contribution from the feeding operation to be isolated. Flow at site five was quantified by measurement of runoff depth and velocity in the ditch.

<u>Sample Site Six</u> - Site six is located in a ditch draining approximately 36 acres of cropland shown in Figure 7. Flow at the site was measured with a V-notch weir.

<u>Sample Site Seven</u> - Site seven, shown in Figure 8, is located at the outlet of a 230 acre drainage area consisting primarily of salt-marsh and vegetated wetlands. Connected through the outlet to passages leading to Isle of Wight and Assawoman Bays, the site is affected by tidal fluctuations in water level and is typical of marshes located throughout the Chincoteague area. This site produces both storm-induced non-point

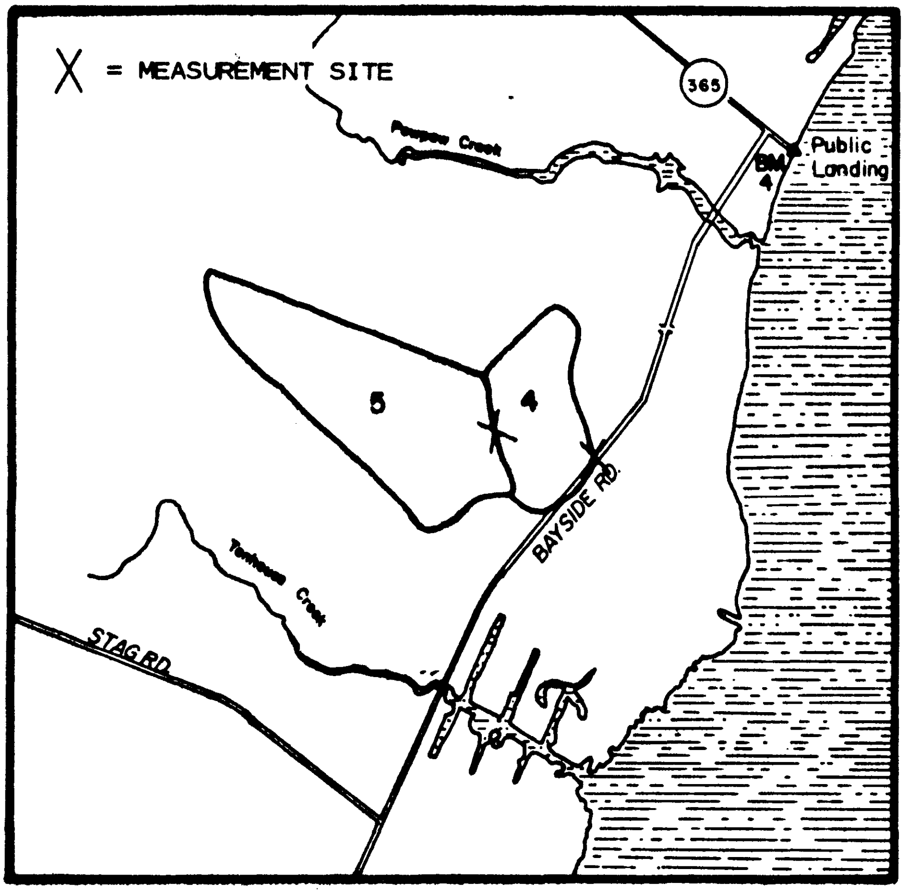


Figure 6. Sample Sites Four and Five.
(U.S.G.S. Public Landing Quadrangle)

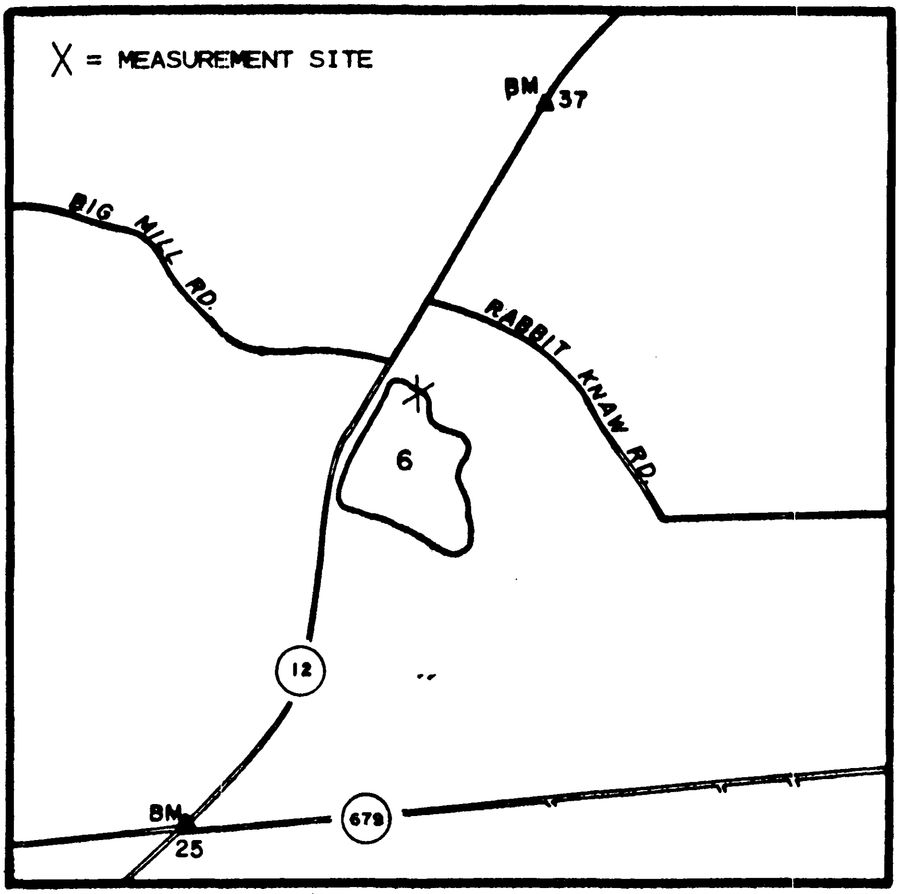


Figure 7. Sample Site Six.
(U.S.G.S. Girdletree Quadrangle)

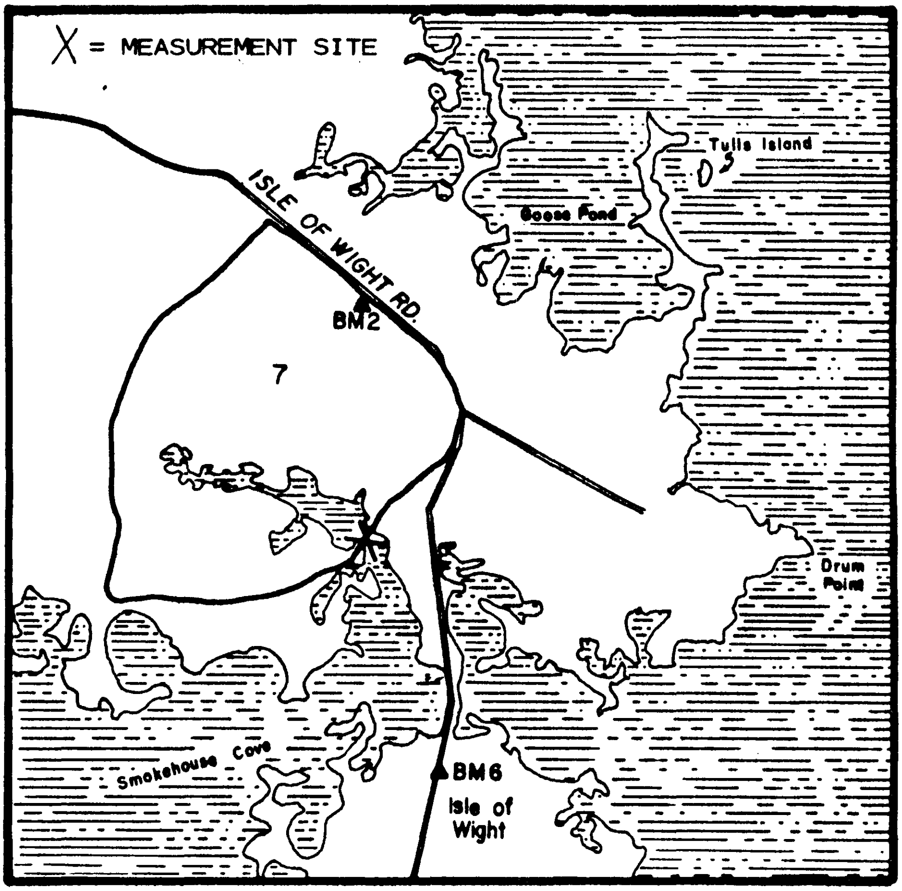


Figure 8. Sample Site Seven. (U.S.G.S. Assawoman Bay Quadrangle)

nutrient loads and nutrient loads due to tidal flushing of the marsh and estimation of these loads presents a unique problem in this study. Flow from the site was quantified using a tidal prism model based on the marsh surface area and fluctuations in the water level. For details of the procedure, see Appendix D.

Sample Site Eight - Site eight is an Ocean City urban site shown along with sites nine and ten in Figure 9. Samples were taken from a storm sewer draining approximately 4.9 acres of the Montego Bay Mobile Home Park. The area is 54% impervious due to the high density of mobile homes and paved areas; the only pervious areas are the small plots between the trailers. Flow was quantified by measuring the depth and velocity of the runoff in the sewer for computation according to Eq. (15) or by volumetric measurements at the sewer outlet in which the time for the runoff to fill a container of known volume was noted.

Sample Site 9 - Site nine is an urban site located in a storm sewer at 119th St. and Rt. 528, Ocean City. The sewer drains approximately 9.2 acres of mixed use land including streets and parking lots, a gas station, residences, and some empty, pervious lots. The drainage area is 84% impervious and flow was quantified by measurements of current and depth in the sewer or by the volumetric method.

Sample Site Ten - Site ten is an urban site located in a storm sewer at Newport Bay and Rt. 528, Ocean City. The sewer drains approximately 6.4 acres of high-rise, multiple

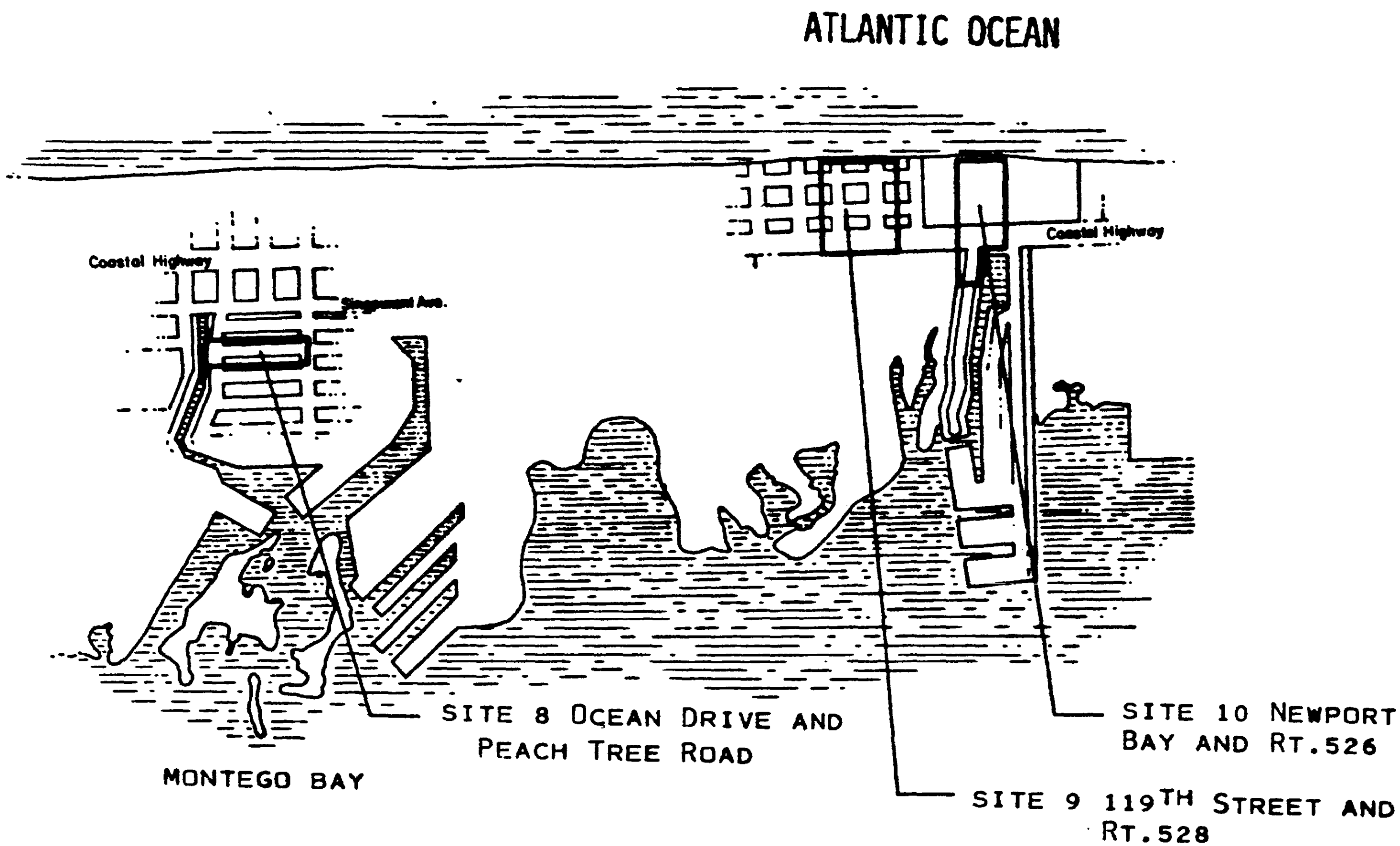


Figure 9. Sample Sites Eight, Nine, and Ten.
(Ocean City, Md.)

unit dwellings and the drainage area is virtually 100% impervious. Flow was quantified by measurements of current velocity and depth in the sewer or by the volumetric method.

D. Sampling Procedure

A typical field survey commenced with the monitoring of Worcester County weather reports. Under conditions of imminent rainfall, a field crew was assembled and dispatched to the sampling sites. Rain gauges and flow measurement devices (if not previously installed) were set up and, upon the initiation of runoff, water samples and measurements of runoff were taken every fifteen minutes for five hours. (Samples for BOD and coliform analyses were taken less frequently due to the additional laboratory effort required in their determination). It was felt that during the five-hour period, the major portion of pollutants (generated by the first-flush effect) would run off and the expense and effort of sampling for a longer duration would not be justified. Water quality samples were dispatched to a laboratory and analyzed for organic, ammonia, and nitrate and nitrite nitrogen, total and ortho-phosphorous, five-day biochemical oxygen demand, total and fecal coliforms, and total organic carbon. Data on runoff quantity was retained and subjected to analysis based on the methods of flow measurement which included V-notch weirs, simultaneous measurement of depth and velocity of flow, and volumetric sampling.

Additional insight into the sampling process may be gained from a set of written instructions presented to the field crews and reproduced as Appendix A.

E. Presentation of the Field Data

All field data used in the model calibration are presented in Appendices B and C. A typical set of rainfall hyetographs, runoff hydrographs and pollutographs is also included. A complete set of field data and additional graphs have been presented to the Maryland DNR.

Laboratory determinations were performed by Maryland DNR while the flow calculations and assembly of the data into usable form were performed by VIMS.

For all sample sites except site seven, the following data are presented:

site number, date, and drainage area,

time and cumulative rainfall measurements,

time and background levels (if any) of pollutants in the water course prior to initiation of runoff,

time, flow-rate, and constituent concentrations of each runoff sample,

average pollutant concentration in the runoff,

total volume and mass runoff for the event, and

total flow and rainfall in inches and cubic feet, and the computed runoff coefficient (no depression storage considered).

For site seven, the marsh site, a different method of analysis was used and the following results are presented:

time, tidal and net volumetric flux and pollutant mass flux in the sampling interval, and

total volumetric and mass flux during one tidal cycle contained within the sampling period.

The methods of data analysis and an explanation of the terminology are presented in Appendices C (for the non-marsh sites) and D (the marsh site).

F. Analysis of the Data Collection Program

The collection of non-point source pollution data proved to be much more difficult than anticipated. The program for the Chincoteague Study was plagued by equipment failure, human error, and extremely dry weather conditions which produced few events of sufficient runoff magnitude.

In several instances, a field crew was assembled and dispatched, based on weather predictions, only to return when no rainfall materialized. At other times, field data were collected, but later deemed inadequate for model analysis.

Initial problems occurred with flow measurement devices. V-notch weirs were installed at several sampling sites. These devices should be easy to read and practically fail-safe. They were installed in small channels which were frequently dry, however, at a level such that large quantities of runoff had to accumulate before the V-notch was breached. In effect, the weirs acted as dams creating large pools behind them and preventing measurable runoff from occurring. These weirs were later removed from all but one site, but not before some sampling effort was wasted.

At sites in which runoff depth and velocity were measured for flow quantification via equation (15), problems also occurred. The runoff often was too shallow or of insufficient quantity to measure with a flow meter. Runoff-borne silt and debris also fouled the meters making the readings unreliable. Sometimes, the field crews returned with measures of velocity but not depth (or vice-versa) making flow calculations impossible. In several instances, no flow data was taken at all.

Even when measureable runoff occurred and was properly sampled, the data is not always of use. To properly calculate the pollutant flux from a watershed and calibrate a model, the entire watershed must contribute - that is, runoff from the most distant portions of the basin must reach the outlet so the loadings and runoff coefficients from these areas may be obtained. If the rainfall is slight or of such short duration that the entire basin does not contribute, the sample is useless, being representative only of the area immediately around the outlet which does contribute.

Additional data problems and efforts to rectify them are presented in the chapter on model calibration. Table II summarizes the results of all collection efforts including the date, site, sampling agency, and quality of data.

In general, it appears that the simplest sampling methods were also the most reliable. The most accurate data obtained in this study came from the sites in which the channel

Table II. Summary of Data Collection Efforts

Date	Site No.	Sampling Agency	Condition of Data	Comments
11/18/75	7	VIMS	Complete	
12/16/75	7	VIMS	Complete	
4/25/76		VIMS,DNR		No runoff occurred
5/11/76	1	-	Unusable	No quantitative data
5/11/76	2	DNR	Unusable	No flow over weir
5/11/76	3	VIMS	Complete	
5/11/76	5	VIMS		No runoff occurred
5/11/76	6	DNR		No runoff occurred
6/17/76		VIMS,DNR		No runoff occurred
9/16/76	8	DNR	Partial	No current readings
9/16/76	9	VIMS	Partial	No current readings
9/16/76	10	VIMS	Partial	No quantitative data
10/9/76	1,2,7, 8,9,10	VIMS,DNR		Sample teams arrived after runoff began
10/24/76	7	VIMS	Complete	
10/25/76	1	DNR	Complete	
10/25/76	4	DNR	Partial	No current data
10/25/76	5	DNR	Complete	Some data restored
10/25/76	6	DNR		No runoff occurred
10/26/76	2	DNR	Complete	
10/26/76	3	VIMS	Partial	Only four flow measurements taken
10/26/76	4	DNR	Partial	No current data
10/26/76	5	DNR	Complete	
10/26/76	6	DNR	Complete	
3/21/77	7	VIMS	Complete	
3/22/77	1	DNR	Complete	
3/22/77	2	DNR	Unusable	No flow over weir
3/22/77	3	DNR	Good	
3/22/77	4	DNR	Unusable	Flow meter malfunction
3/22/77	5	DNR	Unusable	Improper flow measurements
5/2/77	8	DNR	Unusable	Insufficient rain,entire area does not contribute
5/2/77	9	DNR	Unusable	Insufficient rain,entire area does not contribute
5/2/77	10	DNR	Unusable	Insufficient rain,entire area does not contribute
5/31/77		VIMS		No rainfall occurred
7/25/77	8	VIMS	Partial	Quantitative data poor
7/25/77	9	VIMS	Partial	Quantitative data unreliable
7/25/77	10	VIMS	Partial	Quantitative data poor
9/19/77		VIMS		No rainfall occurred

cross-section was measured, the depth of flow properly recorded, and the velocity calculated from the time of travel of a floating particle. This method is inexpensive, reliable, and of sufficient accuracy considering the other sources of error present in a study of this nature. The "time of travel" method is therefore recommended in channels of small cross section (approx. one to ten square feet) which conduct flow primarily after rainfall and are otherwise dry or stagnant. Additional accuracy could be gained in the "time of travel" method by lining a segment of the ditch with a rectangular flume to produce a precisely known cross-section and by correcting the surface velocity to reflect the depth-averaged velocity.

In storm sewers the volumetric method (in which the time required for the flow to fill a container of known volume is noted) is superior.

CHAPTER IV. MODEL CALIBRATION

Implementation of the "STORM" model requires the identification and evaluation of several parameters, the values of which can neither be specified a priori nor measured directly. These parameters, including pervious and impervious runoff coefficients, depression storage, and pollutant accumulation rates, are obtained through the process known as calibration.

In the calibration procedure, estimated values of the unknown parameters are supplied to the model which is then used to predict runoff quality and quantity under conditions identical to those during which the field surveys were conducted. That is, the drainage area, land use, and precipitation for each sample site-event are input to the model along with estimated values of depression storage, runoff coefficients, and pollutant accumulation. Based on these inputs, the STORM model is used to obtain predictions of runoff quantity and quality which are compared to the field measurements. In successive model runs, the calibration parameters are adjusted until a match of predictions and measurements are obtained and the model is considered to be calibrated.

A. General Calibration Procedure

For sample site-events with complete precipitation and runoff quality and quantity data, a general calibration procedure to obtain depression storage, pervious and impervious runoff coefficients, and pollutant accumulation rates may be defined.

The process consists of first finding values of calibration parameters for each site-event which satisfy the following equation equivalent to the coding used by the model to predict runoff volume.

$$r_m = \{f_{per}C_{per} + f_{imp}C_{imp}\}\{P_m - D\} \quad \text{where} \qquad (17)$$

r_m is the measured total runoff

C_{per} is the pervious runoff coefficient (to be calibrated)

C_{imp} is the impervious runoff coefficient (to be calibrated)

f_{per} is the fraction of the site which is pervious

f_{imp} is the fraction of the site which is impervious

P_m is the measured total precipitation

D is depression storage (to be calibrated)

Once values of C_{per}, C_{imp}, and D are obtained, they are used in the STORM model to verify the match of predicted and measured runoff. At the same time, the STORM model is used to predict for each site-event the mass of pollutant washoff based on estimated pollutant accumulation rates. These rates are then adjusted in successive model runs until a fit of predicted and measured pollutant washoff is obtained.

With the evaluation of depression storage, pervious and impervious runoff coefficients, and pollutant accumulation rates, the calibration process for each site-event is complete. The following subsections detail the specific determinations of each of these parameters.

1) Depression Storage - As outlined in Chapter I, depression storage is a term for those processes which intercept and hold stormwater before runoff and infiltration can occur. As incorporated in the STORM model, maximum depression storage may vary among watersheds, but within each watershed it is a fixed constant. Alternate conceptualizations in which depression storage varies with the season of the year and/or with the magnitude and duration of the storm event are also prevelant in the literature.

Difficulties encountered in determining depression storage can be understood by examining Eq. (17). It can be seen that the equation includes three unknowns - C_{per}, C_{imp}, and D. Thus an infinite number of values of D which satisfy Eq. 17 may be selected and compensated by the corresponding infinite possible values of C_{per} and C_{imp}. The ideal calibration process is one which not only satisfies Eq. (17), but provides consistent, rational values for each calibration parameter.

A number of approaches to determining depression storage were attempted. Among these were

(i) the use of constant values selected from literature,

(ii) the use of seasonally varying arbitrary values,

(iii) consideration of depression storage as a variable function of storm magnitude and duration, and

(iv) solution of Eq. (17) simultaneously for several storm events to obtain D, C_{per}, and C_{imp} deterministically.

None of these approaches were deemed successful. Either the selected values of depression storage forced unrealistic values for the runoff coefficients or the selection method was arbitrary and inconsistent and, thus, of little use in a predictive model.

As an alternative, a small, constant value of depression storage, D = 0.01 inches, was selected and applied uniformly to each sample watershed. (An exception is Sample Site Three, a lowland woods in which considerable surface accumulation of water was observed before runoff would occur. Here depression storage was selected as 0.33 inches.) This method is at least consistent and effectively reduces the number of unknowns in Eq. (17).

2) Impervious Runoff Coefficient - The impervious runoff coefficient of a basin can be derived directly from field measurements and from Eq. (17) if a completely impervious watershed (i.e. a watershed in which f_{per} = 0) with known or assumed depression storage is sampled. Unfortunately, no reliable flow data exists for Sample Site Ten which meets the criteria of one-hundred percent imperviousness. Thus the pervious runoff coefficient must be determined alternately and the same difficulties encountered in determining depression

storage occur. Even with depression storage eliminated as an unknown, an infinite number of values of the impervious runoff coefficient, C_{imp}, may be selected and compensated with corresponding values of the pervious runoff coefficient. Therefore, for all watersheds, a value of $C_{imp} = 0.9$, the default value supplied with the STORM model, is applied and Equation (17) is reduced to only a single unknown.

3) Pervious Runoff Coefficient - Once the depression storage and the impervious runoff coefficient are obtained, the pervious runoff coefficient may be easily determined through rearrangement of Eq. (17) to

$$C_{per} = \{\frac{r_m}{P_m - D} - f_{imp}C_{imp}\} f_{per}^{-1} \qquad (18)$$

This method of calibration attributes all differences in runoff volume between watersheds of identical area subject to the same storm conditions solely to dissimilarities in percent imperviousness and in pervious runoff coefficient. This method appears simplistic, but the sparsity of field data and the associated uncertainty inherent in the data collection program render a more sophisticated analysis unjustified.

4) Pollutant Accumulation Rates - After the parameters affecting runoff volume - D, C_{imp}, and C_{per} - are obtained, they are used in the STORM model along with the

relevent sample-site parameters, i.e. basin area, percent imperviousness, and time history of precipitation, to verify the predicted runoff and to obtain a prediction of pollutant mass washoff for comparison with the mass washoff measured in the field. Initially, pollutant accumulation rates provided in the STORM manual (4) are used. As shown in Eq. (5), total mass runoff is a linear function of the pollutant accumulation rate so that improved estimates of pollutant accumulation may be obtained through the formula

$$a_{i,j+1} = a_{i,j} \frac{M_{i_m}}{M_{i_p}} \quad \text{where} \qquad (19)$$

$a_{i,j+1}$ is the improved estimate of the accumulation rate of pollutant i

$a_{i,j}$ is the previous estimate of the accumulation rate of pollutant i

M_{i_m} is the measured mass runoff of pollutant i

M_{i_p} is the predicted mass runoff of pollutant i

Use of Eq. (19) provides a rapid conversion of predicted and measured mass runoff. Usually, only one or two STORM runs in addition to the initial run are needed. Caution in estimating the accumulation rates must be exercised in two areas, however. Equations (11)-(13) show that the accumulation of suspended and settleable solids affects the mass runoff of BOD, nitrogen, and phosphorous independent of the accumulation rate of the latter three pollutants. Since predictions of solids runoff are not desired in this study, their accumulation rate was considered zero and no difficulties were encountered. If predictions of both solids and dissolved pollutants are desired, calibration of solids must be conducted first with the accumulation of BOD, nitrogen, and phosphorous adjusted in successive runs to account for the non-solids related accumulation and washoff.

A more difficult problem is encountered in estimating the parameter LDATE, the number of dry days since the last rain event previous to the precipitation history input to the STORM model. This parameter, equivalent to N_D in Eqs. (3) and (4), initializes both the depression storage and the pollutant accumulation available at the beginning of the model run. The day from which pollutants are assumed to accumulate prior to the sampling period will affect the mass washoff prediction as much as the calibrated accumulation rate. Often, a sample event will be preceeded by one or several small rain events ($\approx$ 0.1 inches) and a larger rain event (0.5 - 1.0 inches). It is up to the modeler to decide which (if any) of these events will have washed away the majority of pollutants requiring accumulation to begin anew. Thus the calibrated accumulation values depend, to some extent, on the judgement of when the last significant rainfall occurred. On longer model runs, e.g. a prediction for a season or year, the importance of LDATE is overshadowed by the sequence of precipitation events occurring in the model run and the estimation of this parameter is not a matter of serious concern.

B. Special Calibration Procedures

Section A of this chapter detailed the general calibration procedure applicable to those sample site-events for which complete precipitation and runoff data are available and used to obtain estimates of depression storage and pervious and impervious runoff coefficients. Table II shows much of the data is only partial or otherwise unusable for this general procedure, however. In most cases, replicate field efforts allowed the unsuitable data to be discarded but occasionally, the data was considered too important to neglect. This is especially true of the data from Site Four, the chicken feeding operation and from urban sites Eight, Nine, and Ten. Runoff estimates from these land uses are a desired result of this study, yet the data base is unsuitable for general calibration. Instead, a special calibration procedure has been devised.

In general, the field data for sites Four, Eight, Nine, and Ten contain reliable measures of pollutant concentration but faulty or no measures of runoff volume. Thus the special calibration procedure seeks to match the predicted and sampled average pollutant concentrations (as opposed to pollutant mass runoff) by relying on runoff coefficient and depression storage values obtained from other sites to predict the runoff volume and on pollutant accumulation rates obtained in a manner similar to the general calibration procedure. Details of the application of the special calibration procedure are presented in the following subsections.

1) <u>Special Calibration of Site Four</u> - Site Four, primarily a chicken feeding operation, is shown schematically along with adjacent agricultural Site Five in Figure 10. It can be seen that the drainage basin of Site Five, primarily a field, is upland of the feeding operation and that runoff from both land uses drains into the same ditch which passes through and partially drains a wooded area before emerging at the measurement point near Bayside Road.

In any event, the pollutant mass contributed by the field and the woods would have to be subtracted from the quantity measured in the roadside ditch before the exclusive contribution of the feeding operation could be found. This process is complicated by the fact that no satisfactory volume measurements were obtained downstream of the feeding operation necessitating an analysis based on pollutant concentrations. Both the quantity and the quality of the runoff from Site Five are known, however, and the contribution from the woods, based on the results of the general calibration of Site Three, may be considered negligible allowing the following analysis.

The objective is to isolate the pollutant contribution from the feeding operation. The principle of mass conservation allows an equation giving the concentration of a pollutant in the combined runoff from Sites Four and Five in terms of the individual runoff from the sites to be formulated:

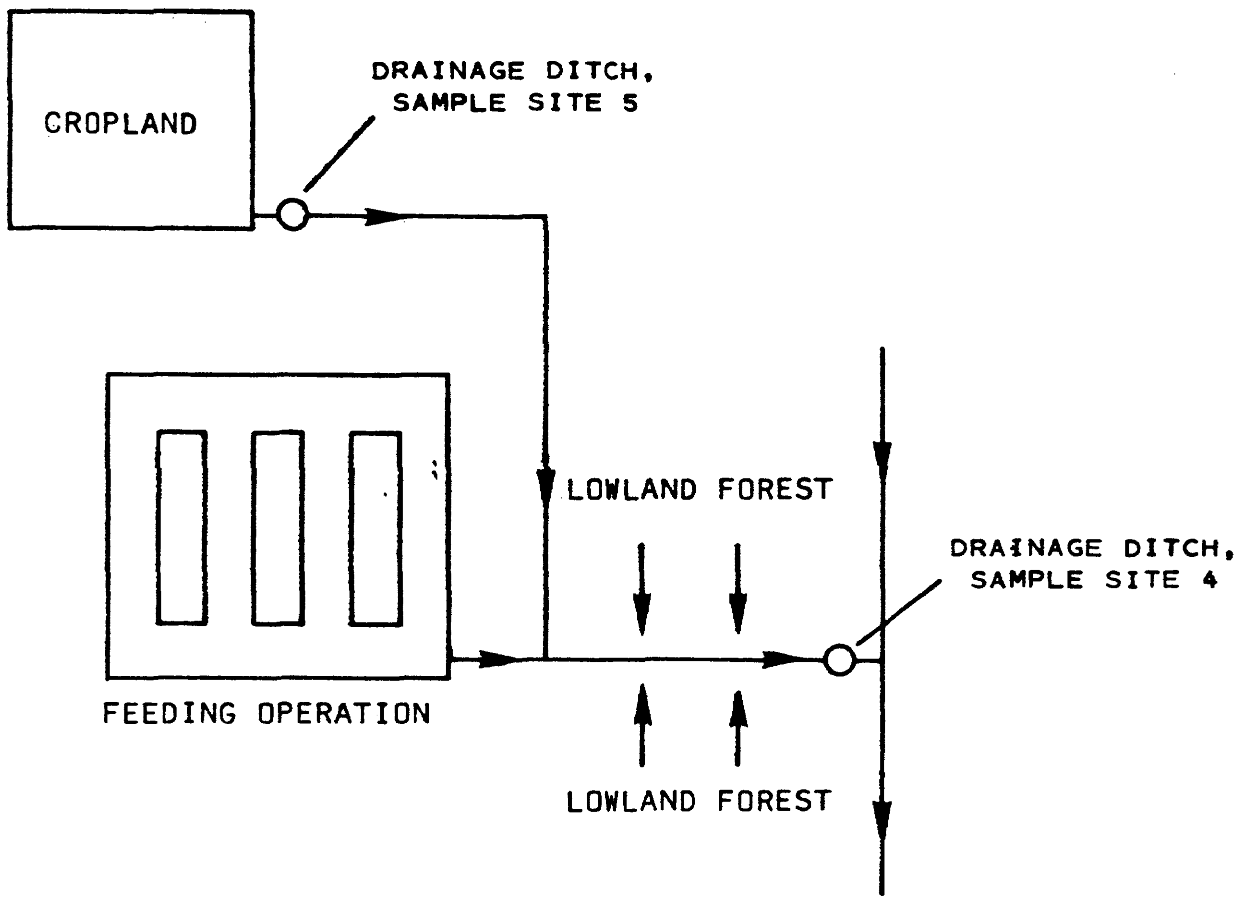


Figure 10. Schematic of Sample Sites Four and Five

$$c_{4+5} = \frac{c_4 Q_4 + c_5 Q_5}{Q_4 + Q_5} \qquad \text{where} \qquad (20)$$

c_{4+5} is the average concentration of the combined runoff (sampled in the roadside ditch)

c_4 is the average concentration of the runoff from the feeding operation (unknown)

c_5 is the average concentration of the runoff from the upland field (known)

Q_4 is the total volume of runoff from the feeding operation (unknown)

Q_5 is the total runoff from the upland field (known)

This equation may be rearranged to solve directly for the desired concentration c_4

$$c_4 = \frac{c_{4+5}(Q_4 + Q_5) - c_5 Q_5}{Q_4} \qquad (21)$$

The runoff, Q_4, is still unknown, however, preventing an immediate solution of Eq. (21). The missing parameter is obtained by assuming that for each sample event the depression storage and pervious and impervious runoff coefficients are the same as those obtained for Site Five on the same date via the general calibration procedure. The value of f_{imp} for Site Four is estimated to be 0.3 and substituting this value along with the measured precipitation record and the parameters derived from Site Five into Eqs. (2) and (1) gives the runoff. Note, Eq. (1) gives the runoff in inches. It may be converted to volume for use in Eq. (21) through multiplication by the basin area and a suitable dimensional constant. In this case, the feeding operation was assumed to occupy half the basin (the remainder being negligibly contributing woods) or 19 acres and the runoff volume is given as

$$Q_4 = 3630\ AP \qquad \text{where} \qquad (22)$$

Q_4 is the runoff volume (ft^3)
A is the drainage area (acres)
P is the total precipitation (inches)

With the estimation of Q_4 completed, Eq. (21) may be solved directly for concentration values of the various pollutants attributed to the feeding operation. These concentrations are given in Table III. Missing values indicate the analysis could not be performed for the parameter on that date due to missing data or other inconsistencies.

Table III. Pollutant Concentrations Attributed to the Feeding Operation

	c_{4+5}	c_5	c_4	
BOD_5 (mg/ℓ)	0.97	1.06	0.58	
Nitrogen (mg/ℓ)	3.16	0.77	13.5	10/25/
Phosphorous (mg/ℓ)	0.06	0.05	0.1	
BOD_5 (mg/ℓ)	4.28	3.04	7.47	10/26/
Nitrogen (mg/ℓ)	2.14	1.08	4.87	

Once the values of pollutant concentration from the feeding operation are synthesized, the pollutant accumulation rate is obtained in a manner similar to the general calibration procedure. The basin area, percent imperviousness, runoff coefficients and depression storage are input to the STORM model along with the measured precipitation record and initial estimates of the pollutant accumulation rates. Based on these parameters, the STORM model provides predictions of both total mass runoff and average pollutant concentration. The predicted concentrations are compared with the synthesized concentration in Table III and the accumulation rates are adjusted in successive runs until a match is achieved. Once the final pollutant accumulation rates are obtained, the special calibration process for Site Four is complete.

2) Special Calibration of Urban Sites Eight, Nine, and Ten - Calibration of the urban sites is also based on pollutant concentration and is achieved in a manner similar to Site Four except there are no upland, tributary watersheds whose contributions must be isolated and thus the analysis is simplified.

Since there are no watersheds adjacent to the urban sites with calibrated pervious runoff coefficients, an average of the pervious runoff coefficients for the site events calibrated by the general procedure is applied to the urban sites along with the default impervious runoff coefficient, values of f_{imp} measured on-site, and the measured precipitation values. These parameters are used in the STORM model along with estimated pollutant accumulation rates to provide predictions of pollutant mass washoff and average concentration. The pollutant accumulation rates are adjusted in successive runs until the predicted and measured average concentrations agree at which point the special calibration procedure is terminated.

C. Calibration of the Marsh Site

Natural, biological processes in the salt marshes which fringe the open waters of the Chincoteague Bay region result in the production and consumption of quantities of nutrients and detritus which might be considered pollutants if they originated from an alternative source. These "pollutants" include (in both particulate and dissolved forms) organic and inorganic nitrogen, organic and inorganic phosphorous, and organic carbon. The flushing action of the tides(which rise and flood the marsh then fall causing drainage to occur)results in the net exchange of these nutrients and detritus between the marsh and the bay. The flood tides bring into the marsh substances dissolved or suspended in the bay waters while the ebb tides return these or similar substances from the marsh to the bay. Biochemical processes occurring in the marsh may result in a change, however, in both the quantity and nature of the substances imported and exported. It is hypothesized, for example (5), that over an annual cycle marshes are net importers of nitrate from open waters which is converted and exported as organic nitrogen and ammonia. In a similar fashion, other nutrients may be imported from the bay and converted to biomass during the growing season then exported as organic detritus at a later date.

One of the results desired from the Chincoteague Basin Non-Point Source study is a quantification of these marsh-generated imports and exports for comparison with the pollutant contributions of conventional point and non-point sources. Field studies were conducted with two objectives: (1) to determine the background level of nutrient import or export from a sample salt marsh, and (2) to determine the incremental import or export due to incident rainfall and washoff. A sample site, described in Chapter III, Section C was selected and experiments were conducted aimed at the quantification of

organic nitrogen,
ammonia,
nitrate and nitrite nitrogen,
total phosphorous,
orthophosphosous, and
total organic carbon.

The field studies and methods of analysis employed are detailed in Appendix D, "Marsh Data Analysis Procedure", while the results of the marsh studies are summarized in Table IV which for each sample event gives

Table IV. Results of Marsh Study

Date	Rain (in.)	Net Flow (ft^3)	Net Transport (lbs/cycle) Org N	NH_3	NO_3+NO_2	Tot P	Ort P	TOC
12/16/75	0.0	2.0×10^5	3.45	0.75	0.57	-0.17	0.25	462.5
11/18/75	0.0	-0.47×10^5	7.79	-0.09	-0.11	-2.95	-1.26	-230.2
10/24/76	0.12	5.2×10^5	87.0	-2.4	-0.46	9.7	8.0	1668.5
10/25/76	0.78	-1.3×10^5	-80.0	5.8	-0.18	-6.9	-6.4	-672.1
3/21/77	0.16	-1.7×10^5	-27.5	-0.85	-0.45	-1.2	-0.47	-174.3

<u>Note</u>: Negative values imply nutrient exports.

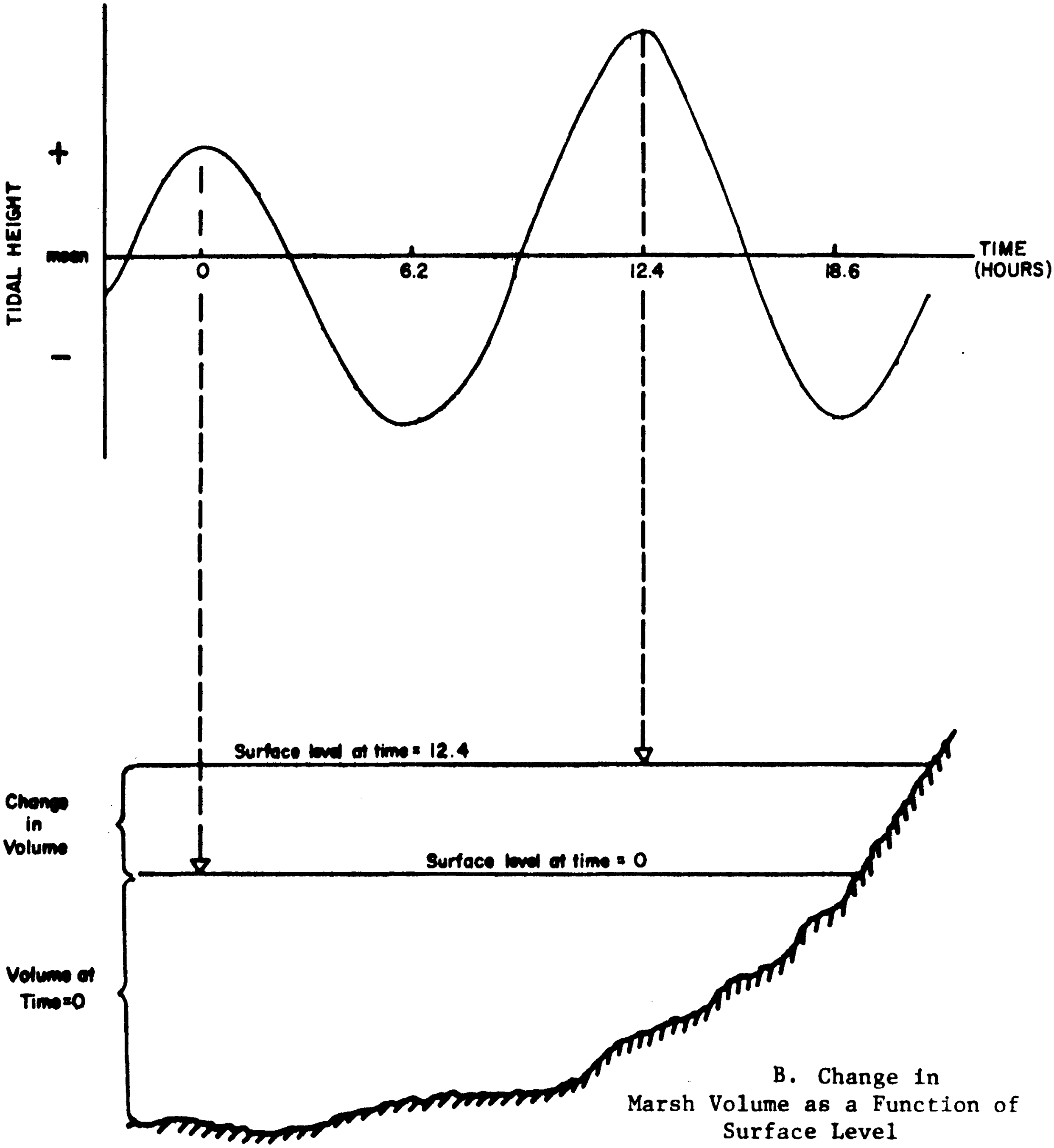
the date, precipitation, net flow, and net transport of the sampled substances over a tidal cycle.

Marsh imports and exports are the result of two processes: rain-induced flushing and tidal flushing. The rain induced flushing is analagous to washoff from a land surface and is readily understood. The tidal flushing process is also easily conceptualized but can produce deceptive results.

Tides in the Chincoteague Bay area possess diurnal inequality resulting in a time history of tidal height vs. time as in Fig. 11a. In a diurnally unequal system, the heights of successive high tides are unequal causing a net change in the volume of the swamp over a tidal cycle (Fig. 11b) and a net flow into or out of the swamp.

Nutrient import and export is thus seen to be influenced by two unrelated factors: biochemical activity and tidal dynamics. In a long-term analysis, (e.g. a growing season or year) positive and negative tidally induced changes in volume and rain-induced flushing will tend to negate each other and biochemical processes will be the dominant factor in import and export. In a short-term analysis (e.g. one tidal cycle or 12.4 hrs.), however, tidal effects will predominate causing deceptively large imports and exports which are mainly due to the temporary change in volume rather than to biochemical activity. In

A. Diurnally Unequal Tide



B. Change in Marsh Volume as a Function of Surface Level

Figure 11. Diurnally Unequal Tides and Their Relation to Marsh Volume.

extreme cases, the trend in biochemically induced production e.g. an export of nitrogen may be completely reversed due to a large change in volume e.g. a large temporary import of nitrogen laden water from the bay. Thus a long-term study and measures taken over more than one tidal cycle are needed to estimate the background level of nutrient export or import from a swamp and to determine the incremental export caused by storm conditions.

In this study, five field surveys were conducted encompassing only one tidal cycle each. It is thus impossible to accurately discern the background and storm-level import and export for each event from the available data. An attempt was made, however, to derive an expression applicable to all events and based on the field data, relating import (or export) to the tidally induced change in volume and to incident precipitation. The expression is of the form

$$M = \hat{a} + \hat{b}\Delta v + \hat{c}P \qquad \text{where} \qquad (23)$$

M is the net mass exchange over a tidal cycle (lbs/cycle)

$\hat{a}$ is the long term average mass exchange in the absence of rain (lbs/cycle)

Δv is the short term change in volume (ft^3/cycle)

$\hat{b}$ is a constant relating deviations in the long-term mass exchange rate to short-term fluctuations in volume (lbs/ft^3)

P is incident precipitation (in/cycle)

$\hat{c}$ is a constant relating deviations in the long term average mass exchange to precipitation (lbs/in)

Equation 23 provides a model from which the individual effects of long-term biological production, tidal import and export, and precipitation can be isolated. The parameters $\hat{a}$, $\hat{b}$, and $\hat{c}$ are evaluated through the linear regression process. In this process, values of net mass exchange, M, short-term volume change, Δv, and precipitation, P, obtained from Table IV are input to a statistical computer package, SPSS (7), which derives values of $\hat{a}$, $\hat{b}$, and $\hat{c}$ such that Eq. 23 is best fit to the field data. A measure of how well the equation fits the data is given by the parameter r^2 which may vary between zero and one. An r^2 value of unity implies perfect agreement between the equation and the data while a value of zero implies no significant fit at all of the equation and the data. The values of $\hat{a}$, $\hat{b}$, $\hat{c}$, and of r^2 obtained via regression for each parameter sampled at Site Seven are given in Table V.

The results expressed in Table V can be interpreted as follows. On the average and in the absence of rain, the marsh examined would import 10.2 pounds of organic nitrogen per tidal cycle. One inch of rain results in a flux of 10.2 lbs/cycle - 193 lbs/in * 1.0 in = -182.8 lbs/cycle. The negative sign implies an export of organic nitrogen caused by rain-induced washoff and flushing. Similar analyses may be applied to obtain the import-export of the other parameters. Note the low r^2 value for nitrate implies no significant statement about nitrate dynamics can be made. The results

Table V. Regression Analysis of Marsh Nutrient Export

Nutrient	$\hat{a}$ (lb/cycle)	$\hat{b}$ (lb/ft^3)	$\hat{c}$ (lb/in)	r^2
Organic Nitrogen	1.02×10^{1}	1.29×10^{-4}	-193	0.88
Ammonia	-8.60×10^{-1}	-1.69×10^{-6}	8.9	0.74
Nitrate	-6.40×10^{-2}	7.28×10^{-8}	-0.36	0.06
Total Phosphorous	7.86×10^{-2}	1.41×10^{-5}	-16.7	0.74
Ortho Phosphorous	8.30×10^{-1}	1.06×10^{-5}	-15.1	0.77
Total Organic Carbon	2.17×10^{2}	2.39×10^{-3}	-2558	0.87

for ammonia appear incongruous stating that rainfall produces a net import of ammonia. Similar results were noted by Axelrad, et al. (5), however, after a rainstorm at their Carter Creek site. No explanation for this phenomenon can be offered.

The analysis used here and Eq. 23 should not be interpreted as providing a precise model for short-term predictions of marsh nutrient dynamics. Lack of sufficient data points and neglect of a number of factors including seasonality and variability from marsh to marsh prevent applications of this nature. The model is rather used only to estimate the order-of-magnitude effects of storm-generated marsh nutrient export. These estimates may be found in Section E of Chapter V - "Calculation of Current Non-Point Pollution Loads".

D. Results and Synthesis of the Calibration Procedure

A total of sixteen sample events were found to provide suitable data for either the general or special calibration procedures. Table VI presents for each of these events the date, site, percent imperviousness, and the calibrated values of pervious runoff coefficient and pollutant accumulation rates. Missing parameter values indicate that no estimate could be obtained.

Both the agricultural sites (Sites One, Two, Five, and Six) and the wooded site (Site Three) were assumed to have zero percent imperviousness. Although these sites do have some impervious areas (e.g. the roofs of farm buildings),

Table VI. Results of the Calibration Procedure

Date	Site	f_{imp}	c_p	BOD_5 Accumulation Rate (lb/acre/day)	N Accumulation Rate (lb/acre/day)	P Accumulation Rate (lb/acre/day)	Coliform Accumulation Rate (10^9/acre/day)
10/25/76	1	0.0	0.837	0.013	0.135	9.3×10^{-3}	2.0
3/22/77	1	0.0	0.118	0.015	0.039	2.03×10^{-4}	0.319
10/26/76	2	0.0	0.030	0.002	0.015	9.0×10^{-5}	0.036
10/25/76	5	0.0	0.710	0.02	0.014	9.0×10^{-4}	
10/26/76	5	0.0	0.314	0.072	0.026	6.1×10^{-3}	28.5
10/26/76	6	0.0	0.206	0.245	0.018	0.016	838.
5/11/76	3	0.0	0.015	6.1×10^{-4}	1.17×10^{-4}	1.9×10^{-5}	7.3×10^{-3}
3/22/77	3	0.0	0.180	0.033	2.65×10^{-3}	3.17×10^{-4}	0.018
10/25/76	4	0.3		0.011	0.253	1.9×10^{-3}	
10/26/76	4	0.3		0.257	0.167		
9/16/76	8	0.54		0.08	9.77×10^{-3}	2.04×10^{-3}	2.56
7/25/76	8	0.54		0.028	4.18×10^{-3}	5.85×10^{-4}	0.424
9/16/76	9	0.84		0.127	0.012	1.86×10^{-3}	8.16
7/25/76	9	0.84		0.385	0.013	7.44×10^{-4}	5.61
9/16/76	10	1.0		0.158	0.018	1.5×10^{-3}	0.86
7/25/76	10	1.0		0.362	0.020	1.7×10^{-3}	7.32

runoff from these areas passes to pervious portions of the sample watersheds rather than directly to the outlet as in the urban basins. Since all the runoff therefore passes over pervious zones, and since the impervious fractions are small, they are neglected.

Inspection of Table VI shows immediately a wide disparity among the sites in calibrated values of pervious runoff coefficient and pollutant accumulation rates. Before a predictive model, based on these parameters could be implemented, a means of analyzing and synthesizing the calibration parameters for use in the model was needed.

Attention first focused on the pervious runoff coefficient. Attempts were made to link it to soil type, season, and antecedent rainfall. After several trials, however, it was decided the best estimate of C_{per} was simply a geometric average* of the runoff coefficients obtained for each site. The resulting value was then applied throughout the basin.

The variability evident in the pollutant accumulation rates is readily accepted on the basis of differing land uses; an urban residential site, for example, would be expected to accumulate pollutants at a different rate than a farm site or wooded area. Thus the synthesis of pollutant

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*The geometric average is defined as

$$\mu_g = \sqrt[n]{\prod_i^n X_i} \qquad \text{where}$$

μ_g is the geometric average of the parameters X_i

n is number of parameters

$\prod_i^n X_i$ represents the product $X_1 \cdot X_2 \cdot X_i \cdots \cdot X_n$

accumulation rates for use in the STORM model is made on the basis of land use with geometric averages of the individually calibrated rates providing the measures of central tendency for each land use type. Table VII gives these average accumulation rates for each land use as well as the averaged pervious runoff coefficient.

Use of the synthesized calibration parameters of Table VII in the STORM model provides a reasonable long term estimate of the runoff quantity and quality from each land use type. Since the parameters represent averages, however, there may be some error associated with model predictions of runoff from any single site on any specific date. In order to obtain an estimate of this possible error, the synthesized parameters were used in the STORM model to predict the runoff quality and quantity from each sample site under conditions of precipitation and antecedent rainfall identical to those which occurred in the field and which were used to calibrate the model. Table VIII compares the field measures with the predictions (based on synthesized parameters) of runoff volume, total nitrogen runoff, total phosphorous runoff, BOD_5 runoff, and total coliform runoff (For site-events subject to the special calibration procedure for which field measurements of runoff volume are unavailable, model predictions of mass runoff obtained using exact calibration parameters are compared with predictions based on synthesized parameters).

Table VII. Synthesis of Calibration Parameters

Pervious Runoff Coefficient $C_p = 0.157$

Land Use	Pollutant Accumulation Rates BOD (lb/acre/day)	N (lb/acre/day)	P (lb/acre/day)	Coliforms (10^9/acre/day)
Forest (Site Three)	0.0136	5.57×10^{-4}	7.7×10^{-5}	0.012
Agricultural (Sites One, Two, Five, Six)	0.023	0.028	1.57×10^{-3}	3.53
Feeding Operation (Site Four)	0.053	0.206	1.9×10^{-3}	28.5
Low Density Urban (Site Eight)	0.047	6.39×10^{-3}	1.09×10^{-3}	1.04
Medium Density Urban (Site Nine)	0.22	0.012	1.17×10^{-3}	6.77
High Density Urban (Site Ten)	0.239	0.019	1.6×10^{-3}	2.5

Table VIII. Comparisons of Measured Runoff Parameters with Predictions Using Synthesized Coefficients

Date	Site	Runoff (inches)		Total Nit. (lbs)		Total Phos. (lbs)		BOD_5 (lbs)		Total Colif. (10^9)	
		Meas.	Pred.	Meas.	Pred.	Meas.	Pred.	Meas.	Pred.	Meas.	Pred.
10/25/76	1	0.11	0.02	11.1	2.3	.077	0.13	1.1	1.9	164.	289.
3/22/77	1	0.03	0.04	3.8	2.7	.02	0.15	1.47	2.2	30.9	342.
10/26/76	2	0.02	0.12	1.7	3.3	.01	0.19	0.24	2.8	4.26	422.
5/11/76	3	0.001	0.01	0.02	0.10	.004	0.01	.105	2.3	1.26	2.06
3/22/77	3	0.02	0.02	0.4	0.09	.05	0.01	5.3	2.2	2.9	1.95
10/25/76	4	0.05	0.03	3.1	2.5	0.02	0.02	0.14	0.65	155.	350.
10/26/76	4	0.95	0.74	19.9	25.	0.23	0.23	31.	6.3	3378.	3390.
10/25/76	5	0.06	0.01	0.90	1.8	0.06	0.10	1.3	1.5	-	-
10/26/76	5	0.59	0.30	12.7	13.8	3.0	0.78	35.2	11.3	14000.	1741.
10/26/76	6	0.45	0.34	4.02	6.4	3.64	0.36	55.8	5.2	191000.	804.8
9/16/76	8	-	-	0.05	0.03	0.01	0.005	0.38	0.22	12.2	4.92
9/25/77	8	-	-	0.12	0.16	0.016	0.027	0.70	1.2	10.7	26.1
9/16/76	9	-	-	0.10	0.10	0.02	0.01	1.1	1.9	67.4	56.
7/25/77	9	-	-	0.58	0.54	0.03	0.05	17.3	9.9	252.	304.
9/16/76	10	-	-	0.11	0.12	0.01	0.01	1.0	1.5	5.5	15.9
7/25/77	10	-	-	0.89	0.96	0.08	0.07	16.5	10.9	333.	114.

The predictions and measurements are generally within a factor of two of each other. This order of accuracy compares favorably with the results of a similar non-point source study conducted in southeastern Virginia (6). Occasional errors of an order of magnitude occur, however, and the predictions of coliforms are especially variable (consistent with the erratic measures obtained in the field). This analysis shows that the model cannot be relied upon to predict for small basins (≈10-100 acres) subject to short duration storms (<5 hrs) runoff quantity and quality with better than factor-of-two accuracy. The uncertainty may be attributed to several factors including:

- uncertainty and errors in field measurements,
- lack of knowledge of detailed land use practices, and
- hydrologic factors significant in small watersheds but omitted from a model intended for large basins.

Estimates of the pollutant runoff for large segments of the Chincoteague Basin obtained from the STORM model are likely more accurate than the runoff estimates obtained for these small sub-basins, however. The variable hydrologic responses of the small watersheds and the positive and negative errors associated with the calibration procedure will tend to cancel out when obtaining the predictions for the entire Chincoteague Basin over seasonal or annual periods as desired in this study.

CHAPTER V. APPLICATION OF THE RUNOFF MODEL

This chapter is concerned with the use of the model to provide estimations of the current non-point source loading of the Chincoteague Bay system and to predict future loadings based on projected land use patterns and indicated assumptions. Quantifications provided include estimates of the following:

Typical monthly non-point source pollutant loads of the basin,

Pollutant loads produced by a 24-hr. design storm event,

Non-point source runoff occurring during the period Aug. 15 - Sept. 1, 1975,

Projected monthly non-point source pollutant loads for the Year 2000, and

Projected loads produced by a 24-hr. design storm for the year 2000.

A. Description of the Chincoteague Basin and Reduction to Sub-Basins

The Chincoteague Basin, located on the DelMarVa peninsula and shown in Fig. 12, measures roughly 45 miles in length and 10 miles in width. The basin is bordered on the west by a divide which separates it from the adjacent Pocomoke River Watershed, on the north by the divide which defines the Assawoman Bay Watershed, on the east by the Atlantic Ocean, and on the south by the marshy islands in the vicinity of Chincoteague, Virginia. A large portion of the basin is occupied by Chincoteague, Sinepuxent, Newport, Isle of Wight, and Assawoman Bays and by the St. Martin River so that its land area

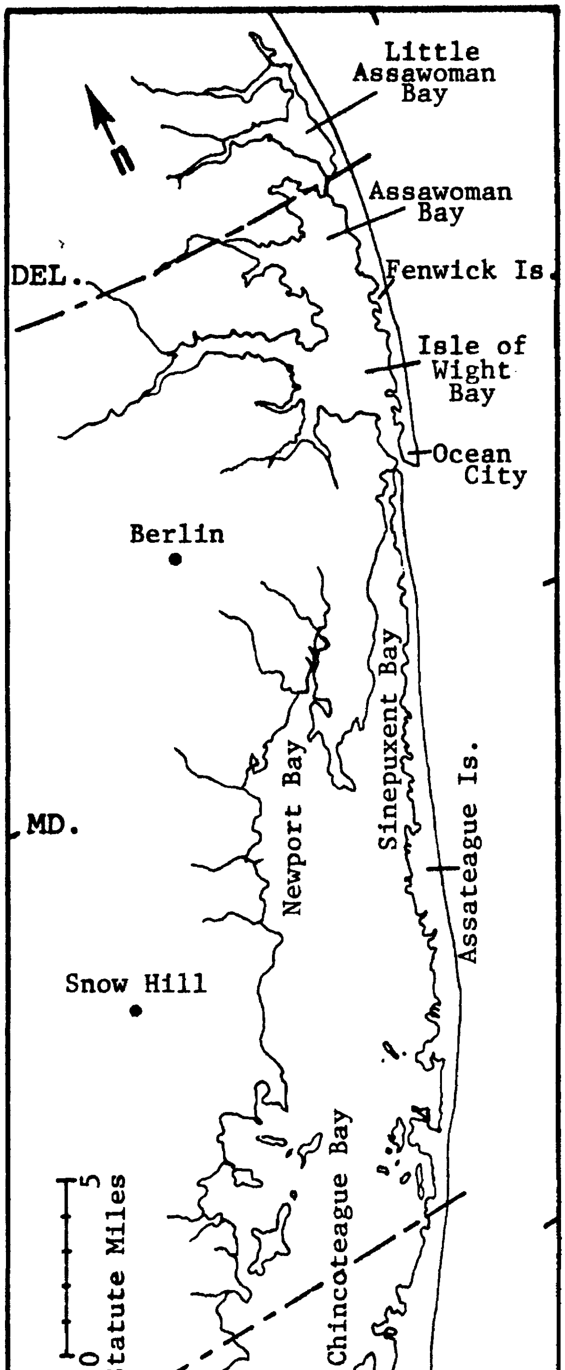


Figure 12. Chincoteague Drainage Basin.

is about 250 square miles. The basin is flat (maximum elevation about fifty feet), encompasses large areas of salt marsh, and is interlaced with numerous small creeks, guts, and drainage ditches.

This combination of topography and drainage renders the Chincoteague Basin unsuited for methods of hydrologic analysis developed for upland watersheds. The typical upland watershed is well-defined by topographic features and the small streams contained within usually combine to form a single outlet channel (Fig. 13). In the coastal region, topographic reliefs are minor or absent and numerous small streams drain directly into the adjacent bays rather than combining to form a few major streams (Fig. 14). Even if delineation of each small stream and its watershed was accomplished there are more of them than could be or need be analyzed.

For this study, the Chincoteague Basin is arbitrarily divided into fifteen sub-basins which are treated as individual watersheds. The runoff produced from each of these sub-basins is the aggregate of the runoff from each individual stream contained within. In this manner, the number of watersheds to be analyzed becomes feasible yet spatial detail in the runoff predictions is maintained. While the size and number of the sub-basins is arbitrary, their borders are defined, wherever possible, along divides which could be discerned from topographic, highway, and other maps of the area. Thus each sub-basin is hydrologically independent of its neighbors.

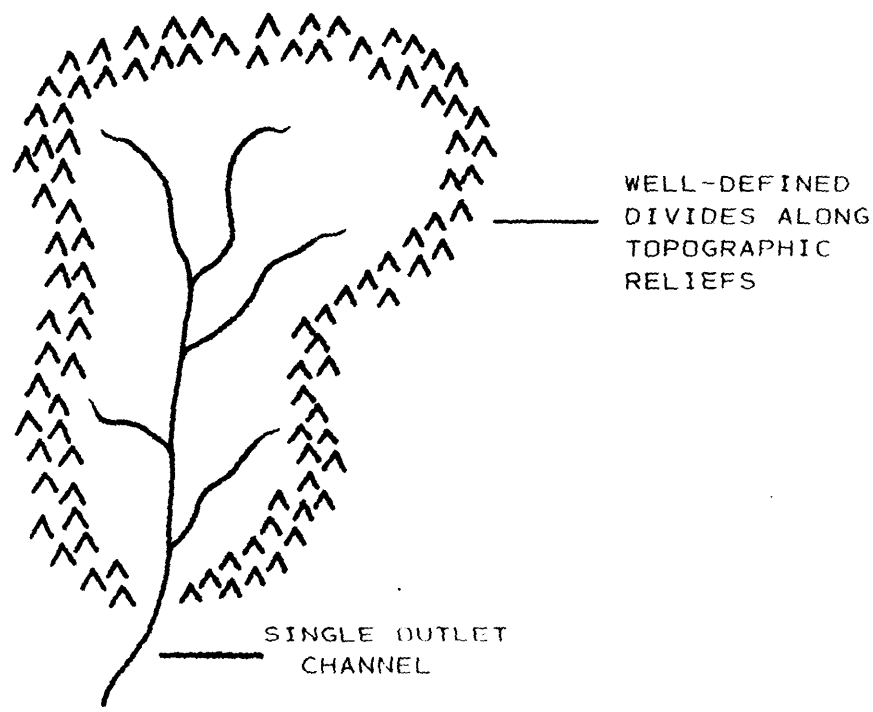


Figure 13. Idealized Upland Watershed

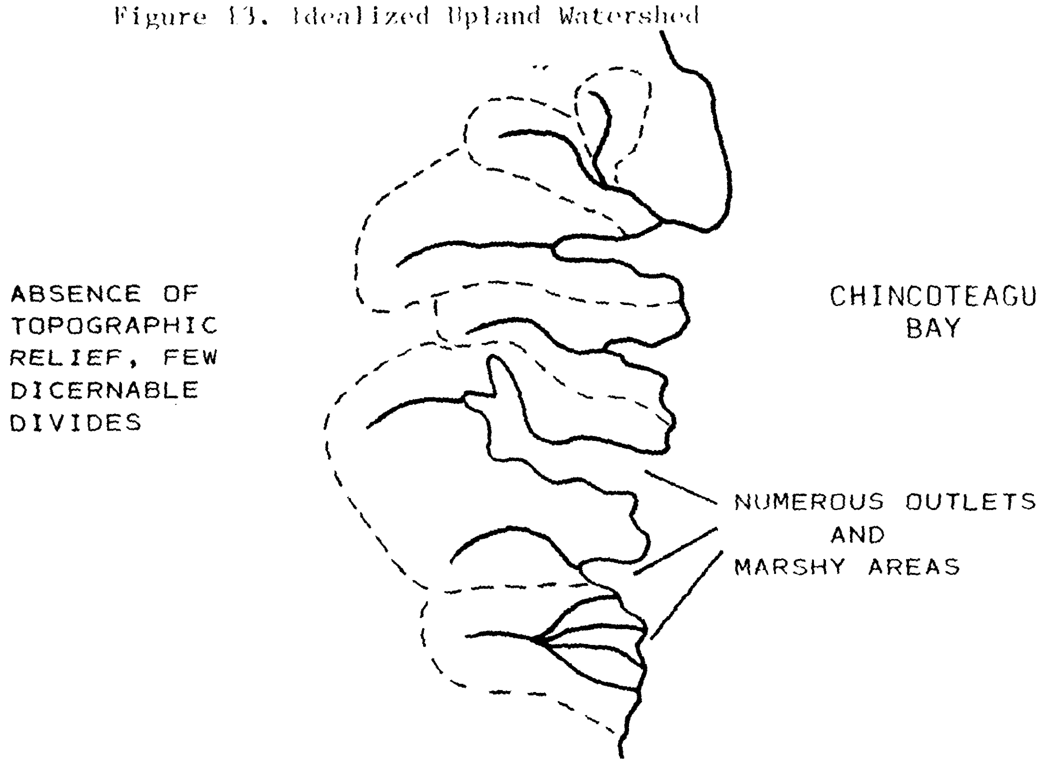


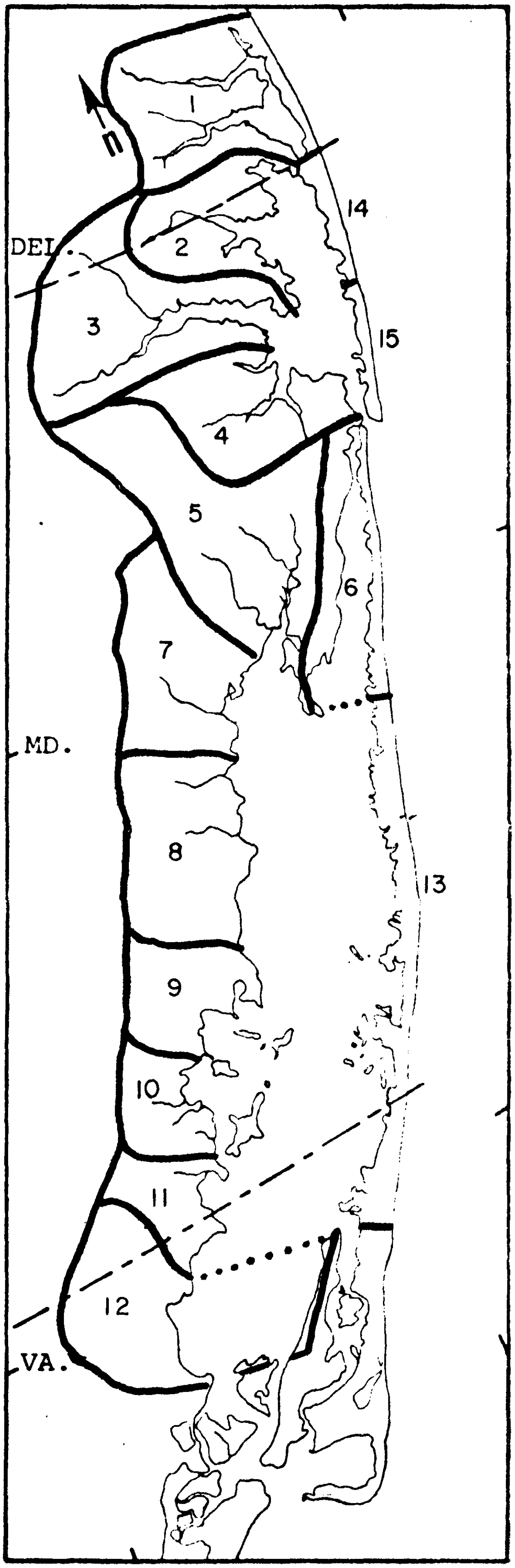
Figure 14. Coastal Drainage Area

The major divides which separate the Chincoteague basin from the Pocomoke watershed and from the drainage basins north of Assawoman Bay were also derived from topographic and similar maps. The major divides were defined to pass through the highest points in their vicinity and such that streams draining the region always flowed away from the divides, never crossing them. The Chincoteague Basin defined in this manner and the sub-basins are shown in Fig. 15.

B. Land Use in the Chincoteague Basin

As detailed in the preceeding chapters, land use is a significant factor in the production of non-point source pollution influencing both the volume of runoff (through the proportion of the land use which is impervious) and the mass of pollutants (through the quantity and nature of the pollutants which accumulate on that land use. A map provided by the Maryland State Department of Planning showing Worcester County, Md. land uses as of 1973 was the prime source of current land-use information for this report. Completion of two tasks, outlined in the following sub-sections, was necessary before the information contained on the map could be applied, however.

1. Enumeration and Quantification of Land-Use Types - The 1973 land-use map was extremely detailed showing 34 separate land uses (Table IX) for the Worcester County portion of the Chincoteague Basin. In order to enumerate and quantify the land-uses within each sub-basin, the land use map was overlain with a transparent map, drawn to the same



1. UPPER ASSAWOMAN
2. LOWER ASSAWOMAN
3. ST. MARTIN
4. TURVILLE
5. TRAPPE
6. SINEPUXENT
7. CHINCOTEAGUE I
8. CHINCOTEAGUE II
9. CHINCOTEAGUE III
10. CHINCOTEAGUE IV
11. CHINCOTEAGUE V
12. CHINCOTEAGUE VI
13. ASSATEAGUE
14. OCEAN CITY NORTH
15. OCEAN CITY SOUTH

Figure 15. Chincoteague Sub-basins

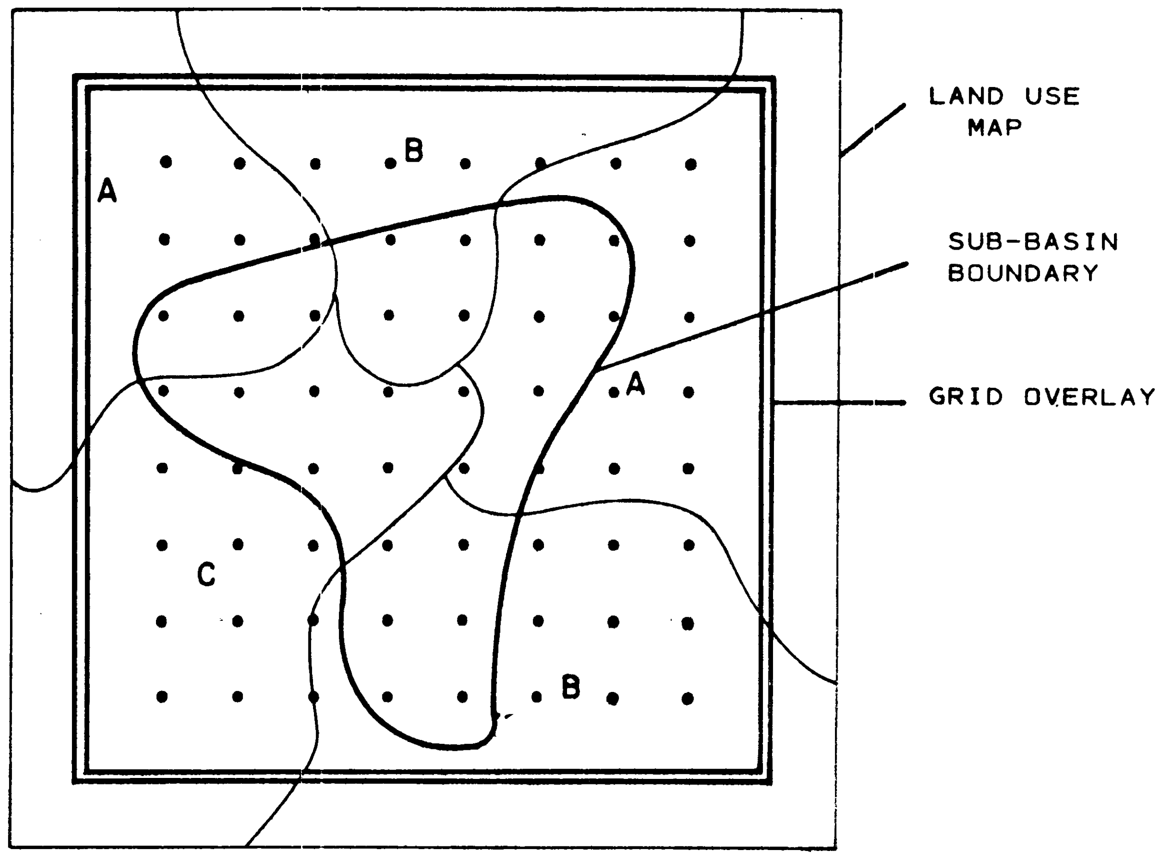
Table IX. Worcester County Land Uses

Code	Land Use
111a	Single Unit Residential (low density)
111b	Single Unit Residential (medium density)
113	Mobile Home and Trailer Parks
121	Retail Sales and Service
142	Quarries and Pits
150	Transportation, Communication, Utilities
151	Airports and Associated Areas
153	Freeways and Highways
154	Marine Terminals
160	Electrical
161	Elementary Schools
162	Secondary Schools
165	Other Institutions
170	Strip and Clustered
190	Open and Other Urban
210	Crop and Pasture Lands
211	Cropland
212	Pasturelands
221	Orchards
230,231	Feeding Operations
410	Deciduous Forest
412	Lowland Deciduous Forest
420	Evergreen Forest
421	Upland Evergreen Forest
422	Lowland Evergreen Forest
430	Mixed Forest
431	Upland Mixed Forest
432	Lowland Mixed Forest
440	Upland Brush
510	Rivers
530	Reservoirs
610	Non-Forested Wetlands
630	Forested Wetlands
720	Beaches

scale, showing the sub-basin divisions. Both were in turn overlain with a third transparency featuring a rectangular grid. The fraction of each land use occupying each sub-basin was determined by counting the number of grid points which fell within each land use type of the sub-basin and next dividing the sum by the total number of grid points falling within the sub-basin. The procedure is shown schematically in Fig. 16. This process eliminated extensive planimetry and summing of each individual land use while maintaining equal or greater accuracy. Portions of the Chincoteague Basin in Delaware and Virginia which fell off the Worcester County land-use map were considered to have the same proportion of land uses as their adjacent Worcester County sub-basins. The total area of each sub-basin was determined via conventional planimetry.

The land use map was considered insufficiently detailed for use in the urbanized Ocean City watersheds and land uses within Ocean City were determined via planimetry of a 1977 zoning map. Ocean City land uses, as provided by the zoning map, are given in Table X.

2. <u>Consolidation of the Land Uses</u> - One objective in conducting the field program was to collect land-use specific runoff data from the sample sites which could be applied to the entire basin. Runoff data were collected and cali-



NUMBER OF GRID POINTS IN SUB-BASIN = 27

FRACTION OF LAND USE A = 10/27

FRACTION OF LAND USE B = 10/27

FRACTION OF LAND USE C = 7/27

Figure 16. Schematic of Grid Point Process

Table X. Ocean City Land Uses

Code	Land Use
R-1	Single Family Residential
R-2	Multiple Family Residential
R-3	General Residential
TR	Trailer Residential
B-1	Local Business
C-1	General Commercial
CM	Commercial Marine
I-1	Industrial

bration parameters have been derived for the following land uses:

forest,
wetlands,
agriculture,
feedlot,
urban-residential,
medium density urban, and
high-density urban.

While data has been collected from seven land uses, there are thirty-four land uses specified on the land-use map and an additional eight land uses from the Ocean City map. Therefore the land uses specified on the maps have been consolidated into groups of similar uses to which are applied the field data and calibration values of depression storage, runoff coefficients, percent imperviousness, and pollutant accumulation obtained for the sample sites. Table XI shows the consolidation of the land uses and the sample sites from which field data and calibration values are applied to each grouping.

In most cases, the groupings are obvious as in the assignment of the forest group. In other cases, the grouping is based on judgement of similarities in imperviousness, pollutant accumulation and other factors, as the assignment of schools and other institutions to the residential group. Occasionally, the assignment is based upon field observations as the grouping of "open and other urban" with wetlands. (Sites designated as "open and other urban" generally proved to be marshes or swamps bordering Ocean City and other developed areas).

Table XI. Consolidated Land Uses

Group	Land Uses - Worcester County	Applicable Sample Site(s)
Forest	Deciduous Forest	Three
	Evergreen Forest	
	Upland Evergreen Forest	
	Mixed Forest	
	Upland Mixed Forest	
	Orchards	
	Upland Brush	
Lowland Forest	Lowland Deciduous Forest	Three*
	Lowland Evergreen Forest	
	Lowland Mixed Forest	
Wetlands	Non-Forested Wetlands	Seven
	Forested Wetlands	
	Open and Other Urban	
Agriculture	Cropland	One, Two, Five, Six
	Pasture Land	
	Crop and Pasture Land	
Feedlot	Feeding Operations	Four
Residential	Single Unit Residential (low and medium densities)	Eight
	Mobile Home and Trailer Parks	
	Elementary Schools	
	Secondary Schools	
	Other Institutions	
Medium Density	Retail Sales and Service	Nine
	Strip and Clustered	

Table XI (Cont'd)

Group	Land Uses - Worcester County	Applicable Sample Site(s)
Transportation	Transportation, Communication, Utilities Electrical Freeways and Highways Airports and Associated Areas Marine Terminals	Ten
Other	Quarries and Pits Reservoirs Rivers Beaches	**

Group	Land Uses - Ocean City	Applicable Sample Site(s)
Low Density	Single Family Residential Trailer Residential	Eight
Medium Density	Multiple Family Residential General Residential	Nine
High Density	Local Business General Commercial Commercial Marine Industrial	Ten

* Lowland forests are assigned a depression storage of 0.33 inches to differentiate them from other forests which are assigned a depression storage of 0.01 inches.

** These land uses are considered to produce no significant runoff.

The percentage of each land-use grouping within each sub-basin and the areas of the sub-basins are given in Table XII. These are the land uses and areas input directly to the STORM model and used to obtain basin-wide estimations and predictions of runoff. Occasionally, the sums of Table XII may not equal exactly one-hundred percent due to rounding. Sub-basins with land-use fractions significantly less than one-hundred percent should be considered as having the balance in the "other" grouping.

C. Apportionment of Pollution Loads Among Sub-Basins and Land Uses

There are seven land uses suitable for STORM analysis: Forest, lowland forest, agriculture, feedlot, residential, medium density, and high density - transportation. (Wetlands are treated separately and the results are presented in a succeeding section). Not all land uses occur in each watershed but there still remains sixty-one land use/sub-basin combinations to be analyzed. The model need not be utilized sixty-one times, however, to predict the pollution contribution of each sub-basin and land use. If uniform rainfall over the entire basin is utilized for the prediction and if consistent calibration parameters are applied to each land use independent of its sub-basin, applications of the model can be reduced to only one for each land use type (i.e. seven applications in this study) while yielding the same information as sixty-one separate runs.

Table XII. Chincoteague Basin Land Uses - Current and Projected

Watershed	Year	% Forest	% Wetlands	% Agricultural	% Feeding Operations	% Residential	% Medium Density	% High Density
#1	1973	25.9	27.2	37.3	1.4	6.7	0.3	
37.5 mi^2	2000	6.0	25.4	45.8	1.7	20.5	0.3	
#2	1973	26.2	27.0	38.0	1.5	6.6		
13.7 mi^2	2000	6.1	25.4	45.9	1.8	20.5		
#3	1973	35.4	4.3	52.2	1.5	6.2		
41.6 mi^2	2000	17.0	1.6	68.6	2.0	10.8		
#4	1973	35.9	9.2	28.3	3.2	23.6		0.6
18.0 mi^2	2000	9.5	1.2	23.0	2.6	62.1		1.6
#5	1973	39.7	14.4	33.3	2.0	6.3		2.4
26.9 mi^2	2000	17.8	11.6	50.2	3.0	12.6		4.8
#6	1973	22.4	33.3	25.4	0.5	2.0		3.0
9.7 mi^2	2000	12.3	33.3	20.9	0.4	16.1		6.0
#7	1973	50.0	16.8	30.7	1.3		0.9	
15.8 mi^2	2000	44.0	16.1	37.0	1.5		0.9	
#8	1973	57.5	12.4	27.0	2.2		0.7	
13.0 mi^2	2000	54.9	12.4	29.2	2.4		0.7	
#9	1973	41.4	24.2	32.4	2.0			
12.2 mi^2	2000	22.4	22.0	52.4	3.2			
#10	1973	40.4	26.8	29.2	1.4			
10.7 mi^2	2000	35.8	26.8	32.8	1.6			
#11	1973	37.8	14.1	39.8	2.5	4.5		0.5
11.9 mi^2	2000	26.9	12.9	52.0	3.2	4.5		0.5

Table XII (Cont'd)

Watershed	Year	% Forest	% Wetlands	% Agricultural	% Feeding Operations	% Residential	% Medium Density	% High Density
#12	1973	37.8	14.1	39.8	2.5	4.5		0.5
20.8 mi^2	2000	26.9	12.9	52.0	3.2	4.5		0.5
#13	1973	3.9	63.0					
15.3 mi^2	2000	3.9	63.0					
Ocean City	1973					16.0	63.9	20.1
North	2000*					16.7	64.2	19.1
2.04 mi^2								
Ocean City	1973					6.0	63.0	31.0
South	2000**					6.4	59.3	34.3
1.35 mi^2								

* 2000 area = 2.63 mi^2
** 2000 area = 1.79 mi^2

Uniform rainfall is used in this study since no information exists as to the variation in rainfall over the basin and the second condition for minimizing the number of model runs is also satisfied; the calibration parameters for each land use are independent of location.

In the simplified process, for each land use the STORM model is utilized once to predict the runoff from an area equal to the total area occupied by that land use in the Chincoteague basin. The predicted pollutant loads are then allocated to the sub-basins according to the fraction of the total land use which occurs in that sub-basin. These total land use areas and fractions are given in Table XIII.

D. Apportionment of Pollutant Fractions

The STORM model predicts the rain-induced washoff of six pollutants:

suspended solids,
settleable solids,
BOD,
total nitrogen,
total phosphorous, and
total coliforms

In this study, however, predictions are desired for a different set of components:

BOD_5,
organic nitrogen,
ammonia nitrogen,
nitrate (and nitrite) nitrogen,*
total phosphorous,
ortho phosphorous,
total coliforms, and
fecal coliforms

Table XIII. Current Land Use Areas and Fractions

Watershed	Land Use						
	Forest	Lowland Forest	Agricultural	Feed Lot	Residential	Medium Density	High Density Transportation
#1 area(mi^2) fraction	9.7 .124		14.0 .163	0.53 .125	2.5 .180	0.11 .044	
#2	3.6 .046		5.2 .060	0.21 .050	0.9 .065		
#3	14.7 .188		21.7 .253	0.62 .146	2.6 .187		
#4	6.5 .083		5.1 .059	0.58 .137	4.2 .302		0.11 .054
#5	10.7 .137		9.0 .105	0.54 .127	1.7 .122		0.65 .320
#6	2.2 .028		2.5 .029	0.05 .012	0.2 .014		0.29 .143
#7	4.6 .059	3.3 .478	4.9 .057	0.21 .050		0.14 .056	
#8	3.8 .049	3.6 .522	3.5 .040	0.29 .068		0.09 .036	
#9	5.1 .065		4.0 .047	0.24 .057			
#10	4.3 .055		3.1 .036	0.15 .035			
#11	4.5 .058		4.7 .055	0.30 .070	0.5 .036		0.06 .030
#12	7.9 .101		8.2 .095	0.52 .123	0.9 .065		.10 .049
#13	0.6 .008						
Ocean City North (#14)					0.32 .023	1.3 .522	0.41 .202
Ocean City South (#14)					0.08 .006	0.85 .341	0.41 .202
Total Area (mi^2) Total Fraction	78.2 1.0	6.9 1.0	85.9 1.0	4.24 1.0	13.9 1.0	2.49 1.0	2.03 1.0

Aspects of the STORM model pertaining to solids have been ignored and the predictions of BOD, total phosphorous, and total coliforms provided by the program are suitable as direct results. A method is needed however, to derive from the predictions of total nitrogen the fractions which are organic, ammonia, and nitrate, to derive from the predictions of total phosphorous the fraction which is inorganic (or ortho-phosphorous), and to derive from the predictions of total coliforms the fraction which are fecal.

These fractions are obtained from the field data by averaging, for each land use, the proportions of the fractional pollutants in the total pollutant runoff of each sample event. Runoff quantities of organic nitrogen, ammonia, nitrate nitrogen,* ortho-phosphorous, and fecal coliforms are thus obtained as follows:

$$\text{Organic Nitrogen} = FON * \text{Total Nitrogen} \qquad 24$$

$$\text{Ammonia} = FNH_3 * \text{Total Nitrogen} \qquad 25$$

$$\text{Nitrate} = FNO_3 * \text{Total Nitrogen} \qquad 26$$

$$\text{Ortho-phosphorous} = FPO_4 * \text{Total Phosphorous} \qquad 27$$

$$\text{Fecal Coliforms} = FFCL * \text{Total Coliforms,} \qquad 28$$

where

FON is the average fraction of the total nitrogen runoff which is organic

FNH_3 is the average fraction of the total nitrogen runoff which is ammonia

*The amount of nitrite runoff is small and this fraction is combined with the nitrate as the former pollutant usually oxidizes rapidly to the latter.

FNO_3 is the average fraction of the total nitrogen runoff which is nitrate

FPO_4 is the average fraction of the total phosphorous runoff which is inorganic

FFCL is the average fraction of the total coliform runoff which is fecal

The specific values of these fractions are given in Table XIV. Note that the urban sites are assumed to have the same pollutant fractions and are averaged together.

Table XIV. Apportionment of Pollutant Fractions

Land Use	FON	FNH_3	FNO_3	FPO_4	FFCL
Forest	.913	.03	.057	.831	.030
Agriculture	.303	.015	.682	.488	.0074
Feedlot	.155	.027	.818	.630	.054
Residential	.348	.204	.448	.675	.030
Medium Density	.348	.204	.448	.675	.030
High Density	.348	.204	.448	.675	.030

E. Calculation of Current Non-Point Pollution Loadings

With the completion of the calibration and synthesis procedures, the division of the Chincoteague Basin into sub-basins and land use fractions, and the apportionment of pollution loads and fractions, the STORM model is ready to be utilized. This section presents the results of STORM applications based on the current land uses presented in Tables XII and XIII and also includes an analysis of the non-point source contribution of nutrients from wetlands.

1. Pollution Loads Resulting from a Design Storm Event - The first result presented is an estimation of the pollution loads washed off the basin during a hypothesized or "design" storm event. A twenty-four hour duration storm with a recurrance of one year and a magnitude of 3.25 inches was selected as the design storm from reference 8. The duration and recurrance imply that a twenty-four hour rainfall of the specified magnitude or greater will occur, on the average, only once annually.

Additional assumptions about the design storm include the following:

(1) The storm increases in magnitude to a peak during the first twelve hours then decreases at a similar rate.

(2) A ten day period of pollutant accumulation precedes the storm.

Figures 17 - 21 present for sub-basin #5* the hourly variation in rainfall, runoff, and pollutant washoff estimated to occur as a result of the design event. Tabulations of the effect of the design storm on the remaining sub-basins have been delivered to Maryland DNR.

2. Hourly Pollutant Loads: Aug. 15 - Sept. 1, 1975 - The sponsor of this program anticipates the development of a

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*Presentation of the results for each sub-basin is not possible within the intended volume of this publication. Sub-basin #5, selected as typical in size, land use, and growth pattern, will therefore be used in this and succeeding sections for illustration purposes.

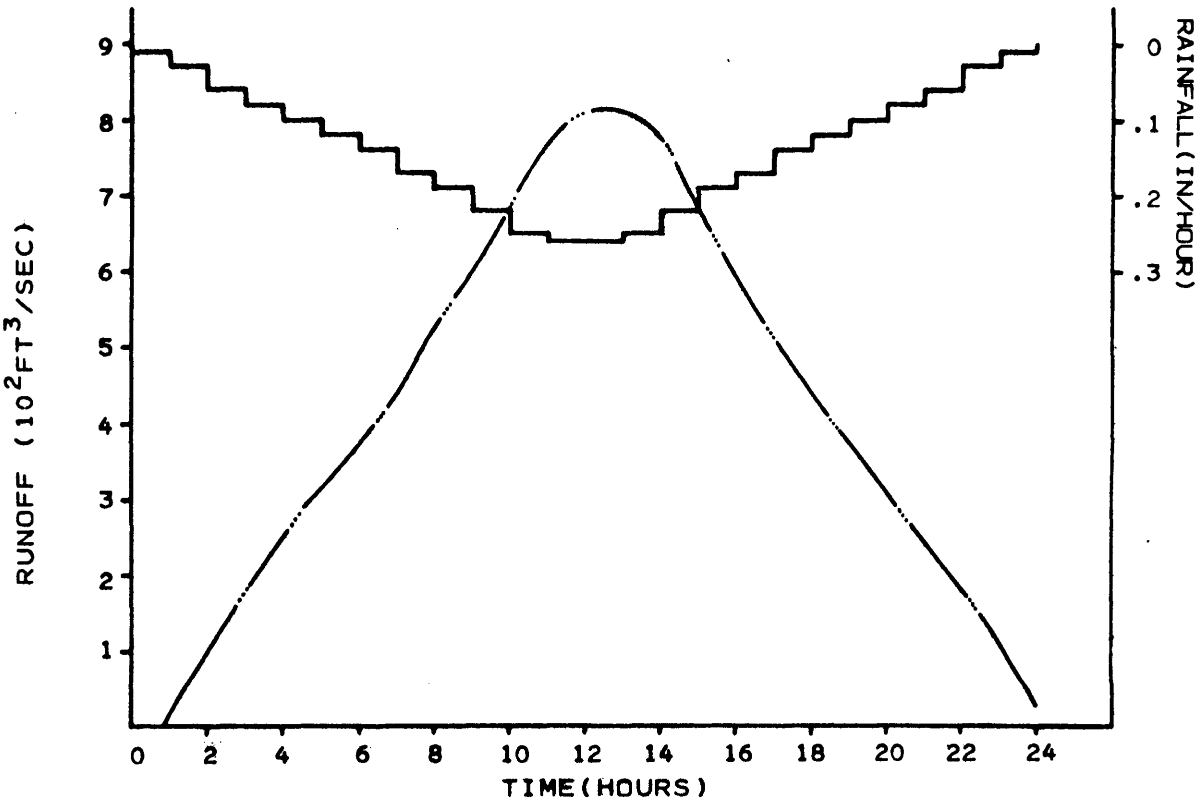


Figure 17. Rainfall and Runoff - 24 hr. Design Storm, Sub-basin #5.

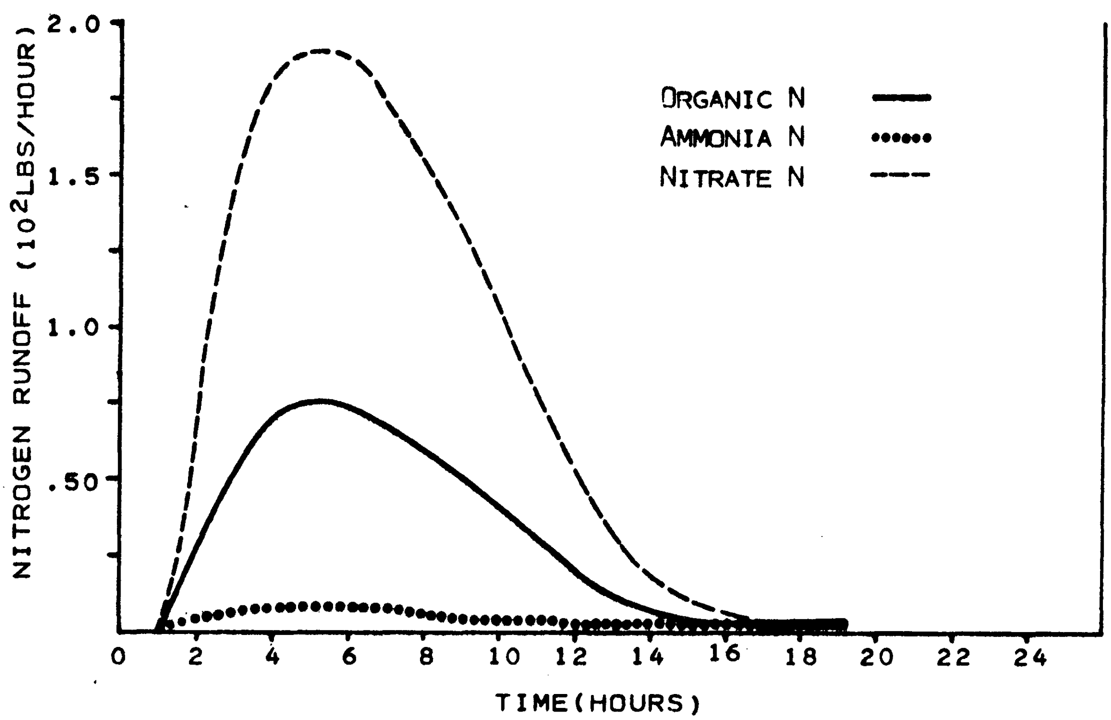


Figure 18. Nitrogen Runoff - 24 hr. Design Storm, Sub-basin #5.

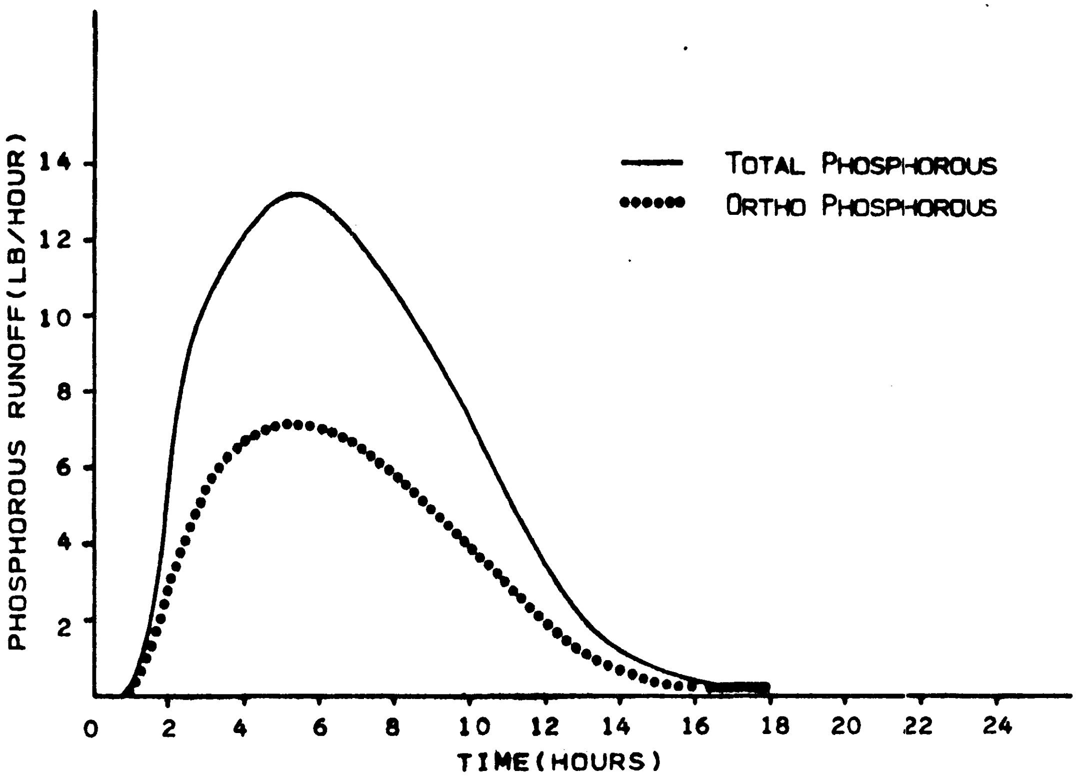


Figure 19. Phosphorous Runoff - 24 hr. Design Storm, Sub-basin #5.

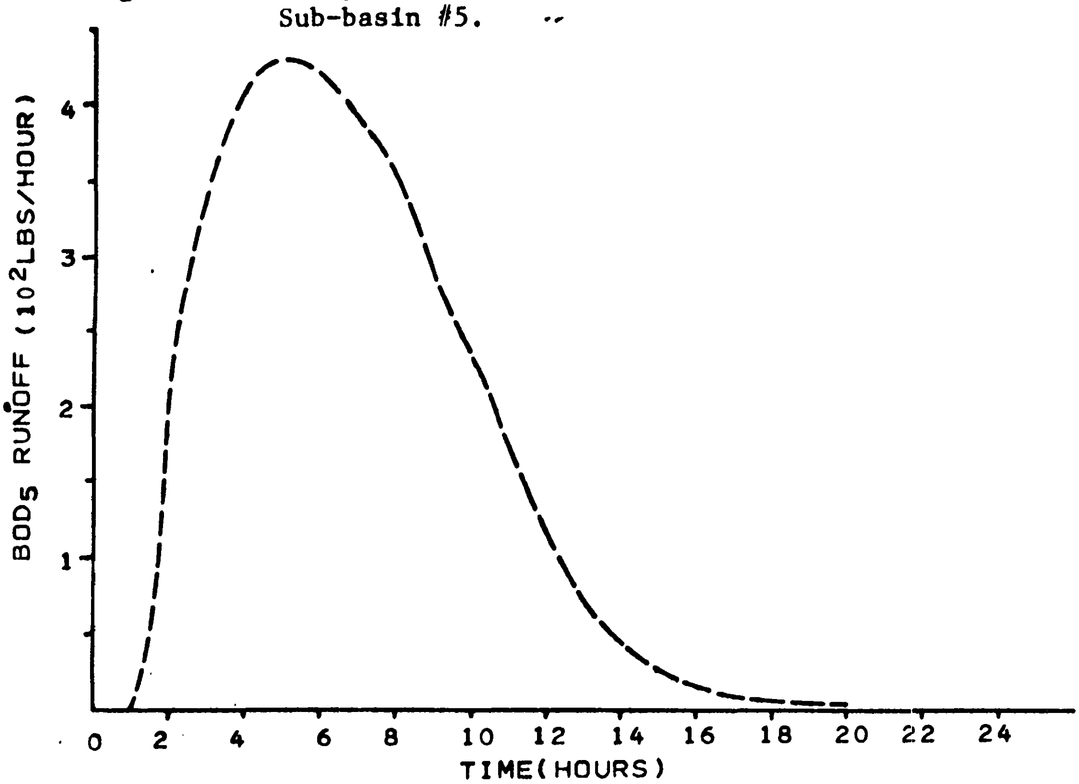


Figure 20. BOD_5 Runoff - 24 hr. Design Storm, Sub-basin #5.

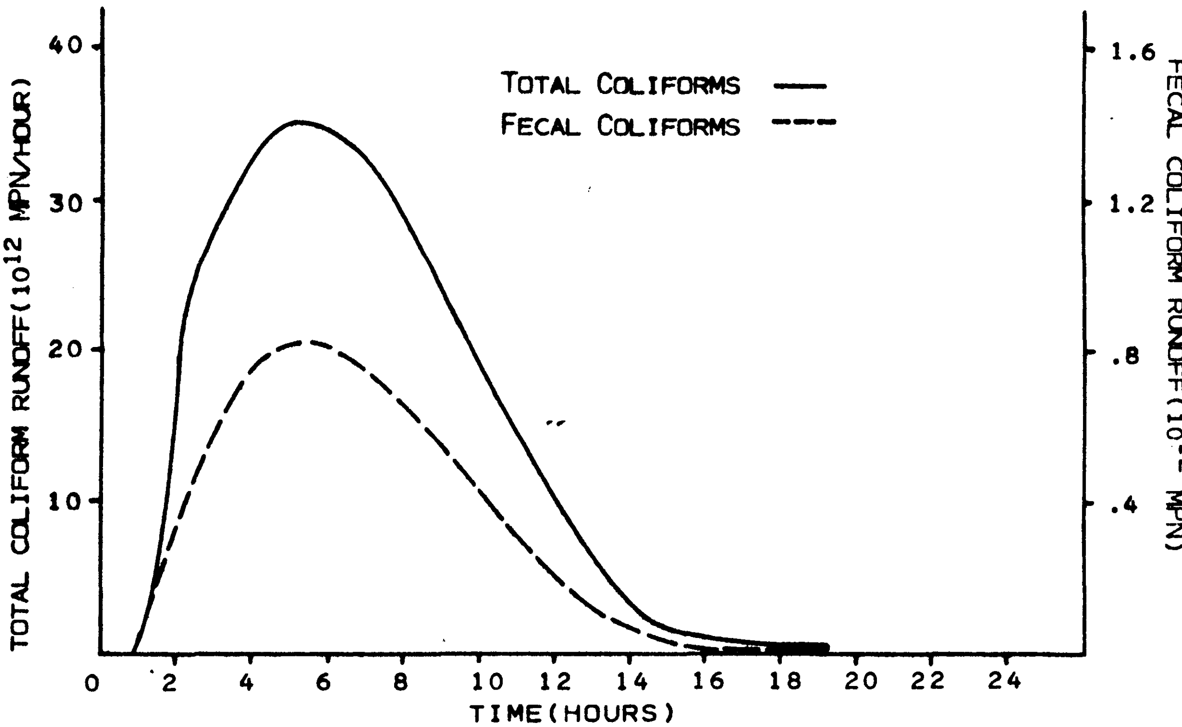


Figure 21. Coliform Runoff - 24 hr. Design Storm, Sub-basin #5.

tidally dynamic water quality model of Chincoteague Bay and its adjacent bays and estuaries. The model is to be calibrated based on hydrodynamic and water quality data collected during the period from Aug. 15 to Sept. 1, 1975 and will include a mathematical representation of pollutant input from surface runoff. Thus, for the calibration to be valid, an estimation of the pollutant runoff during the data collection period is needed.

There are no meteorological stations located within the Chincoteague Basin from which reliable hourly rainfall records for use in the STORM model are available. Therefore, this runoff estimation is based on rainfall data recorded at the Wallops Island, Virginia facility of the National Weather Service. The Wallops Island Station is located on the Eastern Shore of Virginia and borders on the southeast corner of the Chincoteague Basin, approximately twenty-three miles from its center. While the hourly recorded rainfall at the weather service station will not exactly represent the hourly rainfall in the northernmost portions of the Chincoteague Basin (about forty miles distant), the rainfall amounts should be similar and any errors involved will tend to cancel when extended periods are considered.

A summary of the estimated pollutant load contributed by sub-basin #5 during the rainfall events of Aug. 15 to Sept. 1, 1975 is given in Table XV. Tabulations of the estimated runoff from the remaining sub-basins have been delivered to the Maryland DNR.

Table XV. Runoff from Sub-Basin #5 - Aug. 15 - Sept. 1, 1975

Event	Duration		Rain	Runoff	Org N	Ammonia	Nitrate	Total-P	Ortho-P	BOD_5	Total Colif.	Fecal Colif.
	from	to	(in.)	(ft^3)	(lb)	(lb)	(lb)	(lb)	(lb)	(lb)	(10^9 mpn)	(10^9 mpn)
1	0200 Aug 15	0300 Aug 15	0.03	8.21×10^{4}	22.0	2.4	56.3	4.0	2.2	126.8	1.04×10^{4}	2.4×10^{2}
2	0200 Aug 16	0400 Aug 16	0.95	1.07×10^{7}	544.3	59.4	1389.2	95.8	51.7	3129.8	2.57×10^{5}	5.94×10^{3}
3	1900 Aug 16	2100 Aug 16	0.42	4.42×10^{6}	86.5	9.4	220.8	15.3	8.3	497.3	4.09×10^{4}	9.44×10^{2}
4	0000 Aug 23	0200 Aug 23	0.16	1.5×10^{6}	116.2	12.7	296.5	20.7	11.2	668.2	5.49×10^{4}	1.27×10^{3}
5	0600 Aug 23	0700 Aug 23	0.02	5.45×10^{4}	8.1	0.9	20.7	1.3	0.7	46.7	3.84×10^{3}	0.89×10^{2}
6	0900 Sept 1	2400 Sept 1	2.48	2.78×10^{7}	990.0	107.9	2526.9	174.5	94.1	5693.1	4.68×10^{5}	1.08×10^{4}

3. Typical Monthly Pollutant Loads of the Chincoteague Basin - The calculation of current, typical monthly loads of storm-generated pollution running off into the Chincoteague Basin is presented in this section. These pollutant loads provide both an estimation of the annual washoff of pollutants into Chincoteague Bay and its adjacent waters and a basis for comparison with the projected year 2000 pollutant loads. These monthly estimations, based on hourly rainfall data recorded at Wallops Island from Jan. 1 to Dec. 31, 1975, are presented in Table XVI. The monthly data for each individual sub-basin have been delivered to the Maryland DNR.

4. Estimation of the Effect of Wetlands - Section D of Chapter IV detailed the calibration of the data from the marsh site, Site Seven, and the formulation of a model which allows the influences of long-term average mass exchange, short-term tidally induced mass exchange, and rain induced export to be isolated. Caution was expressed that the model not be interpreted as a predictive model for individual events but rather an indicator of average tendencies. Thus the model is not utilized to estimate the pollutant contribution of the wetlands during the design storm or the Aug. 15 - Sept. 1, 1975 calibration period nor are the wetland loads included in the pollutant summary tables. Use may still be made of the marsh model, however. In this section it is employed to provide order of magnitude estimations of the typical impact of a rainfall on the Chincoteague Basin wetlands. The utilization is based on the assumption that, on the average, all marshes in the area export nutrients at the same rate per unit area as the sample marsh.

Table XVI. Monthly Pollutant Load Received by the Chincoteague System

Month	Rain (in.)	Runoff (ft^3)	Org-N (lb)	NH_3-N (lb)	NO_3-N (lb)	Total-P (lb)	Ortho-P (lb)	BOD_5 (lb)	Tot. Colif. (10^9 mpn)	Fecal Colif. (10^9 mpn)
1	5.29	4.67×10^{8}	1.88×10^{4}	1.82×10^{3}	4.75×10^{4}	3.34×10^{3}	1.78×10^{3}	5.64×10^{4}	9.03×10^{6}	1.94×10^{5}
2	4.16	3.69×10^{8}	1.63×10^{4}	1.58×10^{3}	4.11×10^{4}	2.89×10^{3}	1.53×10^{3}	8.56×10^{4}	7.81×10^{6}	1.68×10^{5}
3	6.47	5.69×10^{8}	1.80×10^{4}	1.75×10^{3}	4.55×10^{4}	3.20×10^{3}	1.70×10^{3}	9.45×10^{4}	8.64×10^{6}	1.85×10^{5}
4	2.96	2.54×10^{8}	1.50×10^{4}	1.45×10^{3}	3.78×10^{4}	2.65×10^{3}	1.41×10^{3}	7.81×10^{4}	7.18×10^{6}	1.54×10^{5}
5	2.01	1.61×10^{8}	1.46×10^{4}	1.41×10^{3}	3.68×10^{4}	2.59×10^{3}	1.37×10^{3}	7.56×10^{4}	7.00×10^{6}	1.50×10^{5}
6	2.33	1.97×10^{8}	1.85×10^{4}	1.79×10^{3}	4.65×10^{4}	3.28×10^{3}	1.74×10^{3}	9.78×10^{4}	8.84×10^{6}	1.90×10^{5}
7	4.47	3.94×10^{8}	2.01×10^{4}	1.94×10^{3}	5.06×10^{4}	3.56×10^{3}	1.89×10^{3}	1.06×10^{5}	9.63×10^{6}	2.06×10^{5}
8	4.85	4.32×10^{8}	1.95×10^{4}	1.89×10^{3}	4.93×10^{4}	3.47×10^{3}	1.84×10^{3}	1.03×10^{5}	9.97×10^{6}	2.34×10^{5}
9	4.32	3.62×10^{8}	1.69×10^{4}	1.57×10^{3}	4.27×10^{4}	3.00×10^{3}	1.59×10^{3}	8.86×10^{4}	8.21×10^{6}	1.79×10^{5}
10	5.25	4.68×10^{8}	1.82×10^{4}	1.76×10^{3}	4.59×10^{4}	3.23×10^{3}	1.71×10^{3}	9.55×10^{4}	8.72×10^{6}	1.87×10^{5}
11	2.83	2.56×10^{8}	1.31×10^{4}	1.26×10^{3}	3.27×10^{4}	2.30×10^{3}	1.22×10^{3}	6.77×10^{4}	6.22×10^{6}	1.33×10^{5}
12	3.49	3.07×10^{8}	2.40×10^{4}	2.33×10^{3}	6.06×10^{4}	4.26×10^{3}	2.26×10^{3}	1.26×10^{5}	1.15×10^{7}	2.47×10^{5}
Total	48.43	4.24×10^{9}	2.13×10^{5}	2.06×10^{4}	5.37×10^{5}	3.78×10^{4}	2.00×10^{4}	1.07×10^{6}	1.03×10^{8}	2.23×10^{6}
Avg.	4.03	3.53×10^{8}	1.78×10^{4}	1.72×10^{3}	4.48×10^{4}	3.15×10^{3}	1.67×10^{3}	8.92×10^{4}	8.58×10^{6}	1.86×10^{5}

Table XVII gives the export from Site Seven predicted by the models of Table V to result from a 0.5 inch storm occurring over a tidal cycle. A storm of this magnitude and duration was selected since it is within the range of the field data which was used to derive the model. Note that the net short-term volume flux was considered to be zero for the predictions and that the exports are given on a unit area basis.

The typical storm generated export from the wetlands in each sub-basin is next obtained as the product of the export per unit area of site seven and the sub-basin wetlands area. These sub-basin exports are presented in Table XVIII.

No measures of BOD were taken at the marsh site although total organic carbon (TOC) was sampled. Analysis of data from the Chincoteague Basin sites at which both TOC and BOD were sampled shows the BOD concentration to average 25% of the TOC concentration. Thus the BOD export of the marshes may be approximated as one-fourth the export of TOC.

F. Projection of Non-Point Source Pollution Loads for the Year 2000

In this section, projections of the non-point source pollution runoff from the Chincoteague Basin for the year 2000 are formulated. Projections are made of the reaction of the basin to both the design storm and the annual rainfall used in the estimation of the current loads so that a comparison of the current and future loads under identical storm conditions can be made.

Table XVII. Nutrient Export of Site Seven - 0.5 Inch Storm

Nutrient	Organic Nitrogen	Ammonia	Nitrate*	Total Phosphorous	Ortho Phosphorous	Total Organic Carbon
Export (lbs/acre/cycle)	0.38	-0.016	$1.1x10^{-3}$	0.036	0.029	4.61

Table XVIII. Nutrient Export of Chincoteague Bay Marshes - 0.5 Inch Storm

Sub-Basin	Wetlands Area (acres)	Organic Nitrogen (lb/cycle)	Ammonia (lb/cycle)	Nitrate (lb/cycle)	Total Phosphorous (lb/cycle)	Ortho Phosphorous (lb/cycle)	TOC (lb/cycle)
1	6528	2480	-104	7	235	189	30094
2	2367	899	- 38	3	85	69	10912
3	1145	435	- 18	1	41	33	5278
4	1060	403	- 17	1	38	31	4887
5	2479	942	- 40	3	89	72	11428
6	2007	785	- 33	2	74	60	9529
7	1699	646	- 27	2	61	49	7832
8	1032	392	- 17	1	37	30	4758
9	1890	718	- 30	2	68	55	8713
10	1835	697	- 29	2	66	53	8459
11	1074	408	- 17	1	39	31	4951
12	1877	713	- 30	2	68	54	8653
13	6169	2344	- 99	7	222	179	28439
Total	31222	11864	-500	34	1124	905	143933

*The regression analysis of this component presents unreliable results

Implicit in the projections is the assumption that runoff coefficients, impervious fractions, and pollutant accumulation rates will not vary in the future from their current values. Differences in the year 2000 loads from the present will be solely the result of changes in land use: e.g. the development of forest land for housing. The remainder of this chapter details the methods by which changes in land use were determined and presents the results of the year 2000 projections.

1. Year 2000 Land Uses - Runoff predictions for 2000 can only be as valid as the land use projections upon which they are based. It is not possible to know exactly the future land uses of the area and a number of assumptions and hypotheses are necessary before even a rough estimation can be formulated. Since these assumptions are, to an extent, arbitrary, it is important they be made explicit so the exact bases of the projections and their order of accuracy are understood.

The prime source of future land use estimation for this study is a map illustrating the draft land use plan of the Maryland portion of the basin provided by the Maryland State Department of Planning (MSDP). The map is not well-detailed, showing only six land use types, and includes no plans for Ocean City. In addition, the land use headings on the year 2000 map are not consistent with the headings on the 1973 land use map and occasionally the land uses themselves conflict. For example, in sub-basin #4 an area planned as "conservation district, open space" is shown in 1973 as occupied by single unit dwellings. Still, the year 2000 land use plan is presently the best projection available of future land use in the Chincoteague Basin.

Two tasks had to be completed before the information from the land use plan could be utilized. The first was to group the land use headings specified on the year 2000 map with similar headings given on the 1973 map and in Table XI. The second was to reconcile conflicting land uses between the two maps and account for land uses missing from the year 2000 plan. In addition, projections of land use in Ocean City had to be formulated. The following sub-sections detail the completion of these tasks.

Grouping of Land Uses - The land use types of the year 2000 plan are as follows:

residential,
rural,
town and villages,
rural-agricultural,
open space-conservation area, and
open water

It is desirable for modelling purposes to assign these land uses to the groupings given in Table XI for which calibrated values of runoff coefficients, percent imperviousness, and pollutant accumulation have been obtained. A decision (aided by communication with personnel at the MSDP) was made to equilibrate the year 2000 uses with the groupings of current uses as given in Table XIX.

Table XIX. Grouping of Year 2000 Land Uses

Code	Year 2000 Land Use	Equivalent Current Grouping
10	Residential	Residential
15	Town and Villages	Residential
53	Rural Agricultural	Agricultural
11	Rural	-
66	Open Space-Conservation Area	-
76	Water (Surface)	Other

The headings "rural" and "open space" were judged too nebulous for assignation in this manner. Their final assignment is detailed in the next sub-section.

<u>Missing and Conflicting Land Uses</u> - A number of land uses including wetlands, feedlot, medium density, and transportation are missing from the year 2000 plan. A means was necessary to include them in the projections as well as to resolve apparent conflicts between the two maps. To complete the land use assignments, the following assumptions were made:

(1) In the event of unresolved or conflicting land uses, the 1973 land use map would be accepted as valid.

(2) No currently developed areas would revert to a lesser developed state.

Via these assumptions areas zoned as "rural" or "open space" retained the land use types assigned to them by the 1973 map (usually forest or wetlands) and feedlots, medium density and transportation areas were drawn on the year 2000 map in the same locations as in 1973. In addition, the area devoted to feedlots was projected to grow (or decrease) in the same proportion as the agricultural land use in each sub-basin while the area devoted to transportation was projected to grow in the same proportion as the residential land use. Growth of both these land uses was assumed to occur at the expense of undeveloped areas (i.e. forests or wetlands).

Ocean City Land Uses - No detailed land use plan could be obtained for Ocean City. A projection was therefore made based on the amount of unoccupied but zoned land within the city limits. On the 1977 zoning map (used to obtain current land uses in Ocean City) quantities of land were noted in both the north and south watersheds which were zoned for development but presently occupied either by wetlands or open waters of Sinepuxent Bay. By the year 2000 it was assumed these areas would be filled and developed as zoned. (This trend in development can be seen already. No two maps of Ocean City consulted during this study showed the same western shoreline due to the rapidity of drainage and filling).

Apportionment of Land Uses to Sub-Basins - The final proportion of projected land uses in each sub-basin was obtained in a manner identical to that used to determine the current land uses. The revised year 2000 land use map was overlain with a transparency showing the sub-basin boundaries and with a transparent rectangular grid. The proportion of each sub-basin occupied by a specific land use was determined to be the number of grid points falling within the land-use divided by the total number of grid points falling within the sub-basin. Portions of the Chincoteague Basin outside the planned area were assumed to grow at the same rate as their adjacent planned sub-basins. Projected land uses in the Ocean City sub-basins were determined via planimetry of the zoning map including zoned but undeveloped areas. These land use projections are given in Table XII for comparison with the current land use proportions of the region.

2. Non-Point Source Pollution Produced by a Design Storm: Year 2000 - Once the land use projections for the year 2000 were completed, predictions of the reaction of the basin to a design storm and of the typical annual runoff of the basin were possible. The same meteorological conditions used to estimate the current loadings were applied and the predictions were obtained via the simplified model usage outlined in sections C and D. This utilization required the tabulation presented in Table XX of the fractions of the total projected land uses occupying each sub-basin.

The hourly reaction of sub-basin #5 to a design storm in the year 2000 is presented graphically in Figures 22-26. Additional insight into future trends is gained from Figs. 27-28 and 29-30 which compare, for the urban Ocean City watershed and a rural Virginia sub-basin, the current and projected runoff volumes and BOD_5 loadings produced by the design storm. Tabulation of the runoff from the other sub-basins have been delivered to the Maryland DNR.

Table XX. Projected Land Use Areas and Fractions

Watershed	Land Use						
	Forest	Lowland Forest	Agricultural	Feed Lot	Residential	Medium Density	High Density-Transportation
#1 area(mi^2) fraction	2.3 .056		17.2 .159	0.64 .123	7.7 .233	0.11 .036	
#2	0.8 .019		6.3 .058	0.25 .048	2.8 .085		
#3	7.1 .173		28.5 .264	0.83 .160	4.5 .136		
#4	1.7 .041		4.1 .038	0.47 .090	11.2 .338		0.28 .082
#5	4.8 .119		13.5 .125	0.81 .156	3.4 .103		1.29 .377
#6	1.2 .029		2.0 .019	0.04 .008	1.6 .048		0.58 .170
#7	3.6 .088	3.3 .478	5.8 .053	0.24 .046		0.14 .045	
#8	3.5 .086	3.6 .522	3.8 .035	0.31 .060		0.09 .029	
#9	2.7 .066		6.4 .059	0.39 .075			
#10	3.8 .092		3.5 .032	0.17 .033			
#11	3.2 .078		6.2 .057	0.38 .073	0.5 .015		0.06 .018
#12	5.6 .137		10.8 .100	0.67 .129	0.9 .027		0.10 .029
#13	0.6 .014						
Ocean City North (14)					0.43 .012	1.69 .547	0.50 .146
Ocean City South (15)					0.11 .003	1.06 .343	0.61 .178
Total Area(mi^2) Total Fraction	40.9 1.0	6.9 1.0	108.1 1.0	5.2 1.0	33.1 1.0	3.09 1.0	3.42 1.0

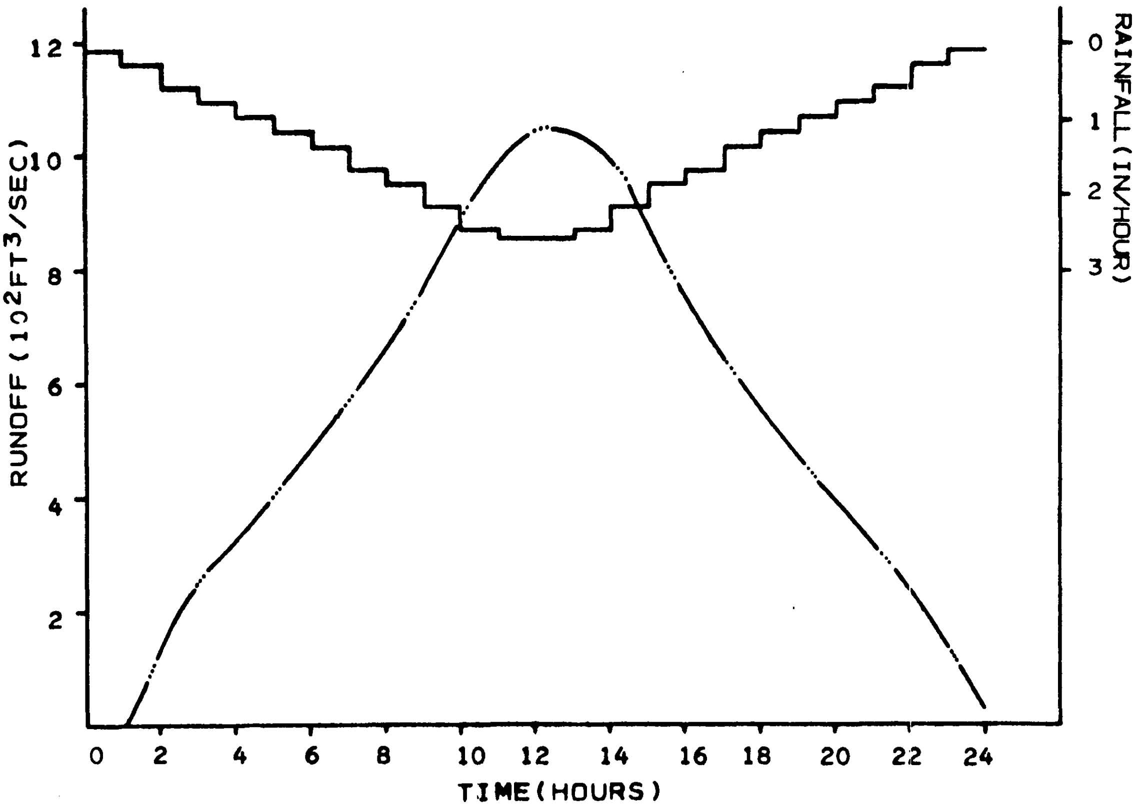


Figure 22. Rainfall and Runoff - 24 hr. Design Storm: Year 2000, Sub-basin #5.

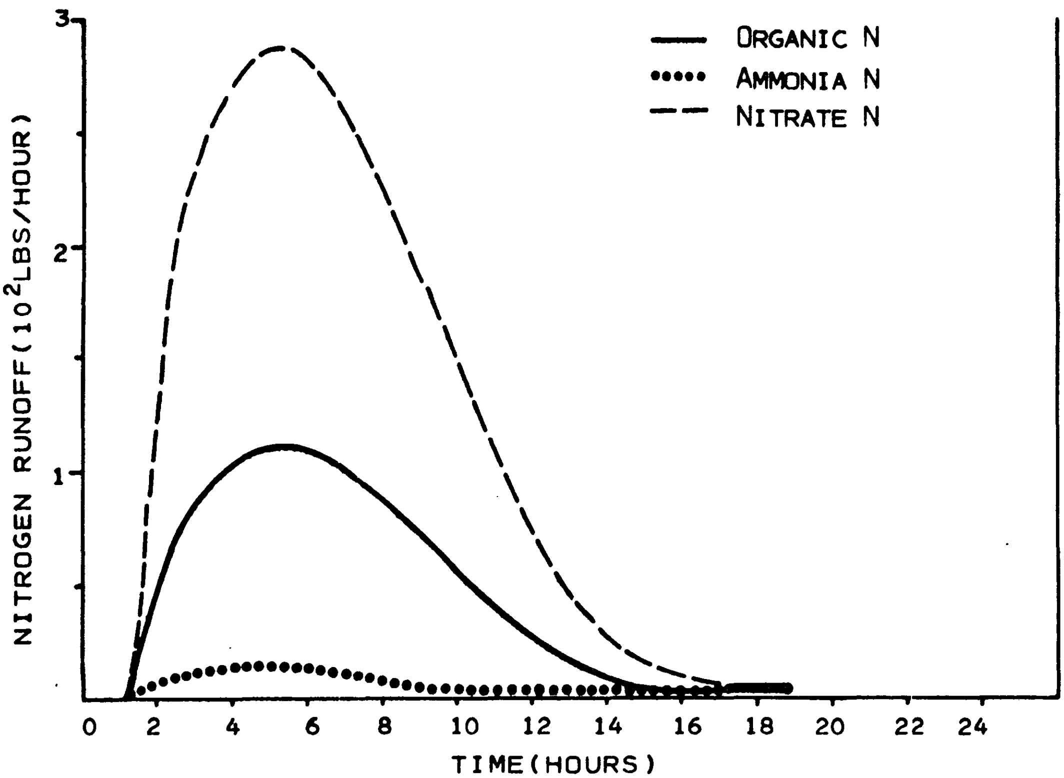


Figure 23. Nitrogen Runoff - 24 hr. Design Storm: Year 2000, Sub-basin #5.

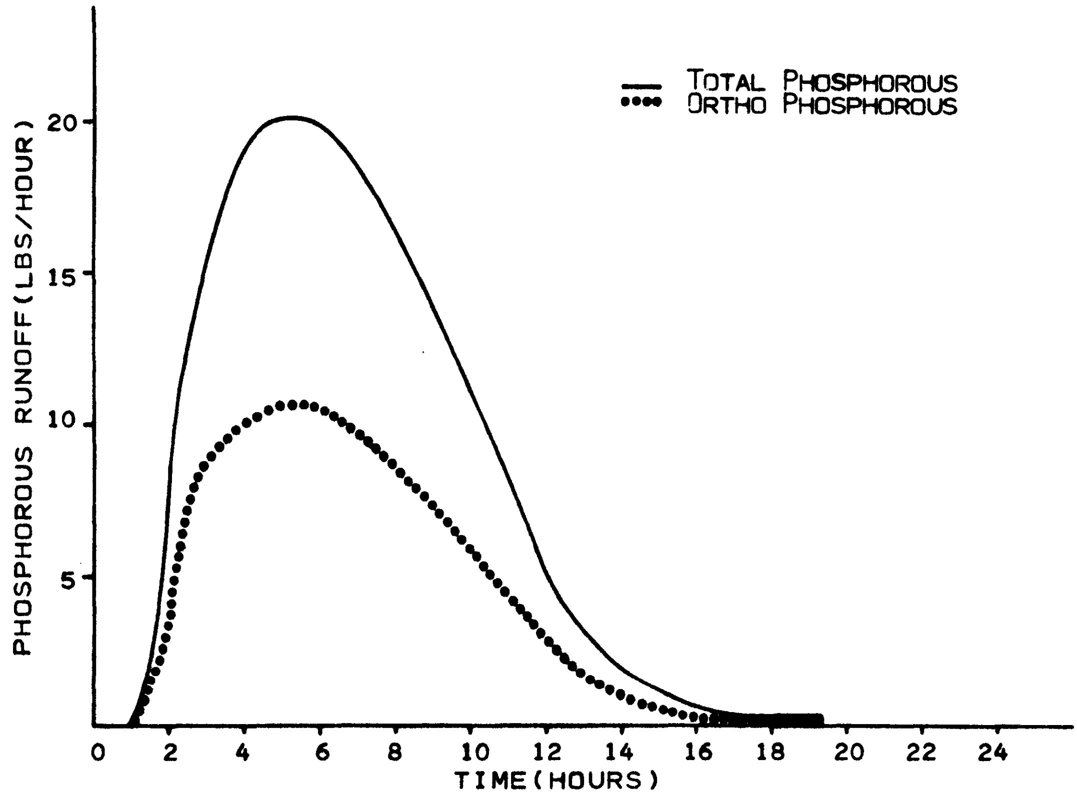


Figure 24. Phosphorous Runoff - 24 hr. Design Storm: Year 2000, Sub-basin #5.

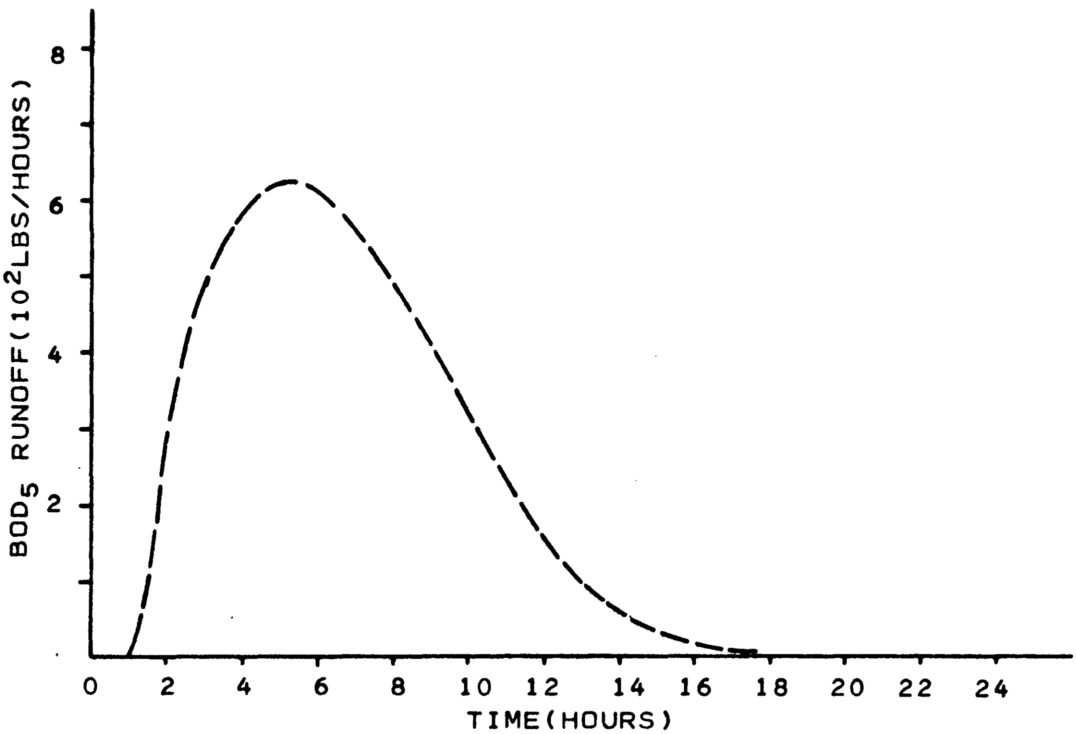


Figure 25. BOD_5 Runoff - 24 hr. Design Storm: Year 2000

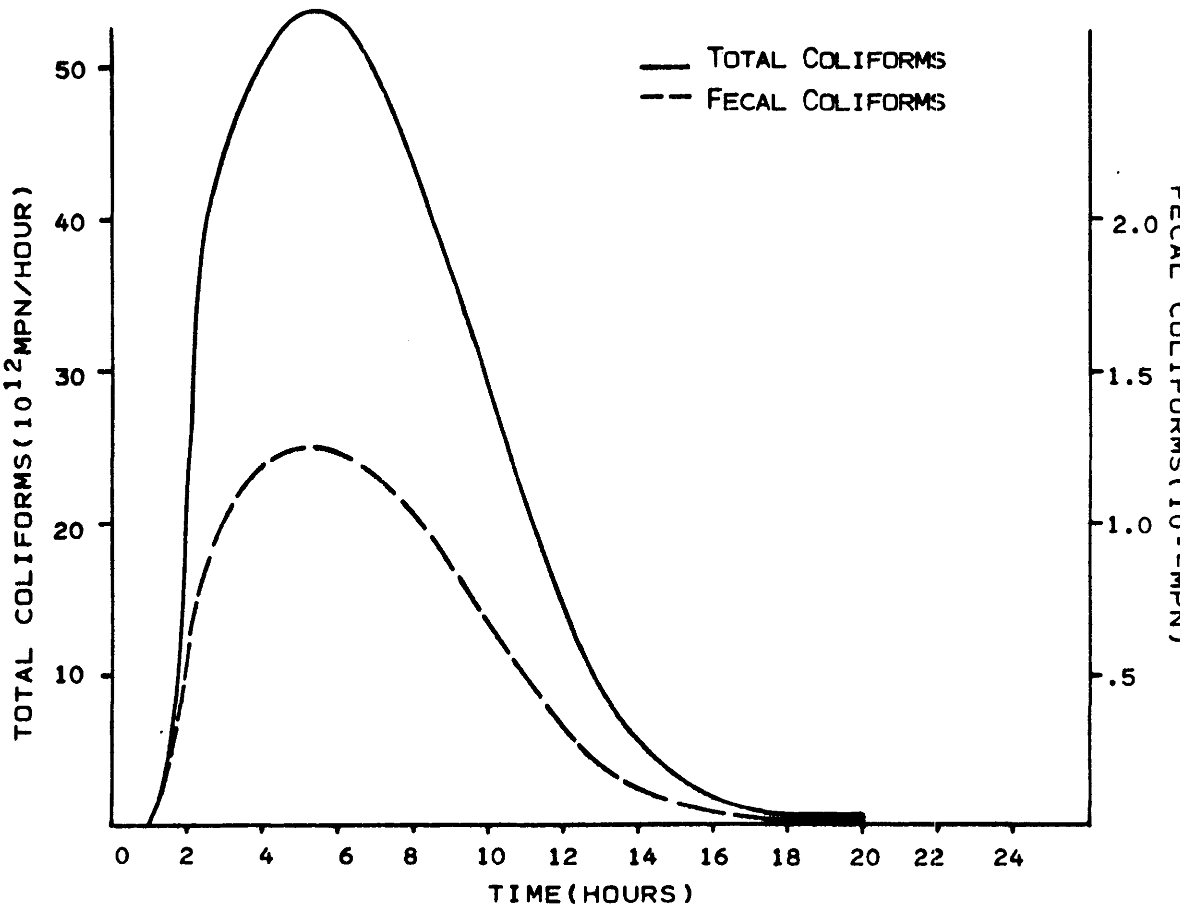


Figure 26. Coliform Runoff - 24 hr. Design Storm: Year 2000, Sub-basin #5.

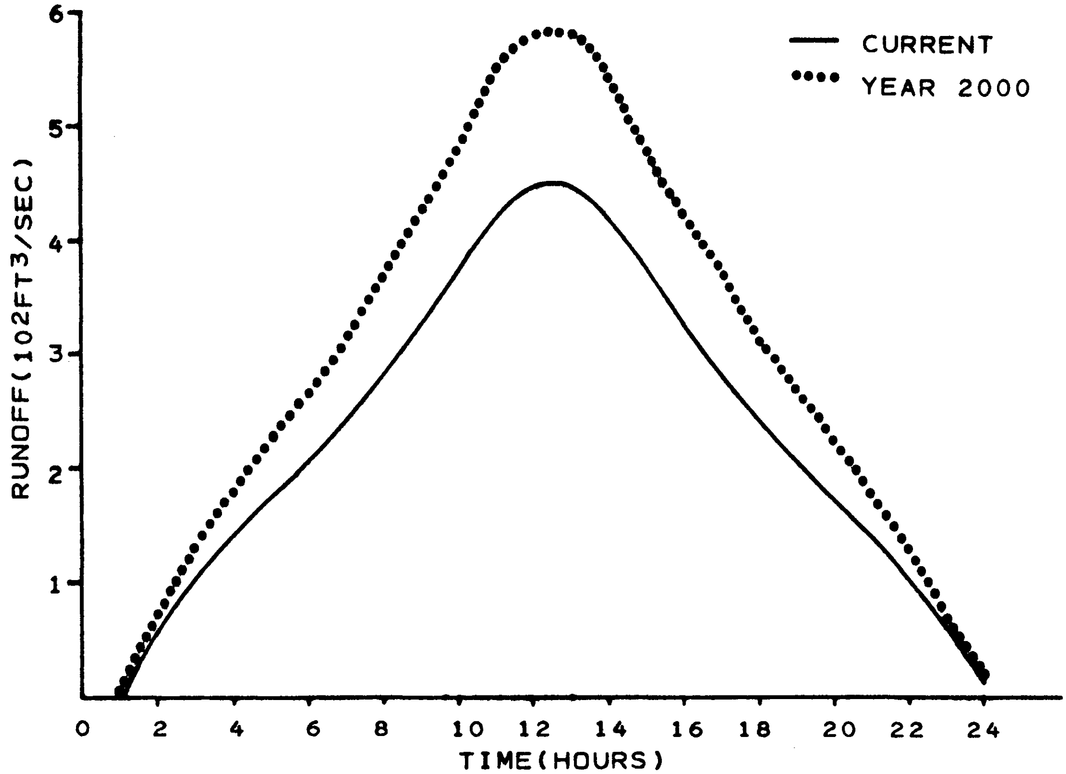


Figure 27. Current and Projected Runoff from Ocean City, Md.

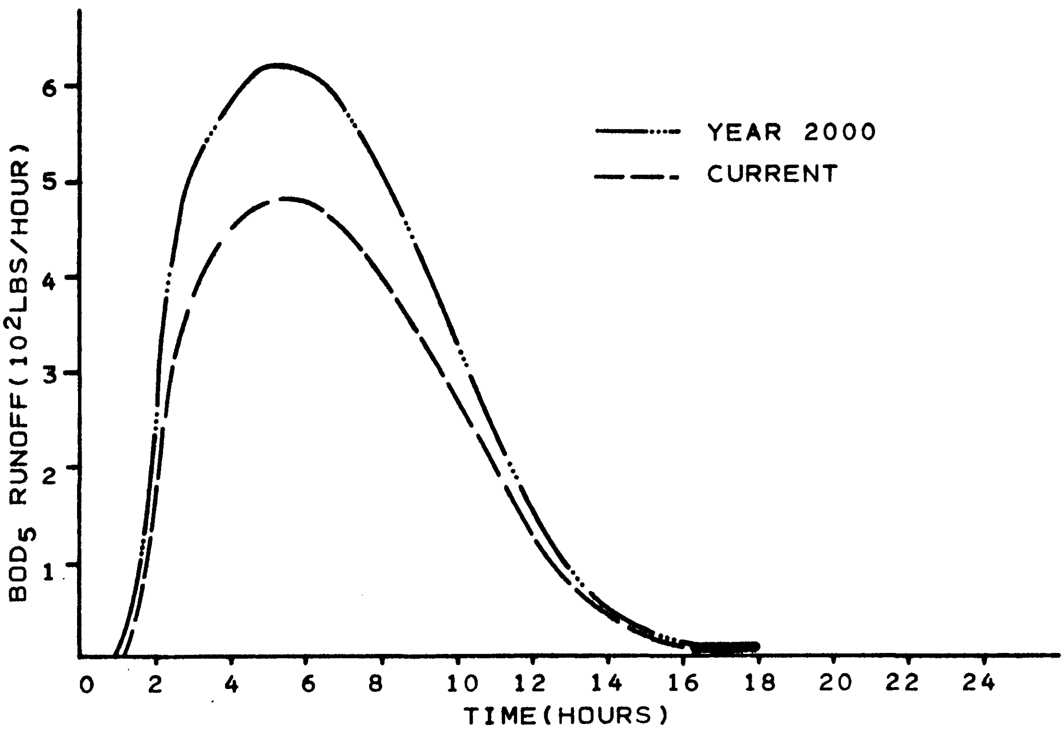


Figure 28. Current and Projected BOD_5 Runoff from Ocean City, Md.

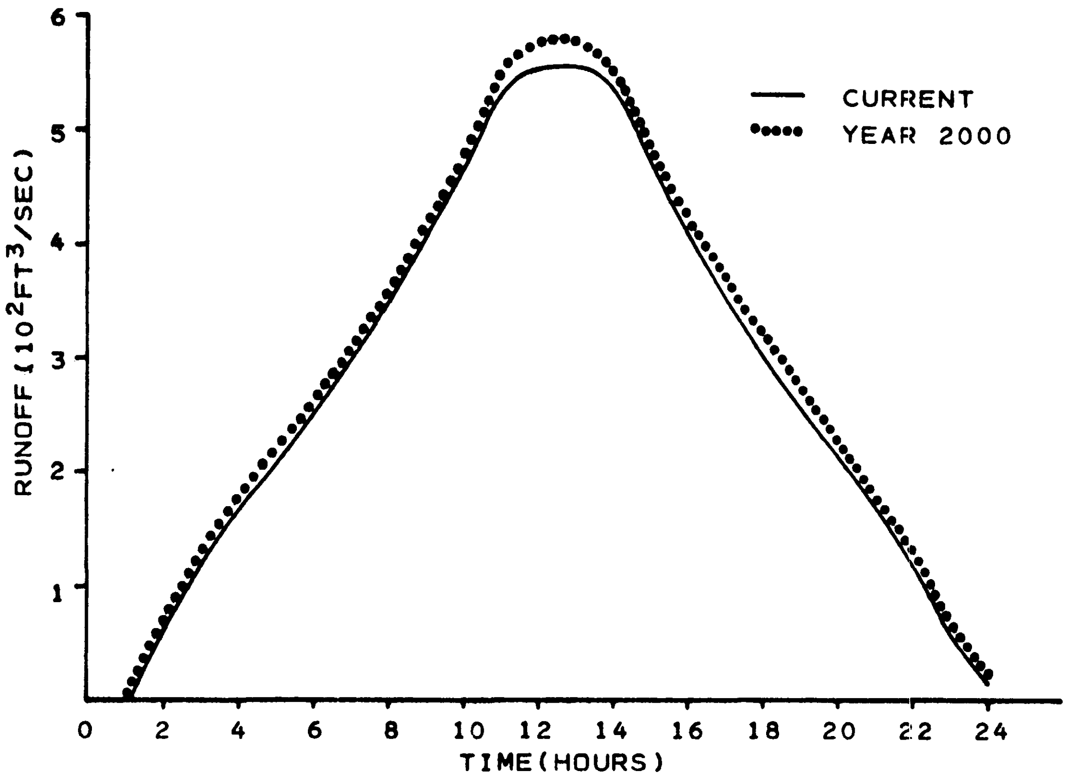


Figure 29. Current and Projected Runoff from a Virginia Sub-Basin.

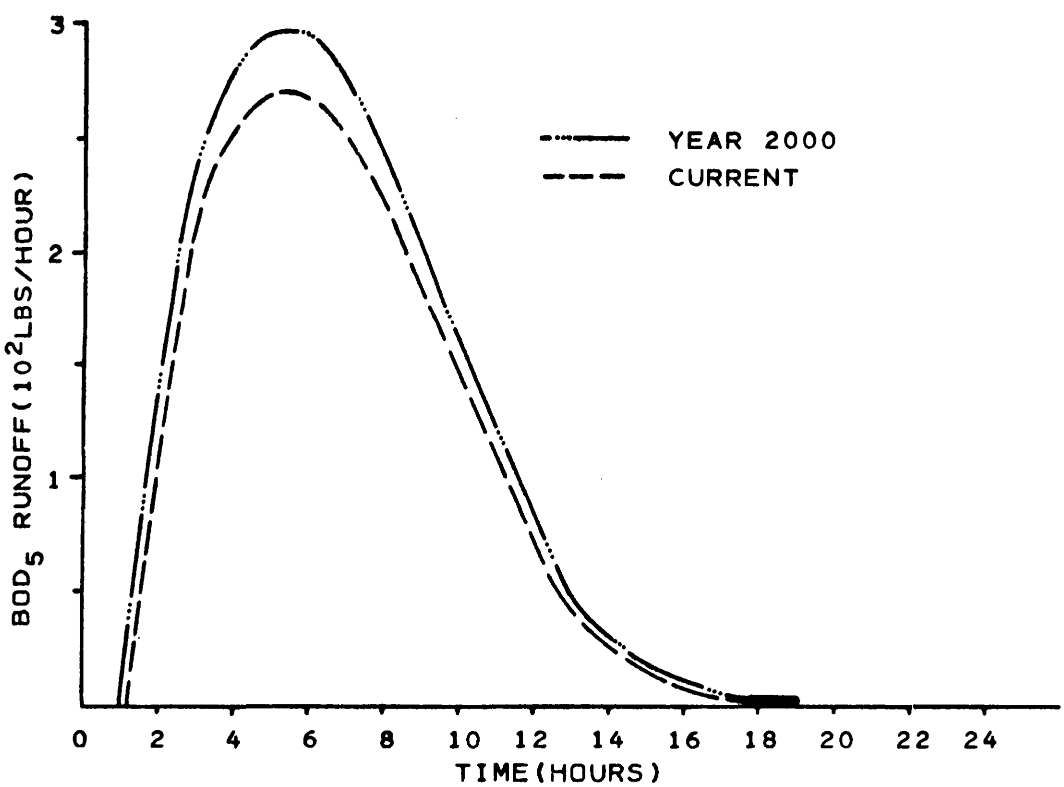


Figure 30. Current and Projected BOD_5 Runoff from a Virginia Sub-Basin.

3. Projected Monthly Loads: Year 2000 - The projected storm-generated monthly load of pollutants washing into the Chincoteague Bay System is presented in Table XXI. Monthly projections for each sub-basin have been delivered to the Maryland DNR.

Table XXI. Projected Monthly Pollutant Loads Received by the Chincoteague System

Month	Rain (in.)	Runoff (ft^3)	Org-N (lb)	NH_3-N (lb)	NO_3-N (lb)	Total-P (lb)	Ortho-P (lb)	BOD_5 (lb)	Tot. Colif. (10^9 mpn)	Fecal Colif. (10^9 mpn)
1	5.29	5.89×10^8	2.36×10^4	2.72×10^3	5.99×10^4	4.44×10^3	2.39×10^3	1.26×10^5	1.16×10^7	2.49×10^5
2	4.16	4.65×10^8	2.05×10^4	2.35×10^3	5.18×10^4	3.84×10^3	2.06×10^3	1.09×10^5	9.99×10^6	2.15×10^5
3	6.47	7.22×10^8	2.16×10^4	2.60×10^3	5.73×10^4	4.25×10^3	2.28×10^3	1.21×10^5	1.11×10^7	2.38×10^5
4	2.96	3.23×10^8	1.88×10^4	2.16×10^3	4.77×10^4	3.53×10^3	1.89×10^3	9.99×10^4	9.19×10^6	1.98×10^5
5	2.01	2.07×10^8	1.83×10^4	2.10×10^3	4.64×10^4	3.43×10^3	1.84×10^3	9.68×10^4	8.95×10^6	1.93×10^5
6	2.33	2.59×10^8	2.32×10^4	2.66×10^3	5.86×10^4	4.36×10^3	2.34×10^3	1.25×10^5	1.13×10^7	2.43×10^5
7	4.47	5.07×10^8	2.52×10^4	2.89×10^3	6.39×10^4	4.74×10^3	2.54×10^3	1.35×10^5	1.23×10^7	2.66×10^5
8	4.85	6.32×10^8	2.45×10^4	2.81×10^3	6.21×10^4	4.61×10^3	2.47×10^3	1.31×10^5	1.06×10^7	2.58×10^5
9	4.32	4.61×10^8	2.12×10^4	2.44×10^3	5.38×10^4	3.99×10^3	2.14×10^3	1.13×10^5	1.04×10^7	2.23×10^5
10	5.25	5.94×10^8	2.28×10^4	2.62×10^3	5.78×10^4	4.29×10^3	2.30×10^3	1.22×10^5	1.12×10^7	2.40×10^5
11	2.83	3.22×10^8	1.63×10^4	1.87×10^3	4.12×10^4	3.06×10^3	1.64×10^3	8.65×10^4	7.95×10^6	1.71×10^5
12	3.49	3.86×10^8	3.02×10^4	3.46×10^3	7.63×10^4	5.67×10^3	3.04×10^3	1.61×10^5	1.47×10^7	3.17×10^5
Total	48.4	5.47×10^9	2.66×10^5	3.07×10^4	6.77×10^5	5.02×10^4	2.69×10^4	1.43×10^6	1.29×10^8	2.81×10^6
Avg.	4.03	4.56×10^8	2.22×10^4	2.56×10^3	5.64×10^4	4.18×10^3	2.21×10^3	1.19×10^5	1.08×10^7	2.34×10^5
% Increase from current loads		29%	25%	49%	26%	33%	33%	33%	26%	26%

Chapter VI. Comparison of Point and Non-Point Sources of Pollution

One of the desired results of this study is a map showing the location of significant point and non-point sources of pollution in the Chincoteague Basin and a comparison of the pollutant quantities. This chapter details the methodology used to provide the map and comparisons and is divided into three sections:

Significant Point Sources of Pollution in the Chincoteague Basin,

Determination of Significant Non-Point Sources, and

Comparison of Point and Non-Point Pollutant Quantities.

A. Significant Point Sources of Pollution in the Chincoteague Basin

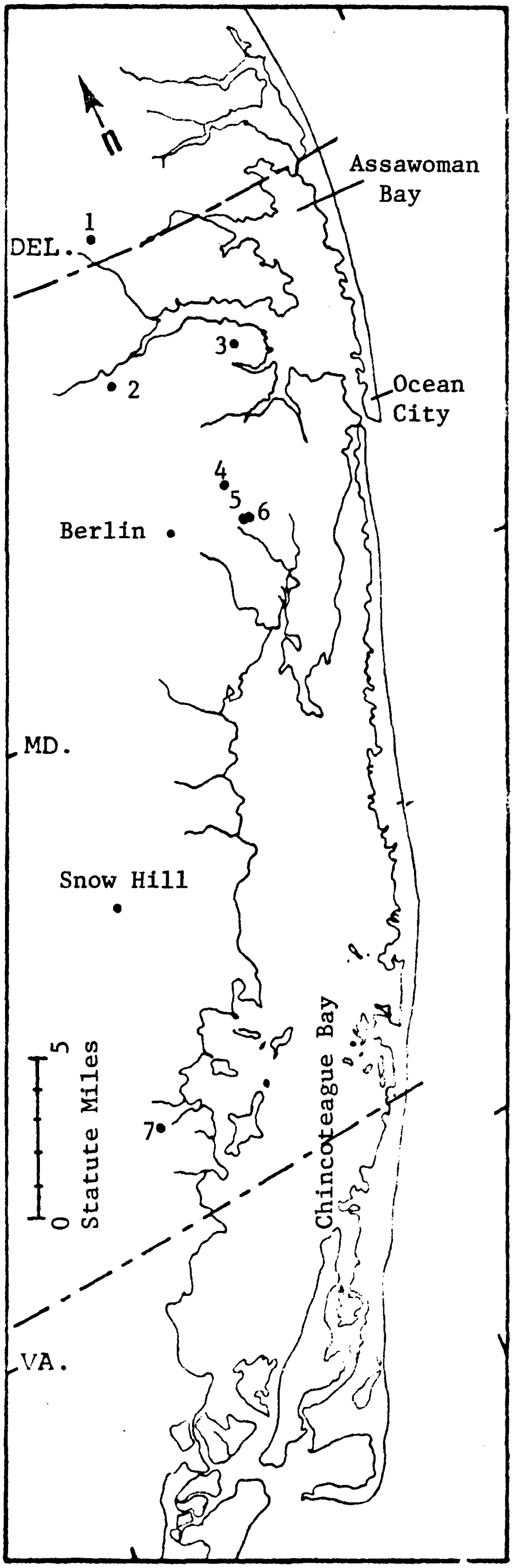
A great deal of conflicting information can be found regarding the existence and magnitude of point sources of pollution in the Chincoteague Basin. The primary source of this conflict appears to be the rapidity with which treatment systems are updated and pollutant discharges reduced or eliminated. The most recent publication which could be located enumerating pollutant sources in the Chincoteague region is the draft environmental impact statement (DEIS) North-Central Ocean Basin Regional Wastewater Treatment Facility - Worcester County, Maryland (9). This statement, released in Aug. 1977, contains a list of point sources as of 1976 which is a prime source of data for this report. Additional information was provided by the Region III Office of the U. S. Environmental Protection Agency which supplied copies of the National Pollution Discharge Elimination System (NPDES) permits for dischargers in the Chincoteague Basin. From these sources, the existance of seven major* pollution sources was determined:

Ocean Pines Sewage Treatment Plant	Ocean Pines, Md.
Showell Poultry	Showell, Md.
Selbyville Sewage Treatment Plant	Selbyville, Del.
Beatrice Foods	Berlin, Md.
Berlin Sewage Treatment Plant	Berlin, Md.
Chesapeake Foods	Berlin, Md.
Golden Pride Poultry	Stockton, Md.

The locations of these dischargers are shown in Fig. 31. A more detailed map showing the dischargers and their receiving streams has been produced for the Maryland DNR.

The DEIS and NPDES permits certified the existance of the point sources and provided estimates of their flow rates. Data regarding the quality of the pollutant discharges was supplied by the Maryland Department of Natural Resources (DNR) which sampled each of the discharges during the period this study was conducted. Table XXII presents for each significant discharge the minimum and maximum sampled pollutant concentrations, the pollutant mass flow rate (computed as the product of the volumetric flow rate and the mid-range

*Several additional minor point sources exist. Their effect is considered negligible, however, and they are omitted from this report.



1. SELBYVILLE STP
2. SHOWELL POULTRY
3. OCEAN PINES STP
4. CHESAPEAKE FOODS
5. BERLIN STP
6. BEATRICE FOODS
7. GOLDEN PRIDE POULTRY

Figure 31. Significant point sources in the Chincoteague Basin.

concentration value), and the discharge sub-basin and receiving stream.

B. Determination of Significant Non-Point Sources

The first tasks in determining the significant non-point sources of pollution in the basin were to define which sources were "significant" and differentiate them from the remaining sources. A decision was made to denote sources occupying the land use which produced the greatest pollutant runoff per unit area as significant sources of that pollutant.

Next, the STORM model was utilized to predict the pollutant runoff produced by one square mile of each land use type subject to a one-year, 24-hr design storm. Calibrated and synthesized values of runoff coefficients, percent imperviousness, and pollutant accumulation were used and a 10-day antecedent dry period was assumed. The results of the model run are presented as Table XXIII.

It can be seen that feedlots produce the greatest quantities of nitrogen and coliforms per unit area while high-density urban sites and sites devoted to transportation related uses produce the greatest quantities of BOD_5. Both feedlots and high-density sites produce the largest (and approximately equivalent) amounts of phosphorous. Hence, these two land uses, feedlots and high density-transportation are defined to be the "significant" sources of non-point pollution.

Table XXII. Significant Point Source Dischargers in the Chincoteague Basin

Ocean Pines STP   Design Capacity 1.0 mgd
Discharges into Isle of Wight Bay, sub-basin #3

	Org-N	NH_3	NO_3	Total-P	Ortho-P	BOD_5	Total Colif.	Fecal Colif.
minimum[1] concentration	0.06	0.03	0.08	0.09	0.04	0.5	3	3
maximum[1] concentration	2.85	0.83	16.	5.25	3.36	6.2	15	3
mass[2]	12.1	3.6	67.	22.3	14.2	27.9	341	114

Showell Poultry   Average Flow = 0.9 mgd
Discharges into tributary of Shingle Landing Prong, sub-basin #3

	Org-N	NH_3	NO_3	Total-P	Ortho-P	BOD_5	Total Colif.	Fecal Colif.
min.conc.	2.3	10.0	0.04	2.2	1.0	115	3	3
max.conc.	2.4	17.6	0.47	7.5	5.0	275	2.1×10^5	2.3×10^4
mass	95.3	103.5	1.9	36.4	22.5	1464	3.97×10^6	4.35×10^5

[1]All concentrations in mg/ℓ except coliform in mpn/100mℓ

[2]All masses in lb/day except coliform in 10^6 mpn/day

Table XXII (Cont'd)

Selbyville STP Average Flow = 0.7 mgd
Discharges into tributary of Bishopville Prong, sub-basin #3

	Org-N	NH_3	NO_3	Total-P	Ortho-P	BOD_5	Total Colif.	Fecal Colif.
concen.	9.8	45.6	0.26	31.2		9.6	10	10
mass	57.2	266.2	1.5	182.1		56.	379	379

Beatrice Foods Average Flow = 1.2 mgd
Discharges into Trappe Creek, sub-basin #5

	Org-N	NH_3	NO_3	Total-P	Ortho-P	BOD_5	Total Colif.	Fecal Colif.
min.conc.	1.8	0.2	0.11	4.4	2.4	15	3	3
max.conc.	17.8	31.	10.	5.4	3.6	145.	-	-
mass	94.6	156.1	50.5	49.0	30.0	800.6	114	114

Berlin STP Design Capacity 0.6 mgd
Discharges into Trappe Creek, sub-basin #5

	Org-N	NH_3	NO_3	Total-P	Ortho-P	BOD_5	Total Colif.	Fecal Colif.
min.conc.	0.01	0.1	3.1	2.3	1.7	5.5	230	43
max.conc.	7.2	5.3	6.4	16.	9.	38.	430	230
mass	18.	13.5	23.8	45.8	26.8	108.8	12490	5166

Table XXII (Cont'd)

Chesapeake Foods Average Flow 0.6 mgd
Discharges into tributary of Trappe Creek, sub-basin #5

	Org-N	NH_3	NO_3	Total-P	Ortho-P	BOD_5	Total Colif.	Fecal Colif.
min.conc.	7.2	14.	0.11	4.7	4.6	2.3	23	4
max.conc.	3.8	15.	0.18	5.6	4.9	3.1	43	4
mass	27.5	72.6	0.7	25.8	23.8	13.5	1249	151

Golden Pride Poultry Average Flow = 0.59 mgd
Discharges into Pikes Creek, sub-basin #10

	Org-N	NH_3	NO_3	Total-P	Ortho-P	BOD_5	Total Colif.	Fecal Colif.
min.conc.	4.9	8.	0.04	4.4	4.0	26.	21	4
max.conc.	31.2	24.1	2.7	24.4	13.7	120.	9300	9300
mass	88.8	79.0	6.7	70.9	43.5	359.2	2.3×10^4	2.3×10^4

Table XXIII. Mass of Pollutant Runoff from Individual Land Uses Subject to Design Storm

Land Use	Org-N (lb/mi^2)	NH_3 (lb/mi^2)	NO_3 (lb/mi^2)	Total P (lb/mi^2)	Ortho P (lb/mi^2)	BOD_5 (lb/mi^2)	Total Coliforms ($10^9/mi^2$)	Fecal Coliforms ($10^9/mi^2$)
Forest	<1	<1	<1	<1	<1	87.	75	2.3
Agriculture	53.6	2.7	120.7	9.	4.4	147.	22528	167
Feedlot	204.5	35.5	1076	10.	6.3	337.	181874	9821
Residential	14.3	8.4	18.3	7.	4.7	300.	6637	199
Medium Density	26.1	15.3	33.6	7.	4.7	1404.	43202	1296
High Density-Transportation	41.8	24.5	53.7	10.	6.8	1525	15956	479

C. Comparison of Point and Non-Point Pollutant Quantities

Table XXIV compares the average monthly load of pollutants produced by the significant non-point sources of pollution in sub-basins containing point sources with the sub-basin total monthly point source loadings (computed as thirty times the daily rate). For purposes of additional comparison, the monthly average total non-point loadings of the sub-basins are also provided as well as the average monthly loading of the entire Chincoteague Basin.

It can be seen that in each sub-basin, the point sources contribute significantly larger amounts of organic nitrogen, ammonia, phosphorous and BOD_5 to the Chincoteague Bay system while the non-point sources contribute larger quantities of nitrate and coliforms. Even when compared with the non-point runoff from the entire Chincoteague watershed, the point sources still contribute greater amounts of ammonia and phosphorous. In comparing the basinwide amounts of other pollutants contributed by point and upland non-point sources, a rough equivalence is found in the amounts of organic nitrogen and BOD_5 while non-point sources are found to contribute significantly larger quantities of nitrate and coliforms.

Table XXIV. Comparison of Monthly Point and Non-Point Source Pollution Loads

Drainage Area	Sources	Org-N (lb)	NH_3-N (lb)	NO_3-N (lb)	Total-P (lb)	Ortho-P (lb)	BOD_5 (lb)	Total Colif. (10^9)	Fecal Colif. (10^9)
Sub-basin #3	point sources	4938	11199	2112	7224	1101	46437	1.19×10^5	1.31×10^4
	significant non-point sources	401	69	2083	23	15	653	3.60×10^5	1.96×10^4
	all non-point sources	4009	299	9723	724	374	15763	1.80×10^6	3.01×10^4
Sub-basin #5	point sources	4203	7266	2250	3618	2418	27687	4.15×10^2	1.63×10^2
	significant non-point sources	397	126	1775	36	25	3392	3.21×10^5	1.66×10^4
	all non-point sources	1977	223	5047	348	188	11372	9.43×10^5	2.20×10^4
Sub-basin #10	point sources	2664	2370	201	2127	1305	10776	6.88×10^2	6.87×10^2
	significant non-point sources	87	15	458	5	3	145	8.01×10^4	4.33×10^3
	all non-point sources	612	40	1553	101	52	2535	2.82×10^5	5.84×10^3
Chincoteague Basin	point sources	1.18×10^4	2.08×10^4	4.56×10^3	1.30×10^4	4.82×10^3	8.49×10^4	1.20×10^5	1.40×10^4
	all non-point sources	1.78×10^4	1.72×10^3	4.48×10^4	3.15×10^3	1.67×10^3	8.92×10^4	8.58×10^6	1.86×10^5

D. Comparison of Pollutant Sources and Marsh Nutrient Exports

As discussed in previous chapters, the Chincoteague marshes export significant quantities of nutrients and minerals which would be deemed pollutants if they originated from an alternate source. In Table XXV the predicted nutrient releases from the Chincoteague marshes resulting from a 0.5 inch storm are compared with the monthly average point source and upland non-point source pollution loads. It can be seen that the marsh exports of organic nitrogen, total phosphorous and BOD_5 from a single storm are of the same order of magnitude as the average monthly runoff from the rest of the basin. Organic nitrogen and BOD_5 marsh exports are also of the same order of magnitude as the monthly average point source discharges. Thus the largest sources of "pollution" in the Chincoteague Basin may be the extensive natural marsh areas.

Table XXV. Comparison of Pollutant Sources and Marsh Nutrient Exports

	Org-N (lb)	NH_4-N (lb)	Tot-P (lb)	Ortho-P (lb)	BOD_5 (lb)
Monthly Average Point Source Loads	1.18×10^4	2.08×10^4	1.30×10^4	4.82×10^3	8.49×10^4
Monthly Average Upland Non-Point Source Loads	1.78×10^4	1.72×10^3	3.15×10^3	1.67×10^3	8.92×10^4
Marsh Exports 0.5 Inch Storm	1.19×10^4	-5.00×10^2	1.12×10^3	9.05×10^2	3.60×10^4

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9) EcolSciences, Inc., Draft Environmental Impact Statement - North Central Ocean Basin Wastewater Treatment Facility; Worcester County, Maryland, U. S. Environmental Protection Agency, Philadelphia, Pa., 1977.

Appendix A. Sampling Procedure

I. If the site has a weir

a) Before rain starts:

Place the rain guage (with windshield) into the ground in a spot as open as possible.

Take a staff guage reading. If the staff guage reading varies significantly (0.01 feet) before the rain begins, reread the staff guage every 15 minutes to an hour depending on the time scale of the variation.

b) When rain begins:

Read the rain guage every 15 minutes.

c) 15 minutes after runoff begins:

{The beginning of runoff will be defined as when

a) There is a measurable amount of rain in the rain guage and it is still raining.

and b) Flow begins over the weir, if there had previously been no flow;

or the staff guage reading increased by at least 0.01 feet compared to its reading just before the rain started, if there had previously been flow.}

Every 15 minutes for 5 hours (20 times):

Take a staff guage reading.

Take the following water samples in the previously-labeled bottles:

1 coliform (1c)

1 BOD bottle (1B): Take a BOD sample with care to avoid entrapping air bubbles. Before stoppering the bottle measure oxygen with an oxygen probe taking care not to displace so much water that an air bubble will be trapped in stoppering the bottle (that is, in order to stopper the bottle properly an excess of sample must be present so that some overflows the neck). Add a "shot" of nitrification inhibitor and stopper bottle. Shake bottle, then add distilled water to neck as a water seal.

1 500-ml bottle (1N) ($HgCl_2$ previously added)

There are extra bottles provided in case any of the labeled ones break.

The water samples should be taken about a few feet upstream (upstream of the backwater, if possible) of the weir.

All samples should be kept on ice.

Date all bottles when sampling is completed.

Keep the notch in the weir free of weeds and debris, since these may affect the flow measurements.

Make a note if at any time flow occurs at a place other than through the notch in the weir (e.g. over the top or around the sides).

II. If the site is to be sampled with a current meter

a) Before the rain starts:

Place the rain guage (with windshield) into the ground in as open a spot as possible.

<u>If there is no flow</u>, take a staff guage reading.

<u>If there is flow</u>, take a staff guage reading and a current reading. See instructions for current meter measurements further on. If these readings vary significantly (2% difference of the staff reading, 10 clicks/min. or 1 sec./meter difference for the current reading) before the rain starts, reread them at intervals of 15 minutes to an hour depending on the time scale of the variations.

b) When rain begins:

Read the rain guage every 15 minutes.

c) 15 minutes after runoff begins:

{The beginning of runoff will be defined as when

a) There is a measurable amount of rain in the rain guage and it is still raining.

and b) Compared to the measurements made just before the rain began. <u>Either</u> there is a significant increase in the staff guage reading (even if the velocity decreases)

<u>or</u> there is a significant increase in the current reading with a constant or increasing staff reading.}

Every 15 minutes for 5 hours (20 times):

Take a staff guage reading

Take a current measurement

Take a set of water samples in previously-labelled bottles as follows:

1 coliform (1c)

1 BOD bottle (1B): Take a BOD water sample with care to avoid entrapping air bubbles. Before stoppering the bottle measure oxygen with an oxygen probe taking care not to displace so much water that an air bubble will be trapped in stoppering the bottle (that is, in order to stopper the bottle properly an excess of sample must be present so that some overflows the neck). Add a "shot" of nitrification inhibitor and stopper bottle. Shake bottle, then add distilled water to neck as a water seal.

1 500-ml bottle (1N) ($HgCl_2$ previously added)

There are extra bottles provided in case any of the labelled ones break.

The water samples should be taken from the main channel.

All samples should be kept on ice.

Current measurements:

Place the current meter in the center of the channel of flow, about a foot upstream of the staff guage at 60% depth (that is, 60% down from the water surface). The meter should be placed so that the shaft is parallel to the flow with the cable crossing the downstream end. Measure the number of clicks in a 1 minute period.

II. Appendix

If the water is too shallow to immerse the current meter the water velocity will be estimated by timing the travel of a float for a measured distance.

First mark off a measured distance in the water (for example, one meter). A set of twigs stuck in the mud along the shore will do. Do not use anything that significantly disrupts the flow of water.

Use a small piece of paper or a leaf for a float. Place the float in the water well upstream of the upstream marker. Be sure it is in the center of flow. Use a stopwatch to time the duration of travel between the two markers. Take 2 or 3 readings and record the average.

III. Whether to continue sampling for the full 5 hours

The ideal rain storm for this survey would be at least 0.1 inch in a 2-hour period. If this occurs, sample for the full 5 hours.

If after 2 hours there is at least 0.05 inches of rain and it is still raining and some significant runoff has begun, continue sampling. If the 0.1 inch level (or close) is reached by the end of the 5 hours, this sampling set should be adequate as long as there is significant runoff.

If the rain stops before the 0.1 inch level is reached or approached but a significant amount of flow is generated (as in a previously-dry pipe), continue sampling. If the runoff lasts for the full 5 hours the sampling set should be adequate.

APPENDIX B

FIELD DATA

SITE ONE 10/25/76 AREA = 72.00

CUMULATIVE RAIN FALL IN INCHES

TIME	23:30	3:30	8:00	11:45	14:30
RAINFALL	0.010	0.040	0.100	0.140	0.142

BACKGROUND SAMPLES
ALL CONCENTRATIONS IN MG/L EXCEPT COLIFORMS IN MPN/100ML -- FLOW IN CFS

TIME	FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
0:00	0.060	0.44	0.01	8.88	0.04	0.01	1.40	1.00	0.43E 04	0.43E 02

RUNOFF SAMPLES
ALL CONCENTRATIONS IN MG/L EXCEPT COLIFORMS IN MPN/100ML -- FLOW IN CFS
MISSING DATA INDICATED BY *****

TIME	FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
9:45	0.130	0.82	0.01	4.73	0.04	0.01	*****	8.00	0.15E 05	0.93E 02
10:00	0.190	0.41	0.01	8.13	0.06	0.01	0.60	4.00	0.93E 05	0.43E 02
10:15	0.240	0.81	0.02	6.25	0.05	0.01	*****	8.00	0.23E 04	0.21E 02
10:30	0.290	0.62	0.01	5.25	0.06	0.03	0.50	16.00	0.93E 03	0.93E 02
10:45	0.348	0.62	0.01	0.53	0.04	0.02	*****	11.00	********	********
11:00	0.203	0.20	0.01	5.00	0.06	0.02	1.30	7.80	********	********
11:15	0.803	0.82	0.01	4.68	0.06	0.01	*****	9.00	********	********
11:30	0.961	0.11	0.02	8.13	0.05	0.01	0.60	8.00	0.23E 04	0.90E 01
11:45	1.660	0.41	0.01	7.50	0.03	0.01	*****	10.00	********	********
12:00	2.030	0.20	0.01	5.63	0.03	0.01	0.50	10.50	********	********
12:15	1.220	1.64	0.02	4.21	0.04	0.01	*****	10.50	********	********
12:30	1.820	0.82	0.01	6.87	0.06	0.02	0.50	8.00	********	0.43E 02
12:45	2.010	0.20	0.01	7.50	0.04	0.02	*****	11.50	********	********
13:00	2.170	0.30	0.02	7.78	0.04	0.01	0.80	11.50	********	********
13:15	2.320	0.31	0.02	7.50	0.04	0.01	*****	6.20	0.15E 05	0.43E 02
13:30	1.860	0.41	0.01	4.06	0.06	0.02	0.50	7.00	********	0.43E 02
13:45	2.630	0.82	0.01	6.35	0.04	0.01	*****	8.00	********	********
14:00	4.150	0.29	0.01	5.00	0.04	0.01	0.50	8.80	********	********
14:15	4.280	0.81	0.02	4.00	0.04	0.01	*****	13.50	********	********
14:30	2.220	0.72	0.03	4.21	0.05	0.03	0.50	8.00	********	********

AVERAGE CONCENTRATIONS
ALL CONCENTRATIONS IN MG/L EXCEPT COLIFORMS IN MPN/100ML -- FLOW IN CFS

FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
1.577	0.56	0.01	5.67	0.05	0.01	0.63	9.26	0.21E 05	0.49E 02

CUMULATIVE VALUES
FLOW IN CUBIC FEET. -- COLIFORMS IN BILLIONS -- ALL OTHER PARAMETERS IN POUNDS
AVERAGE VALUES ASSUMED FOR MISSING PARAMETERS

FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
0.284E 05	0.940E 00	0.265E-01	0.101E 02	0.765E-01	0.240E-01	0.105E 01	0.170E 02	0.164E 03	0.374E 00

TOTAL RAINFALL 0.142 (INCHES) 0.371E 05 (CUBIC FEET)
TOTAL RUNOFF 0.109 (INCHES) 0.284E 05 (CUBIC FEET)
STANDARDIZED RUNOFF COEFFICIENT 0.764728E 00

SITE ONE 3/22/77 AREA = 72.00

CUMULATIVE RAIN FALL IN INCHES

TIME	4:45	5:45	6:45	7:45	9:00
RAINFALL	0.090	0.095	0.120	0.200	0.280

NO BACKROUND SAMPLES TAKEN

RUNOFF SAMPLES
ALL CONCENTRATIONS IN MG/L EXCEPT COLIFORMS IN MPN/100ML -- FLOW IN CFS
MISSING DATA INDICATED BY *****

TIME	FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
4:00	0.269	0.53	0.02	7.04	0.03	0.02	1.50	11.00	0.93E 04	0.93E 02
4:15	0.334	0.35	0.03	7.68	0.04	0.02	*****	12.50	0.43E 04	0.14E 02
4:30	0.364	0.40	0.02	7.04	0.03	0.02	3.00	11.00	0.23E 04	0.15E 03
4:45	0.422	0.21	0.04	7.68	0.04	0.02	*****	12.50	0.23E 05	0.90E 01
5:00	0.351	0.27	0.01	6.40	0.03	0.02	3.00	11.50	********	********
5:15	0.269	0.41	0.01	7.04	0.03	0.02	*****	12.50	0.23E 04	0.29E 02
5:30	0.403	0.26	0.02	0.02	0.10	0.05	1.60	11.00	********	********
5:45	0.403	0.49	0.02	7.36	0.03	0.02	*****	11.00	********	********
6:00	0.273	0.57	0.02	8.40	0.03	0.02	5.40	11.00	********	********
6:15	0.390	0.27	0.02	7.84	0.03	0.02	*****	12.00	0.43E 05	0.39E 03
6:30	0.410	0.21	0.04	7.68	0.06	0.03	2.30	13.50	********	********
6:45	0.351	0.51	0.02	7.30	0.03	0.01	*****	13.00	********	********
7:15	0.453	0.39	0.03	7.04	0.02	0.02	*****	12.09	********	********
7:30	0.532	0.60	0.03	6.72	0.03	0.01	2.20	12.50	********	********
7:45	0.537	0.22	0.03	7.04	0.11	0.04	*****	13.00	********	********
8:00	0.557	0.42	0.02	7.28	0.03	0.01	7.80	14.00	********	********
8:15	0.520	0.42	0.02	7.60	0.03	0.02	*****	15.00	0.75E 04	0.23E 02
8:30	0.543	0.24	0.01	6.72	0.02	0.01	1.20	13.50	********	********
8:45	0.650	0.49	0.01	7.04	0.02	0.01	*****	14.50	********	********
9:00	0.650	0.24	0.01	7.04	0.04	0.02	0.80	16.00	********	********

AVERAGE CONCENTRATIONS
ALL CONCENTRATIONS IN MG/L EXCEPT COLIFORMS IN MPN/100ML -- FLOW IN CFS

FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
0.438	0.37	0.02	6.90	0.04	0.02	2.88	12.65	0.13E 05	0.10E 03

CUMULATIVE VALUES
FLOW IN CUBIC FEET. -- COLIFORMS IN BILLIONS -- ALL OTHER PARAMETERS IN POUNDS
AVERAGE VALUES ASSUMED FOR MISSING PARAMETERS

FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
0.824E 04	0.189E 00	0.110E-01	0.355E 01	0.199E-01	0.102E-01	0.147E 01	0.663E 01	0.309E 02	0.235E 00

TOTAL RAINFALL 0.280 (INCHES) 0.732E 05 (CUBIC FEET)
TOTAL RUNOFF 0.032 (INCHES) 0.824E 04 (CUBIC FEET)
STANDARDIZED RUNOFF COEFFICIENT 0.112566E 00

SITE TWC 10/26/76 AREA = 29.00

CUMULATIVE RAIN FALL IN INCHES

TIME	20:15	21:15	0:30	1:00	2:00
RAINFALL	0.010	0.100	0.320	0.560	0.780

BACKGROUND SAMPLES
ALL CONCENTRATIONS IN MG/L EXCEPT COLIFORMS IN MPN/100ML -- FLOW IN CFS

TIME	FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
19:45	0.086	0.49	0.01	11.05	0.05	0.01	2.10	11.00	0.93E 04	0.23E 03

RUNOFF SAMPLES
ALL CONCENTRATIONS IN MG/L EXCEPT COLIFORMS IN MPN/100ML -- FLOW IN CFS
MISSING DATA INDICATED BY *****

TIME	FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
21:15	0.086	0.24	0.01	12.63	0.05	0.01	2.10	7.00	0.43E 04	0.15E 03
21:30	0.095	0.49	0.01	11.58	0.07	0.02	1.50	9.00	0.93E 04	0.93E 02
21:45	0.095	0.24	0.01	12.10	0.13	0.03	0.50	7.00	********	0.43E 02
22:00	0.095	0.24	0.01	12.10	0.07	0.01	1.50	9.00	0.23E 04	0.93E 02
22:15	0.095	0.44	0.01	8.40	0.17	0.10	*****	3.00	********	********
22:30	0.095	0.49	0.01	11.05	0.05	0.01	*****	7.00	********	********
22:45	0.095	0.49	0.01	12.10	0.05	0.01	3.60	6.00	********	********
23:00	0.095	0.49	0.01	11.57	0.05	0.01	*****	7.00	********	********
23:15	0.095	0.49	0.01	12.01	0.05	0.02	1.50	11.00	********	0.93E 02
23:30	0.095	0.99	0.01	11.58	0.10	0.03	*****	9.00	********	********
23:45	0.095	0.49	0.01	11.05	0.05	0.03	0.80	8.00	********	0.43E 02
24:00	0.104	0.74	0.01	12.63	0.10	0.02	*****	6.00	********	********
0:15	0.104	0.49	0.01	11.66	0.05	0.01	2.00	1.00	0.93E 04	0.43E 03
0:30	0.104	0.49	0.01	19.52	0.07	0.03	*****	7.00	********	********
0:45	0.113	0.74	0.01	11.57	0.07	0.01	*****	7.00	********	********
1:00	0.269	0.49	0.01	11.05	0.07	0.01	1.50	8.00	********	********
1:15	0.258	0.49	0.01	11.57	0.10	0.01	1.30	8.00	********	********
1:30	0.223	0.49	0.01	11.05	0.07	0.02	*****	9.00	********	********
1:45	0.238	0.49	0.01	10.05	0.05	0.03	*****	1.00	********	********
2:00	0.253	0.49	0.01	12.11	0.05	0.02	*****	10.00	********	********

AVERAGE CONCENTRATIONS
ALL CONCENTRATIONS IN MG/L EXCEPT COLIFORMS IN MPN/100ML -- FLOW IN CFS

FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
0.132	0.50	0.01	11.42	0.07	0.02	1.63	7.00	0.63E 04	0.14E 03

CUMULATIVE VALUES
FLOW IN CUBIC FEET. -- COLIFORMS IN BILLIONS -- ALL OTHER PARAMETERS IN POUNDS
AVERAGE VALUES ASSUMED FOR MISSING PARAMETERS

FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
0.238E 04	0.744E-01	0.149E-02	0.169E 01	0.106E-01	0.310E-02	0.239E 00	0.105E 01	8.426E 01	0.917E-01

TOTAL RAINFALL 0.780 (INCHES) 0.821E 05 (CUBIC FEET)
TOTAL RUNOFF 0.023 (INCHES) 0.238E 04 (CUBIC FEET)
STANDARDIZED RUNOFF COEFFICIENT 0.290221E-01

SITE THREE 5/11/76 AREA = 262.00

CUMULATIVE RAIN FALL IN INCHES

TIME	17:30	18:30	18:54	21:05	0:35
RAINFALL	0.040	0.190	0.260	0.370	0.370

BACKROUND SAMPLES
ALL CONCENTRATIONS IN MG/L EXCEPT COLIFORMS IN MPM/100ML -- FLOW IN CFS

TIME	FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
18:54	******	0.64	0.03	0.11	0.08	0.03	6.00	29.50	0.43E 03	0.90E 01

RUNOFF SAMPLES
ALL CONCENTRATIONS IN MG/L EXCEPT COLIFORMS IN MPN/100ML -- FLOW IN CFS
MISSING DATA INDICATED BY *****

TIME	FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
19:55	0.043	0.55	0.03	0.07	0.06	0.03	3.60	27.00	0.75E 03	0.23E 02
20:05	0.038	0.47	0.03	0.08	0.05	0.03	*****	31.50	0.93E 04	0.23E 03
20:25	0.038	0.30	0.03	0.11	0.06	0.08	3.60	26.50	0.23E 05	0.23E 02
20:35	0.037	0.44	0.03	0.06	0.06	0.04	*****	38.00	0.23E 05	0.23E 02
20:50	0.037	0.39	0.03	0.11	0.05	0.04	3.00	36.00	0.93E 04	0.39E 02
21:05	0.058	0.47	0.03	0.08	0.06	0.05	*****	36.00	0.43E 04	0.43E 02
21:20	0.033	0.47	0.03	0.06	0.06	0.04	3.60	35.00	0.93E 03	0.93E 02
21:35	0.058	0.47	0.03	0.11	0.05	0.03	*****	26.50	0.21E 03	0.70E 01
21:50	0.050	0.55	0.03	0.06	0.04	0.03	3.00	31.50	0.75E 03	0.23E 02
22:05	0.046	0.30	0.03	0.11	0.05	0.03	*****	26.00	********	********
22:20	0.037	0.64	0.03	0.03	0.08	0.03	3.00	30.00	0.39E 03	0.43E 02
22:35	0.025	0.47	0.03	0.03	0.04	0.03	*****	28.00	********	********
22:50	0.025	0.55	0.03	0.06	0.06	0.04	*****	35.00	0.23E 05	0.90E 01
23:05	0.021	0.39	0.03	0.08	0.06	0.05	*****	35.00	********	********
23:20	0.021	0.47	0.03	0.03	0.09	0.04	1.80	26.50	0.15E 05	0.90E 01
23:35	0.021	0.64	0.03	0.01	0.09	0.06	*****	26.00	********	********
23:50	0.017	0.30	0.03	0.03	0.05	0.04	2.40	38.50	0.43E 04	0.40E 01
0:05	0.017	0.47	0.03	0.08	0.06	0.04	*****	35.50	********	********
0:20	0.017	0.97	0.03	0.06	0.05	0.04	1.80	39.00	0.43E 04	0.43E 04
0:35	0.317	0.30	0.03	0.06	0.08	0.04	*****	23.00	********	********

AVERAGE CONCENTRATIONS
ALL CONCENTRATIONS IN MG/L EXCEPT COLIFORMS IN MPN/100ML -- FLOW IN CFS

FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
0.033	0.48	0.03	0.07	0.06	0.04	2.87	31.52	0.85E 04	0.35E 03

CUMULATIVE VALUES
FLOW IN CUBIC FEET. -- COLIFORMS IN BILLIONS -- ALL OTHER PARAMETERS IN POUNDS
AVERAGE VALUES ASSUMED FOR MISSING PARAMETERS

FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
0.572E 03	0.168E-01	0.107E-02	0.259E-02	0.207E-02	0.142E-02	0.105E 00	0.112E 01	0.126E 01	0.367E-01

TOTAL RAINFALL 0.370 (INCHES) 0.352E 06 (CUBIC FEET)
TOTAL RUNOFF 0.001 (INCHES) 0.572E 03 (CUBIC FEET)
STANDARDIZED RUNOFF COEFFICIENT 0.162586E-02

SITE THREE 3/22/77 AREA = 262.00

CUMULATIVE RAIN FALL IN INCHES

TIME	4:00	6:45	8:00	9:30	11:00
RAINFALL	0.060	0.170	0.250	0.350	0.440

BACKGROUND SAMPLES
ALL CONCENTRATIONS IN MG/L EXCEPT COLIFORMS IN MPN/100ML -- FLOW IN CFS

TIME	FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
4:00	******	0.23	0.01	0.01	0.03	0.03	3.00	14.00	0.39E 02	0.30E 01

RUNOFF SAMPLES
ALL CONCENTRATIONS IN MG/L EXCEPT COLIFORMS IN MPN/100ML -- FLOW IN CFS
MISSING DATA INDICATED BY *****

TIME	FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
6:30	0.216	0.20	0.01	0.01	0.04	0.03	6.00	15.00	0.43E 03	0.30E 01
6:45	0.276	0.30	0.01	0.01	0.03	0.02	*****	11.50	0.43E 03	0.70E 01
7:00	0.504	0.33	0.01	0.01	0.04	0.03	6.00	14.00	0.23E 02	0.40E 01
7:15	0.694	0.29	0.01	0.01	0.03	0.02	3.00	12.50	********	********
7:30	0.992	0.23	0.01	0.01	0.03	0.02	2.40	13.00	0.23E 04	0.90E 01
7:45	1.020	0.20	0.01	0.01	0.04	0.02	*****	13.00	********	********
8:00	1.160	0.33	0.01	0.01	0.03	0.02	3.00	12.50	********	********
8:15	1.160	0.27	0.01	0.01	0.03	0.02	*****	13.00	********	********
8:30	1.160	0.67	0.01	0.01	0.04	0.03	6.00	13.00	0.28E 02	0.40E 01
8:45	1.160	0.33	0.01	0.01	0.03	0.02	*****	13.00	********	********
9:00	1.230	0.33	0.01	0.01	0.04	0.02	2.40	13.50	********	********
9:15	1.230	0.33	0.01	0.01	0.09	0.03	*****	13.00	********	********
9:30	1.400	0.33	0.01	0.01	0.03	0.02	6.00	13.50	********	********
9:45	1.400	0.23	0.01	0.01	0.07	0.04	*****	13.00	********	********
10:00	1.570	0.20	0.01	0.01	0.03	0.02	2.40	13.00	********	********
10:15	1.480	0.23	0.01	0.01	0.04	0.02	*****	13.00	0.20E 02	0.90E 01
10:30	1.520	0.83	0.01	0.01	0.03	0.02	6.00	12.50	********	********
10:45	1.450	0.32	0.01	0.01	0.09	0.07	*****	14.00	********	********
11:00	1.480	0.33	0.01	0.01	0.04	0.03	6.60	13.00	********	********

AVERAGE CONCENTRATIONS
ALL CONCENTRATIONS IN MG/L EXCEPT COLIFORMS IN MPN/100ML -- FLOW IN CFS

FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
1.112	0.33	0.01	0.01	0.04	0.03	4.53	13.21	0.54E 03	0.60E 01

CUMULATIVE VALUES
FLOW IN CUBIC FEET. -- COLIFORMS IN BILLIONS -- ALL OTHER PARAMETERS IN POUNDS
AVERAGE VALUES ASSUMED FOR MISSING PARAMETERS

FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
0.130E 05	0.407E 00	0.119E-01	0.119E-01	0.519E-01	0.320E-01	0.533E 01	0.156E 02	0.292E 01	0.333E-01

TOTAL RAINFALL 0.440 (INCHES) 0.418E 06 (CUBIC FEET)
TOTAL RUNOFF 0.020 (INCHES) 0.190E 05 (CUBIC FEET)
STANDARDIZED RUNOFF COEFFICIENT 0.454530E-01

SITE FOUR 10/25/76 AREA = 117.00

CUMULATIVE RAIN FALL IN INCHES

TIME	6:45	8:30	9:00	11:00	16:45
RAINFALL	0.020	0.040	0.060	0.080	0.080

BACKROUND SAMPLES
ALL CONCENTRATIONS IN MG/L EXCEPT COLIFORMS IN MPM/100ML -- FLOW IN CFS

TIME	FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
17:30	******	0.20	0.01	2.50	0.06	0.03	2.10	7.50	********	********
6:30	******	0.76	0.07	21.00	0.04	0.03	1.60	36.50	********	********

RUNOFF SAMPLES
ALL CONCENTRATIONS IN MG/L EXCEPT COLIFORMS IN MPN/100ML -- FLOW IN CFS
MISSING DATA INDICATED BY *****

TIME	FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
6:45	******	0.35	0.10	2.00	0.06	0.03	2.40	11.80	********	********
8:00	******	0.41	0.01	2.38	0.04	0.03	0.50	7.60	********	********
9:00	******	0.73	0.10	1.81	0.06	0.03	1.30	4.80	********	********
11:30	******	0.77	0.06	2.19	0.07	0.04	1.30	5.00	********	********
12:00	******	0.20	0.01	2.25	0.06	0.04	1.10	4.50	********	********
13:00	******	0.82	0.01	1.42	0.04	0.02	0.50	7.00	********	********
13:30	******	0.82	0.01	1.69	0.10	0.05	0.50	9.00	********	********
13:45	******	0.28	0.05	2.38	0.06	0.03	*****	9.50	********	********
14:00	******	0.41	0.01	14.20	0.05	0.04	0.50	10.50	********	********
14:15	******	0.38	0.05	1.63	0.06	0.03	*****	2.50	********	********
14:30	******	0.26	0.07	1.74	0.05	0.03	0.60	10.50	********	********
14:45	******	0.22	0.01	1.88	0.06	0.04	*****	10.50	********	********
15:00	******	0.39	0.03	1.74	0.05	0.04	*****	9.00	********	********
15:15	******	0.15	0.27	2.11	0.05	0.04	*****	8.00	********	********
15:30	******	0.40	0.02	1.94	0.07	0.03	*****	6.00	********	********
15:45	******	2.27	0.03	2.00	0.07	0.03	*****	1.50	********	********
16:00	******	0.41	0.01	1.81	0.06	0.03	*****	7.80	********	********
16:15	******	0.39	0.03	2.11	0.05	0.05	*****	12.50	********	********
16:30	******	0.41	0.01	2.11	0.05	0.04	*****	11.00	********	********

AVERAGE CONCENTRATIONS
ALL CONCENTRATIONS IN MG/L EXCEPT COLIFORMS IN MPN/100ML -- FLOW IN CFS

FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
0.000	0.51	0.05	2.60	0.06	0.04	0.97	7.81	0.00E 00	0.00E 00

CUMULATIVE VALUES
FLOW IN CUBIC FEET. -- COLIFORMS IN BILLIONS -- ALL OTHER PARAMETERS IN POUNDS
AVERAGE VALUES ASSUMED FOR MISSING PARAMETERS

FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
*********	*********	*********	*********	*********	*********	*********	*********	*********	*********

TOTAL RAINFALL 0.080 (INCHES) 0.340E 05 (CUBIC FEET)
NO RUNOFF COEFFICIENT CAN BE COMPUTED

SITE FOUR 10/26/76 AREA = 117.00

CUMULATIVE RAIN FALL IN INCHES

TIME	23:30	0:35	1:40	2:55	5:25
RAINFALL	0.110	0.500	1.060	1.510	1.950

NO BACKGROUND SAMPLES TAKEN

RUNOFF SAMPLES
ALL CONCENTRATIONS IN MG/L EXCEPT COLIFORMS IN MPN/100ML -- FLOW IN CFS
MISSING DATA INDICATED BY *****

TIME	FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
0:25	******	0.68	0.03	1.94	0.12	0.04	4.80	7.00	0.23E 04	0.39E 02
0:40	******	0.57	0.06	2.23	0.66	0.04	*****	*****	0.43E 04	0.15E 03
0:55	******	0.36	0.01	2.41	0.07	0.05	3.00	5.00	0.93E 04	0.43E 02
1:10	******	0.57	0.07	1.29	0.07	0.07	*****	5.00	0.93E 04	0.43E 02
1:25	******	0.45	0.05	2.47	0.05	0.02	3.80	10.00	0.93E 04	0.12E 03
1:40	******	0.56	0.01	2.41	0.07	0.05	*****	9.00	0.15E 05	0.43E 03
1:55	******	0.92	0.01	2.47	0.10	0.08	1.60	9.00	0.23E 05	0.43E 03
2:10	******	0.68	0.03	1.71	0.19	0.07	*****	14.00	********	********
2:25	******	0.50	0.07	1.12	0.12	0.03	2.70	14.00	********	********
2:40	******	0.20	0.01	1.24	0.13	0.08	*****	19.00	********	********
2:55	******	0.49	0.01	1.29	0.13	0.10	2.70	25.00	0.12E 06	0.43E 03
3:10	******	0.36	0.07	2.29	0.06	0.02	*****	16.00	********	********
3:25	******	0.50	0.07	1.29	0.09	0.08	4.80	32.00	********	********
3:40	******	0.31	0.03	1.06	0.13	0.09	*****	33.00	********	********
3:55	******	0.54	0.03	1.00	0.10	0.10	7.00	28.00	********	********
4:10	******	0.28	0.07	1.24	0.16	0.11	*****	20.00	********	********
4:25	******	0.47	0.03	1.16	0.30	0.23	7.00	20.00	********	********
4:40	******	0.42	0.01	1.24	0.23	0.20	*****	18.00	********	********
4:55	******	0.37	0.01	1.11	0.23	0.20	5.40	29.00	********	********
5:10	******	0.42	0.01	1.24	0.23	0.20	*****	9.00	********	********
5:25	******	0.56	0.08	1.24	0.17	0.14	4.30	16.00	********	********

AVERAGE CONCENTRATIONS
ALL CONCENTRATIONS IN MG/L EXCEPT COLIFORMS IN MPN/100ML -- FLOW IN CFS

FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
0.000	0.51	0.04	1.59	0.16	0.10	4.28	16.45	0.24E 05	0.21E 03

CUMULATIVE VALUES
FLOW IN CUBIC FEET. -- COLIFORMS IN BILLIONS -- ALL OTHER PARAMETERS IN POUNDS
AVERAGE VALUES ASSUMED FOR MISSING PARAMETERS

FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
*********	*********	*********	*********	*********	*********	*********	*********	*********	*********

TOTAL RAINFALL 1.950 (INCHES) 0.828E 06 (CUBIC FEET)
NO RUNOFF COEFFICIENT CAN BE COMPUTED

SITE FIVE 10/25/76 AREA = 79.00

CUMULATIVE RAIN FALL IN INCHES

TIME	7:00	11:15	12:30	14:00	16:30
RAINFALL	0.100	0.100	0.100	0.100	0.100

BACKGROUND SAMPLES
ALL CONCENTRATIONS IN MG/L EXCEPT COLIFORMS IN MPN/100ML -- FLOW IN CFS

TIME	FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
13:30	******	*****	0.01	0.03	0.06	0.03	2.40	5.60	********	********

RUNOFF SAMPLES
ALL CONCENTRATIONS IN MG/L EXCEPT COLIFORMS IN MPN/100ML -- FLOW IN CFS
MISSING DATA INDICATED BY *****

TIME	FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
11:30	0.210	0.41	0.01	0.06	0.06	0.03	0.50	6.50	********	********
11:50	0.450	0.32	0.01	0.06	0.04	0.03	*****	7.50	********	********
12:30	0.731	1.65	0.01	0.03	0.06	0.02	*****	7.00	********	********
13:15	0.773	0.82	0.01	0.05	0.05	0.04	*****	7.00	********	********
13:30	0.773	1.03	0.01	0.03	0.06	0.03	1.10	9.00	********	********
13:45	1.120	0.52	0.01	0.03	0.06	0.04	*****	5.50	********	********
14:00	1.190	0.82	0.01	0.03	0.06	0.03	1.10	2.50	********	********
14:15	1.190	0.62	0.01	0.11	0.04	0.01	*****	5.50	********	********
14:30	1.190	0.67	0.01	0.03	0.06	0.03	1.10	10.50	********	********
15:00	1.160	0.82	0.01	0.03	0.04	0.02	0.50	10.00	********	********
15:30	1.190	0.62	0.01	0.06	0.06	0.03	0.50	5.50	********	********
16:00	1.190	0.44	0.01	0.03	0.04	0.03	1.30	14.00	********	********
16:30	1.190	0.41	0.01	0.03	0.05	0.03	2.40	3.00	********	********

AVERAGE CONCENTRATIONS
ALL CONCENTRATIONS IN MG/L EXCEPT COLIFORMS IN MPN/100ML -- FLOW IN CFS

FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
0.981	0.72	0.01	0.04	0.05	0.03	1.06	7.19	0.00E 00	0.00E 00

CUMULATIVE VALUES
FLOW IN CUBIC FEET. -- COLIFORMS IN BILLIONS -- ALL OTHER PARAMETERS IN POUNDS
AVERAGE VALUES ASSUMED FOR MISSING PARAMETERS

FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
0.183E 05	0.838E 00	0.114E-01	0.473E-01	0.586E-01	0.319E-01	0.127E 01	0.854E 01	*********	*********

TOTAL RAINFALL 0.100 (INCHES) 0.287E 05 (CUBIC FEET)
TOTAL RUNOFF 0.064 (INCHES) 0.183E 05 (CUBIC FEET)
STANDARDIZED RUNOFF COEFFICIENT 0.637570E 00

SITE FIVE 11/26/76 AREA = 79.00

CUMULATIVE RAIN FALL IN INCHES

TIME	11:00	0:30	1:15	2:45	5:15
RAINFALL	0.150	0.480	1.000	1.500	1.900

NO BACKROUND SAMPLES TAKEN

RUNOFF SAMPLES
ALL CONCENTRATIONS IN MG/L EXCEPT COLIFORMS IN MPN/100ML -- FLOW IN CFS
MISSING DATA INDICATED BY *****

TIME	FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
0:15	0.847	0.52	0.03	0.22	0.14	0.09	6.50	8.00	0.93E 03	0.40E 01
0:30	1.180	0.65	0.03	0.19	0.22	0.13	*****	13.50	0.23E 04	0.15E 02
0:45	1.970	0.74	0.03	0.33	0.70	0.44	3.20	25.00	0.93E 05	0.75E 03
1:00	1.780	0.64	0.02	0.25	0.38	0.33	*****	10.00	0.23E 05	0.43E 02
1:15	3.330	0.82	0.01	0.14	0.13	0.13	1.50	14.00	0.43E 04	0.43E 02
1:30	4.330	0.62	0.01	0.22	0.13	0.09	*****	3.00	0.43E 04	0.23E 02
1:45	5.457	0.62	0.01	0.17	0.05	0.02	1.50	3.50	0.23E 04	0.43E 02
2:00	5.090	0.82	0.01	0.22	0.18	0.18	*****	9.00	********	********
2:15	6.000	0.44	0.02	0.14	0.10	0.10	4.00	14.00	0.93E 05	0.23E 04
2:30	6.730	0.62	0.01	0.25	0.17	0.17	*****	13.00	********	0.23E 04
2:45	8.820	0.82	0.01	0.28	0.17	0.17	3.20	12.00	********	********
3:00	11.400	0.40	0.02	0.28	0.17	0.16	*****	15.00	********	********
3:15	12.200	0.74	0.01	0.39	0.22	0.22	4.00	15.00	0.23E 05	0.15E 04
3:30	12.400	1.08	0.03	0.50	0.28	0.22	*****	5.00	********	********
3:45	15.200	1.24	0.01	0.44	0.28	0.28	3.20	15.00	********	********
4:00	17.800	0.76	0.01	0.50	0.26	0.24	*****	13.50	********	********
4:15	19.600	0.86	0.02	0.56	0.34	0.27	3.20	*****	0.93E 06	0.23E 03
4:30	13.100	0.32	0.01	0.22	0.35	0.31	*****	16.00	********	********
4:45	14.000	0.48	0.02	0.55	0.38	0.31	4.80	13.00	********	********
5:00	14.000	0.76	0.01	0.56	0.40	0.27	*****	7.00	********	********
5:15	14.000	0.76	0.01	0.56	0.44	0.32	4.30	10.00	0.93E 06	0.75E 04

AVERAGE CONCENTRATIONS
ALL CONCENTRATIONS IN MG/L EXCEPT COLIFORMS IN MPN/100ML -- FLOW IN CFS

FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
9.009	0.73	0.02	0.33	0.26	0.21	3.04	11.72	0.19E 06	0.12E 04

CUMULATIVE VALUES
FLOW IN CUBIC FEET. -- COLIFORMS IN BILLIONS -- ALL OTHER PARAMETERS IN POUNDS
AVERAGE VALUES ASSUMED FOR MISSING PARAMETERS

FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
0.170E 06	0.820E 01	0.154E 00	0.432E 01	0.299E 01	0.250E 01	0.352E 02	0.126E 03	0.140E 05	0.756E 02

TOTAL RAINFALL 1.900 (INCHES) 0.545E 06 (CUBIC FEET)
TOTAL RUNOFF 0.594 (INCHES) 0.170E 06 (CUBIC FEET)
STANDARDIZED RUNOFF COEFFICIENT 0.312514E 00

SITE SIX 10/25/76 AREA = 36.00

CUMULATIVE RAIN FALL IN INCHES

TIME	0:00	0:30	1:00	3:15	5:00
RAINFALL	0.080	1.000	1.300	1.950	2.200

NO BACKROUND SAMPLES TAKEN

RUNOFF SAMPLES
ALL CONCENTRATIONS IN MG/L EXCEPT COLIFORMS IN MPN/100ML -- FLOW IN CFS
MISSING DATA INDICATED BY *****

TIME	FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
0:30	0.410	0.71	0.06	0.50	0.59	0.58	16.00	45.00	0.23E 08	0.23E 05
0:45	0.812	1.12	0.03	0.40	0.51	0.51	*****	57.00	0.24E 07	0.43E 04
0:50	1.220	*****	0.02	0.37	0.47	0.47	20.00	67.00	********	********
1:00	1.510	0.71	0.06	0.25	0.44	0.43	*****	67.00	0.93E 07	0.43E 04
1:15	1.730	0.93	0.03	0.22	0.33	0.33	*****	61.00	0.43E 08	0.23E 04
1:30	1.920	1.51	0.03	0.54	0.98	0.71	26.00	48.00	0.24E 07	0.12E 07
1:45	2.230	0.36	0.02	0.41	0.78	0.78	*****	38.00	0.43E 07	0.15E 05
2:00	2.760	0.74	0.03	0.20	0.73	0.60	16.00	38.00	0.93E 07	0.21E 06
2:15	3.730	0.76	0.01	0.27	0.98	0.89	*****	39.50	********	********
2:30	4.280	0.74	0.03	0.30	1.05	0.88	16.00	44.00	********	********
2:45	4.820	1.13	0.02	0.33	1.27	0.91	*****	35.50	********	********
3:00	4.320	1.14	0.01	0.30	1.24	0.88	16.07	35.00	********	********
3:15	4.920	0.76	0.01	0.34	1.13	0.88	*****	33.50	********	********
3:30	5.270	0.37	0.01	0.25	0.96	0.82	12.30	30.00	********	********
3:45	5.591	0.74	0.03	0.26	0.82	0.78	*****	30.00	********	********
4:00	5.100	0.56	0.02	0.32	0.95	0.84	13.40	35.00	0.24E 07	0.21E 06
4:15	5.300	0.74	0.03	0.40	1.24	0.78	*****	30.00	********	********
4:30	3.860	0.51	0.07	0.33	1.09	0.88	10.50	29.00	********	********
4:45	3.790	0.35	0.03	0.34	0.91	0.82	*****	28.50	********	********
5:00	3.550	0.93	0.03	0.30	1.00	0.89	11.00	17.00	********	********

AVERAGE CONCENTRATIONS
ALL CONCENTRATIONS IN MG/L EXCEPT COLIFORMS IN MPN/100ML -- FLOW IN CFS

FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
3.345	0.72	0.03	0.33	0.87	0.73	15.72	40.40	0.12E 08	0.21E 06

CUMULATIVE VALUES
FLOW IN CUBIC FEET. -- COLIFORMS IN BILLIONS -- ALL OTHER PARAMETERS IN POUNDS
AVERAGE VALUES ASSUMED FOR MISSING PARAMETERS

FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
0.592E 05	0.277E 01	0.943E-01	0.116E 01	0.364E 01	0.297E 01	0.558E 02	0.130E 03	0.191E 06	0.376E 04

TOTAL RAINFALL 2.200 (INCHES) 0.287E 06 (CUBIC FEET)
TOTAL RUNOFF 0.453 (INCHES) 0.592E 05 (CUBIC FEET)
STANDARDIZED RUNOFF COEFFICIENT 0.205917E 00

SITE EIGHT 9/16/76 AREA = 4.92

CUMULATIVE RAIN FALL IN INCHES

TIME	7:30	8:00	9:00	9:15	11:45
RAINFALL	0.080	0.090	0.090	0.100	0.100

NO BACKROUND SAMPLES TAKEN

RUNOFF SAMPLES
ALL CONCENTRATIONS IN MG/L EXCEPT COLIFORMS IN MPN/100ML -- FLOW IN CFS
MISSING DATA INDICATED BY *****

TIME	FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
7:30	******	0.08	0.59	0.13	0.18	0.14	4.20	12.50	0.23E 05	0.15E 02
7:45	******	0.13	0.62	0.14	0.18	0.18	*****	11.00	0.15E 05	0.43E 02
8:00	******	0.05	0.62	0.18	0.13	0.13	10.00	14.00	********	********
8:15	******	0.15	0.35	0.19	0.16	0.14	*****	19.00	0.93E 05	0.15E 04
8:30	******	0.05	0.59	0.15	0.11	0.11	6.00	15.50	0.93E 05	0.43E 03
8:45	******	0.12	0.71	0.17	0.13	0.07	*****	14.50	********	********
9:00	******	0.08	0.59	0.13	0.11	0.11	7.80	13.00	********	********
9:15	******	0.08	0.59	0.13	0.17	0.17	*****	18.00	********	********
9:30	******	0.01	0.59	0.13	0.09	0.09	7.80	15.50	0.23E 05	0.93E 02
9:45	******	0.08	0.35	0.23	0.16	0.14	*****	11.50	********	********
10:00	******	0.02	0.65	0.15	0.22	0.22	6.00	10.50	********	********
10:15	******	0.08	0.59	0.13	0.13	0.13	*****	17.50	********	********
10:30	******	0.12	0.88	0.13	0.18	0.11	*****	13.00	0.43E 05	0.93E 02
11:00	******	0.01	0.82	0.13	0.23	0.16	5.40	11.00	********	********
11:15	******	0.08	0.59	0.13	0.18	0.18	*****	14.00	********	********
11:30	******	0.02	0.65	0.13	0.33	0.26	*****	12.50	********	********
11:45	******	0.08	0.59	0.13	0.24	0.24	*****	12.50	********	********

AVERAGE CONCENTRATIONS
ALL CONCENTRATIONS IN MG/L EXCEPT COLIFORMS IN MPN/100ML -- FLOW IN CFS

FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
0.000	0.07	0.61	0.15	0.17	0.15	6.74	13.85	0.48E 05	0.36E 03

CUMULATIVE VALUES
FLOW IN CUBIC FEET. -- COLIFORMS IN BILLIONS -- ALL OTHER PARAMETERS IN POUNDS
AVERAGE VALUES ASSUMED FOR MISSING PARAMETERS

FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
*********	*********	*********	*********	*********	*********	*********	*********	*********	*********

TOTAL RAINFALL 0.100 (INCHES) 0.179E 04 (CUBIC FEET)
NO RUNOFF COEFFICIENT CAN BE COMPUTED

SITE EIGHT 7/25/77 AREA = 4.92

CUMULATIVE RAIN FALL IN INCHES

TIME	16:00	16:30	18:43	21:32	23:17
RAINFALL	0.020	0.100	0.140	0.190	0.190

NO BACKGROUND SAMPLES TAKEN

RUNOFF SAMPLES
ALL CONCENTRATIONS IN MG/L EXCEPT COLIFORMS IN MPN/100ML -- FLOW IN CFS
MISSING DATA INDICATED BY *****

TIME	FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
18:47	0.005	0.36	0.04	0.62	0.16	0.10	4.10	33.00	0.93E 04	0.23E 03
19:02	0.005	0.47	0.37	0.64	0.11	0.07	*****	35.00	********	********
19:17	0.003	0.32	0.08	0.64	0.11	0.08	7.20	32.00	0.23E 05	0.23E 03
19:32	0.003	0.11	0.09	0.64	0.11	0.08	*****	35.50	********	********
19:47	0.003	0.38	0.04	0.61	0.13	0.07	10.20	22.50	0.23E 05	0.12E 03
20:02	0.003	0.31	0.09	0.64	0.13	0.08	*****	28.00	********	********
20:17	0.002	0.11	0.09	0.64	0.14	0.08	6.20	37.00	0.23E 05	0.23E 03
20:32	0.001	0.13	0.07	0.08	0.20	0.20	*****	56.50	********	********
20:47	0.001	0.23	0.07	0.61	0.11	0.08	5.60	29.50	0.75E 04	0.75E 03
21:02	0.001	0.46	0.04	0.68	0.16	0.08	5.10	31.00	********	********
21:17	0.001	0.16	0.04	0.65	0.18	0.08	*****	26.50	0.23E 05	0.93E 02
21:32	0.001	0.46	0.04	0.61	0.11	0.08	7.20	45.00	0.23E 04	0.43E 02
21:47	0.001	0.25	0.05	0.66	0.13	0.07	*****	32.50	********	********
22:02	0.001	0.36	0.04	0.63	0.11	0.04	10.20	23.50	0.93E 05	0.15E 04
22:17	0.001	0.26	0.04	0.61	0.13	0.10	*****	31.00	********	********
22:32	0.001	0.16	0.04	0.59	0.13	0.04	3.60	23.50	0.23E 04	0.43E 03
23:02	0.001	0.27	0.03	0.67	0.09	0.07	*****	22.50	********	********
23:17	0.000	0.16	0.04	0.68	0.10	0.08	3.60	38.50	0.23E 04	0.23E 03

AVERAGE CONCENTRATIONS
ALL CONCENTRATIONS IN MG/L EXCEPT COLIFORMS IN MPN/100ML -- FLOW IN CFS

FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
0.002	0.27	0.06	0.61	0.13	0.08	6.30	32.39	0.21E 05	0.39E 03

CUMULATIVE VALUES
FLOW IN CUBIC FEET. -- COLIFORMS IN BILLIONS -- ALL OTHER PARAMETERS IN POUNDS
AVERAGE VALUES ASSUMED FOR MISSING PARAMETERS

FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
0.281E 02	0.530E-03	0.109E-03	0.107E-02	0.228E-03	0.146E-03	0.112E-01	0.568E-01	0.159E 00	0.260E-02

TOTAL RAINFALL 0.190 (INCHES) 0.339E 04 (CUBIC FEET)
TOTAL RUNOFF 0.002 (INCHES) 0.281E 02 (CUBIC FEET)
STANDARDIZED RUNOFF COEFFICIENT 0.827502E-02

SITE NINE 9/16/76 AREA = 9.24

CUMULATIVE RAIN FALL IN INCHES

TIME	7:15	7:45	8:15	10:00	11:45
RAINFALL	0.020	0.050	0.080	0.100	0.100

NO BACKGROUND SAMPLES TAKEN

RUNOFF SAMPLES
ALL CONCENTRATIONS IN MG/L EXCEPT COLIFORMS IN MPN/100ML -- FLOW IN CFS
MISSING DATA INDICATED BY *****

TIME	FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
7:15	0.010	0.47	0.03	0.50	0.10	0.07	11.40	33.50	0.23E 05	0.75E 03
7:30	0.015	0.31	0.02	0.25	0.05	0.05	*****	21.00	0.23E 05	0.43E 04
7:45	0.025	0.93	0.02	0.25	0.07	0.07	7.80	11.00	0.23E 05	0.15E 04
8:00	0.030	0.65	0.02	0.25	0.08	0.07	*****	19.00	********	0.15E 04
8:15	0.040	0.31	0.02	0.25	0.04	0.03	6.60	19.00	********	********
8:30	0.040	0.31	0.02	0.23	0.04	0.04	*****	17.50	********	********
8:45	0.040	0.17	0.03	0.20	0.08	0.08	6.50	17.50	********	********
9:00	0.040	1.18	0.02	0.20	0.03	0.03	*****	18.00	0.24E 06	0.39E 04
9:15	0.040	0.38	0.02	0.25	0.05	0.05	7.80	27.50	********	********
9:30	0.040	0.58	0.02	0.28	0.04	0.35	*****	20.00	********	********
9:45	0.040	0.33	0.02	0.30	0.05	0.05	7.70	23.00	********	********
10:00	0.050	0.34	0.02	0.30	0.05	0.02	*****	22.50	0.93E 05	0.15E 04
10:15	0.050	0.36	0.04	0.30	0.18	0.13	6.00	27.50	********	********
10:30	0.050	0.35	0.05	0.30	0.15	0.13	*****	28.50	********	********
10:45	0.042	0.37	0.03	0.26	0.20	0.20	8.40	31.50	********	********
11:00	0.032	0.37	0.03	0.30	0.25	0.22	*****	30.50	0.24E 06	0.93E 04
11:15	0.012	0.16	0.04	0.27	0.28	0.20	*****	35.50	********	********
11:30	0.002	0.35	0.05	0.30	0.20	0.20	*****	36.50	********	********
11:45	0.001	0.35	0.05	0.30	0.35	0.22	*****	35.50	********	********

AVERAGE CONCENTRATIONS
ALL CONCENTRATIONS IN MG/L EXCEPT COLIFORMS IN MPN/100ML -- FLOW IN CFS

FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
0.031	0.44	0.03	0.28	0.12	0.12	7.77	25.00	0.11E 06	0.33E 04

CUMULATIVE VALUES
FLOW IN CUBIC FEET. -- COLIFORMS IN BILLIONS -- ALL OTHER PARAMETERS IN POUNDS
AVERAGE VALUES ASSUMED FOR MISSING PARAMETERS

FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
0.537E 03	0.150E-01	0.897E-03	0.898E-02	0.327E-02	0.352E-02	0.253E 00	0.780E 00	0.174E 02	0.500E 00

TOTAL RAINFALL 0.100 (INCHES) 0.335E 04 (CUBIC FEET)
TOTAL RUNOFF 0.016 (INCHES) 0.537E 03 (CUBIC FEET)
STANDARDIZED RUNOFF COEFFICIENT 0.159976E 00

SITE NINE 7/25/77 AREA = 9.24

CUMULATIVE RAIN FALL IN INCHES

TIME	16:07	17:22	18:22	18:52	20:07
RAINFALL	0.030	0.080	0.100	0.180	0.180

NO BACKROUND SAMPLES TAKEN

RUNOFF SAMPLES
ALL CONCENTRATIONS IN MG/L EXCEPT COLIFORMS IN MPN/100ML -- FLOW IN CFS
MISSING DATA INDICATED BY *****

TIME	FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
16:07	0.095	1.09	0.91	2.14	0.15	0.12	*****	*****	0.11E 07	0.46E 06
16:22	0.171	0.51	0.74	1.49	0.11	0.10	*****	*****	********	********
16:38	0.033	0.68	0.65	1.27	0.12	0.12	54.50	*****	0.23E 05	0.23E 05
16:52	0.509	0.43	0.57	1.26	0.11	0.10	*****	*****	********	********
17:07	0.308	0.76	0.57	1.31	0.12	0.10	51.30	*****	0.23E 05	0.23E 05
17:22	0.047	1.06	0.61	1.27	0.15	0.12	*****	*****	********	0.43E 05
17:38	0.044	0.65	0.52	1.17	0.17	0.13	54.50	*****	0.45E 06	0.43E 05
17:52	0.012	0.52	0.48	1.10	0.15	0.10	*****	*****	********	********
18:07	0.005	0.69	0.48	1.16	0.17	0.12	57.80	*****	0.23E 05	0.23E 05
18:22	0.002	0.62	0.48	1.23	0.16	0.15	*****	73.00	********	********
18:38	0.697	0.43	0.17	0.51	0.09	0.09	*****	36.80	0.93E 04	0.93E 04
18:52	0.137	0.63	0.17	0.54	0.09	0.08	*****	45.00	********	********
19:07	0.057	0.58	0.22	0.61	0.09	0.08	43.60	39.50	0.23E 05	0.93E 04
19:22	0.021	0.38	0.22	0.70	0.11	0.07	*****	43.56	********	********
19:38	0.004	0.19	0.21	0.73	0.11	0.11	48.70	55.50	0.23E 05	0.23E 05
19:52	******	0.43	0.17	0.85	0.09	0.09	*****	55.00	********	********
20:07	******	0.58	0.22	0.80	0.09	0.08	43.60	48.50	0.93E 05	0.93E 05

AVERAGE CONCENTRATIONS
ALL CONCENTRATIONS IN MG/L EXCEPT COLIFORMS IN MPN/100ML -- FLOW IN CFS

FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
0.089	0.61	0.43	1.07	0.12	0.10	62.20	*****	0.20E 06	0.75E 05

CUMULATIVE VALUES
FLOW IN CUBIC FEET. -- COLIFORMS IN BILLIONS -- ALL OTHER PARAMETERS IN POUNDS
AVERAGE VALUES ASSUMED FOR MISSING PARAMETERS

FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
0.121E 04	0.417E-01	0.263E-01	0.642E-01	0.785E-02	0.720E-02	0.778E 01	0.683E 01	0.542E 02	0.210E 02

TOTAL RAINFALL 0.180 (INCHES) 0.604E 04 (CUBIC FEET)
TOTAL RUNOFF 0.036 (INCHES) 0.121E 04 (CUBIC FEET)
STANDARDIZED RUNOFF COEFFICIENT 0.200431E 00

SITE TEN 9/16/76 AREA = 6.40

CUMULATIVE RAIN FALL IN INCHES

TIME	7:00	7:45	8:30	10:00	11:15
RAINFALL	0.040	0.060	0.100	0.110	0.110

NO BACKROUND SAMPLES TAKEN

RUNOFF SAMPLES
ALL CONCENTRATIONS IN MG/L EXCEPT COLIFORMS IN MPN/100ML -- FLOW IN CFS
MISSING DATA INDICATED BY *****

TIME	FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
7:00	******	0.31	0.09	0.92	0.10	0.07	*****	24.50	0.21E 05	0.43E 03
7:15	******	0.27	0.06	0.67	0.15	0.06	7.20	22.00	0.93E 04	0.39E 03
7:30	******	0.64	0.03	0.50	0.08	0.08	*****	15.50	0.93E 04	0.23E 03
7:45	******	0.65	0.02	0.42	0.05	0.04	7.30	20.50	0.43E 04	0.23E 03
8:00	******	0.34	0.03	0.50	0.08	0.06	*****	19.50	0.93E 04	0.43E 03
8:15	******	0.45	0.05	0.33	0.05	0.05	6.60	20.00	*********	*********
8:30	******	0.28	0.05	0.42	0.05	0.05	*****	19.50	*********	*********
8:45	******	0.44	0.06	0.38	0.05	0.04	7.40	20.00	0.93E 04	0.75E 04
9:00	******	0.27	0.06	0.42	0.05	0.05	*****	21.00	*********	*********
9:15	******	0.54	0.06	0.59	0.13	0.06	8.40	22.50	*********	*********
9:30	******	0.34	0.06	0.42	0.23	0.08	*****	23.00	*********	*********
9:45	******	0.58	0.09	0.59	0.05	0.05	7.30	27.00	0.93E 04	0.39E 04
10:00	******	0.28	0.09	0.50	0.05	0.05	*****	28.50	*********	*********
10:15	******	0.51	0.09	0.42	0.08	0.08	12.00	32.50	*********	*********
10:30	******	0.58	0.09	0.50	0.05	0.05	*****	18.00	*********	*********
10:45	******	0.26	0.11	0.42	0.08	0.07	10.80	33.00	*********	*********

AVERAGE CONCENTRATIONS
ALL CONCENTRATIONS IN MG/L EXCEPT COLIFORMS IN MPN/100ML -- FLOW IN CFS

FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
0.000	0.42	0.06	0.49	0.08	0.06	8.37	22.88	0.10E 05	0.19E 04

CUMULATIVE VALUES
FLOW IN CUBIC FEET. -- COLIFORMS IN BILLIONS -- ALL OTHER PARAMETERS IN POUNDS
AVERAGE VALUES ASSUMED FOR MISSING PARAMETERS

FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
*********	*********	*********	*********	*********	*********	*********	*********	*********	*********

TOTAL RAINFALL 0.110 (INCHES) 0.256E 04 (CUBIC FEET)
NO RUNOFF COEFFICIENT CAN BE COMPUTED

SITE TEN 7/25/77 AREA = 6.40

CUMULATIVE RAIN FALL IN INCHES

TIME	15:40	16:10	17:40	18:40	20:40
RAINFALL	0.020	0.090	0.140	0.240	0.270

NO BACKGROUND SAMPLES TAKEN

RUNOFF SAMPLES
ALL CONCENTRATIONS IN MG/L EXCEPT COLIFORMS IN MPN/100ML -- FLOW IN CFS
MISSING DATA INDICATED BY *****

TIME	FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
15:40	0.362	1.39	0.03	0.65	0.15	0.08	76.40	*****	0.46E 06	0.42E 06
15:55	0.086	4.03	1.30	2.26	0.37	0.23	*****	*****	********	********
16:10	0.264	1.59	0.74	1.68	0.14	0.10	51.80	*****	0.43E 05	0.43E 04
16:25	0.301	0.43	0.57	1.03	0.14	0.08	*****	*****	********	********
16:40	0.098	0.72	0.61	1.15	0.16	0.15	46.70	*****	0.43E 05	0.43E 04
16:55	0.148	1.52	0.65	1.15	0.25	0.19	*****	*****	********	********
17:10	0.098	1.39	0.61	1.19	0.29	0.19	54.50	*****	0.24E 06	0.43E 05
17:25	0.199	0.85	0.48	0.95	0.23	0.19	*****	*****	********	********
17:40	0.079	1.19	0.43	1.30	0.23	0.19	76.90	*****	0.43E 05	0.93E 04
17:55	0.104	1.02	0.48	1.05	0.17	0.15	*****	*****	********	********
18:10	0.065	1.07	0.43	1.20	0.19	0.17	69.10	*****	0.15E 06	0.43E 05
18:25	0.348	1.16	0.44	1.38	0.27	0.13	*****	33.00	********	********
18:40	0.476	0.20	0.20	0.55	0.11	0.05	7.20	28.50	0.43E 04	0.43E 04
18:55	0.439	0.58	0.22	0.62	0.18	0.08	*****	34.50	********	********
19:10	1.580	0.54	0.25	0.66	0.18	0.13	30.50	23.00	0.21E 06	0.21E 06
19:25	2.473	0.74	0.26	0.72	0.24	0.10	*****	55.00	********	********
19:40	25.500	0.54	0.26	0.77	0.22	0.20	45.10	55.50	0.24E 06	0.24E 06
19:55	11.500	0.78	0.22	0.80	0.27	0.15	*****	58.50	********	********
20:10	21.200	0.58	0.22	0.78	0.24	0.10	42.00	66.00	0.46E 06	0.46E 06
20:25	26.900	1.03	0.17	0.86	0.27	0.18	*****	74.50	********	********
20:40	26.900	0.68	0.22	0.84	0.27	0.27	17.90	91.50	0.46E 06	0.46E 06

AVERAGE CONCENTRATIONS
ALL CONCENTRATIONS IN MG/L EXCEPT COLIFORMS IN MPN/100ML -- FLOW IN CFS

FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
5.622	1.08	0.42	1.03	0.22	0.15	47.10	*****	0.21E 06	0.17E 06

CUMULATIVE VALUES
FLOW IN CUBIC FEET. -- COLIFORMS IN BILLIONS -- ALL OTHER PARAMETERS IN POUNDS
AVERAGE VALUES ASSUMED FOR MISSING PARAMETERS

FLOW	ORG-N	NH3-N	NO3-N	TOTPHS	ORTPHS	BOD-5	TOC	TOTCOL	FCLCOL
0.106E 06	0.514E 01	0.147E 01	0.539E 01	0.166E 01	0.122E 01	0.257E 03	0.469E 03	0.958E 04	0.913E 04

TOTAL RAINFALL 0.270 (INCHES) 0.627E 04 (CUBIC FEET)
TOTAL RUNOFF 4.374 (INCHES) 0.106E 06 (CUBIC FEET)
STANDARDIZED RUNOFF COEFFICIENT 0.169404E 02

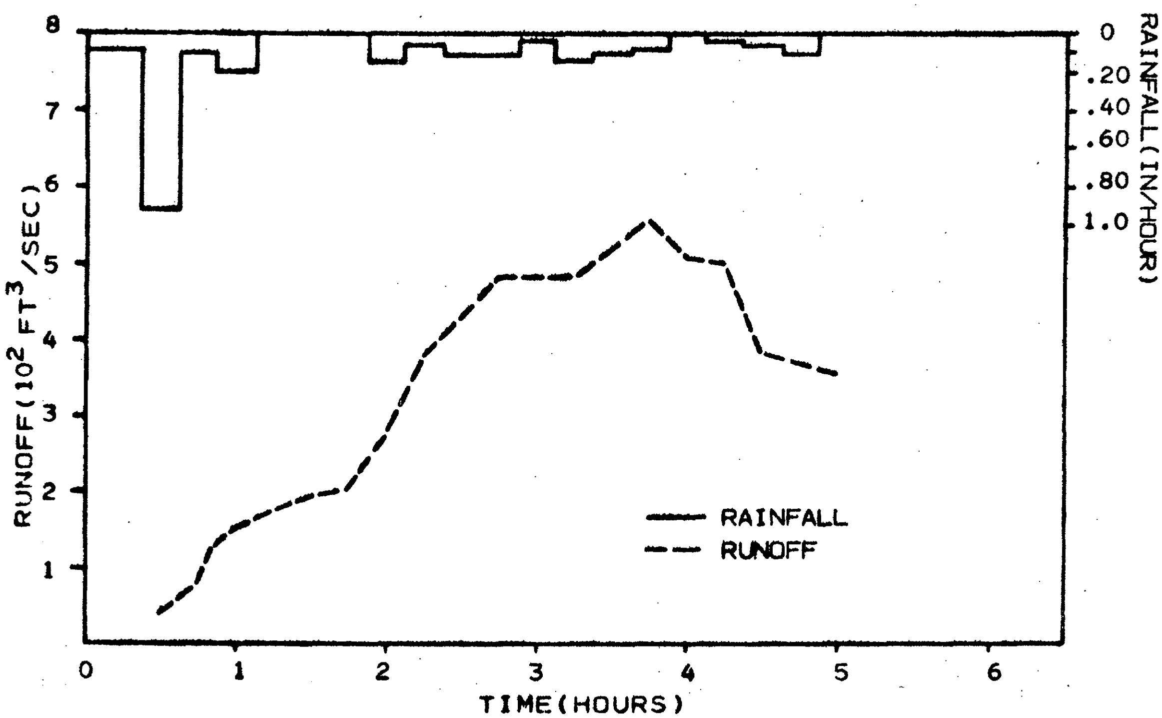

Figure B1. Rainfall and Runoff Sample Site 6, 10/26/76.

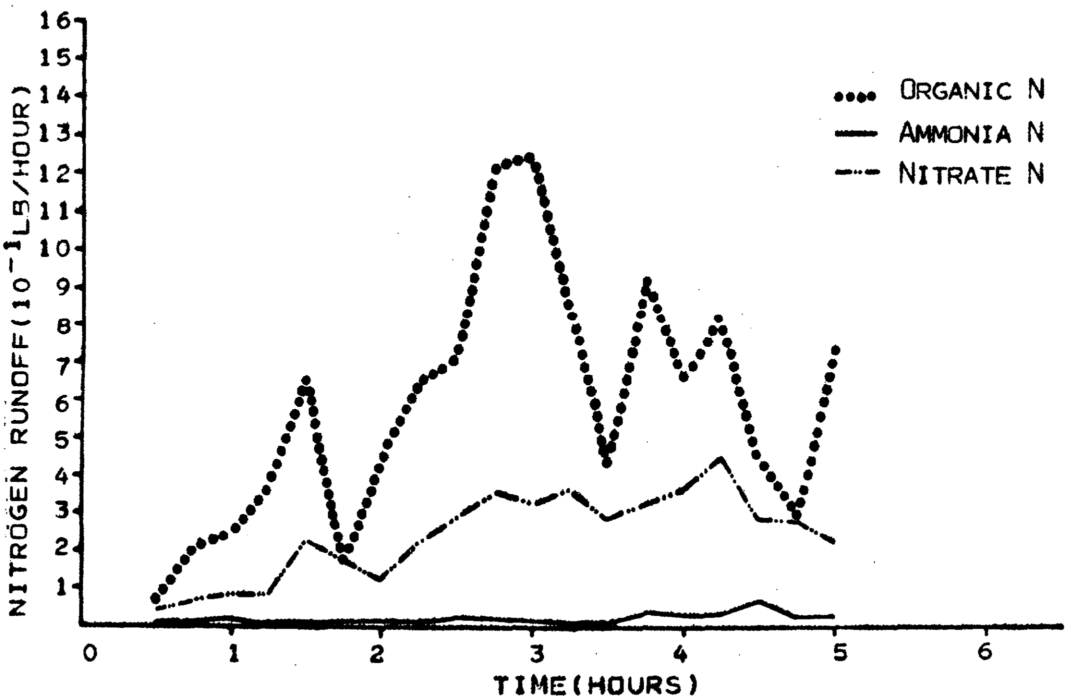

Figure B2. Nitrogen Runoff Sample Site 6, 10/26/76.

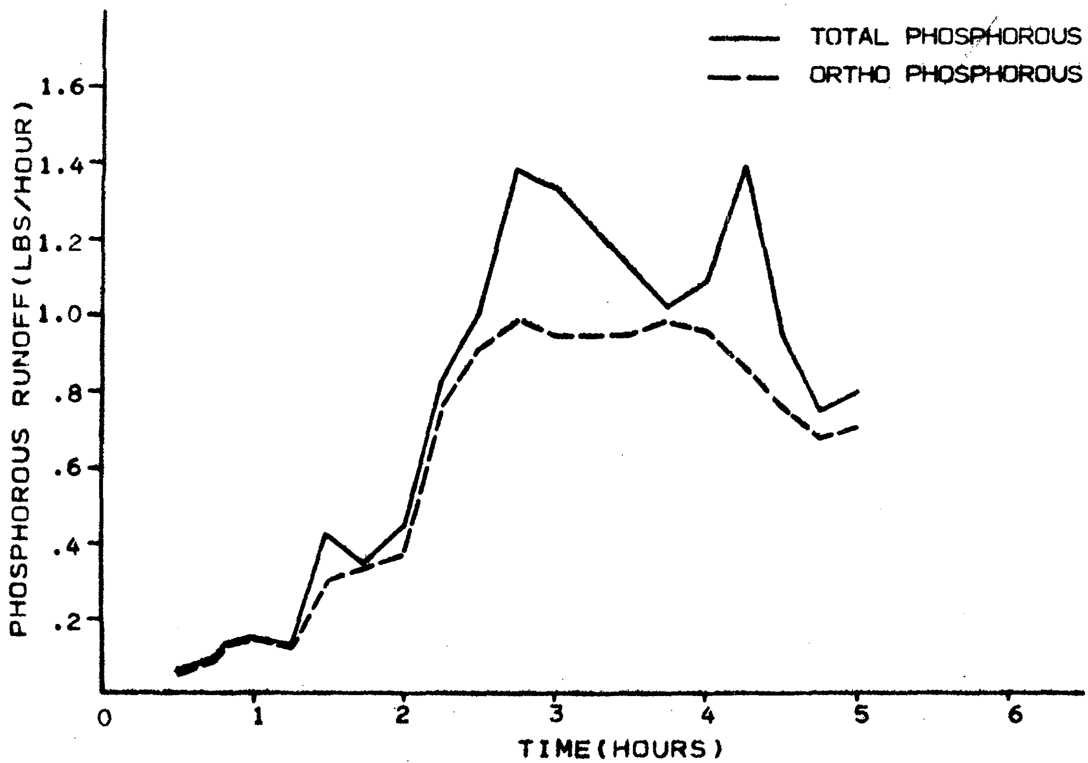

Figure B3. Phosphorous Runoff Sample Site 6, 10/26/76.

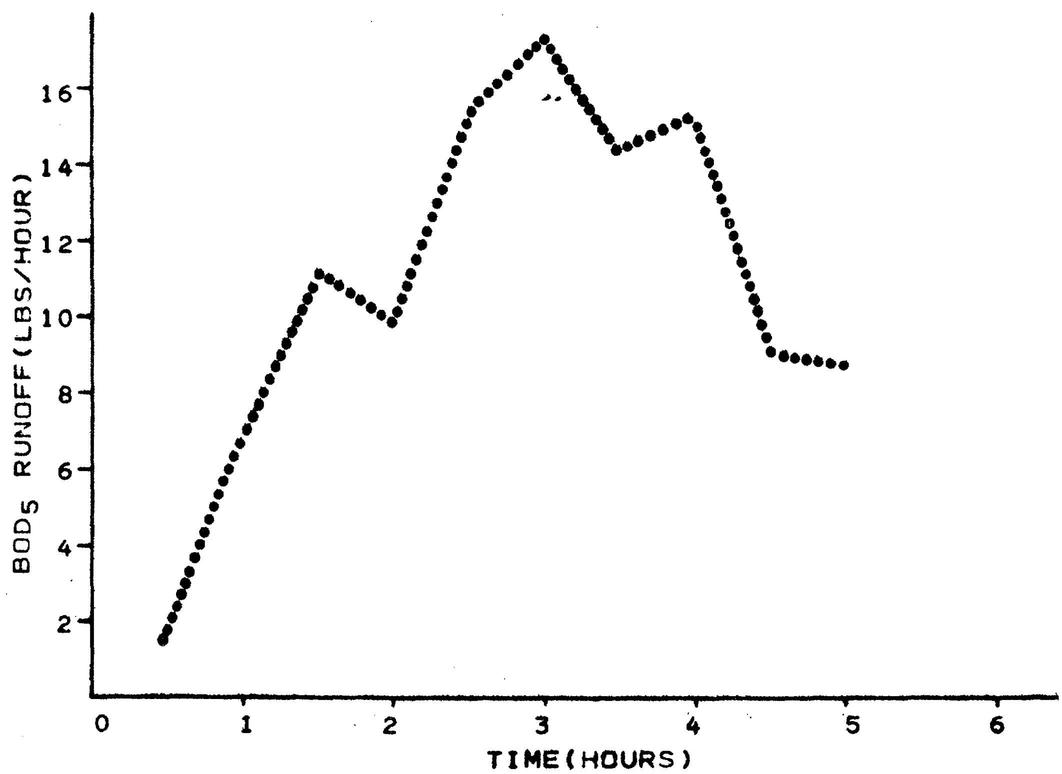

Figure B4. BOD_5 Runoff Sample Site 6, 10/26/76.

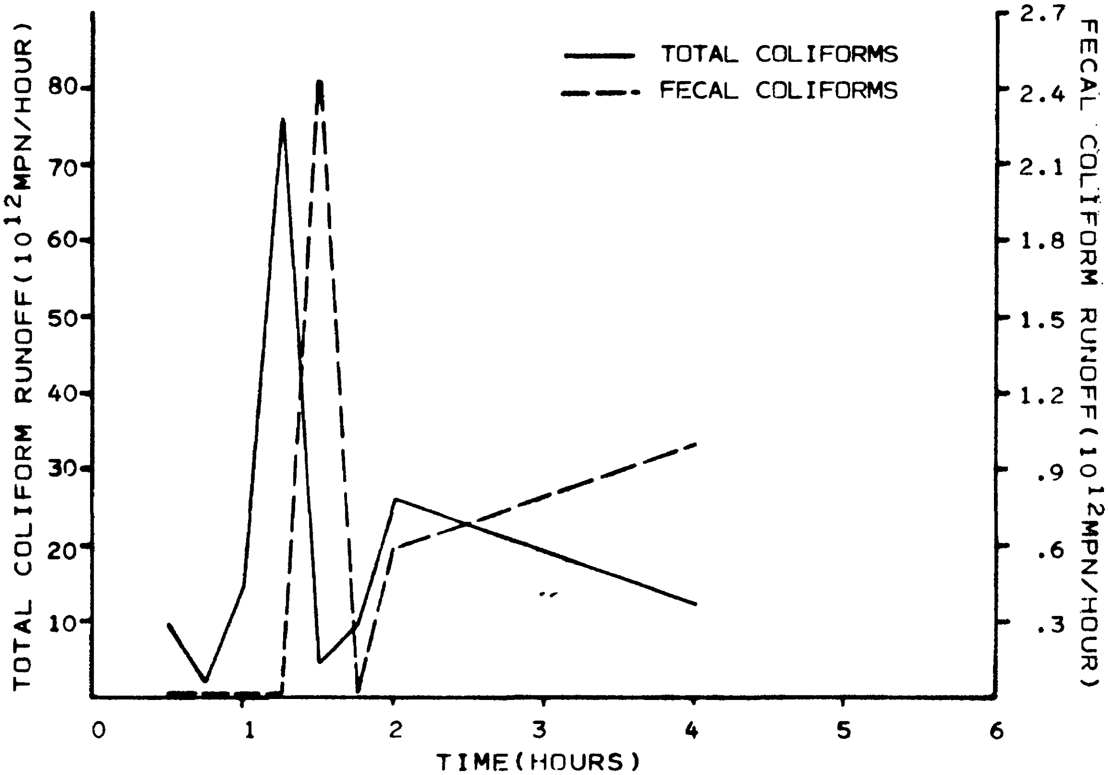

Figure B5. Coliform Runoff Sample Site 6, 10/26/76.

Appendix C. Data Analysis Procedure

This appendix details the methodology and assumptions used to obtain the parameters reported in Appendix B from the raw field data for sites one through six and eight through ten.

1) Cumulative Rainfall - Measurements of cumulative rainfall (in inches) were generally taken every fifteen minutes during the rainfall event. Frequently, however, no incremental rainfall (or else only a very small amount) fell during a fifteen minute interval. To minimize the reporting of repetitive data, rainfall measures reported here are generally grouped into hourly accumulations except when significant information would be lost by the consolidation.

2) Background Samples - If there was water in the drainage ditch at a site before runoff occurred, a background water quality sample was sometimes taken. (The data sheets do not always indicate whether or not such a sample was taken, however, and the existance of a background sample is occasionally inferred from the absence of flow data for the initial water quality sample or by the time of the sample). This section of the printout reports the time the background sample was taken, and the constituent concentrations.

3) Runoff Samples - The time, computed flow rate, and laboratory determination of pollutant concentration for each runoff sample is reported here.

Flow computations were performed by VIMS, usually via Eqs. (15) or (16), or else the flow rate was given directly from volumetric samples needing only conversion to consistent units. Incomplete or erroneous flow rates are reported for the sake of completeness. The reader is referred to Table II and Chapter IV for a determination of reliable data.

Chemical analyses were performed by a DNR laboratory.

4) Average Concentrations - This section reports the arithmetic average of the flow rate and constituent concentrations of the runoff samples. Missing values are ignored. The average is given by

$$P = \sum_{i=1}^{n} p_i \qquad \text{where} \qquad \text{C1}$$

P is the mean of all samples

p_i is the value of the considered parameter from runoff sample i

n is the number of values sampled during the event

5) Cumulative Values - The total volume of runoff, mass of pollutants, and number of coliforms which ran off during the event are reported here. The volume of runoff is computed via the equation

$$Q_T = \sum_{i=1}^{n} Q_i \Delta t_i \qquad \text{where} \qquad \text{C2}$$

Q_T is the total volume of runoff (ft^3)

Q_i is the flow rate of runoff at sample interval i (ft^3/sec)

Δt_i is the length of the sampling interval centered at the time the runoff sample was taken (sec)

n is the total number of samples

The mass of pollutant runoff is computed via the equation

$$M_T = \sum_{i=1}^{n} \rho \, c_i Q_i \Delta t_i \qquad \text{where} \qquad \text{C3}$$

M_T is the total mass of pollutant runoff (lbs.)

ρ is the density of water - 62.4 lb/ft^3

c_i is the concentration of the pollutant at sample interval i (ppm)

Total numbers of coliforms are computed as

$$N_T = \sum_{i=1}^{n} c_i Q_i \Delta t_i / 3.532 \times 10^6 \qquad \text{where} \qquad \text{C4}$$

N_T is the total coliform number (billions)

c_i is the coliform concentration at sample interval i (mpn/100 ml)

Average values of BOD_5 and coliform concentrations, obtained from Eq. (C1), are substituted during intervals in which no samples were taken. Missing values of flow are treated as zero, resulting in underestimations of total pollutant runoff for events in which flow parameters are missing. In the event of no reported flow values, no computation of total pollutant runoff is possible.

6) Additional Parameters - Also reported, for comparison purposes, are the rainfall volume in ft^3, the total runoff in inches, and a simplified runoff coefficient. Rainfall

volume is computed as

$$V_R = R_T A/12 \quad \text{where} \qquad \text{C5}$$

V_R is the rainfall volume (ft^3)

R_T is the total rainfall (in.)

A is the area of the sample watershed (ft^2)

Runoff, in inches, is computed as

$$V_i = 12Q_T/A \quad \text{where} \qquad \text{C6}$$

V_i is the total runoff (inches)

Q_T is the total runoff (ft^3)

The runoff coefficient is computed as

$$r_s = Q_T/V_R \quad \text{where} \qquad \text{C7}$$

r_s is the fraction of the rainfall which ran off

This coefficient, r_s, is simplified and differs from r of Eq. (1) in that no depression storage is considered.

Appendix D. Marsh Data and Analysis Procedure

Determination of the non-point source nutrient loads contributed by the Chincoteague marshes represents a unique problem in this study. While the methodology of predicting non-point pollution loads from conventional land uses such as urban watersheds or farms is well established, methods of analysis of marshland, when attempted, are often nebulous and arbitrary. This appendix details the procedures used to assemble and analyze the field data only; modelling and predictions of the runoff from marshy areas are included in the main body of the report.

A) Introduction

The marsh chosen for this study, Fig. 8, is roughly funnel-shaped with only one outlet which connects the marsh to Smokehouse Cove and open bay waters. Nutrient fluxes may enter the marsh through two processes:

1) as storm-generated runoff from upland areas draining into the marsh and as detritus dislodged from marsh soil and biota by the force of the raindrops, or

2) as flux carried by the incoming tide through the channel from Smokehouse Cove and the open adjacent waters.

Nutrient flux out of the marsh may occur only through the outlet as tidal flux and/or storm drainage.

The initial intent in this study was to sample the flow rate and nutrient concentration entering or leaving the swamp over a tidal cycle during several dry periods to ascertain the background level of nutrient flux contributed by the marsh. Measurements of flow rate and nutrient concentration during storm events would then be compared to the background contributions to determine the incremental, storm-generated export.

A recording current meter and tide gauge were placed in the neck connecting the marsh to Smokehouse Cove to obtain the velocity and depth measurements necessary for flow quantification via Eq. (16). (The channel was previously sounded and its cross sectional area as a function of tidal stage determined.) Samples for chemical analyses were drawn automatically at hourly or half-hourly intervals by an ISCO sampler placed on a float located in the middle of the channel. At the end of the tidal cycle or storm event, the ISCO was recovered and the samples dispatched to the laboratory for analysis.

Since the samples were collected remotely, they were not iced or otherwise preserved and thus no BOD or coliform analyses were performed.

While the water quality samples which were collected are considered to be reliable, equipment malfunctions and incomplete data have rendered flow quantification as originally intended impossible. Instead a different method, based on a tidal flushing model, is used.

B) Principles of Analysis

In a small, enclosed marsh with only one outlet, any flow through the outlet will result in a change in the volume of water occupying the marsh. This volume change may be related to the flow rate via the relationship

$$Q = \frac{dV}{dt} = A(h)\,\frac{dh}{dt} \qquad \text{where} \qquad \text{D1}$$

Q is the flow rate (ft^3/sec)

$\frac{dV}{dt}$ is the rate of change of volume, V, with respect to time, t (ft^3/sec)

$\frac{dh}{dt}$ is the rate of change of the depth of the water volume, h, with respect to time (ft/sec).

$A(h)$ is the surface area (ft^2) of the water volume and may be a function of depth.

The flux rate of a substance dissolved in the flow is the product of the flow rate and the concentration

$$\frac{dM}{dt} = \rho c Q = \rho c A(h)\,\frac{dh}{dt} \qquad \text{where} \qquad \text{D2}$$

$\frac{dM}{dt}$ is the mass flux rate of the substance (lb/sec)

ρ is the density of water - 62.4 lb/ft^3

c is the concentration of the dissolved substance.

Integration of Eq. (D2) allows the net mass flux of a substance entering or leaving the marsh during any time interval $t_2 - t_1$ to be calculated as the product of density, concentration, surface area, and the change in surface elevation.

$$M_T = \rho c A \, (h_2 - h_1) \qquad \text{where} \qquad \text{D3}$$

M_T is the total mass flux during the time interval $t_2 - t_1$

h_2 is the surface level at time t_2

h_1 is the surface level at time t_1

(Note: the simplifying assumption that surface area, A, is not a function of depth, h, has been made.) It can be seen that a positive value of $h_2 - h_1$ corresponds to an increase in the surface level of the water body and produces a positive mass flux. Conversely, a negative value of $h_2 - h_1$ corresponds to a decrease in surface level and produces a negative mass flux.

If the concentration, c, of the dissolved substance is not constant over the interval $t_2 - t_1$, but is known at discrete times, the mass flux may be approximated.

$$M_T = \rho A \sum_i^n c_i (h_{i+\Delta t/2} - h_{i-\Delta t/2}) \qquad \text{where} \qquad \text{D4}$$

c_i is the concentration at time i

n is the number of sample concentrations

$h_{i+\Delta t/2}$ is the surface level at one-half time interval after c_i is sampled

$h_{i-\Delta t/2}$ is the surface level at one-half time interval before c_i is sampled

Inclusion of precipitation on the marsh in the flow calculations requires a change in Eq. (D1) based on the following assumptions:

1. The flow process is linear - that is, the flow produced by the incident precipitation may be added directly to the tidally induced flow.

2. Flow produced by precipitation is always out of the swamp and the flow rate is equivalent to the precipitation rate. This implies there is no change in the swamp volume or surface level due to precipitation.

3. All the incident precipitation runs off - that is, there is no significant infiltration or depression storage in the marsh. The assumption of no infiltration is justified in that the marsh consists primarily of open water or saturated mud incapable of absorbing significant infiltration. The assumption of no depression storage is less justified in that marsh vegetation probably does intercept a fraction of the rainfall. Little data is available on this topic, however, and its incorporation is considered unwarranted in view of the approximations and inaccuracies

incorporated elsewhere in the analysis. These assumptions are further clouded in a marsh watershed which includes some upland drainage area in which infiltration and interception may be present. Again, however, these factors are considered insignificant.

Based on these assumptions, the equation for the flow rate, Eq. (D1) becomes

$$Q = A \left\{\frac{dh}{dt} - P\right\} \quad \text{where} \qquad D5$$

P is the precipitation rate (in units consistent with dh/dt)

If the marsh watershed includes a portion which is not tidally inundated, e.g. an upland, Eq. (D5) requires further modification to reflect the fact that the area receiving precipitation and producing precipitation generated flux is not the same as the area affected by tidal flux. The general equation for flow rate now becomes

$$Q = A \left\{a \frac{dh}{dt} - P\right\} \quad \text{where} \qquad D6$$

a is the fraction of the marsh which is above the high tide level.

Values of Q which are corrected in this manner for precipitation and/or upland fractions are then carried through in the computations of mass flux, Eqs. (D2) - (D4).

C) Application to Study Area

In lieu of reliable measures of surface level, NOAA tables were consulted for the times and relative levels of the high and low tides in Isle of Wight Bay during the sampled intervals. A tidal period of 12.4 hours was assumed and the tidal level other than the high and low extremes was determined as a function of time by fitting a seven-term Fourier series to be reported data. The Fourier series is a mathematical function, composed of the sum of sine and cosine waves, capable of reproducing the periodicity of the tide level and was used to provide values of h used in Eq. D4.

The area of the marsh watershed, was obtained by planimetry of a topographic map. The fraction of the marsh, a, below the high tide level was determined from a series of aerial infrared photographs of the marsh, one of which is reproduced as Fig. D1. In the photograph, inundated areas show up as black in contrast to the more lightly shaded land areas allowing the surface area of the water-covered portion to be determined via planimetry. This area is 11.5 acres or 5.0% of the marsh area yielding a value of 0.05 for a.

The series of photographs, taken over the course of a tidal cycle, also verify that in this case the area of the inundated fraction is relatively constant permitting the simplification of Eq. (D3).

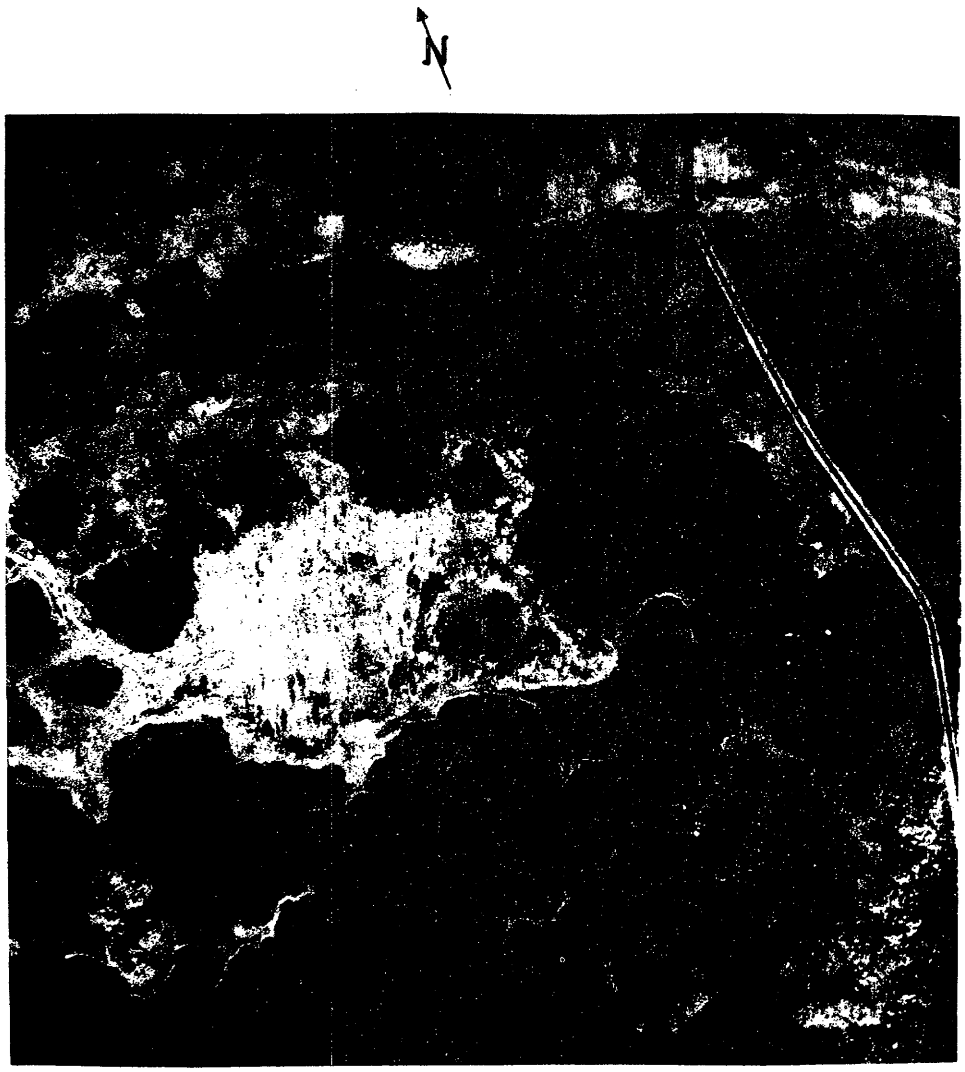

Figure D1. Aerial Photo of Marsh Site.

D) Key to Marsh Data Summary

The methodology used to obtain the parameters reported for the marsh site in Appendix B has been detailed in subsection B, Principles of Analysis, of this appendix. This subsection is a key to understanding the terminology of the computerized output which contains headings as follows:

"TIME HR." - Hour of the day at which the sample was taken. If the sampling period lasted over night, hours of the second day may be computed by subtracting twenty-four from the reported figure.

"RAIN IN." - No rain measurements were taken at the marsh site. Data from 11/18/75 and 12/16/75 are background samples and no rain occurred. On 10/24/76 and 10/25/76, incremental measures of rain from nearby urban sites are used. For 3/21/77, no rain data is available.

"TIDAL LEVEL FT." - Surface level obtained from NOAA tables or Fourier series.

"TIDAL FLOW FT**3" - Tidal flow resulting from tidal fluctuations in surface level of the marsh. Reported in cubic feet and computed for the interval centered on the reported time interval. For the methods of computation of this and the following parameter, see the appendix on marsh data analysis.

"NET FLOW FT**3" - The sum of tidal flow and precipitation induced flow. Negative values represent flow out of the marsh.

"ORG N CONC. MG/L" - Concentration of organic nitrogen, in milligrams per liter, recorded at the specified time.

"ORG N FLUX LB." - Net flux of organic nitrogen during the interval centered at the reported time. Computed as ρCQ where ρ is the density of water, C is the parameter concentration, and Q is the net flow during the period. Similar concentrations and fluxes are reported for the following parameters:

"NH3 N" - Ammonia nitrogen

"NO3 N" - Total nitrate and nitrite nitrogen,

"TOTPHS" - Total phosphorous

"ORTPHS" - Orthophosphorous, and

"TOC" - Total organic carbon

"FOR THE TIDAL CYCLE BEGINNING AT ... HRS. AND ENDING AT ... HRS., THE NET MASS FLUXES ARE:" - This section contains the total flows and mass fluxes over a 12.4 hour tidal cycle contained within the field data. This cycle starts at the beginning of the interval centered at the first time and is completed at the end of the interval centered at the second time. Therefore, the reported times will be less than 12.4 hours apart.

Sample Site 7

11/18/79 BACKGROUND

TIME HR.	RAIN IN.	TIDAL LEVEL FT.	TIDAL FLOW FT**3	NET FLOW FT**3	ORG N CONC. MG/L	NH3 N CONC. MG/L	NO3 N CONC. MG/L	TOTPHS CONC. MG/L	ORTPHS CONC. MG/L	TOC CONC. MG/L
16.0	0.0	0.76	0.21E 06	0.21E 06	0.88E 00	0.30E-01	0.37E-01	0.80E-01	0.30E-01	0.45E 02
16.8	0.0	1.19	0.23E 06	0.23E 06	0.65E 00	0.30E-01	0.37E-01	0.60E-01	0.30E-01	0.25E 02
17.8	[illegible]	1.64	0.18E 06	0.18E 06	0.11E 01	0.30E-01	0.37E-01	0.80E-01	0.30E-01	0.29E 02
18.8	0.0	1.89	0.51E 05	0.51E 05	0.11E 01	0.30E-01	0.37E-01	0.60E-01	0.30E-01	0.29E 02
19.8	[illegible]	1.84	-.90E 05	-.90E 05	0.88E 00	0.30E-01	0.37E-01	0.11E 00	0.30E-01	0.21E 02
20.8	0.0	1.53	-.21E 06	-.21E 06	0.88E 00	0.30E-01	0.37E-01	0.80E-01	0.30E-01	0.29E 02
21.8	0.0	1.04	-.27E 06	-.27E 06	0.88E 00	0.30E-01	0.37E-01	0.80E-01	0.30E-01	0.26E 02
22.8	[illegible]	0.49	-.26E 06	-.26E 06	0.88E 00	0.30E-01	0.37E-01	0.70E-01	0.30E-01	0.27E 02
23.8	[illegible]	0.04	-.18E 06	-.18E 06	0.88E 00	0.30E-01	0.37E-01	0.70E-01	0.30E-01	0.26E 02
24.8	[illegible]	-0.19	-.41E 05	-.41E 05	0.65E 00	0.30E-01	0.37E-01	0.70E-01	0.30E-01	0.29E 02
25.8	[illegible]	-0.11	0.11E 06	0.11E 06	0.11E 01	0.30E-01	0.37E-01	0.60E-01	0.30E-01	0.26E 02
26.8	0.0	0.26	0.25E 06	0.25E 06	0.65E 00	0.30E-01	0.37E-01	0.60E-01	0.30E-01	0.26E 02
27.8	[illegible]	0.85	0.33E 06	0.33E 06	0.13E 01	0.30E-01	0.37E-01	0.70E-01	0.30E-01	0.29E 02
28.8	[illegible]	1.56	0.34E 06	0.34E 06	0.13E 01	0.30E-01	0.37E-01	0.80E-01	0.30E-01	0.23E 02
29.8	[illegible]	2.19	0.27E 06	0.27E 06	0.11E 01	0.30E-01	0.37E-01	0.60E-01	0.30E-01	0.26E 02
30.8	[illegible]	2.6[illegible]	0.13E 06	0.13E 06	0.11E 01	0.30E-01	0.37E-01	0.60E-01	0.30E-01	0.27E 02
31.8	[illegible]	2.7[illegible]	-.38E 05	-.38E 05	0.88E 00	0.30E-01	0.37E-01	0.60E-01	0.30E-01	0.36E 02
32.8	0.0	2.45	-.20E 06	-.20E 06	0.76E 00	0.30E-01	0.37E-01	0.70E-01	0.30E-01	0.28E 02
33.8	0.0	1.9[illegible]	-.31E 06	-.31E 06	0.88E 00	0.30E-01	0.37E-01	0.80E-01	0.30E-01	0.22E 02
34.8	[illegible]	1.24	-.35E 06	-.35E 06	0.13E 01	0.30E-01	0.37E-01	0.70E-01	0.40E-01	0.46E 02
35.8	[illegible]	0.57	-.31E 06	-.31E 06	0.11E 01	0.30E-01	0.87E-01	0.17E 00	0.90E-01	0.26E 02
36.8	0.0	0.15	-.19E 06	-.19E 06	0.11E 01	0.30E-01	0.37E-01	0.60E-01	0.30E-01	0.29E 02
37.8	0.0	-0.19	-.42E 05	-.42E 05	0.11E 01	0.30E-01	0.37E-01	0.70E-01	0.30E-01	0.25E 02
38.8	0.0	-0.12	0.11E 06	0.11E 06	0.13E 01	0.30E-01	0.37E-01	0.60E-01	0.30E-01	0.29E 02
39.8	0.0	0.23	0.23E 06	0.23E 06	0.88E 00	0.30E-01	0.37E-01	0.60E-01	0.30E-01	0.27E 02
40.8	[illegible]	0.75	0.27E 06	0.27E 06	0.65E 00	0.30E-01	0.37E-01	0.80E-01	0.40E-01	0.33E 02

TIME HR.	RAIN IN.	TIDAL LEVEL FT.	TIDAL FLOW FT**3	NET FLOW FT**3	ORG N FLUX LB.	NH3 N FLUX LB.	NO3 N FLUX LB.	TOTPHS FLUX LB.	ORTPHS FLUX LB.	TOC FLUX LB.
16.0	0.0	0.78	0.21E 06	0.21E 06	0.11E 02	0.39E 00	0.48E 00	0.10E 01	0.39E 00	0.58E 03
16.8	[illegible]	1.19	0.23E 06	0.23E 06	0.91E 01	0.42E 00	0.52E 00	0.84E 00	0.42E 00	0.35E 03
17.8	0.0	1.64	0.18E 06	0.18E 06	0.12E 02	0.33E 00	0.41E 00	0.89E 00	0.33E 00	0.32E 03
18.8	[illegible]	1.89	0.51E 05	0.51E 05	0.35E 01	0.95E-01	0.12E 00	0.19E 00	0.95E-01	0.92E 02
19.8	[illegible]	1.84	-.90E 05	-.90E 05	-.[illegible]E 01	-.17E 00	-.21E 00	-.62E 00	-.17E 00	-.12E 03
20.8	[illegible]	1.53	-.21E 06	-.21E 06	-.11E 02	-.39E 00	-.48E 00	-.10E 01	-.39E 00	-.38E 03
21.8	[illegible]	1.04	-.27E 06	-.27E 06	-.15E 02	-.5[illegible]E 00	-.62E 00	-.13E 01	-.50E 00	-.44E 03
22.8	0.0	0.49	-.26E 06	-.26E 06	-.14E 02	-.48E 00	-.60E 00	-.11E 01	-.48E 00	-.44E 03
23.8	[illegible]	0.04	-.18E 06	-.18E 06	-.97E 01	-.33E 00	-.41E 00	-.77E 00	-.33E 00	-.29E 03
24.8	[illegible]	-0.19	-.41E 05	-.41E 05	-.17E 01	-.77E-01	-.95E-01	-.18E 00	-.77E-01	-.74E 02
25.8	0.0	-0.11	0.11E 06	0.11E 06	0.79E 01	0.21E 00	0.26E 00	0.57E 00	0.21E 00	0.19E 03
26.8	[illegible]	0.26	0.25E 06	0.25E 06	0.10E 02	0.47E 00	0.58E 00	0.94E 00	0.47E 00	0.41E 03
27.8	0.0	0.85	0.33E 06	0.33E 06	0.29E 02	0.63E 00	0.77E 00	0.15E 01	0.63E 00	0.60E 03
28.8	[illegible]	1.56	0.34E 06	0.34E 06	0.28E 02	0.64E 00	0.79E 00	0.17E 01	0.64E 00	0.49E 03
29.8	[illegible]	2.19	0.27E 06	0.27E 06	0.19E 02	0.50E 00	0.62E 00	0.10E 01	0.50E 00	0.44E 03
30.8	[illegible]	2.6[illegible]	0.13E 06	0.13E 06	0.91E 01	0.25E 00	0.30E 00	0.49E 00	0.25E 00	0.22E 03
31.8	[illegible]	2.7[illegible]	-.38E 05	-.38E 05	-.21E 01	-.72E-01	-.83E-01	-.14E 00	-.72E-01	-.86E 02
32.8	[illegible]	2.45	-.20E 06	-.20E 06	-.94E 01	-.37E 00	-.46E 00	-.87E 00	-.37E 00	-.35E 03
33.8	[illegible]	1.9[illegible]	-.31E 06	-.31E 06	-.17E 02	-.58E 00	-.72E 00	-.16E 01	-.58E 00	-.43E 03
34.8	[illegible]	1.24	-.35E 06	-.35E 06	-.29E 02	-.66E 00	-.81E 00	-.15E 01	-.87E 00	-.10E 04
35.8	0.0	0.57	-.31E 06	-.31E 06	-.21E 02	-.57E 00	-.71E 00	-.33E 01	-.15E 01	-.50E 03
36.8	[illegible]	[illegible]	-.19E 06	-.19E 06	-.13E 02	-.36E 00	-.45E 00	-.73E 00	-.36E 00	-.35E 03
37.8	[illegible]	-0.19	-.42E 05	-.42E 05	-.29E 01	-.79E-01	-.97E-01	-.18E 00	-.79E-01	-.66E 02
38.8	[illegible]	-0.12	0.11E 06	0.11E 06	0.92E 01	0.21E 00	0.25E 00	0.41E 00	0.21E 00	0.20E 03
39.8	[illegible]	0.23	0.23E 06	0.23E 06	0.12E 02	0.42E 00	0.52E 00	0.84E 00	0.42E 00	0.38E 03
40.8	0.0	0.75	0.27E 06	0.27E 06	0.11E 02	0.51E 00	0.63E 00	0.14E 01	0.69E 00	0.57E 03

FOR THE TIDAL CYCLE BEGINNING AT 16.0 HRS. AND ENDING AT 39.8 HRS.. THE NET MASS FLUXES ARE:

TIDAL FLOW	NET FLOW	ORGANIC N	AMMONIA N	NITRATE N	TOTAL P	ORTHO P	TOTAL ORG C
-0.4657[illegible]9E 05	-0.465739E 05	0.778629E 01	-0.871872E-01	-0.107531E 00	-0.295164E 01	-0.126288E 01	-0.230247E 03

Sample Site 7

12/15/75 BACKROUND

TIME HR.	RAIN IN.	TIDAL LEVEL FT.	TIDAL FLOW FT**3	NET FLOW FT**3	ORG N CONC. MG/L	NH3 N CONC. MG/L	NO3 N CONC. MG/L	TOTPHS CONC. MG/L	ORTPHS CONC. MG/L	TOC CONC. MG/L
9.0	0.0	0.96	-.59E 06	-.59E 06	0.11E 01	0.35E 00	0.46E-01	0.30E 00	0.13E 00	0.47E 02
10.9	0.0	-0.03	-.26E 06	-.26E 06	0.30E 00	0.60E-01	0.46E-01	0.20E 00	0.20E-01	0.11E 02
11.9	0.0	-0.20	-.22E 05	-.22E 05	0.30E 00	0.60E-01	0.46E-01	0.60E-01	0.20E-01	0.50E 01
12.8	0.0	-0.12	0.96E 05	0.96E 05	0.49E 00	0.60E-01	0.46E-01	0.60E-01	0.20E-01	0.90E 01
13.8	0.0	0.17	0.18E 06	0.18E 06	0.30E 00	0.60E-01	0.46E-01	0.40E-01	0.20E-01	0.13E 02
14.8	0.0	0.59	0.22E 06	0.22E 06	0.30E 00	0.60E-01	0.46E-01	0.60E-01	0.20E-01	0.70E 01
15.7	0.0	1.04	0.21E 06	0.21E 06	0.39E 00	0.60E-01	0.46E-01	0.60E-01	0.20E-01	0.18E 02
16.6	0.0	1.40	0.14E 06	0.14E 06	0.39E 00	0.60E-01	0.46E-01	0.60E-01	0.20E-01	0.80E 01
17.6	0.0	1.58	0.41E 05	0.41E 05	0.49E 00	0.60E-01	0.46E-01	0.60E-01	0.20E-01	0.12E 02
18.5	0.0	1.55	-.68E 05	-.68E 05	0.49E 00	0.60E-01	0.46E-01	0.60E-01	0.20E-01	0.20E 01
19.5	0.0	1.32	-.16E 06	-.16E 06	0.49E 00	0.60E-01	0.46E-01	0.80E-01	0.20E-01	0.50E 01
20.4	0.0	0.93	-.22E 06	-.22E 06	0.39E 00	0.60E-01	0.46E-01	0.10E 00	0.20E-01	0.40E 01
21.4	0.0	0.48	-.22E 06	-.22E 06	0.30E 00	0.60E-01	0.46E-01	0.60E-01	0.20E-01	0.60E 01
22.3	0.0	0.09	-.17E 06	-.17E 06	0.49E 00	0.60E-01	0.46E-01	0.40E-01	0.20E-01	0.30E 01
23.3	0.0	-0.16	-.69E 05	-.69E 05	0.39E 00	0.60E-01	0.46E-01	0.60E-01	0.20E-01	0.60E 01
24.3	0.0	-0.17	0.53E 05	0.53E 05	0.30E 00	0.60E-01	0.46E-01	0.40E-01	0.20E-01	0.90E 01
25.2	0.0	0.05	0.17E 06	0.17E 06	0.49E 00	0.60E-01	0.46E-01	0.60E-01	0.20E-01	0.13E 02
26.1	0.0	0.50	0.26E 06	0.26E 06	0.39E 00	0.60E-01	0.46E-01	0.40E-01	0.20E-01	0.70E 01
27.1	0.0	1.07	0.30E 06	0.30E 06	0.49E 00	0.60E-01	0.46E-01	0.40E-01	0.20E-01	0.50E 01
28.0	0.0	1.65	0.27E 06	0.27E 06	0.30E 00	0.60E-01	0.46E-01	0.40E-01	0.20E-01	0.40E 01
29.0	0.0	2.12	0.19E 06	0.19E 06	0.30E 00	0.60E-01	0.46E-01	0.10E 00	0.20E-01	0.70E 01
29.9	0.0	2.38	0.61E 05	0.61E 05	0.30E 00	0.60E-01	0.46E-01	0.40E-01	0.20E-01	0.20E 01
30.9	0.0	2.36	-.78E 05	-.78E 05	0.30E 00	0.60E-01	0.46E-01	0.40E-01	0.20E-01	0.60E 01

TIME HR.	RAIN IN.	TIDAL LEVEL FT.	TIDAL FLOW FT**3	NET FLOW FT**3	ORG N FLUX LB.	NH3 N FLUX LB.	NO3 N FLUX LB.	TOTPHS FLUX LB.	ORTPHS FLUX LB.	TOC FLUX LB.
9.0	0.0	0.96	-.59E 06	-.59E 06	-.41E 02	-.13E 02	-.17E 01	-.11E 02	-.48E 01	-.17E 04
10.9	0.0	-0.03	-.26E 06	-.26E 06	-.50E 01	-.99E 00	-.76E 00	-.33E 01	-.33E 00	-.18E 03
11.9	0.0	-0.20	-.22E 05	-.22E 05	-.42E 00	-.84E-01	-.64E-01	-.84E-01	-.28E-01	-.70E 01
12.8	0.0	-0.12	0.96E 05	0.96E 05	0.29E 01	0.36E 00	0.28E 00	0.48E 00	0.12E 00	0.54E 02
13.8	0.0	0.17	0.18E 06	0.18E 06	0.35E 01	0.69E 00	0.53E 00	0.46E 00	0.23E 00	0.15E 03
14.8	0.0	0.59	0.22E 06	0.22E 06	0.42E 01	0.84E 00	0.64E 00	0.84E 00	0.28E 00	0.98E 02
15.7	0.0	1.04	0.21E 06	0.21E 06	0.39E 01	0.77E 00	0.59E 00	0.77E 00	0.26E 00	0.23E 03
16.6	0.0	1.40	0.14E 06	0.14E 06	0.34E 01	0.53E 00	0.40E 00	0.53E 00	0.18E 00	0.70E 02
17.6	0.0	1.58	0.41E 05	0.41E 05	0.12E 01	0.15E 00	0.12E 00	0.15E 00	0.51E-01	0.31E 02
18.5	0.0	1.55	-.68E 05	-.68E 05	-.21E 01	-.26E 00	-.20E 00	-.26E 00	-.85E-01	-.85E 01
19.5	0.0	1.32	-.16E 06	-.16E 06	-.49E 01	-.60E 00	-.46E 00	-.80E 00	-.20E 00	-.50E 02
20.4	0.0	0.93	-.22E 06	-.22E 06	-.40E 01	-.81E 00	-.62E 00	-.13E 01	-.27E 00	-.54E 02
21.4	0.0	0.48	-.22E 06	-.22E 06	-.41E 01	-.81E 00	-.62E 00	-.81E 00	-.27E 00	-.81E 02
22.3	0.0	0.09	-.17E 06	-.17E 06	-.51E 01	-.62E 00	-.47E 00	-.41E 00	-.21E 00	-.31E 02
23.3	0.0	-0.16	-.69E 05	-.69E 05	-.17E 01	-.26E 00	-.20E 00	-.26E 00	-.86E-01	-.26E 02
24.3	0.0	-0.17	0.53E 05	0.53E 05	0.99E 00	0.20E 00	0.15E 00	0.13E 00	0.66E-01	0.30E 02
25.2	0.0	0.05	0.17E 06	0.17E 06	0.52E 01	0.64E 00	0.49E 00	0.64E 00	0.21E 00	0.14E 03
26.1	0.0	0.50	0.26E 06	0.26E 06	0.63E 01	0.97E 00	0.75E 00	0.65E 00	0.32E 00	0.11E 03
27.1	0.0	1.07	0.30E 06	0.30E 06	0.91E 01	0.11E 01	0.85E 00	0.74E 00	0.37E 00	0.93E 02
28.0	0.0	1.65	0.27E 06	0.27E 06	0.51E 01	0.10E 01	0.78E 00	0.68E 00	0.34E 00	0.68E 02
29.0	0.0	2.12	0.19E 06	0.19E 06	0.35E 01	0.70E 00	0.54E 00	0.12E 01	0.23E 00	0.82E 02
29.9	0.0	2.38	0.61E 05	0.61E 05	0.11E 01	0.23E 00	0.18E 00	0.15E 00	0.76E-01	0.76E 01
30.9	0.0	2.36	-.78E 05	-.78E 05	-.15E 01	-.29E 00	-.22E 00	-.20E 00	-.98E-01	-.29E 02

FOR THE TIDAL CYCLE BEGINNING AT 14.8 HRS. AND ENDING AT 26.1 HRS., THE NET MASS FLUXES ARE:

TIDAL FLOW	NET FLOW	ORGANIC N	AMMONIA N	NITRATE N	TOTAL P	ORTHO P	TOTAL ORG C
0.200180E 06	0.200180E 06	0.345141E 01	0.749471E 00	0.574594E 00	-0.172379E 00	0.249824E 00	0.462534E 03

Sample Site 7

1 /24/76 RAIN SITE1

TIME HR.	RAIN IN.	TIDAL LEVEL FT.	TIDAL FLOW FT**3	NET FLOW FT**3	ORG N CONC. MG/L	NH3 N CONC. MG/L	NO3 N CONC. MG/L	TOTPHS CONC. MG/L	ORTPHS CONC. MG/L	TOC CONC. MG/L
16.3	0.0	-0.67	0.53E 06	0.53E 06	0.25E 01	0.10E-01	0.23E-01	0.29E 00	0.16E 00	0.27E 02
18.3	0.0	0.97	0.98E 06	0.88E 06	0.21E 01	0.10E-01	0.33E-01	0.14E 00	0.80E-01	0.11E 02
20.3	0.0	2.41	0.38E 06	0.38E 06	0.25E 01	0.10E-01	0.33E-01	0.20E 00	0.10E 00	0.22E 02
22.3	0.0	2.33	-.44E 06	-.44E 06	0.70E-01	0.76E 00	0.33E-01	0.17E 00	0.10E 00	0.60E 01
24.3	0.030	0.88	-.82E 06	-.65E 06	0.41E 00	0.30E-01	0.62E-01	0.14E 00	0.80E-01	0.55E 01
26.3	0.005	-0.52	-.38E 06	-.38E 06	0.41E 00	0.10E-01	0.33E-01	0.17E 00	0.11E 00	0.90E 01
28.3	0.005	-0.36	0.53E 06	0.53E 06	0.44E 00	0.19E-01	0.33E-01	0.11E 00	0.80E-01	0.14E 02
30.3	0.010	1.42	0.11E 07	0.11E 07	0.18E 01	0.10E-01	0.33E-01	0.26E 00	0.18E 00	0.20E 02
32.3	0.055	3.38	0.64E 06	0.60E 06	0.44E 00	0.10E-01	0.33E-01	0.14E 00	0.11E 00	0.15E 02
34.3	0.020	3.64	-.42E 06	-.44E 06	0.12E 01	0.70E-01	0.33E-01	0.18E 00	0.14E 00	0.50E 01
36.3	0.020	1.38	-.11E 07	-.11E 07	0.21E 01	0.20E-01	0.11E 00	0.24E 00	0.11E 00	0.12E 02
38.3	0.0	-0.29	-.80E 06	-.80E 06	0.41E 00	0.19E-01	0.53E-01	0.13E 00	0.70E-01	0.19E 02

TIME HR.	RAIN IN.	TIDAL LEVEL FT.	TIDAL FLOW FT**3	NET FLOW FT**3	ORG N FLUX LB.	NH3 N FLUX LB.	NO3 N FLUX LB.	TOTPHS FLUX LB.	ORTPHS FLUX LB.	TOC FLUX LB.
16.3	0.0	-0.67	0.53E 06	0.53E 06	0.82E 02	0.33E 00	0.76E 00	0.96E 01	0.53E 01	0.89E 03
18.3	0.0	0.97	0.98E 06	0.88E 06	0.11E 03	0.55E 00	0.18E 01	0.77E 01	0.44E 01	0.61E 03
20.3	0.0	2.41	0.38E 06	0.38E 06	0.59E 02	0.24E 00	0.79E 00	0.48E 01	0.24E 01	0.51E 03
22.3	0.0	2.33	-.44E 06	-.44E 06	-.19E 01	-.21E 02	-.91E 00	-.47E 01	-.28E 01	-.17E 03
24.3	0.030	0.88	-.82E 06	-.65E 06	-.22E 02	-.16E 01	-.33E 01	-.74E 01	-.42E 01	-.29E 03
26.3	0.005	-0.52	-.38E 06	-.38E 06	-.98E 01	-.24E 00	-.79E 00	-.41E 01	-.26E 01	-.22E 03
28.3	0.005	-0.36	0.53E 06	0.53E 06	0.15E 02	0.33E 00	0.11E 01	0.36E 01	0.26E 01	0.45E 03
30.3	0.010	1.42	0.11E 07	0.11E 07	0.12E 03	0.66E 00	0.22E 01	0.17E 02	0.12E 02	0.13E 04
32.3	0.055	3.38	0.64E 06	0.60E 06	0.16E 02	0.37E 00	0.12E 01	0.52E 01	0.41E 01	0.54E 03
34.3	0.020	3.64	-.42E 06	-.44E 06	-.32E 02	-.19E 01	-.90E 00	-.49E 01	-.38E 01	-.14E 03
36.3	0.020	1.38	-.11E 07	-.11E 07	-.15E 03	-.14E 01	-.81E 01	-.17E 02	-.78E 01	-.82E 03
38.3	0.0	-0.29	-.80E 06	-.80E 06	-.20E 02	-.50E 00	-.26E 01	-.65E 01	-.35E 01	-.95E 03

FOR THE TIDAL CYCLE BEGINNING AT 24.3 HRS. AND ENDING AT 34.3 HRS., THE NET MASS FLUXES ARE:

TIDAL FLOW	NET FLOW	ORGANIC N	AMMONIA N	NITRATE N	TOTAL P	ORTHO P	TOTAL ORG C
0.520577E 06	0.520576E 06	0.869773E 02	-0.237355E 01	-0.458376E 00	0.968522E 01	0.797643E 01	0.166849E 04

Sample Site 7

10/25/76 RAIN SITE2

TIME HR.	RAIN IN.	TIDAL LEVEL FT.	TIDAL FLOW FT**3	NET FLOW FT**3	ORG N CONC. MG/L	NH3 N CONC. MG/L	NO3 N CONC. MG/L	TOTPHS CONC. MG/L	ORTPHS CONC. MG/L	TOC CONC. MG/L
20.0	0.0	2.30	0.25E 06	0.25E 06	0.19E 01	0.20E-01	0.22E-01	0.13E 00	0.50E-01	0.15E 02
21.0	0.060	2.59	0.34E 05	-.16E 05	0.19E 01	0.20E-01	0.22E-01	0.23E 00	0.40E-01	0.13E 02
22.0	0.020	2.44	-.18E 06	-.23E 06	0.19E 01	0.10E-01	0.22E-01	0.29E 00	0.11E 00	0.19E 02
23.0	0.000	1.89	-.35E 06	-.40E 06	0.23E 01	0.10E-01	0.22E-01	0.19E 00	0.15E 00	0.22E 02
24.0	0.020	1.09	-.42E 06	-.44E 06	0.12E 01	0.20E-01	0.22E-01	0.18E 00	0.70E-01	0.15E 02
25.0	0.360	0.26	-.39E 06	-.69E 06	0.28E 01	0.10E-01	0.22E-01	0.10E 00	0.70E-01	0.17E 02
26.0	0.220	-0.43	-.25E 06	-.43E 06	0.27E 01	0.20E-01	0.22E-01	0.70E-01	0.50E-01	0.14E 02
27.0	0.0	-0.69	-.29E 05	-.29E 05	0.19E 01	0.60E-01	0.22E-01	0.12E 00	0.60E-01	0.14E 02
28.0	0.0	-0.51	0.21E 06	0.21E 06	0.18E 01	0.40E-01	0.22E-01	0.12E 00	0.40E-01	0.16E 02
29.0	0.0	0.15	0.42E 06	0.42E 06	0.15E 01	0.30E-01	0.22E-01	0.30E-01	0.30E-01	0.15E 02
30.0	0.0	1.14	0.54E 06	0.54E 06	0.15E 01	0.40E-01	0.22E-01	0.80E-01	0.40E-01	0.12E 02
31.0	0.0	2.25	0.53E 06	0.53E 06	0.22E 01	0.90E-01	0.22E-01	0.16E 00	0.50E-01	0.12E 02
32.0	0.0	3.20	0.39E 06	0.39E 06	0.18E 01	0.90E-01	0.22E-01	0.13E 00	0.40E-01	0.11E 02
33.0	0.0	3.74	0.14E 06	0.14E 06	0.11E 01	0.90E-01	0.22E-01	0.13E 00	0.60E-01	0.25E 02
34.0	0.0	3.73	-.15E 06	-.15E 06	0.15E 01	0.40E-01	0.22E-01	0.70E-01	0.40E-01	0.14E 02
35.0	0.0	3.17	-.40E 06	-.40E 06	0.18E 01	0.70E-01	0.22E-01	0.14E 00	0.50E-01	0.13E 02
36.0	0.0	2.17	-.56E 06	-.56E 06	0.15E 01	0.40E-01	0.22E-01	0.80E-01	0.40E-01	0.19E 02
37.0	0.0	1.00	-.58E 06	-.58E 06	0.15E 01	0.70E-01	0.22E-01	0.18E 00	0.60E-01	0.15E 02
38.0	0.0	-0.07	-.46E 06	-.46E 06	0.11E 01	0.90E-01	0.22E-01	0.80E-01	0.70E-01	0.17E 02
39.0	0.0	-0.79	-.24E 06	-.24E 06	0.30E 01	0.60E-01	0.22E-01	0.10E 00	0.50E-01	0.12E 02
40.0	0.0	-1.00	0.27E 05	0.27E 05	0.18E 01	0.90E-01	0.22E-01	0.15E 00	0.90E-01	0.21E 02

TIME HR.	RAIN IN.	TIDAL LEVEL FT.	TIDAL FLOW FT**3	NET FLOW FT**3	ORG N FLUX LB.	NH3 N FLUX LB.	NO3 N FLUX LB.	TOTPHS FLUX LB.	ORTPHS FLUX LB.	TOC FLUX LB.
20.0	0.0	2.30	0.25E 06	0.25E 06	0.29E 02	0.31E 00	0.34E 00	0.20E 01	0.77E 00	0.23E 03
21.0	0.060	2.59	0.34E 05	-.16E 05	-.19E 01	-.20E-01	-.22E-01	-.23E 00	-.39E-01	-.12E 02
22.0	0.020	2.44	-.18E 06	-.23E 06	-.26E 02	-.14E 00	-.32E 00	-.42E 01	-.16E 01	-.27E 03
23.0	0.000	1.89	-.35E 06	-.40E 06	-.57E 02	-.25E 00	-.54E 00	-.47E 01	-.37E 01	-.54E 03
24.0	0.020	1.09	-.42E 06	-.44E 06	-.32E 02	-.55E 00	-.50E 00	-.49E 01	-.19E 01	-.41E 03
25.0	0.360	0.26	-.39E 06	-.69E 06	-.12E 03	-.43E 00	-.94E 00	-.43E 01	-.30E 01	-.71E 03
26.0	0.220	-0.43	-.25E 06	-.43E 06	-.72E 02	-.54E 00	-.59E 00	-.19E 01	-.13E 01	-.36E 03
27.0	0.0	-0.69	-.29E 05	-.29E 05	-.34E 01	-.11E 00	-.40E-01	-.22E 00	-.11E 00	-.25E 02
28.0	0.0	-0.51	0.21E 06	0.21E 06	0.24E 02	0.54E 00	0.29E 00	0.16E 01	0.54E 00	0.21E 03
29.0	0.0	0.15	0.42E 06	0.42E 06	0.40E 02	0.79E 00	0.58E 00	0.79E 00	0.79E 00	0.38E 03
30.0	0.0	1.14	0.54E 06	0.54E 06	0.51E 02	0.14E 01	0.74E 00	0.27E 01	0.14E 01	0.41E 03
31.0	0.0	2.25	0.53E 06	0.53E 06	0.73E 02	0.30E 01	0.73E 00	0.53E 01	0.17E 01	0.40E 03
32.0	0.0	3.20	0.39E 06	0.39E 06	0.44E 02	0.22E 01	0.53E 00	0.31E 01	0.96E 00	0.26E 03
33.0	0.0	3.74	0.14E 06	0.14E 06	0.92E 01	0.78E 00	0.19E 00	0.11E 01	0.52E 00	0.22E 03
34.0	0.0	3.73	-.15E 06	-.15E 06	-.14E 02	-.37E 00	-.20E 00	-.65E 00	-.37E 00	-.13E 03
35.0	0.0	3.17	-.46E 06	-.40E 06	-.47E 02	-.18E 01	-.55E 00	-.35E 01	-.13E 01	-.33E 03
36.0	0.0	2.17	-.56E 06	-.56E 06	-.52E 02	-.14E 01	-.77E 00	-.28E 01	-.14E 01	-.65E 03
37.0	0.0	1.00	-.58E 06	-.58E 06	-.53E 02	-.25E 01	-.79E 00	-.65E 01	-.22E 01	-.54E 03
38.0	0.0	-0.07	-.46E 06	-.46E 06	-.30E 02	-.26E 01	-.63E 00	-.23E 01	-.20E 01	-.47E 03
39.0	0.0	-0.79	-.24E 06	-.24E 06	-.45E 02	-.89E 00	-.33E 00	-.15E 01	-.74E 00	-.18E 03
40.0	0.0	-1.09	0.27E 05	0.27E 05	0.31E 01	0.15E 00	0.37E-01	0.26E 00	0.15E 00	0.36E 02

FOR THE TIDAL CYCLE BEGINNING AT 21.0 HRS. AND ENDING AT 32.0 HRS., THE NET MASS FLUXES ARE:

TIDAL FLOW	NET FLOW	ORGANIC N	AMMONIA N	NITRATE N	TOTAL P	ORTHO P	TOTAL ORG C
0.516132E 06	-0.133866E 06	-0.799745E 02	0.578889E 01	-0.183774E 00	-0.690355E 01	-0.641292E 01	-0.672113E 03

Sample Site 7

3/21/77 RAIN SITE 2

TIME HR.	RAIN IN.	TIDAL LEVEL FT.	TIDAL FLOW FT**3	NET FLOW FT**3	ORG N CONC. MG/L	NH3 N CONC. MG/L	NO3 N CONC. MG/L	TOTPHS CONC. MG/L	ORTPHS CONC. MG/L	TOC CONC. MG/L
19.5	0.0	2.27	0.97E 05	0.97E 05	0.74E 00	0.10E-01	0.22E-01	0.11E 00	0.30E-01	0.28E 02
20.0	0.0	2.42	0.58E 05	0.58E 05	0.81E 00	0.20E-01	0.11E-01	0.10E 00	0.50E-01	0.21E 02
20.5	0.0	2.50	0.15E 05	0.15E 05	0.16E 01	0.20E-01	0.22E-01	0.90E-01	0.20E-01	0.21E 02
21.0	0.0	2.48	-.28E 05	-.28E 05	0.87E 00	0.10E-01	0.21E-01	0.60E-01	0.20E-01	0.19E 02
21.5	0.0	2.38	-.71E 05	-.71E 05	0.11E 01	0.10E-01	0.22E-01	0.13E 00	0.50E-01	0.19E 02
22.0	0.0	2.20	-.11E 06	-.11E 06	0.81E 00	0.20E-01	0.22E-01	0.90E-01	0.40E-01	0.17E 02
22.5	0.0	1.95	-.14E 06	-.14E 06	0.12E 01	0.20E-01	0.22E-01	0.70E-01	0.20E-01	0.18E 02
23.0	0.0	1.64	-.16E 06	-.16E 06	0.99E 00	0.10E-01	0.23E-01	0.11E 00	0.30E-01	0.19E 02
23.5	0.0	1.30	-.18E 06	-.18E 06	0.73E 00	0.20E-01	0.22E-01	0.80E-01	0.20E-01	0.18E 02
24.0	0.0	0.94	-.18E 06	-.18E 06	0.15E 01	0.30E-01	0.22E-01	0.90E-01	0.20E-01	0.20E 02
24.5	0.0	0.59	-.17E 06	-.17E 06	0.97E 00	0.30E-01	0.22E-01	0.90E-01	0.40E-01	0.19E 02
25.0	0.0	0.27	-.15E 06	-.15E 06	0.57E 00	0.20E-01	0.21E-01	0.70E-01	0.30E-01	0.18E 02
25.5	0.0	-0.01	-.12E 06	-.12E 06	0.10E 01	0.10E-01	0.21E-01	0.60E-01	0.20E-01	0.18E 02
26.0	0.0	-0.22	-.87E 05	-.87E 05	0.86E 00	0.20E-01	0.21E-01	0.50E-01	0.20E-01	0.17E 02
26.5	0.0	-0.35	-.46E 05	-.46E 05	0.55E 00	0.10E-01	0.11E-01	0.80E-01	0.20E-01	0.18E 02
27.0	0.0	-0.40	-.23E 04	-.23E 04	0.95E 00	0.20E-01	0.23E-01	0.90E-01	0.30E-01	0.19E 02
27.5	0.0	-0.36	0.41E 05	0.41E 05	0.87E 00	0.10E-01	0.21E-01	0.60E-01	0.40E-01	0.19E 02
28.0	0.100	-0.24	0.30E 05	-.31E 04	0.82E 00	0.10E-01	0.42E-01	0.90E-01	0.30E-01	0.20E 02
28.5	0.0	-0.05	0.11E 06	0.11E 06	0.43E 00	0.10E-01	0.21E-01	0.80E-01	0.30E-01	0.18E 02
29.0	0.010	0.21	0.22E 06	0.21E 06	0.72E 00	0.20E-01	0.21E-01	0.10E 00	0.30E-01	0.19E 02
30.0	0.010	0.83	0.24E 06	0.23E 06	0.98E 00	0.0	0.22E-01	0.90E-01	0.20E-01	0.23E 02
30.5	0.0	1.15	0.16E 06	0.16E 06	0.57E 00	0.20E-01	0.21E-01	0.60E-01	0.30E-01	0.18E 02
31.0	0.040	1.45	0.14E 06	0.11E 06	0.17E 01	0.20E-01	0.22E-01	0.10E 00	0.20E-01	0.21E 02
31.5	0.0	1.71	0.12E 06	0.12E 06	0.58E 00	0.10E-01	0.21E-01	0.60E-01	0.30E-01	0.18E 02

TIME HR.	RAIN IN.	TIDAL LEVEL FT.	TIDAL FLOW FT**3	NET FLOW FT**3	ORG N FLUX LB.	NH3 N FLUX LB.	NO3 N FLUX LB.	TOTPHS FLUX LB.	ORTPHS FLUX LB.	TOC FLUX LB.
19.5	0.0	2.27	0.97E 05	0.97E 05	0.45E 01	0.60E-01	0.13E 00	0.66E 00	0.18E 00	0.17E 03
20.0	0.0	2.42	0.58E 05	0.58E 05	0.29E 01	0.72E-01	0.40E-01	0.36E 00	0.18E 00	0.76E 02
20.5	0.0	2.50	0.15E 05	0.15E 05	0.16E 01	0.19E-01	0.21E-01	0.87E-01	0.19E-01	0.20E 02
21.0	0.0	2.48	-.28E 05	-.28E 05	-.15E 01	-.18E-01	-.37E-01	-.11E 00	-.35E-01	-.33E 02
21.5	0.0	2.38	-.71E 05	-.71E 05	-.48E 01	-.44E-01	-.97E-01	-.57E 00	-.22E 00	-.82E 02
22.0	0.0	2.20	-.11E 06	-.11E 06	-.55E 01	-.14E 00	-.15E 00	-.61E 00	-.27E 00	-.11E 03
22.5	0.0	1.95	-.14E 06	-.14E 06	-.10E 02	-.18E 00	-.19E 00	-.61E 00	-.18E 00	-.15E 03
23.0	0.0	1.64	-.16E 06	-.16E 06	-.10E 02	-.10E 00	-.24E 00	-.11E 01	-.31E 00	-.19E 03
23.5	0.0	1.30	-.18E 06	-.18E 06	-.81E 01	-.22E 00	-.24E 00	-.88E 00	-.22E 00	-.20E 03
24.0	0.0	0.94	-.18E 06	-.18E 06	-.16E 02	-.34E 00	-.25E 00	-.10E 01	-.22E 00	-.22E 03
24.5	0.0	0.59	-.17E 06	-.17E 06	-.10E 02	-.32E 00	-.23E 00	-.96E 00	-.43E 00	-.20E 03
25.0	0.0	0.27	-.15E 06	-.15E 06	-.54E 01	-.19E 00	-.20E 00	-.66E 00	-.28E 00	-.16E 03
25.5	0.0	-0.01	-.12E 06	-.12E 06	-.78E 01	-.76E-01	-.16E 00	-.46E 00	-.15E 00	-.13E 03
26.0	0.0	-0.22	-.87E 05	-.87E 05	-.46E 01	-.11E 00	-.11E 00	-.27E 00	-.11E 00	-.92E 02
26.5	0.0	-0.35	-.46E 05	-.46E 05	-.16E 01	-.28E-01	-.31E-01	-.23E 00	-.57E-01	-.51E 02
27.0	0.0	-0.40	-.23E 04	-.23E 04	-.14E 00	-.29E-02	-.33E-02	-.13E-01	-.43E-02	-.27E 01
27.5	0.0	-0.36	0.41E 05	0.41E 05	0.22E 01	0.25E-01	0.53E-01	0.15E 00	0.10E 00	0.47E 02
28.0	0.100	-0.24	0.30E 05	-.31E 04	-.16E 00	-.20E-02	-.82E-02	-.18E-01	-.59E-02	-.39E 01
28.5	0.0	-0.05	0.11E 06	0.11E 06	0.31E 01	0.71E-01	0.15E 00	0.57E 00	0.21E 00	0.13E 03
29.0	0.010	0.21	0.22E 06	0.21E 06	0.94E 01	0.26E 00	0.27E 00	0.13E 01	0.39E 00	0.25E 03
30.0	0.010	0.83	0.24E 06	0.23E 06	0.14E 02	0.0	0.32E 00	0.13E 01	0.29E 00	0.33E 03
30.5	0.0	1.15	0.16E 06	0.16E 06	0.56E 01	0.20E 00	0.21E 00	0.78E 00	0.29E 00	0.18E 03
31.0	0.040	1.45	0.14E 06	0.11E 06	0.12E 02	0.13E 00	0.15E 00	0.67E 00	0.13E 00	0.14E 03
31.5	0.0	1.71	0.12E 06	0.12E 06	0.42E 01	0.73E-01	0.15E 00	0.44E 00	0.22E 00	0.13E 03

FOR THE TIDAL CYCLE BEGINNING AT 19.5 HRS. AND ENDING AT 31.5 HRS., THE NET MASS FLUXES ARE:

TIDAL FLOW	NET FLOW	ORGANIC N	AMMONIA N	NITRATE N	TOTAL P	ORTHO P	TOTAL ORG C
-0.170152E 06	-0.303484E 06	-0.274540E 02	-0.846035E 00	-0.454827E 00	-0.119251E 01	-0.468516E 00	-0.174338E 03

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