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Procedures and preliminary findings of a study designed to simulate rural stormwater runoff.

Public officials have long advocated land management techniques as a method of control for nonpoint source problems. This position is based on many studies which have demonstrated the different types and magnitudes of stormwater pollution originating from urban and rural activities (e.g. Grizzard and Brown, 1979). Yet, because of the many factors which influence runoff in addition to land use, the relationships between land uses and runoff loads are, in many instances, not yet advanced with the specificity needed to make sound management decisions. The management problem is further magnified by the fact that different types of receiving waters respond in many different ways to nonpoint source loads. To understand and to make effective decisions regarding nonpoint source control, the entire system must be considered, including the source lands, the streams, and the receiving water body.

The Ware River Study is one of five small watershed projects sponsored by the EPA Chesapeake Bay Program. These projects are designed to provide data on nutrient and organic loadings entering the Bay over the wide range of topographies, climates, and land uses which occupy its watershed. Each provides information on a particular geographic segment of the Bay region. In particular, the Ware study is intended to document special characteristics of runoff from low relief coastal plain environments, and to document their impacts on a small estuarine receiving water.

Many details of the study reflect the data requirements of the various runoff, transport, and receiving water models currently available. The Ware basin is typical of many small tidal rivers and creeks which extend only a few miles inland along both sides of the Bay shore. The small drainage area of 59.4 sq. miles (174 sq. km.) is conducive to

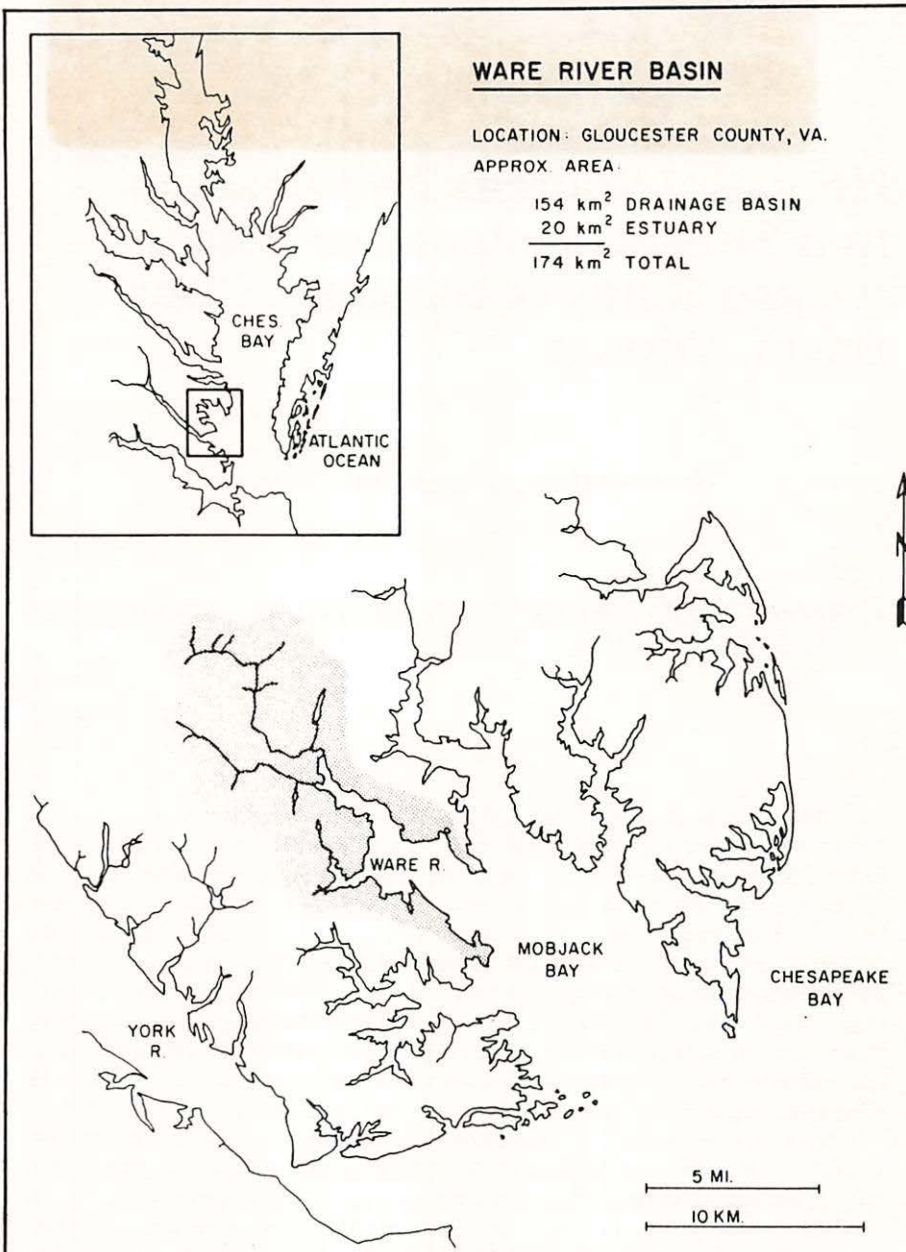

Figure 1. Location of the study area. Shaded portion delineates drainage boundaries of the Ware River watershed. (Data source: Environmental Photographic Interpretation Complex, U.S. Environmental Protection Agency, Warrenton, Va. 1980).

intensive basinwide monitoring and modeling. The purpose of this paper is to describe the experimental procedures used in the field program and to provide a general interpretation of data collected during the first year of this two-year project.

Description of the Study Area

The Ware River is a mesohaline sub-estuary within Mobjack Bay located on the southwestern shore of Chesapeake Bay (Fig. 1). Beaverdam Swamp and Foxmill Run are two freshwater tributaries which drain the upper reaches of the basin, and provide continuous flows to the estuary. In addition to the two main stems of the river, two small subbasins drain into man-made impoundments before discharging into tidal waters. The main channel of the estuary is generally broad and shallow. The river depth varies from 8 m at the mouth (MHW) to less than 1.5 m in the headwaters. Salinities range from 17 $^{o}/oo$ (parts per thousand) downstream to 8 $^{o}/oo$ in the headwaters, and reflect the strong influence of Chesapeake Bay.

Land use in the basin is characterized as rural, with over 70 percent of the land area occupied by unused forest. Agriculture in the basin is primarily row-crop, with annual rotation of corn and soybeans. This accounts for about 12 percent of the total land area. Residential and commercial uses account for only about 7.2 percent of the basin; the majority of this development is centered at Gloucester Courthouse, located near the center of the watershed. A single point source to the estuary, a sewage treatment plant serving the Courthouse, is located on Foxmill Run. Approximately 2.8 x 10^7 liter/day (10^4 gpd) of secondary effluent are discharged 0.54 kilometers above the tidal reaches.

The freshwater discharge entering the Ware River is small. The long term average discharge at the USGS gaging station on Beaverdam Swamp is 0.198 m^3/sec. If this yield is applied to the entire basin, the total freshwater flow is 2.213 m^3/sec. Annual rainfall is 111.43 cm (43.9 in), based on a thirty year record from 27 gages in Virginia's coastal plain (U.S. Environmental Data Service, 1979).

Data Collection Program

Land Use Studies—Four small drainage catchments each occupied by a single land use were selected based on several sets of criteria. First, the sites had to be occupied by land uses typical not only of the Ware basin, but also typical of the Chesapeake Bay region. It was recommended by EPA that a forested site, a residential site, and two row-crop agriculture sites be monitored. These types of uses occupy about 87 percent of the land area in the Ware basin, and are generally typical of Virginia, Maryland, and North Carolina. Secondly, it was desirable that catchments drained at least 100 acres so that microvariations in the drainage properties of the catchments would exert minimal variability on the results. The latter was impossible since the flat topography of the basin precluded drainage from such large areas through a single monitorable waterway.

The properties of the four catchments chosen for study are summarized in Table 1. The two row-crop sites are in the typical corn/soybean annual rotation, each being planted in corn during 1979. Both farmers use conventional tillage practices, apply fertilizer, and use herbicides to control weeds. An important point illustrated by the table is the difference in slope and soil properties between the sites due to their location eastward or westward of the Suffolk Scarp, a geologic landform created by an ancient high stand of sea level. The scarp strikes through the basin in a southwest-northeast aspect. The lowland sites, located eastward of the scarp, have poorly drained heavy soils, while the upland soils are light, erosive, but well drained. Relief is more pronounced at the upland sites.

				Soils	
Land Use	Location	Area (ha)	Average Slope (%)	Texture	Permeability
Row-crop agriculture	lowland	17.46	0.1	sandy loam	slow-moderately slow
Row-crop agriculture	upland	6.95	3.3	loamy sand	moderately rapid
Low density residential	lowland	2.51	0.1	fine sandy	moderate
Mixed unused	upland	8.88	2.1	sandy loam	moderately slow

Table 1. Summary of single land use site characteristics. Note differences in topography and soils between upland vs. lowland study sites. Row crop fields were both planted in corn during the 1979 growing season. Soils data courtesy of U.S. Dept. of Agriculture-Soil Conservation Service, Gloucester, Va. 1979.

The low density residential site is a small subdivision located adjacent to the shoreline of the estuary. It is the only subdivision located on the estuarine portion of the river and one of few established residential areas in the entire watershed. It was selected in part because the homes have septic tanks, whereas nearly all other established subdivisions are within the local sanitary district and served by central sewerage systems. Stormwater runoff from this site flows through a series of roadside ditches, a typical feature of rural residences.

The fourth site, an undisturbed mixed forest, was selected primarily because the catchment was exclusively forested yet easily accessible. Other large forested areas were excluded because they were inhabited by beavers. The study site is above the scarp and has moderate slopes but poorly drained soils underlying the debris on the forest floor.

Of the four sites, three have continuous base flows during winter due to high water table conditions. The upland agriculture site exhibits no base flow whatsoever. Flows at all sites were monitored by installing H-flumes in the drainageways according to specifications outlined in the USDA *Field Manual for Research in Agricultural Hydrology* (1979 ed.). Flowmeters were installed at each flume to continuously monitor baseflow and stormflow conditions. Automatic composite water samplers were used, the sampler being paced by the flowmeter to deliver an aliquot of sample to a single container at a pre-set increment of flow. The result is a single composite sample in which each aliquot added to it represents the chemical constituency of a fixed volume of water passing through the flume. The advantage is that a single analysis can be performed to characterize the total flux of constituents passing during a variable flow runoff event. In addition to runoff monitoring instruments, a recording rain gauge sensitive to 0.01 in. was installed at each site.

Samples were routinely collected during dry periods when base flow occurred in order to characterize loadings during nonstorm conditions. Base flow and runoff samples were analysed for total and dissolved phosphorus, total and dissolved Kjeldahl nitrogen, BOD_5, suspended solids, total and dissolved ammonia and nitrate-nitrite nitrogen, and dissolved silica according to methods outlined in the EPA *Manual of Chemical Methods for Water and Waste* (U.S. EPA, 1979).

The area of each catchment was walked during storms to delimit drainage area boundaries. These limits were traced on standard USGS topographic sheets (1:24,000) and the areas determined using an integrating digitizer.

It was necessary to separate out the base flow loading in order to get a more accurate estimate of storm load. This is especially important in a region influenced by a high water table as the groundwater area contributing to streamflow does not necessarily correspond in size to the area contributing to surface runoff. Unfortunately, stripchart recorders were not available until January, 1980. This precluded accurate separation of base flow using the commonly practiced recession curve technique. Instead, the rate of base flow recorded immediately prior to events was used with chemical data from baseflow sampling to subtract out mass flux due to the baseflow component. It should be noted that this probably underestimates the baseflow component and thus increases the estimates of storm load.

Mass flux was then calculated for each chemical constituent for each rain event sampled. Each loading value was then divided by the drainage area and the total rainfall for the storm in order to derive a flux/area/cm value. By multiplying this value by the annual mean rainfall, the average annual loading for each catchment was estimated.

Trend Monitoring and Stormwater Impact Assessment

A stormwater survey was conducted in the spring of 1980 to provide information on estuarine response times to organic pulse loads caused by runoff. A series of nine high water slack surveys were conducted over a 20-day period (April 25 - May 14, 1980) to study a significant rain event. Following a nine-day dry spell (previous spring dry spells lasted only three days), an average of three inches of rain fell in the watershed over several days, just after the spring application of agricultural fertilizers. Nineteen nutrient parameters were selected to detect enrichment; grab samples were taken at eleven estuarine and four freshwater stream sites. These results were compared against annual trends which had been obtained through bi-weekly slackwater sampling during both wet and dry weather conditions.

Results and Discussion

Single Land Use Studies – Eight months of runoff data (September 1979 through March 1980) are summarized in Table 2. Since annual loadings were calculated from data collected during individual events, a range of loading estimates are reported for each constituent at each site. In addition, the number of storm events and the arithmetic mean of the loading rates are reported along with the average annual runoff calculated for each.

Runoff rates are well above the annual average runoff calculated from the 21 years of record at the USGS gage on Beaverdam Swamp. The average runoff for the 17.17 km^2 gaged area was 12.82 inches per year, or about 533 $m^3/ha/yr$ (Virginia Division of Water Resources, 1972). Our catchments exhibited much higher flows, with annual runoff from the residential site estimated at over ten times the long term average. The high flow rates may be attributed to the technique used in the base flow computation, in which runoff flows were probably overestimated. A more likely explanation is the fact that evapotranspiration during the winter months is minimal, with a much greater fraction of rainfall entering runoff than during the rest of the year. Evaporation and transpiration by plants accounts for significant losses of water from a watershed, and can be an order of magnitude greater during the summer months than in winter (Viehmeyer, 1964). In fact, evaporation data collected by the National Weather Service near Norfolk, Va., indicate that evaporation is negligible from November

	Lowland Agriculture	Upland Agriculture	Low Density Residential	Mixed Forest
No. of Storm Events	3	5	6	7
Average Annual Stormflow ($10^3 m^3$/ha/yr)	2.53	0.23	9.67	2.90
Period of Record (days)	91	266	243	272
Total Phosphorus	1.30 0.23-3.28	0.56 0.20-1.36	1.45 0.74-2.38	0.25 0.09-0.51
Total Nitrogen	4.00 1.73-6.35	0.62 0.23-1.57	8.94 3.35-15.50	1.70 0.59-3.74
Suspended Solids	214.4 55.8-556.2	111.5 10.36-426.8	426.6 91.7-969.8	169.2 50.9-259.3
BOD_5	24.3 ---	1.82 1.45-2.34	14.5 8.17-16.8	5.81 0.6-21.0
Dissolved Silica	5.99 3.45-8.53	0.13 0.07-0.18	23.7 5.42-41.80	4.16 2.93-7.93

Table 2. Mean and range of areal loadings of water quality parameters, kg/ha/yr, estimated from storm event data collected at four single land use sites in the Ware River basin, September 1979 through March 1980. Annual stormflow, $10^3 m^3$/ha/yr, is the average of the storm events monitored at each site during this period.

through March, reaching a maximum of about 13m^3/ha/day during June and July (Environmental Data Service, 1977).

Among the four study sites, the residential area produced the most runoff on an areal basis. This was expected since the man-made drainage system should serve to accelerate runoff flows, and about 10 percent of the surface area is impervious due to buildings and roads which also accelerate runoff. The well-drained upland agriculture site produced the least amount of runoff, an effect of the rapidly permeable soils.

Loading values for the various chemical constituents are generally consistent with the range of values reported in the summary paper of Grizzard and Brown (1979). The loading rates calculated from the Ware data are at the lower end of the range of literature values, however, which was unexpected for a number of reasons. The Ware coefficients are based on winter data, the yields per centimeter of rain should have been higher than if the annual yield were based on data including the summer months. Also, multiplying yields per centimeter by the annual rainfall should have over-estimated loads since not all of the 111.4 cm of annual rain produces runoff. For these study sites, loading rates appear to be related to runoff production.

The residential site, which had the greatest runoff yields, also produced the highest loads. Ammonia and nitrate-nitrite nitrogen were particularly high here, possibly due to leaching from septic tank drain fields. The values are similar to figures reported for a much more populous urbanized area in the Occoquan Watershed in Northern Virginia (Randall, 1978).

The upland agricultural site produced the lowest areal loads, with values well below the ranges reported by Grizzard and Brown (1979). Although this site produced the least amount of runoff, chemical constituents were the most concentrated here than at all other sites. Runoff from the site can be characterized as infrequent, yet potent, due to the high concentrations. High ratios of total *vs.* dissolved fractions of nitrogen and phosphous indicates that loading is associated with the particulate fraction in runoff, the high concentrations of solids being attributable to the moderately erosive soils.

The lowland agricultural site produced more runoff than the upland site, and although constituents were less concentrated, there was greater export of phosphorus, nitrogen and solids due to the large volume of flow. Annual loads from the lowland site can be compared to values reported from the Rhode River in the Maryland coastal plain (Correll, 1977), and the Chowan River basin in the Carolina and Virginia piedmont (Overcash, 1977). Coastal plain row-crop values were 1.4 and 3.81 kg/ha/yr for phosphorus and nitrogen, respectively. For large basins in the Chowan, values of 1.4 and 14 kg/ha/yr were reported. There can be a wide range among values from various geographical regions, however, making interpretation of the data difficult. For example, Gambrell (1975) reported nitrogen export as high as 47.0 kg/ha/yr from row-crop agriculture in the coastal plain of North Carolina. Clark, *et al.* (1974), as cited by Correll (1977), reported phosphorus export of 0.63 kg/ha/yr from row-crop agriculture in the Pennsylvania piedmont. Values for row-crop corn reported in the literature review by Grizzard and Brown (1979) ranged from 4.3 to 59.3 kg/ha/yr for nitrogen and 0.2 to 9.1 kg/ha/yr for phosphorus.

Although the forested site produced a relatively large runoff volume, chemical constituents in storm flow were the least concentrated of all four sites monitored; thus, annual export from the forested site was low. The values are comparable to 0.2 and 1.7 kg/ha/yr for phosphorus and nitrgoen, respectively, observed from a forested site in the Rhode River watershed (Correll, 1977). Low nutrient export in runoff from forested areas may be explained as due to the high uptake by plants; thus, phosphorus and nitrogen export in streams should be greatest during late fall and winter (Swank, 1977).

In summary, loading rates from our catchments appeared to be dependent on the areal water yield of each, except for the forested site, in which low concentrations of constituents in runoff accounted for the low transport of nitrogen, phosphorus, and suspended solids. This partially suggests that factors influencing the infiltration of rainwater into the soils has a significant effect on nonpoint source loads, particularly in this rural setting. This is supported by the disparity in yields between the upland and lowland agriculture sites. Residential land-uses produce high loads due to their modified surface drainage. Permeability is, of course, a major controlling factor in urban and commercial areas, where more than 70 percent of water from a rain event can be exported as runoff (Wanielista, 1978). Our data suggests that differences between areas subject to very similar rural land-use (in this case, conventionally tilled corn) are no less subtle than differences among various urban areas. Data from a lowland forested site or an upland residential site would have helped substantiate this hypothesis. In general, loading rates were at the lower end of the range of literature values, suggesting that loadings from this coastal plain area may be low relative toother rural areas in the Bay region.

Receiving Water Studies

Results from the first year's trend monitoring indicate that the Ware River can be typified as a "clean" estuarine system and thus provides a good medium for analyzing nonpoint source impacts on small coastal plain receiving waters. Extremely low nutrient concentrations for silicates, total and ortho phosphates, suspended solids, organic nitrogen, and nitrate-nitrite nitrogen were found in the mouth waters. Statistical comparisons between stations using Duncan's Multiple Range Test showed the mouth and headwater nutrient means to be different ($\alpha = .05$). Analysis of variance similarly displayed a significant difference ($\alpha = .05$) in nutrient concentrations between the mouth and headwater stations for 11 of the 19 analyzed parameters, with nutrient concentrations generally higher upstream. Based on this distinction, the river was divided into two groups, labelled "BAY" and "BRACK," reflecting mouth (bay) and headwater (brackish) stations, respectively. These two groups were also compared with freshwater tributary stations (called "STREAM") in order to assess annual water quality trends and the estuarine responses to organic pι · loads resulting from runoff.

An initial dissolved oxygen (DO) sag was obseι -d at the BRACK stations following the first day of rain (Fig. 2). Dissolved oxygen concentrations ranged from 4-5 mg/l representing an average decrease in DO of 2.2 mg/l from the seasonal mean of 6.8 mg/l. This is consistent with Rimer (1978), who noted that in the Neuse River, NC, stormwater runoff generally depressed DO concentrations below the low flow antecedent level by about 1 mg/l. This DO depression lasted for less than a day; thus, two closely spaced storms could cause a decrease in DO of more than 3mg/l. Although patterns in the Ware generally were similar, due to the numerous and consecutive rain days during the survey, DO curves fluctuated somewhat and the sag period lasted longer, with maximum sag occurring two days following the last rainfall (Fig. 2).

Chlorophyll *a* values were highest at the BRACK stations 24 hours after the rain began (30.6 ug/l). With continuing rainfall and increased flow, chlorophyll *a* values decreased but remained above the seasonal average of 11.5 ug/l. STREAM stations similarly were highest after the first day of rain (8.4 ug/l) and remained above the seasonal average of 4.5 ug/l. Chlorophyll *a* values at the BAY stations did not show a peak response until 15 days later.

Increases in nitrate-nitrite nitrogen concentrations following the rain event were not detected at any site within the estuary (<0.01 mg/l for BRACK and BAY stations). Loftus, *et al.* (1972) reported similar values in the Rhode River and suggested that the turnover time for available nitrogen and/or the uptake rate of the phytoplankton must be extremely rapid to explain the low inorganic nitrogen levels. Notably, however, nitrate-nitrite nitrogen, total Kjeldahl nitrogen, total phosphorus, and chlorophyll *a* values exceeded seasonal averages in the STREAM stations.

Freshwater influence on the BAY stations were minimal: salinity varied 1.5 °/oo during the 20 days, whereas BRACK station salinities were lowest four days following the rainfall and changes in salinity averaged 4.4 °/oo at that time.

In summary, preliminary results indicate that the extent, duration and severity of impacts on the estuarine Ware River following a major storm event are slight, although they may present short term stress upon the system. Generally, nutrient concentrations within the estuary did not increase significantly above pre-storm conditions for the 20 days of the rain survey. Deviations from seasonal mean values were slight, especially at the BAY stations. Large changes, however, were measured in the headwaters of the estuary, where low DO concentrations (< 5 mg/l) were found following the onset of 0.5 in. of rainfall. Furthermore, it was found that DO levels were lowest in the brackish estuarine headwaters than in the freshwater streams due to the greater oxygen carrying capacity of freshwater.

From this it can be concluded that although high concentrations of nutrients may be present in the freshwater tributaries, these loadings are rarely detected in the estuary more than three kilometers downstream. These results may be explained by several hydrographic features of the Ware River basin. First, slow stream flushing times, as

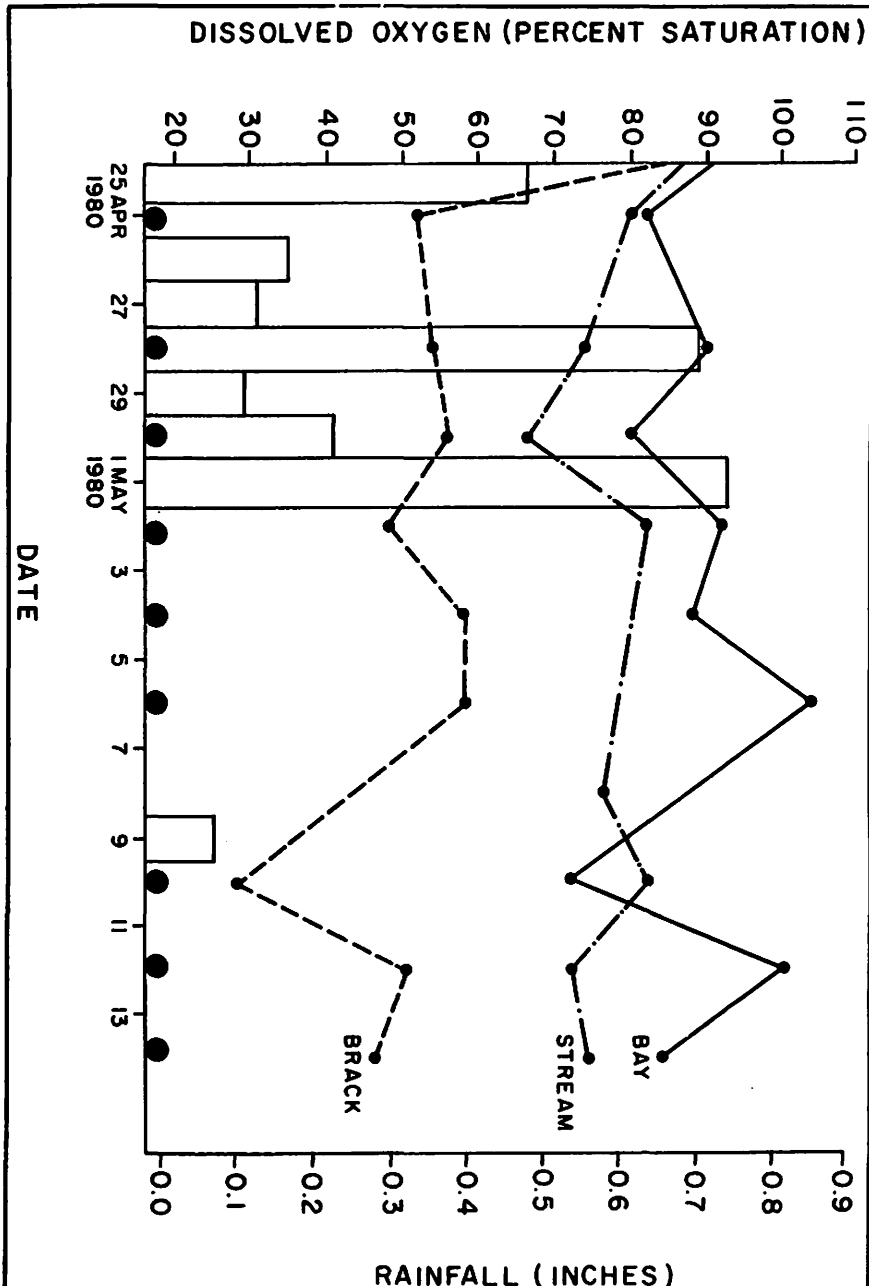

Figure 2. Plot of BAY, BRACK, and STREAM dissolved oxygen, percent saturation vs. time. Bar graphs reflect storm events in inches of rainfall. Circles represent sampling dates. Note initial D.O. sag within 24 hours of first rainfall. Maximum D.O. sag in the estuary occurred on May 10th.

determined from a dry weather time-of-travel dye study, suggest that suspended solids and nutrients associated with particulate matter entering the streams from runoff may dilute and settle out before entering the estuarine headwaters. Secondly, there is a large ratio of receiving (estuarine) water volume to drainage area when compared to other larger coastal plain basins.

Plans for the second year of study include sampling the freshwater streams to better describe the transport of pulse loads of nutrients from the land to the estuary, and to examine nutrient cycling in the estuary to determine how low levels of DO occur in the brackish waters when nutrient levels are also depleted.

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