

**SUMMARY OF THE HAMPTON ROADS 208
WATER QUALITY MODELLING STUDIES**

by
Bruce J. Neilson

**A Report to the Hampton Roads
Water Quality Agency**

**Special Report No. 170
in Applied Marine Science and
Ocean Engineering**

**Virginia Institute of Marine Science
Gloucester Point, Virginia 23062**

**William J. Hargis, Jr.
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The material presented in this report is to a great extent the culmination of the purely technical portion of the Hampton Roads 208 Study. It is based upon the work of many individuals working in various disciplines in a number of agencies and consulting firms. Their ranks are too great to be enumerated individually, but their contributions are hereby gratefully acknowledged. Special credit is due to my colleagues at VIMS who conducted the field surveys, performed the laboratory analyses, processed the data and calibrated, verified and ran the mathematical models.

Although credit for success should be given to all persons who have contributed to the work effort, blame for omissions, faulty interpretations of the data, and other errors rests solely with the author. The comments and conclusions are his and do not necessarily represent policy statements by either the Virginia Institute of Marine Science or the Hampton Roads Water Quality Agency.

Introduction

The purpose of the Hampton Roads 208 Study is to assess the present and future water quality conditions in the study area and to develop a wastewater management plan to achieve certain water quality goals. The study included all major estuaries in the area and, among other things, took account of population and industrial growth, effluent quality (as mandated by PL92-500) and nonpoint sources of pollution. Land use maps for 1976, estimates of future land use, population projections and many other elements of the study initiated in 1974 provided the foundation upon which the water quality work was based. Projections of point source discharges, both flows and pollutant loads, were developed by Betz Environmental Engineers (Task Package 4). The studies of nonpoint sources of pollution were conducted primarily by Malcolm Pirnie Engineers, Inc. (Task Package 5). Twenty-five sites in the two planning districts were sampled during each of two rain events by VIMS during the period March through October 1976. Data from these field studies were used by MPEI to calibrate the mathematical model of surface runoff called STORM (Storm, Treatment, Overflow and Runoff Model). This model then was used to project nonpoint loads at the time of water quality surveys and for future times.

Water quality studies were in Task Package 3, with VIMS (the Virginia Institute of Marine Science) the consultant. This work involved five steps: 1) intensive surveys of water quality in nine estuaries in the study area; 2) review of the field data to determine present (1975/76) conditions; 3) the calibration and verification of mathematical models of water quality; 4) projections of water quality conditions for each estuary in the years 1977, 1983 and 1995; and 5) development of regional strategies using the information gathered in the earlier portions of the study. The model studies synthesize, in great part, the work of most elements in the entire 208 study: specifically,

the model projections use estimates of point and nonpoint loadings from task packages 4 and 5.

Field studies were conducted in nine estuaries within the 208 study area: the Pagan, Nansemond and Elizabeth Rivers, the James River up to the confluence with the Chickahominy River, the York River, Back and Poquoson Rivers, Little Creek Harbor and the Lynnhaven Bay system (see Figure 1). This report summarizes in very brief form the results of the field surveys and the findings of the model runs for 1977, 1983 and 1995 conditions.

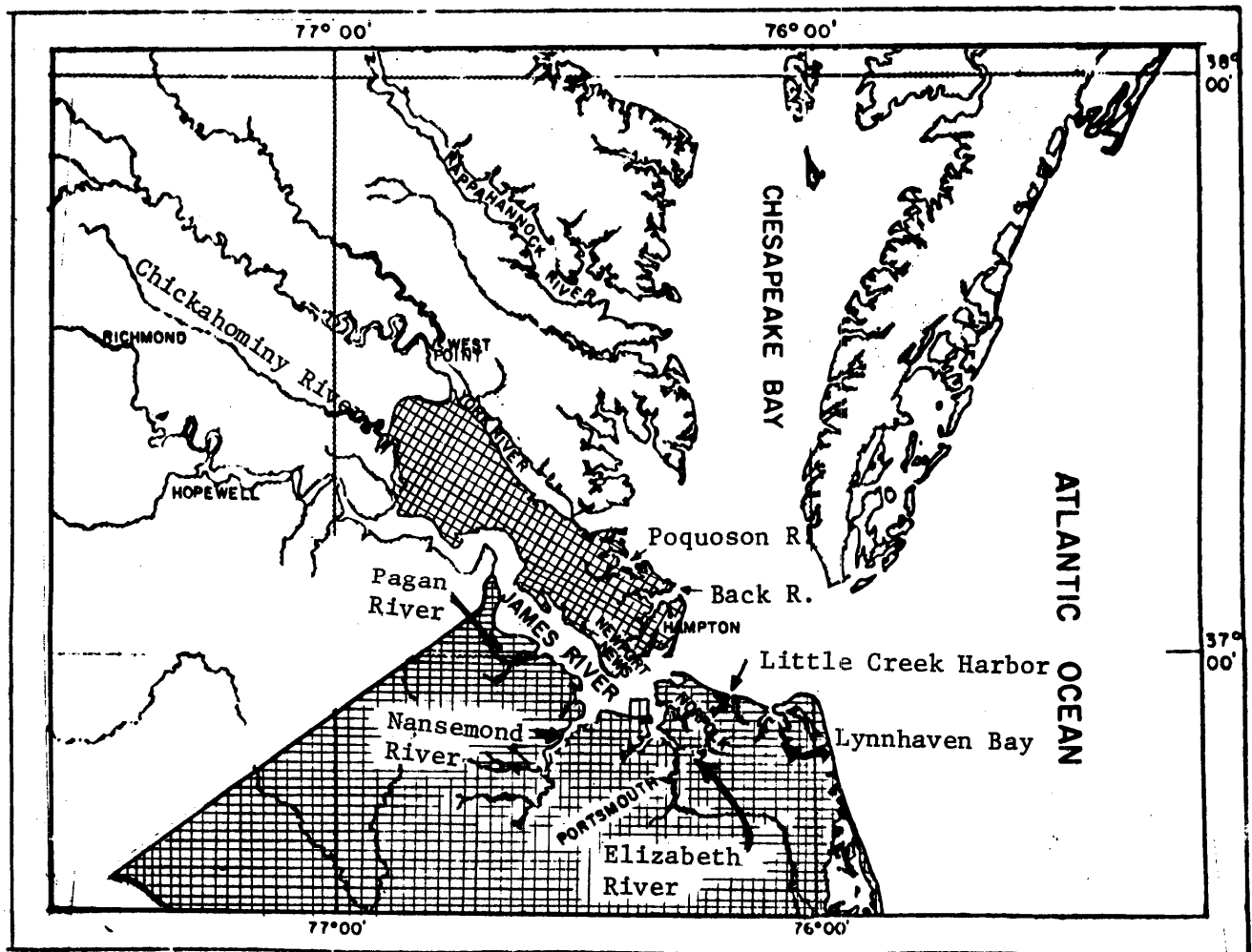


Figure 1. The Hampton Roads 208 Study Area showing the estuaries surveyed and modelled.

Factors Controlling Water Quality

One of the interesting results of the Hampton Roads 208 Study is that each of the estuaries has a character that is distinct and different from the others. However, a few general principles will hold true in all instances. Some of these will be presented to assist the reader in the interpretation of field and modelling results.

Physical factors are extremely important ones for the environment. An old adage is that "the solution to pollution is dilution". What this means is that the impact of a pollutant will be greatly ameliorated if the concentration of that pollutant is reduced through dilution. For the major estuaries the volume of water which is available to dilute wastes is enormous. The tidal prism, the volume between low water and high water, for the James River is around 3×10^8 cubic meters and that for the York is $1.2 \times 10^8 \text{ m}^3$. Mean low water volumes for the James and York Rivers are $2400 \times 10^6 \text{ m}^3$ (more than half a cubic mile) and $909 \times 10^6 \text{ m}^3$ (about a fifth of a cubic mile) respectively. The oscillating tidal currents bring in large volumes of "clean water" on each flood tide and disperse waste streams. Consequently, these systems show very moderate responses to changes in pollutant discharge rates.

The moderating influence of the tides is great for those pollutants which either are dissolved in the water or are suspended in the water column. Materials adsorbed onto particles which settle out to the bottom will remain in the river for a long period of time and will be flushed out of the system by different processes. Heavy metals and pesticides are two contaminants which tend to adsorb onto particles and often accumulate in the bottom sediments. The residence time for this type of contaminant is much longer and the assimilation capacity of the system for these contaminants is much smaller than it is for a dissolved pollutant, such as oxygen demanding substances.

The moderating influence of the tides also diminishes towards the upper ends of the estuaries. In particular, for the small estuaries tributary to the James, tidal currents are

extremely weak and tidal flushing is poor in the upper reaches of the rivers. Freshwater flow to these estuaries also can be small which results in a very slow transport of pollutants downriver. Materials which are discharged to the headwaters of one of these subestuaries will tend to remain in that area for long periods of time, often causing significant environmental degradation.

The solubility of oxygen in water varies with both temperature and salinity and in an inverse fashion for both. Thus, dissolved oxygen (DO) levels can be expected to decrease slightly from freshwater areas to those with salty water. And DO levels will be higher in the winter than in the summer. Unfortunately, the dry periods in late summer frequently result in elevated water temperatures (up to 30°C) and the highest salinity values of the year. Combined, these reduce the saturation value of oxygen to levels only slightly higher than the water quality standards.

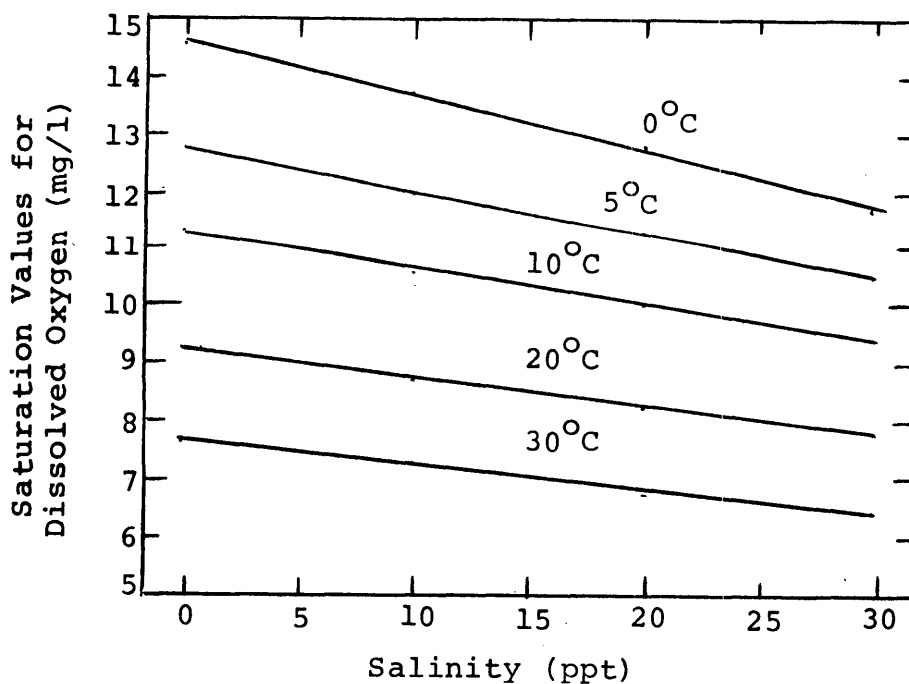


Figure 2. Variation of dissolved oxygen saturation values with salinity and temperature.

Biological processes are important too, especially when water temperatures are high and the rates of the processes are rapid. For example, in winter organic matter discharged to an estuary decomposes very slowly, and while this occurs it also is being transported downriver. Consequently, the impact of this process is spread out over long reaches of the river. In the summer, the physical transport processes can be very slow, as mentioned earlier, but the rate of decomposition can be quite rapid. The bacteria which degrade the organic matter utilize oxygen. The end result is that the impact of a pollutant discharge is compressed to a small portion of the river and DO levels in that segment can be depressed greatly.

Nutrient levels can vary as a result of sedimentation and interaction with the plant life. The math models include the uptake of the nutrients phosphorus and nitrogen by phytoplankton (algae), and the eventual release of these elements back to the water column as the dead plant cells are decomposed. Nitrogen and phosphorus enter the estuaries in domestic sewage, some industrial wastewaters, and storm runoff, especially from heavily fertilized agricultural lands.

The models also simulate the distribution of fecal coliform bacteria, a particular type of bacteria which is used by many public health agencies to evaluate the cleanliness of waters, especially shellfish growing areas. The models include the physical processes which will transport and disperse the bacteria and the biological rate of death. A fixed portion of the bacteria are assumed to die each day. Bacterial levels normally are low in the estuaries, except after rain events when runoff transports large numbers of bacteria.

Basic Philosophy used in the Modelling of Water Quality

In recent years, the field of mathematical modelling of water quality has blossomed, and a wide variety of models exists for studying environmental questions. The philosophy for modelling was begun by the parent agencies of the Hampton Roads Water Quality Agency in their initial proposals to the Environmental Protection Agency. During the course of the study, this philosophy was defined and refined by the modellers jointly with the management consultant and the other contractors. The following section attempts to document the approach which was used to facilitate interpretation of the results of the modelling studies:

Number of Dimensions - from the point of view of computer time and complexity of computer programs, the dimensions of time and space are interchangeable. Thus, "steady state" models frequently include two-dimensional features, while non-steady state models simplify the spatial characterization of the water bodies. One decision which was made early in the program was to use "real time" models which would include variations in water quality during the flood and ebb tidal cycles and following transient events such as rainstorms. All models utilized have time varying aspects, although those used for Little Creek Harbor and Lynnhaven Bay give predictions for high water slack only. Since temporal variations were a major feature of the models, it was necessary to employ one-dimensional models in most cases. For rivers which are much longer than they are wide, such as the Pagan River, this is completely reasonable since the dominant water quality changes occur along the longitudinal axis of the river. For broad rivers, water quality can vary across the river as well as down its axis. Therefore, for the James River Estuary a model was employed which includes both horizontal dimensions. For the York River, the field data indicated that there were significant variations in water quality in the vertical direction as well, so, a "quasi-three dimensional" model was used. The river was divided into a large number of segments or "boxes" with many

boxes along the river length, three across the river at any point and two layers in the vertical direction. In general, models were selected to capture the essential characteristics of the water body under study.

Water quality measures - the models generally included ten variables. Dissolved oxygen is probably the most important single measure of water quality. DO levels are affected by physical features, as well as organic loads (included as BOD) and nitrification of organic and ammonia nitrogen. Nutrient cycling was modelled, with chlorophyll "a" representing the mass of algae present in the water. And fecal coliforms were included as the indicator of bacterial quality of the water.

Although many other constituents and substances could have been modelled, it was not possible within this study to collect the necessary data to accomplish this. The modelling studies are much more comprehensive than most prior studies since they provide predictions of: 1) dissolved oxygen, which is needed by most aquatic organisms for survival and which is prescribed by standards; 2) the level of nutrient enrichment (eutrophication) as shown by nitrogen, phosphorus and phytoplankton levels; and 3) bacterial quality of the water, using fecal coliforms as the indicator organism, which is important for Tidewater since the estuaries are used to grow shellfish and for numerous recreational activities.

Point sources - volumetric flow rates and pollutant discharge rates for major industries and municipal treatment plants were projected by Betz Environmental Engineers and supplied to VIMS for use in the water quality modelling. For the 1977 projections, dischargers were assumed to be using "Best Practicable Treatment" technology, and for the 1995 projections, it was assumed that "Best Available Technology" was being utilized. For the year 1983 both BPT and BAT projections were available, and both data sets were used for water quality predictions.

Nonpoint sources - nonpoint source estimates were developed by Malcolm Pirnie Engineers, Inc. through use of the math model STORM. A portion of the rainfall record for 1957 was used to determine the quantity and quality of runoff for a series of storm events with differing rainfall durations, intensities and total precipitation. The projected runoff loads were apportioned to river segments by accounting for land use, natural drainage patterns, and other germane factors; they were entered into the water quality model on a daily basis for those days having precipitation sufficient to cause runoff. A more detailed and complete description of how the rainfall sequence was selected is given in the interim report for "work elements 5.3 and 5.5" by MPEI to the 208 Agency.

Hydrographic conditions - conditions observed in the 1975 and 1976 field surveys were used with a few important exceptions. For most of the small estuaries, no streamflow gaging stations exist within the drainage basins. In general, base freshwater flows were assumed to be zero except during rain events, when flows predicted by STORM were used. The initial salinity profiles were those observed in 1975/76. (This assumption was an absolute necessity in several instances since virtually no data, other than the 208 data, exists to characterize conditions.) Water temperature was held at 28°C in all estuaries for all model projections. A review of water temperature data collected at the VIMS pier near Gloucester Point in the York River between 1954 and 1977 shows several facts: 1) water temperatures reached or exceeded 28° in 15 of the 23 years for which summer data was available; 2) the maximum daily average temperature was 30°, and the maximum temperature observed was 31.5°; 3) during six of the 23 years, daily average water temperatures were at or above 28° for 8 consecutive days or longer. During both 1955 and 1977, this period lasted 19 consecutive days.

Boundary conditions - frequently it is necessary to set boundary conditions for models. Water quality conditions observed in 1975/76 were used since there was no method available to predict what the boundary conditions would be at future times. Since water quality conditions are likely to improve as higher levels of treatment are implemented, the use of present boundary conditions is conservative, that is, it is likely to slightly exaggerate any problems that might occur.

Modelling philosophy - as the preceding paragraphs indicate, the scientist or engineer eventually must specify all conditions to be tested in the mathematical model. Contrary to popular belief, neither computers nor models solve our problems. Rather they only allow us to ask more difficult questions and to get quantitative answers. The choice of the question, though, remains with us.

For the 208 study, the objective was to evaluate present and future water quality and develop management plans. To be meaningful, the study had to address real and difficult problems. To be practical, it could not attempt to resolve every possible environmental problem. To further complicate matters, many of the test conditions which have been specified for free-flowing rivers and streams (such as the "seven-day, ten-year low flow" for river discharge) cannot be carried over to the estuarine environment. Additionally, the modelling program was ambitious and probably beyond the "state of the art" for normal planning studies. In the end, it was necessary to use engineering judgement in many cases, and, therefore, it is necessary to elucidate the philosophy or approach used in making those decisions.

The goal was to select an appropriate set of test conditions so that the eventual management plan would result in high quality waters throughout the study area. Realizing that the best plan is useless if the costs of implementation are unreasonable, it was necessary to accept the fact that water quality would not be good on every single day in each and every year of the future. Allowance had to be made for "rare events",

such as Tropical Storm Agnes. Conditions were chosen to have a recurrence frequency of once in two to five years. A rainfall record approximating the design sequence is estimated to occur every two or three years. Similarly, one can expect water temperatures to be above 28° for a week or more about once every four years. The final set of hydrographic conditions, the design rainfall record and other input requirements for the model are believed to represent conditions which can and do occur every few years. As a result, this set of conditions represents a "critical period" which is likely to occur often in the future. It is neither the "typical summer condition" nor could it be called a "rare event".

Model Study Results

The models were calibrated and verified using the field data sets collected in the summers of 1975 and 1976. The models were then used to project conditions in 1977, 1983 and 1995. In those instances where water quality standards were violated, various control measures for both point and nonpoint sources were tested in the models. The following sections describe the results of these model runs:

Pagan River

The intensive survey showed that the Pagan River had numerous water quality problems. The entire river is condemned for the direct harvesting of shellfish. Fecal coliform counts were so high in the upper reaches of the river that primary contact recreation should not be permitted. Nutrient levels increased with distance upriver from the mouth. Algal concentrations increased in a similar fashion and were sufficiently dense to constitute a bloom in the vicinity of Smithfield. Because of the dense phytoplankton population, a pronounced diurnal variation in dissolved oxygen levels was observed. Where algal levels were high, the magnitude of the DO variation was large and daily minimum values frequently were below 4 mg/l. Values as low as 2 mg/l were observed on occasion. Benthic oxygen demand was higher than that occurring in similar nearby estuaries and contributed to the low DO levels.

Stormwater runoff predictions showed that heavily forested areas had less runoff per inch of rainfall than many other land uses and that pollutant loads, on a unit area basis, were lower than for agricultural lands. Changes in nonpoint loads between 1977 and 1995 were very small, except for a few locations. In one instance, the percentage of residential area increased from 7% to 16%, with most of the reduction occurring in cropland acreages. As a result nutrient loads (nitrogen and phosphorus) were reduced considerably, but fecal coliform loads increased.

Projections for dry weather conditions show that DO standards will not be violated but that eutrophic conditions would exist in the future. Chlorophyll "a" concentrations generally ranged up to about 80 µg/l and DO values show distinct diurnal variations. Nonpoint loads from the adjacent land, especially croplands, were projected to be very large. As a result, fecal coliform levels skyrocketed and DO levels plummeted following major rain events (ones which produced runoff from all portions of the basin).

Improving effluent quality from "BPT" to "BAT" levels showed only modest improvements in water quality. Complete elimination of point discharges resulted in a significant improvement in dry weather water quality: chlorophyll "a" levels reduced by about 20%, inorganic nutrients reduced by about 50% and BOD reduced by around 10%. The DO values also were reduced as a result of the lower algal densities. However, following a rain event, very little difference could be observed between conditions with and without point discharges. A 50% reduction in the benthic oxygen demand, on the other hand, improved both wet and dry weather conditions. The original projections for 1995 showed oxygen reserves depleted at times following storms, but reducing the benthic demand kept DO levels above 1 mg/l.

Reducing nonpoint loads improved conditions following storms, but since the projected loads were so large, a very substantial reduction was required before significant improvements in post-rain-event conditions occurred. To illustrate the magnitude of the problem, dissolved oxygen values well below the 4 mg/l standards are predicted for many segments of the river following rain events even with complete elimination of point sources, a 50% reduction in benthic oxygen demand and a 40% reduction in nonpoint loads.

Stated somewhat differently, following the rainfall sequence for 1995 conditions, DO values in the upper 6 km of the river are projected to range from zero to 0.2 mg/l. If agricultural "best management practices" are implemented and settling basins are built, the DO levels still fall below 4

mg/l, but range between 0.5 and 1.5 mg/l in the upper reaches of the river. It should be noted that if either point sources, nonpoint loads or both are controlled, it is very likely that there will be less accumulation of sediment, nutrients and organic matter along the bottom of the river. This eventually could result in a lower benthic oxygen demand. But at present, our knowledge is insufficient to state that this definitely would occur or to quantify the magnitude of the change.

Fecal coliform levels are predicted to be higher than the shellfish growing water standard following major rain events. But within two or three days the levels are reduced by dilution and die-off to less than the 14 MPN/100 ml standard. It is unlikely that any control method exists to eliminate these transient effects.

In summary, it appears that all possible actions should be taken to reduce pollutant discharges to the Pagan River. Since prior engineering studies have considered extending the proposed Nansemond STP service area into Isle of Wight County, the option of transferring point discharges to that system should be studied. Projected nonpoint loads were extremely large, so that sizeable reductions are needed in order to achieve reasonable water quality following rain events. Although the feasibility of reducing benthic oxygen demand (by dredging, for example) has not been studied, it is recommended that such studies be considered. Another aspect of this question is the determination of changes in benthic demand following changes in point and/or nonpoint discharges.

Nansemond River

Water quality conditions in the Nansemond River are similar to those of the Pagan. High levels of nutrients, phytoplankton and fecal coliforms have been recorded in the past, along with extremely low dissolved oxygen concentrations. The 1976 slack water surveys showed similar conditions: nutrient and chlorophyll levels were high and increased with distance from the river mouth. Fecal coliform counts rose dramatically, so much so that the water near Suffolk was unfit for secondary

recreational activities. DO values near the bottom frequently were below the 4 mg/l standard.

Model results were somewhat different from those for the Pagan. Projections for 1983 were made first with all existing point sources at "BPT" and then with all but a small industry removed, since the proposed Nansemond treatment plant should be in operation by that time. A comparison of results showed dramatic changes. Even during dry weather, when point sources existed, DO levels were well below the 4 mg/l standard in the uppermost 5 kilometres of the river. Following rain events, the extent of the impacted area increased and a second area with low DO's developed slightly further downriver. Removing the point sources resulted in dry weather DO's above 6 mg/l for most reaches. The extent and severity of the impact due to nonpoint loads also were reduced greatly. The use of agricultural Best Management Practices (BMP) for 1995 conditions lessened the severity of the nonpoint impacts, but did not alter the area impacted. Even with the removal of the point sources and implementation of agricultural BMP, dissolved oxygen levels below the 4 mg/l standard were predicted for many reaches following major rain events.

The water supply reservoirs along the Nansemond receive a large portion of the nonpoint loads generated in the basin. Model results show that water quality in the river would be even further degraded if this runoff were not intercepted by the impoundments. It is likely that nutrients are accumulating in the sediments of the lake bottoms. Some portion of the nutrients probably enters the Nansemond, but primarily in the winter and spring when rainfall is great and the reservoirs overflow. In short, the water supply reservoirs act as large settling basins and improve the quality of the water in the Nansemond by reducing nonpoint source loads.

Elizabeth River

Large volumes of treated municipal and industrial wastewaters are discharged to the Elizabeth River. Consequently, there are water quality problems. During the intensive survey chlorophyll "a" levels normally were at or below 20 µg/l, but in the upper reaches of the Southern Branch there was an algal bloom with chlorophyll ranging up to 130 µg/l. Dissolved oxygen levels fell below 4 mg/l occasionally at many stations. Between Lambert's Point and Deep Creek daily averages were often below 5 mg/l and readings below 4 mg/l were common. Fecal coliform levels were very high in much of the river, ranging up to several thousand MPN per 100 milliliters of water.

Model projections indicate that some of these problems will continue into the future. The 1995 projections were made both with and without point source discharges. Nutrient, chlorophyll "a" and BOD levels dropped around 10% with removal of the point sources, but dissolved oxygen values increased only about 1%. For both cases chlorophyll values ranged up to around 50 µg/l, a level that causes daily fluctuations of several milligrams of oxygen per liter. Following the rain events, DO levels drop below 4 mg/l in the main stem, Southern, Eastern and Western Branches. Conditions in the uppermost reaches of the Southern Branch recover slowly, requiring 5 to 10 days before violations of the standards disappear. Fecal coliform counts increase in all parts of the river but drop down below the shellfish standard (14 MPN/100 ml) in around 2 days.

Reductions in nonpoint loads, due to agricultural "best management practices" and/or settling basins, lessen the severity of the impact of stormwater runoff. However, roughly the same area is affected and DO values well below 4 mg/l are projected for the Southern Branch and the Eastern Branch even with nonpoint source controls. The low DO's result from the combined effects of exertion of the large BOD load brought in by the runoff and reduced oxygen production by plankton due to the cloudy skies associated with storms. Dry weather nutrient concentrations

and chlorophyll levels must be reduced drastically and non-point loads lessened in order to ameliorate the poor water quality conditions after storms. It is not clear that this is possible, let alone feasible, for the Elizabeth River system. Model results indicate that total elimination of point sources results in only marginal reductions of most nutrient forms, ammonia-nitrogen being the major exception with about a 25% reduction predicted. Comparison of point and nonpoint loads shows that both are contributing large quantities of nutrients and both must be controlled to have an effective scheme. Nutrient inputs from the Dismal Swamp and the marshes fringing the river must be better quantified as well. And finally, it is very likely that reducing the concentrations of nutrients in the water column would allow for greater release of nutrients from the bottom sediments. This benthic release could mask the improvement due to point and nonpoint controls and could persist for many years due to the very high concentrations of nitrogen and phosphorus in the Elizabeth River sediments. In-stream aeration and/or other non-traditional methods may be best suited for resolving the dissolved oxygen problems in the Elizabeth River system.

James River

During the July 1976 intensive field survey, water quality in the lower James River was quite good. Dissolved oxygen values normally were around 6 mg/l, with only a few measurements below 5 mg/l, most of these occurring in the very deep portion of Hampton Roads near Sewell's Point. Chlorophyll "a" concentrations generally were around 10 µg/l or less, and the maximum values observed were about 25 µg/l. Fecal coliform levels were high in a few areas: the northern shore of Hampton Roads, and near the mouth of the Elizabeth River.

Model projections show that conditions will be the same or better in the future. Following the major rain event in 1995, fecal coliform levels go above the 14 MPN/100 ml shellfish standard at 82 of 179 points at which water quality is

calculated. One day later, only 50 points showed high fecal coliform counts, and the number decreased to only 17 by the third day. All of these locations were located either in the Elizabeth River or immediately adjacent to Craney Island, and were predicted to have high bacterial levels prior to the rain event. In other words, the elevated coliform levels are due to conditions in the Elizabeth River and not due to runoff or discharges to the James. The area predicted to have poor quality water presently is condemned for shellfish harvesting. The 1976 surveys showed fecal coliform levels much higher than those which can be attributed to point sources and stormwater runoff. This, plus the fact that water quality in Hampton Roads and the Elizabeth are inter-related, makes it difficult to specify boundary conditions for the future. Therefore existing conditions were used, although future conditions may be better.

Chlorophyll "a" projections were around 10 $\mu\text{g}/\text{l}$, levels that should not result in environmental stresses. Stormwater runoff increased BOD levels, so that dissolved oxygen concentrations dropped below 5 mg/l for a small number of stations. However, the minimum DO predicted was 4.87 mg/l , which does not represent severe pollution or a critical problem.

In summary, water quality in the James was observed to be reasonably good in 1976 and is predicted to be good in future years. Following heavy rains or storms, fecal coliform concentrations will increase and be above shellfish growing standards for a sizeable portion of the lower James. However, dilution and die-off will rapidly reduce levels in a few days. Bacterial quality is likely to be poor near the mouth of the Elizabeth River until conditions in that estuary improve.

Runoff from a major storm (rainfall greater than 10 cm.) produced a minimal degradation in water quality, with the minimum predicted DO concentration of 4.87 mg/l for 1995 conditions.

York River

In many respects, the York River is in good health, probably because there are few industrial or municipal discharges to the river. However, water quality is compromised in several ways. First, bacterial quality is not good near West Point and in the small tributaries. The municipal discharge from the City of West Point may be the cause of the former situation, which appears to be aggravated by the effluent and/or runoff from the Chesapeake Corporation. At any rate, bacterial levels are elevated in the main channel of the river below West Point, and the river is closed for direct shellfish harvesting. Additionally, virtually all of the tributary streams are condemned because of nonpoint pollution.

The second problem area is the depletion of dissolved oxygen reserves in the bottom waters of the lower reaches of the York, specifically between the Coleman Bridge and Chesapeake Bay. The intensive survey showed that dissolved oxygen concentrations were below 4 mg/l much of the time for water at or below 4 metres depth. For intermediate depth (4 to 10 metres) values frequently were between 2 and 4 mg/l, while at great depths (more than 10 metres) values often were between 1 and 2 mg/l. These bottom waters even had a few readings below 1 mg/l. The exact cause of this condition, how it develops and so on are not well known. However, it appears that the physical processes are not capable of supplying enough oxygen to bottom waters to satisfy the oxygen demand. This occurs even though salinity stratification usually is not strong (surface to bottom differences of around 2 to 4 parts per thousand).

Model projections showed that similar conditions would exist in the future. Because of the large tidal prism, dilution is great, so that BOD, nutrient, fecal coliform and phytoplankton (chlorophyll "a") concentrations were low. Dissolved oxygen levels in the upper layer normally were above 5 mg/l but DO's in the bottom layer were virtually always below the 4 mg/l standard. The nonpoint loadings had very little impact on water quality, probably because the volume of dilution water is so large.

For the York River, control of point and nonpoint sources may not result in the desired water quality conditions. Point sources presently are few, especially given the large volume of the receiving waters and the strong tidal flushing. Nonpoint loads are not great, at least relative to some of the small estuaries, probably because federal facilities have maintained much of the drainage area in forest and other land uses which produced limited runoff of reasonable quality. Nonetheless, present (1978) conditions are not at desired levels. Non-traditional approaches may be required, such as installation of in-stream aerators. Additionally, there is a shallow sill (depth around 10 metres) where the river joins the Bay which is believed to inhibit circulation in the lower reaches of the river. Modification of the river geometry, in particular dredging a channel through the sill, might improve circulation patterns and water quality. Detailed examination of the bathymetry of the river and bay would be required plus appropriate engineering studies to demonstrate that this approach would work.

Back and Poquoson Rivers

Both Back River and Poquoson River had good water quality at the time of the July 1975 intensive surveys. However, pronounced diurnal fluctuations in dissolved oxygen concentrations indicated that algal levels perhaps were higher than desirable, as a result of nutrient enrichment. Examination of slack water data gathered in September 1975, shortly after a heavy rain storm, showed high nutrient levels and fecal coliform counts well above the standards for shellfish growing waters.

Model predictions were for generally good water quality. Following rain events fecal coliform levels are predicted to be higher than shellfish standards for two or three days. An algal bloom usually follows rain events by several days, with maximum chlorophyll "a" concentrations of about 40 µg/l in Back River and 20 µg/l in Poquoson River. Additionally, the

influx of BOD results in substandard DO levels in several segments of the Poquoson. Values in the upper reaches of Chisman Creek fall slightly below 4 mg/l for a day, while daily average DO's for portions of Bennett Creek are between 4.5 and 5 mg/l.

The impact of land use can be seen in the model results. Nonpoint BOD loads for the Poquoson were around 45% of those for the Back River for most rain events. However, the largest of the design storms had a total rainfall of nearly 4 inches, causing runoff even from agricultural lands. For this storm, the Poquoson nonpoint BOD load was about two-thirds of the load entering the Back. Since much of the Back drainage basin is urban in character, even small storms produce runoff, and as a result, nutrient levels and algal densities are relatively high. The Poquoson basin includes a larger portion of forest and agricultural lands, so that runoff and nonpoint loads are not great except for storms with heavy rainfall. At these times, though, the DO is depressed due to the relatively large nonpoint input of BOD.

Plots for both chlorophyll "a" and dissolved oxygen have been made for segments 2 (upriver) and 5 (near the mouth) of Back River for the period following the initial rain event. One can note that there is a very strong diurnal trend for both variables in reach #2, and that an algal bloom occurs following the storm. In segment #5, one can note a tidal variation to chlorophyll "a" concentrations in addition to the diurnal cycle. Although there is an impact due to the storm, the magnitude is greatly reduced, showing the moderating influence of the Bay on the lower reaches of the river.

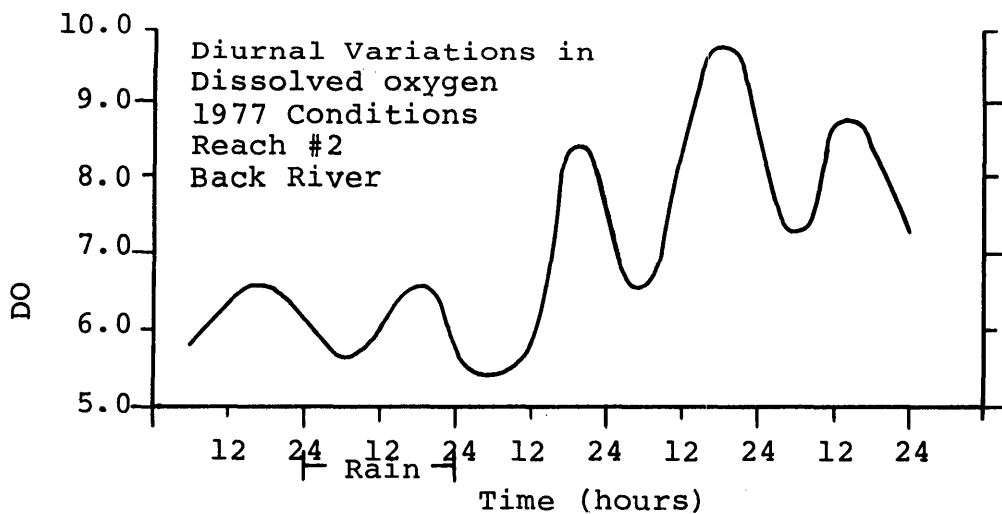
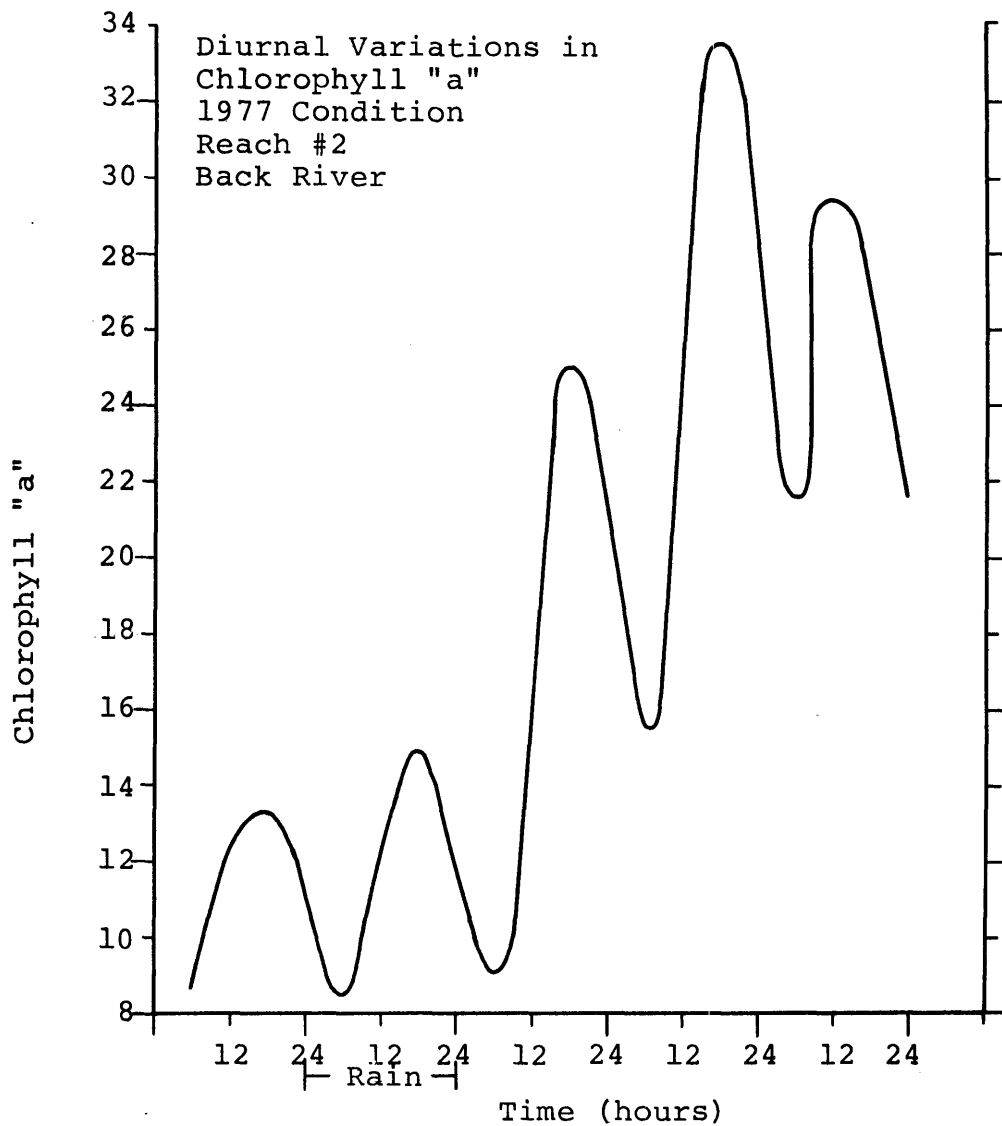


Figure 3. Variation in chlorophyll "a" and dissolved oxygen in Reach #2 of the Back River following initial design storm.

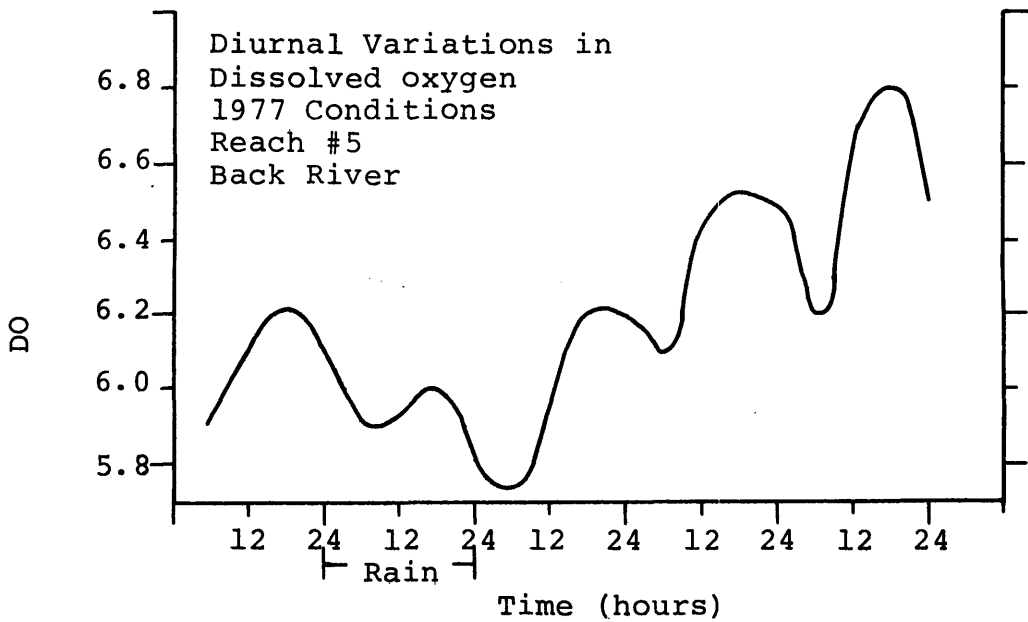
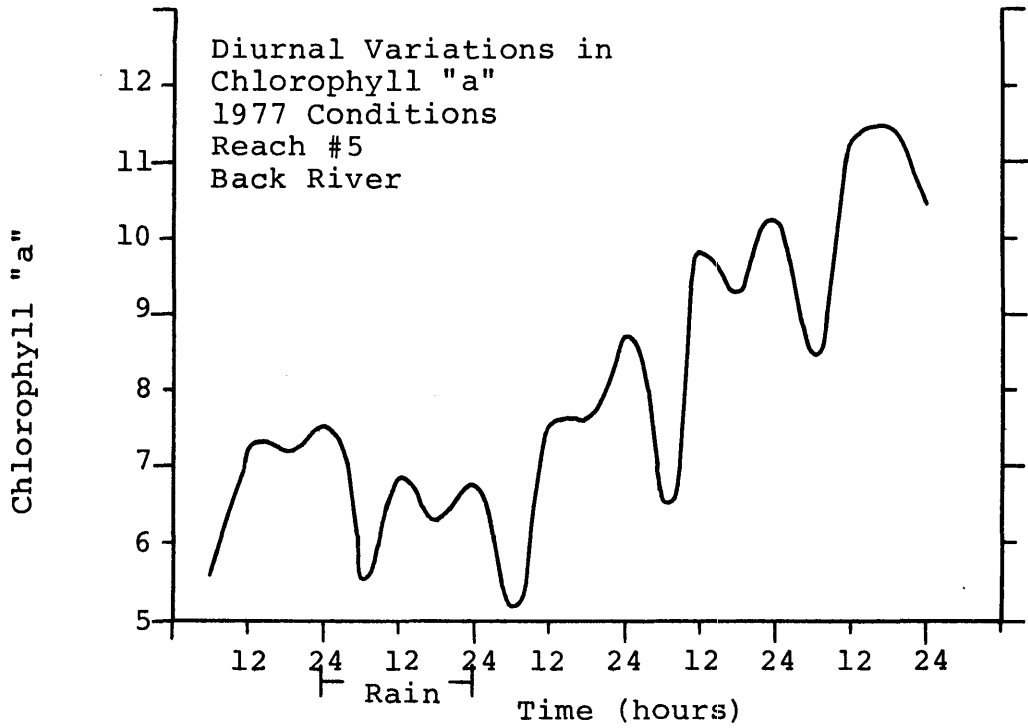


Figure 4. Diurnal and tidal variations in chlorophyll "a" and dissolved oxygen in Reach #5 of the Back River following the initial design storm.

Little Creek Harbor

Water quality in Little Creek Harbor during the September 1975 intensive survey was good, with the exception of bacterial quality. Both total and fecal coliform counts were well above the respective standards for shellfish growing waters. In fact, the harbor has been condemned since 1935, and the adjacent portion of Chesapeake Bay since 1969.

Model projections are generally quite similar. Since much of the natural drainage system for Little Creek has been dammed for many years to create water supply reservoirs for the City of Norfolk, very little stormwater runoff enters the harbor. Therefore, the impact of nonpoint sources is not great, except for bacterial quality. Fecal coliform counts remain above the shellfish standard for several weeks following a rain event. Dissolved oxygen levels in three model segments dropped slightly below 5 mg/l following the major 1995 design storm. Two of the segments recovered within a day, but the third segment required nearly 10 days to return to 5 mg/l. The minimum average DO value was only 4.75 mg/l even for this "worst case". Chlorophyll "a" values for Little Creek, the only branch of the Harbor that is not impounded, ranged up to 50 µg/l, which is probably excessive since the creek is shallow and tidal exchange is limited. Because the model gives tidal averages only, it is not possible to determine the daily fluctuation in DO's. Except for Little Creek, the harbor is not suitable for natural shellfish culture because of the water depth. Also, it is unlikely that health officials will open the area as long as naval vessels dock there. Since nonpoint loads are limited and water quality impacts slight, nonpoint source control measures are not urgently needed.

The Lynnhaven Bay System

Present water quality in Lynnhaven, Broad and Linkhorn Bays is good in most respects. During the September 1975 intensive survey, dissolved oxygen values were around 7 mg/l in Lynnhaven Bay and around 8 mg/l in Broad and Linkhorn Bays. Algal populations were not excessive; chlorophyll "a" concentrations were nearly always below 20 µg/l and averaged about 10 µg/l. Fecal coliform and total coliform levels were variable with the stage of the tide; values above the shellfish standards were observed at most stations. Public health officials state that stormwater runoff is sufficiently poor in quality to require closure of the shellfish grounds during rainy periods.

Modelling studies show that there will be some problems in the Lynnhaven system in the future. First, the model results indicate that during warm, dry weather (water temperature = 28°) some of the more upriver segments will have DO's less than 5 mg/l. This occurs in the Linkhorn Bay and the Eastern Branch of Lynnhaven Bay. It is interesting to note that this situation will develop in the Western Branch of Lynnhaven Bay if the Birchwood Gardens STP is eliminated. This somewhat anomalous result indicates both the limitations of the model and the role of phytoplankton in determining dissolved oxygen levels. First, the model predicts only conditions at high water slack, so that we cannot determine DO levels for intermediate times. Second the model is run using normal sunlight except during the rain events. Since sunlight is strong during the summer, there normally is a net production of oxygen from photosynthesis, hence, higher DO values. The STP effluent supplies the nutrients necessary for plankton growth. Therefore, when it is removed, nutrient levels decline and algal populations decrease as well. As a result of the lower algal density, DO levels drop too. This "scenario" might lead one to conclude that high levels of plankton were desirable. However, the negative side is that the variation in DO's between dusk (at the end of the growth period) and dawn (at the end of the non-growth period) can be great. DO concentrations can be

depressed to zero or near zero if there is an algal bloom or if a prolonged cloudy period exists. Stated in a different way, when phytoplankton levels are high, average DO's probably will be high, but the variation in DO concentrations during a day will be large as well.

Following rain events DO levels decline and fecal coliform levels increase. Within two or three days most of the system has bacterial levels less than the shellfish standard. Coliform levels, however, remain high for periods of a week or 10 days in the Little Neck Creek portion of Linkhorn Bay and the Western Branch of Lynnhaven Bay. The impact worsens with time since the quality of the runoff is projected to deteriorate over the years. Because land that is presently "open" will become residential in the future, the runoff will contain more nutrients, BOD and fecal coliforms. Land use changes are shown in the attached tables. 1995 projections were made for 7-day street sweeping and results were compared to other 1995 projections. Although pollutant loads were reduced, the extent of the impacted zone was not changed and water quality was improved only marginally.

It is not surprising that the dry weather violations were projected to occur in the Lynnhaven system rather than one of the other estuaries. First, the proximity of Lynnhaven Bay to the Atlantic Ocean means that this system will have high salinities. Secondly, Lynnhaven Bay is shallow in most places so that solar warming will be great; some areas probably will have water temperatures in excess of the 28^o used in the model studies. As a result of the high salinity and temperature, the saturation value for oxygen in water is low. This combined with the high rate of biological activity (and therefore rapid utilization of oxygen) can result in localized areas with DO's below the 4 mg/l standard, even during dry weather.

TABLE 1-A. Land Use of Drainage Basin of Western Branch of
Lynnhaven Bay: Existing and Future Projections
(source: Malcolm Pirnie Engineers, Inc.)

<u>Type</u>	<u>1977</u>	Percentage in	
		<u>1983</u>	<u>1995</u>
Residential (low density)	42.3	52.2	60.2
Residential (multi-family)	2.7	3.6	4.1
Commercial	9.0	16.2	20.1
Industrial	0.6	0.6	0.6
Institutional	2.3	4.0	5.0
Open	42.4	22.7	9.3
Tidal marsh	0.7	0.7	0.7

Total drainage area: 13,361 acres

TABLE 1-B. Land Use of Drainage Basin of Eastern Branch of
Lynnhaven Bay: Existing and Future Projections
(source: Malcolm Pirnie Engineers, Inc.)

<u>Type</u>	<u>1977</u>	Percentage in	
		<u>1983</u>	<u>1995</u>
Residential (low density)	32.2	40.6	47.4
Residential (multi-family)	2.2	2.7	3.0
Commercial	8.1	14.3	16.8
Industrial	6.9	7.1	7.3
Institutional	2.0	3.6	4.2
Open	48.4	31.5	21.1
Tidal marsh	0.2	0.2	0.2

Total drainage area: 13,727 acres

TABLE 1-C. Land Use of Broad Bay Drainage Basin:
Existing and Future Projections

(source: Malcolm Pirnie Engineers, Inc., 1977)

<u>Type</u>	<u>1977</u>	Percentage in <u>1983</u>	<u>1995</u>
Residential (single family)	24.4	28.6	34.3
Residential (multi-family)	5.8	6.2	6.7
Commercial	5.5	9.0	11.9
Industrial	3.6	3.6	3.6
Institutional	1.4	2.3	3.0
Open	59.3	50.3	40.5

Total drainage area: 11,435 acres

Summary and Conclusions

It is difficult to summarize the findings since each basin has a distinct and special character. However, some generalization of the findings is likely to provide a few insights into the nature of and problems caused by nonpoint sources of pollution.

First, for the major estuaries both the low water volume and the tidal prism are very large and tidal currents are strong, so that point and nonpoint loads are rapidly dispersed and greatly diluted. Therefore, these systems are relatively insensitive to loadings, and even large transient loads produce relatively small changes in water quality.

For the smaller estuaries, the assimilation capacity varies greatly from the mouth to the head. Near the mouth, tidal oscillations bring in large volumes of "new water" each flood tide, diluting and removing pollutants. Conditions there are controlled primarily by conditions in the larger estuary or bay to which the smaller one is tributary. Water quality measures show variations with tidal stage as well as time of day. In the headwaters, tidal currents are weak. Frequently, freshwater flows are small so that transport through the headwaters is slow. The result is poor water quality. The tidal variations of most measures of water quality are small relative to diurnal fluctuations. The impact of nonpoint loadings can be both large and long lasting. Since natural drainage systems often funnel the runoff to a few points, usually a large portion of the nonpoint load enters the estuary in its most upriver reaches, further aggravating water quality problems there.

Much work is needed to determine if there is any base freshwater flow during dry periods and to quantify these flows for both wet and dry periods. The numerous marshy areas which exist along many of the smaller estuaries affect the tides, nutrient concentrations in the water, sediment transport and other important aspects of water quality. Their role, especially when stormwater runoff must pass through such areas to reach the main channel, should be better defined in future studies.

Land use changes can either increase or decrease nonpoint loads. For example, forested areas produce little runoff and light loads. Therefore, transfer of the land to residential use generally means increased nutrient and fecal coliform loads. On the other hand, turning cropland into housing developments reduces the amount of sediment and nutrients that leaves the land with the runoff. In general, nonpoint load projections for 1995 did not differ significantly from those for 1977.

Nonpoint loads do not always vary directly with drainage area, land use differences and the existence of impoundments being two important factors which modify the nonpoint loadings. The three estuaries tributary to the James, in particular have large nonpoint loads. BOD loads for the design storm and 1995 conditions are listed by drainage basin in the following table:

BOD LOAD (IN POUNDS) FOR THE
MAJOR DESIGN STORM - 1995 CONDITIONS

<u>River</u>	<u>BOD (#)</u>
York	240,000
Poquoson	23,000
Back	36,000
Pagan	86,000
Nansemond	79,000
Elizabeth	200,000
James	183,000
Little Creek	6,000
Lynnhaven	37,000

The nonpoint load for the Elizabeth is actually larger than the load to the James between the mouth of the Chieka hominy River and Chesapeake Bay. The Pagan and Nansemond each receive nonpoint loads about half as large as that entering the James. Since these subestuaries are narrow, and shallow in their headwaters, it is not surprising that the impacts due to stormwater runoff were great.

Preliminary findings show that nonpoint sources are difficult to control and that the control measures do not necessarily reduce the loads to the degree required for some basins. It is unlikely that the fecal coliform problem can ever be resolved by control measures. However, since the bacteria die off in a geometric fashion, the impacts are short-lived. Reduction of benthic oxygen demand showed the biggest change for both wet and dry periods. However, it is not known if dredging of bottom sediments would be environmentally acceptable, if it would result in the desired change or that the change would be long-lasting.

The alteration of natural runoff patterns by impoundments is shown most clearly for the Little Creek system. All but one arm of the natural drainage system have been dammed for water supply reservoirs. As a consequence, nonpoint loads entering Little Creek Harbor were very small relative to the other coastal basins.

Water quality conditions for the entire study area were reasonably good with a few glaring exceptions. In general, projections were for conditions to improve between 1977 and 1995, although all problems will not be eliminated. When making such an analysis, one quickly becomes aware of the limited tools for gaging water quality. Outside of dissolved oxygen and fecal coliform standards, there are few guidelines. It is quite likely that several of the small estuaries already are overenriched and a few others are approaching this condition. Since the physical characteristics of the water bodies differ sharply, it is unlikely that a single standard, such as a chlorophyll "a" limit, will improve the situation. Rather, since the models are available, a set of test conditions should

be defined to assess the conditions. As a first step, the models could be run with prescribed periods of clear, sunny weather (to stimulate algal growth) followed by overcast periods (to determine the extent to which DO reserves will be depleted). Eventually, it would be good to know more about the changes in the plankton community which occur as densities increase.

Sometimes the results of the field surveys and model studies will not match up with colloquial descriptions of these systems. Although one or the other may be incorrect, this need not be the case. The 208 program included dissolved oxygen, nutrients, phytoplankton and fecal coliforms as the measures of water quality. The river systems, however, will respond to many other water and sediment constituents. For example, the field and model results showed few problems now and in the future for the James River. This differs from the perceptions of many watermen, sport fishermen and marine biologists. The work described in this report is able to show where BOD loads, nutrient enrichment or fecal contamination are a problem. For those instances where none of these problems occurred, and where the state of health of the system is commonly perceived to be poor, the list of causes has been reduced. In later studies, these problems need not be re-examined, but the resources should be directed to determine what is causing the water quality problems. For the case of the James, kepone is one obvious contaminant that has had deleterious effects on water quality. The 208 Studies were not able to include such toxic substances. They have shown that if the James is in poor shape it is not because of BOD loadings or eutrophication, but rather other variables are controlling the conditions in the river.