Marina Water Quality Models

Prepared for:

U.S. Environmental Protection Agency
Region IV
Atlanta, Georgia

Prepared by:

Tetra Tech, Inc.
Fairfax, Virginia

EPA Contract #68-C9-0013
Work Assignment Numbers 1-62 and 2-35

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EXECUTIVE SUMMARY

In 1985 U.S. Environmental Protection Agency (EPA) Region IV instituted a strong policy of protecting public uses of coastal waters from degradation by marina development. The sighting of new marinas has been influenced in particular by the need for protection of shellfish harvesting areas. Growth in the coastal areas of the southeastern United States during the past two decades has been accompanied by an increasing demand for recreational facilities such as marinas and boat maintenance facilities.

This report addresses the impacts of coastal marinas on water quality. Specifically, it deals with the selection and use of the best available computer models for analyzing the impact of a marina on water quality. A methodology for evaluating the water quality impacts of proposed marina development has been formulated. This methodology balances the need for accurate assessments of potential impacts with the limited data and resources often available during the planning stage of a project.

Initially, all water quality models applicable to marinas were surveyed and divided into three categories: simple, mid-range, and complex models. Simple models include desktop screening methodologies that calculate seasonal or annual mean pollutant concentrations based on steady-state conditions and simplified flushing time estimates. These models are designed to examine and isolate trouble spots for more detailed analyses. They should be used to highlight major water quality issues and important data gaps in the early stage of a study.

Mid-range models include computerized steady-state or tidally averaged quasidynamic simulation models, which generally use a box or compartment-type network. These models use a constant flow condition that neglects the temporal variability of tidal heights and currents. Tidally averaged models simulate the net flow over a tidal cycle. These models cannot predict the variability and range of dissolved oxygen (DO) and pollutants throughout each tidal cycle, but they are capable of simulating variations in tidally averaged concentrations over time. The mid-range models should be used to corroborate the results of the simple models when the simple models indicate adverse water quality impacts.

Complex models include computerized one-dimensional (1-D) models, quasi-2-D models, and a variety of 2-D intratidal models that simulate variations in tidal height and velocity throughout each tidal cycle. The complex models are generally composed of separate but compatible hydrodynamic and water quality models. These two models are run sequentially, and the output of the hydrodynamic model becomes part of the input to the water quality model. These models enable the characterization of phenomena rapidly varying within each tidal cycle, such as pollutant spills, stormwater runoff, and batch discharges. Complex models also are deemed appropriate for systems for which the tidal boundary impact, as a function of the hydrodynamics and water quality, is important to the modeled system within a tidal period. In their treatment of conventional pollutants, complex models deal mainly with biochemical processes. Complex models considered here can simulate simple biochemical oxygen demand-dissolved oxygen (BOD-DO) interactions. Complex models are also better predictive tools for proposed marinas.

The best qualified model in each category was selected. The selection criteria were appropriateness when applied to a variety of marina types (including one-segment, two-segment, three-segment, flow-through, and open water marinas) and the usefulness of each assessment technique for determining water quality impacts (i.e., how well it can predict DO variations). The Tidal Prism Analysis and the NCDEM DO model were selected as the method of choice in the simple model category. The Tidal Prism Model (TPM) is recommended for the mid-range category, and the Water Quality Analysis Simulation Program (WASP4) is the model of choice for the complex category. A variation of WASP4 using a full two-dimensional hydrodynamic model is also recommended for proposed marinas.

The best qualified models were applied to two coastal marinas in the southeastern United States. Results of model calibrations and applications are summarized herein. Comparisons between predicted and observed data are documented for the two applications. Furthermore, a water quality analysis of a proposed recreational boat canal is included. This example demonstrates the application of a complex model to a proposed marina site.

The predictive models (tools) are recommended for use by regulatory agencies as well as developers to determine and evaluate problem areas pertinent to marina development. It is anticipated that marina developers will utilize the models to determine whether a proposed marina will be in compliance with water quality regulatory requirements.

1. INTRODUCTION

1.1 Background

In 1983, the U.S.Environmental Protection Agency (EPA) Region IV Environmental Assessment Branch initiated an environmental assessment of the development and operation of coastal marinas. The study responded to existing resource-use conflicts between shellfishermen and marina developers in Region IV coastal states and addressed the growing regulatory concerns for balancing the development and operation of coastal marinas with the need to conserve and protect coastal resources. The objectives of the assessment were to identify pertinent environmental concerns and issues and to provide guidance for environmentally sound coastal marina development and operation.

In 1985 EPA Region IV instituted a strong policy of protecting public uses of coastal waters from degradation by marina development. The sighting of new marinas has been influenced by the protection of shellfish harvesting areas in particular. The coastal areas of the Southeast have undergone significant residential, industrial, and commercial growth during the past two decades. This growth has been accompanied by an increasing demand for recreational facilities such as marinas and boat maintenance facilities.

The *Coastal Marinas Assessment Handbook* (April 1985) was developed by the NEPA Compliance Section of the Environmental Assessment Branch. This handbook provides information on environmentally sound practices for the sighting and development of coastal marinas. However, recent studies and new policies regarding coastal marinas have afforded new insights and approaches for dealing with coastal marina issues.

Several states have already decided that the newly created basin connected to Class SA waters would automatically carry the SA (shellfishing) classification, even if its intended purpose was for use as a marina. The intent of this action was to encourage the construction of marina basins in dug-out, high-ground areas rather than in SA waters. Initial evaluation of some proposed sites indicated the possibility of dissolved oxygen problems.

The design, construction, and operation of coastal marinas and associated boating activities have the potential for undesirable environmental impacts to marine and coastal ecosystems. The potential for environmental impacts and their significance will not be the same for all marinas. Many factors work to determine the eventual impact a marina will have on the water quality within the immediate vicinity of the marina and areas of the adjacent waterway. Initial marina site selection is one very important factor. Selection of a site that has favorable hydrographic characteristics and requires the least amount of modification can do a great deal to reduce potential water quality impacts. Because of the potential impacts marina development can have on dissolved oxygen concentrations, many waters with average dissolved oxygen concentrations barely at or below state standards would be found unsuitable for marina development.

Marina-related development and operation activities are also significant factors impacting water quality. Dredging and dredged material disposal, wastewater disposal, fueling operations, stormwater runoff, and boat maintenance and repair are typical development and operation activities. Discharges from marine sanitation devices and bilges can also impact water quality in the marina waters. In inadequately flushed basins, discharges from these sources have the potential to reduce dissolved oxygen supply and to increase turbidity, sewage bacteria concentrations, and nutrient, metals, or hydrocarbon levels.

Perhaps the most significant factor affecting a marina's potential for water quality impacts is basin configuration. Whether a marina has open construction (i.e., is located directly on a river, bay, or barrier island) or semi-enclosed construction (i.e., is located in an embayment or other protected area) affects circulation and flushing characteristics, which play important roles in the distribution and dilution of potential contaminants. Circulation and flushing can be influenced by the natural or dredged basin orientation regarding prevailing winds. The final design is usually a compromise that will provide the most desirable combination of marina capacity, services, and access, while minimizing environmental impacts, dredging, protective structures, and other site development costs (Tetra Tech, 1988).

The construction and operation of marinas have been shown to have the potential for adverse impacts on water quality and aquatic organisms. Increasingly, it has been found that marina activities can adversely impact water quality. A study conducted by the North Carolina Department of Environmental Management (NCDEM,1990) pointed out, among other findings, that increasing the number of segments in a marina design decreases dissolved oxygen in the basin and in the surrounding waters. Several state regulatory agencies require that applicants for proposed marinas provide a documented water quality assessment to show that water quality standards will not be violated. The types of impacts on water quality resulting from marinas include the following:

- Microbiological contamination of adjacent shellfish and swimming areas;
- Depletion of dissolved oxygen in the water or in the sediments;
- Disruption of the bottom during dredging and positioning of pilings;
- Leaching of chemicals used to protect boats and wooden dock structures from destruction and fouling by marine organisms;
- Introduction of microbial pathogens or substances with a high biological oxygen demand into the water during marina construction or through the deliberate or accidental discharge of sanitary wastes from boats;
- Introduction of petroleum hydrocarbons into the water during normal boat engine operations; and
- Shoreline erosion due to bulkheading and motorboat wake.

1.2 Objectives

To determine the effects of the above processes, a valid site-specific water quality assessment that includes modeling should be implemented. This report addresses the coastal marina issues, dealing with their impact on water quality. Specifically, it discusses selecting and using the best available computer models for analyzing a marina's impact on water quality. The purposes of this report are the following:

1. Review available information.
2. Select the best available marina water quality models.
3. Compare model capabilities.
4. Develop a comprehensive data collection plan.
5. Calibrate and evaluate the recommended models.

This report provides information on the recommended environmental assessment methods for predicting potential impacts to water quality. Predicting the dissolved oxygen and fecal coliform concentrations in a coastal marina is the primary focus of the impact assessment methods presented in this report. These assessment techniques can be used by decision-makers when evaluating marina permit applications. These predictive tools should also be used by marina developers to show that a proposed marina will be in compliance with water quality regulatory requirements.

1.3 Report Organization

This report is organized into seven chapters and six appendices. Chapter 2 reviews available information concerning marina modeling and monitoring studies. The focus of the chapter is to describe all known numerical models and methods appropriate for solving marina water quality problems. For this study, only public domain models are considered. Models considered are grouped into three categories: simple, mid-range, and complex models. The list of all known marina water quality methods is reduced to a short list of those models that best meet the needs of the regulatory agencies. Reasons for including a model on the short list are also discussed.

Chapter 3 provides an overview of the short-listed simple, mid-range, and complex marina water quality models. This chapter summarizes data requirements and operating costs for the short-listed models. In addition, Chapter 3 discusses the applicability of the selected model to marina type and to water quality constituents modeled.

Chapter 4 discusses the mathematical models that are recommended to address marina water quality issues. A listing of the input variables required by the short-listed models is provided. Chapter 4 discusses the reasons for selecting the best qualified models and presents a brief description of each of the recommended models.

Chapter 5 provides a data collection plan for the best qualified models. The plan documents the physical and water quality information necessary to properly apply the best qualified marina models.

Chapter 6 summarizes and reviews data collected at three marinas in the Southeast, discusses the nature of the available data, and identifies data gaps. In addition, Chapter 6 presents the results of the application of the best qualified simple, mid-range, and complex models to the three Southeast marinas. The models are calibrated using the available data. Model predictions are then compared to observed data taken at the two marinas. Chapter 6 also evaluates the best qualified models according to their performance.

Chapter 7 presents a summary of the major findings of this study along with recommendations.

Appendix A presents annotated input data files for the best qualified simple, mid-range, and complex models. Appendix B provides a user's guide for the selected models, and Appendix C provides a contact list of key persons who provided valuable information and publications relevant to this study. Appendix D contains additional information that was generated during the WASP4 model application. Appendix E describes a successful model application to a proposed recreational boat canal on the St. Johns River, Florida. Finally, Appendix F presents the sensitivity analysis results for the simple, mid-range, and complex marina models.

2. MODEL SELECTION AND REVIEW

2.1 Model Sources

The identification phase of finding relevant models was multifaceted. The first approach was a sampling of the agencies now dealing with marina water quality issues. The environmental agencies of the states of Delaware, Florida, and North Carolina were contacted. Those responding said they had no set procedures or models by which to evaluate water quality. They reported that they dealt with applications or problems on a case-by-case basis or they referred to the simplified approaches discussed later in this report. There were no procedures in place to address complex problems requiring numerical models.

The second approach was a review of the literature. A number of estuarine and coastal modeling monographs that survey available models and discuss model applications have them published (Heaps, 1986; Nihoul, 1979, Nihoul and Jamart, 1987; Fischer, 1981; Johns, 1983; Ramming and Kowalik, 1980). Additional source material was sought in the refereed literature *(Journal of Hydraulics, Marine Technology Society, Estuarine, Coastal and Shelf Science)* and reports from universities and other organizations.

The third approach was networking within the modeling community. This approach was most fruitful, particularly networking accomplished through an American Society of Civil Engineering (ASCE) conference held on Estuarine and Coastal Modeling in Newport, Rhode Island, November 15-17, 1989. The emphasis of this conference was on two- and three-dimensional numerical model development and applications for both hydrodynamic and water quality models. A number of modelers were queried as to the status and availability of their models.

A recommendation for full 3-D models is difficult. Full 3-D models that can predict longitudinal, lateral, and vertical transport are the most complex and expensive models to set up and to run. The 3-D models are newer than 2-D models and therefore have fewer applications by which to determine their usefulness. Most 3-D models are considered research tools.

2.2 Model Attributes

The focus of this section is the description of all known numerical models appropriate for solving marina water quality problems. Not surprisingly, these models were developed with the much larger viewpoint of coastal and estuarine hydrodynamics and pollutant transport. In fact, most of the models are model systems composed of a hydrodynamic model to predict circulation patterns and a water quality model that uses those patterns along with biochemical kinetics to predict concentrations of various water quality parameters. There is no feedback from the water quality model to the hydrodynamics, and therefore the models can be run serially with the hydrodynamic model calibrated and verified first.

Marina water quality models may be classified in different and somewhat arbitrary ways. Some models may not quite fit into any category; others may fit well into several categories. In addition, models tend to evolve with use and the exact capabilities of the individual models described here may change. Therefore, for simplicity, water quality models applicable to marinas are divided into three groups: (1) simple models, (2) mid-range models, and (3) complex models. Models selected for discussion here are listed in Table 2-1. These models are general purpose, in the public domain, and available from or supported by public agencies.

Models summarized in this section represent the typical range of capabilities currently available. Other available computer programs can generally be grouped into one of the following categories:

- Variants of the models discussed here;
- Proprietary models held by consulting firms; or
- Models developed for research purposes.

In this chapter, Sections 2.2.1 through 2.2.3 briefly describe the range of mathematical models that are available to address marina water quality issues and specify available documentation.

Section 2.3 presents a "short list" of recommended models that are capable of assessing potential water quality impacts from a coastal marina. The short list contains between two and five models in each of the these categories (simple, mid-range, and complex).

2.2.1 Simple Models

The methods listed here include desktop screening methodologies that calculate seasonal or annual mean pollutant concentrations based on steady-state conditions and simplified flushing time estimates. These models are designed to examine and isolate trouble spots for more detailed analyses. These methods should be used to highlight major water quality issues and to identify data gaps in the early stage of a study.

2.2.1.1 Tidal Prism Analysis

The impact assessment methods presented in Chapter 4 of the *Coastal Marina Assessment Handbook* (EPA, 1985) are appropriate screening tools. Methods presented in this section, particularly some of the mathematical descriptions, are simplifications of more sophisticated techniques. However, these techniques as presented can provide reasonable approximations for screening potential impact problems when site-specific data are not available.

TABLE 2-1. List of Marina Water Quality Models

Simple Models	Mid-range Models	Complex Models
Tidal Prism Analysis Flushing Characteristics Diagram	North Carolina Division of Environmental Management (NCDEM) DO Model Tidal Prism Model	Water Quality Assessment Simulation Program (WASP4) Dynamic Estuary Model (DEM) M.I.T. Dynamic Network Model (MITDNM) Waterways Experiment Station Model (CE-QUAL-W2) H.S. Chen Two-Dimensional Water Quality Model (WQM2-D) M.I.T. Tidal Embayment Analysis and Eulerian-Lagranian Transport Models (TEA/ELA) M.I.T. CAFE-1/DISPER-1 Models Waterways Experiment Station Open-Channel Flow and Sedimentation Model (TABS-2) Waterways Experiment Station Implicit Flooding Model (WIFM) Solute Transport Model for Tidal Canal Networks (CANNET3) Waterways Experiment Station Three-Dimensional Models (CH3-D/CBWQM)

Flushing Characteristics

Semi-enclosed Marina

Flushing time for a marina within a semi-enclosed area (Figure 2-1) can be estimated using simplified dilution calculations. For semi-enclosed marinas the flushing time can be approximated by the following equation:

$$T_F = \frac{[T_C \times LOG(D)]}{LOG\left(\frac{(A \times L)+(b \times A \times R)-(I \times T_C)}{(A \times H)}\right)} \tag{2-1}$$

If nontidal freshwater inflow from runoff or stream discharge into the marina basin can be ignored and the marina has relatively vertical sides, Equation 2-1 becomes:

$$T_F = \frac{[T_C \times LOG(D)]}{LOG\left(\frac{(A \times L)+(b \times A \times R)}{(A \times H)}\right)} \tag{2-2}$$

and for marinas with nonvertical sides Equation 2-2 becomes:

$$T_F = \frac{[T_C \times LOG(D)]}{LOG\left(\frac{V_L+b \times V_P}{V_H}\right)} \tag{2-3}$$

where:

T_F = Flushing time (hours)
T_C = Tidal cycle (hours)
A = Surface area of marina (m^2)
D = Desired dilution factor
R = Range of tide (m)
b = Return flow factor (dimensionless)
I = Nontidal freshwater inflow (m^3/hour)
R = Range of tide (m)
b = Return flow factor (dimensionless)
I = Nontidal freshwater inflow (m^3/hour)
L = Average depth at low tide (m)
H = Average depth at high tide (m)
V_L = Volume of marina at low tide (m^3)
V_H = Volume of marina at high tide (m^3)
V_P = Volume of marina tidal prism (V_H - V_L)

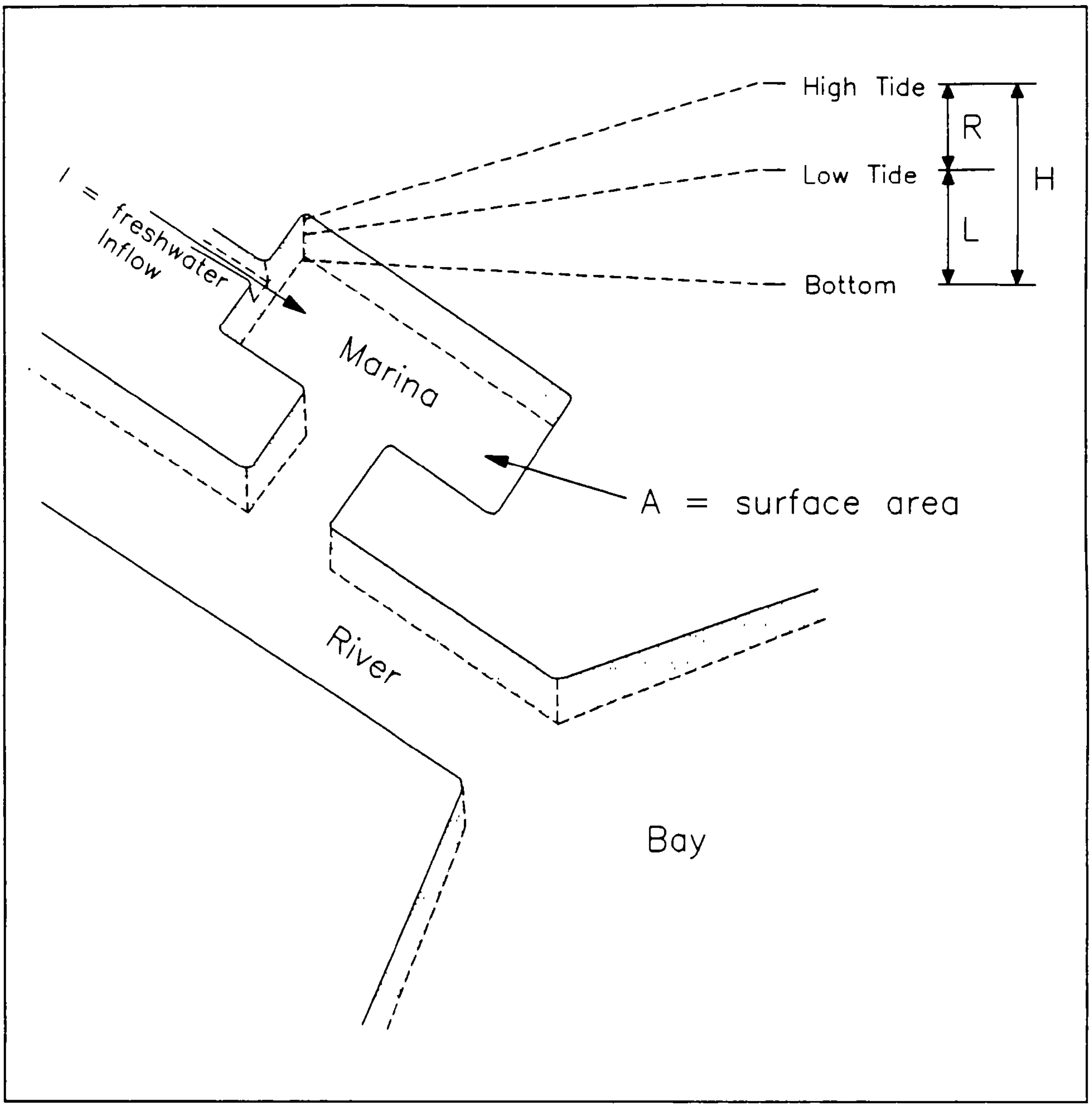

Figure 2-1. Representative Semi-enclosed Marina Basin.

Open Marinas

Marinas located directly on rivers, bays, or estuaries (Figure 2-2) and not entirely enclosed by protective barriers would have flushing characteristics generally similar to those for the water body. The actual flushing potential of a specific area within a large water body can be characterized using the fraction of freshwater method (Mills et al., 1985)

$$T_F = \sum_{i=1}^{n} \left(\frac{\frac{S_W - S_i}{S_W} \ x \ V_i}{I_i} \right) \tag{2-4}$$

where:

T_F = Flushing of total water body (hours)
S_W = Seawater salinity (ppt)
S_i = Mean salinity in the segment (ppt)
V_i = Freshwater volume in segment i (m^3)
I_i = Freshwater inflow in segment i (m^3/hour)
n = Number of segments

Dilution Methods

Semi-Enclosed Marinas

For a slug addition of pollutant in a semi-enclosed marina basin, pollutant concentrations can be estimated by using an expression such as (EPA, 1985):

$$C_t = \left[\frac{A \ x \ L \ + b \ x \ A \ x \ R}{A \ x \ H} \right]^N x \left[\frac{M}{F_{11} \ x \ V_L} \right] e^{-kt} + C_A \ x \ e^{-kt} \tag{2-5}$$

where:

C_t = Concentration of pollutant at time t (mg/L)
C_A = Ambient concentration of pollutant prior to addition of discharge (mg/L)
M = Mass of pollutant discharged into basin (mg)
k = Decay rate for nonconservative pollutants (day^{-1})
t = Time (days)
N = Number of tidal cycles ($24t/T_c$)
F_{11} = 1000 (converts units to mg/L)

All other parameters are as defined previously in Equations 2-1 through 2-3.

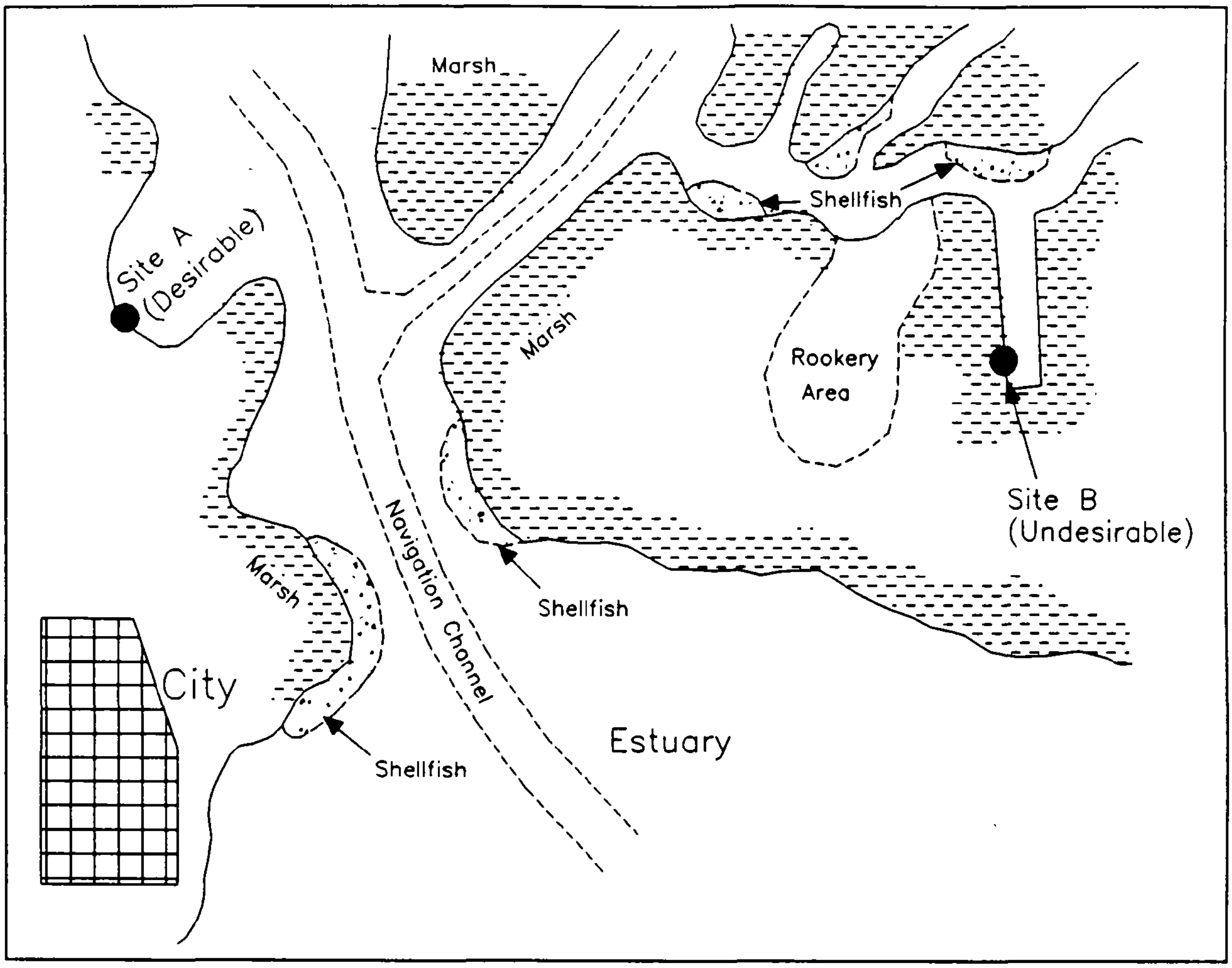

Figure 2-2. Representative Open Marina Basin (Site A).

For a continuous discharge of pollutant into a marina basin, an estimate of long-term concentrations (steady-state conditions) may be obtained by:

$$C = \frac{M_r \ x \ T_c \ x \ F_{12}}{(1 - b) \ x \ V_p} + C_A \tag{2-6}$$

where:

- C = Concentration of conservative pollutant (mg/L)
- M_r = Total mass flow rate of pollutant into basin, including input by freshwater inflow (mg/day)
- F_{12} = 4.7 x 10^{-5} (converts units to mg/L)

All other parameters are as defined previously in Equations 2-1 through 2-3.

Equation 2-6 estimates steady-state concentrations for conservative pollutants. For cases where nonconservative pollutant concentrations versus time are of interest, Equation 2-7 may be used:

$$C_n = \left[\left(\frac{V_L + bxV_P}{V_H} \right)^n x \ e^{\frac{-kT_c}{24}} x \ C_A \right] x \ e^{\frac{-kT_c}{24}} + \left[\frac{T_c \ x \ M_r}{24000 \ x \ V_H} + \frac{(1 - b) \ x \ V_P \ x \ C_A}{V_H} \right] x \sum_{i=1}^{n} \left[\frac{V_L + bxV_P}{V_H} \ x \ e^{\frac{-kT_c}{24}} \right]^{(i-1)} x \ e^{\frac{-kT_c}{24}} \tag{2-7}$$

Equation 2-7 approximates the continuous dilution of a pollutant discharged into the marina basin, resulting in a lower cumulative concentration over the flushing time than would be estimated using Equation 2-2. Therefore, if Equation 2-2 produces results that are acceptable, such as an indication that the pollutant concentration will be low, the more complex Equation 2-3 may be avoided.

Equations 2-1 through 2-3 represent desktop screening methodologies for estimating pollutant concentrations. The methodologies are intended for identifying trouble spots prior to more sophisticated analyses. *Water Quality Assessment: A Screening Procedure for Toxic and Chemical Pollutants* (Mills et al., 1985) provides additional and more detailed descriptions of the screening methodologies. When required, more sophisticated analyses of pollutant fate and transport can be accomplished through the use of estuarine water quality models as described in Section 6.3.4.

Dissolved Oxygen

Low dissolved oxygen levels are indicators of serious water quality impacts that may result from poorly designed and maintained marinas (NCDEM, 1990). Assessments of DO impacts are complicated because the kinetics of dissolved oxygen are very complex and because the DO concentrations vary greatly over short periods of time (Thomann and Mueller, 1987).

The best way to assess marina impacts on water quality is to design a sampling strategy and physically measure dissolved oxygen values. During the sampling, sediment oxygen demand and other data can be collected, which may be used to estimate future dissolved oxygen levels using mathematical modeling procedures described in the *North Carolina Coastal Marinas Water Quality Assessment* (NCDEM, 1990) and the *Technical Guidance Manual for Performing Wasteload Allocations* (EPA, 1989). Prior to data collection, screening procedures such as the equation below and those described in Thomann and Mueller (1987) and Mills et al. (1985) may be used to identify trouble spots. Equations 2-8a and 2-8b may be used to successively estimate dissolved oxygen concentrations at high and low tide in a semi-enclosed marina.

$$DO_H = \Big(1000 \times DO_A \times V_P + 1000 \times V_P \times (DO_S - DO_A) \times (1 - e^{-k_a \times \frac{T_c}{24}}) - 1000 \times V_L \times C_B \times (1 - e^{-k_1 \times \frac{T_C}{24}}) - B \times A \times \frac{T_C}{24} + 1000 \times V_L \times DO_L + DO_I \times I \times T_C\Big) / (1000 \times V_H) \tag{2-8a}$$

$$DO_L = \frac{1000 \times DO_H \times V_L - 1000 \times V_L \times C_B \times (1 - e^{-K_1 \times \frac{T_C}{24}}) - \frac{B \times A \times T_C}{24}}{1000 \times V_L} \tag{2-8b}$$

where:

DO_H	=	Approximate dissolved oxygen at high tide (mg/L)
DO_A	=	Ambient dissolved oxygen of water flushing into marina (mg/L)
DO_L	=	Dissolved oxygen level in marina at low tide (mg/L)
DO_I	=	Dissolved oxygen in nontidal freshwater inflow (mg/L)
K_1	=	Oxidation coefficient (day^{-1})
DO_S	=	Saturated dissolved oxygen concentration (mg/L)
k_a	=	Reaeration coefficient (day^{-1})
B	=	Sediment oxygen demand ($mg/m^2/day$)
C_B	=	Biochemical oxygen demand (mg/L)

Equation 2-8a may be used to estimate dissolved oxygen levels for successive high tides by using the new value of DO_H in place of DO_L. Initially, the value of DO_L is set equal to DO_A, which is assumed constant over the period of analysis. Reaeration due to mixing, photosynthesis, or other sources is not considered. Loss of DO due to nitrification also is not considered.

2.2.1.2 Flushing Characteristics Diagram

Christensen (1989) presented a simple analytical model that can be used to evaluate the flushing characteristics of coastal marinas and residential canal systems. This method is developed in the form of a convective one-dimensional (plug-flow) model that will provide the flushing time of a system with a given layout. Tidal action and wind effects are considered, and both dead-end and flow-through systems are treated.

In the case of tidal flushing without flow-through action, both accidental and continuous inflow of pollutant are considered. Marina flushing time is calculated through use of formulas and charts provided in Christensen's paper. Christensen (1989) also shows that unsatisfactory flushing can be improved by introducing marsh areas and/or reducing the mean water depth. The use of this approach is demonstrated in the second numerical example.

Wind-induced flushing is considered in flow-through and dead-end systems. Formulas for the flushing time and the time required for the wind to accelerate the water to a useful velocity are also provided.

The Flushing Characteristics Diagram is applicable only to conservative substances; however, this method is applicable to all marina types (i.e., open, semi-enclosed, and flow-through systems).

2.2.2 Mid-range Models

This section focuses on the numerical mid-range models appropriate for solving marina water quality problems. This category includes computerized steady-state or tidally averaged quasidynamic simulation models, which generally use a box or compartment-type network. Steady-state models use an unvarying flow condition that neglects the temporal variability of tidal heights and currents. Tidally averaged models simulate the net flow over a tidal cycle. These models cannot predict the variability and range of DO and pollutants throughout each tidal cycle, but they are capable of simulating variations in tidally averaged concentrations over time. The mid-range models should be used to corroborate the results of the simplified methods discussed in the previous section when the simplified methods indicate adverse water quality impacts.

2.2.2.1 North Carolina Division of Environmental Management DO Model

This model assumes that the marina to be evaluated can be approximated by two segments. A one-segment version of the model should be used for basins without a distinctive inlet channel.

Runoff is assumed to be equal to zero, and the volume of wastewater discharged to the basin other than from boats is also assumed to be equal to zero. The forcing function is the changing depth of the ambient water, which brings water into the marina during the rising tide and takes it out during the falling tide.

An initial version of this model utilized a return flow factor (b). Dye studies conducted by NCDEM (1990) seemed to indicate that little or none of the water that had previously been in the marina returned on the next tide. Therefore, the return flow factor has been eliminated from the current version of the model.

The tidal variation is assumed to follow a sinusoidal distribution. For simplicity a 12-hour tidal cycle is used. Calculations are performed at hourly time increments. Each segment is assumed to be completely mixed at the end of each time increment.

Changes in DO are possible from advection, reaeration, or bottom sediment oxygen demand. Boat discharges were included in an earlier version, but they were shown to be of minor effect and have been eliminated from the current version. The average DO in the inlet channel or the marina basin for a given tidal cycle is the average of hourly values through that cycle. The computer model assumes some initial values, iterates through 18 tidal cycles, and then prints out the results of the next two tidal cycles. This allows sufficient interactions for a steady state to be reached. The program is written in BASIC for use on an IBM-compatible computer.

2.2.2.2 Tidal Prism Model

A water quality model has been developed for easy application to small coastal embayments. The simulation of physical transport processes is based on Ketchum's tidal prism theory, modified and expanded such that it becomes applicable to cases where the embayment is treated as a branch and/or freshwater discharge is negligibly small. A model coastal embayment is divided into segments of lengths equal to local tidal excursions. Instead of starting the segmentation from the landward end with freshwater discharge and tidal prism as two non-zero parameters, the modified model subdivides the water body starting from the seaward end with the difference between tidal prism and freshwater discharge as a single parameter. The mass balance within each segment is formulated by considering the exchange of water with its neighboring segments due to the flushing of freshwater discharge, as well as the tidal prism on ebb cycle, and due to the mixing of the tidal prism on flood tide. This results in an algebraic equation that may be solved for concentration in each segment by successive substitution. For a nonconservative substance, the biochemical reaction terms are then added to the algebraic equation without complicating the solution scheme. The model has been applied to a number of tidal creeks and coastal embayments in Virginia (Kuo, 1976; Kuo et al., 1988).

The nonconservative substances considered in the model include organic nitrogen, ammonia nitrogen, nitrate-nitrite nitrogen, organic phosphorus, inorganic phosphorus, phytoplankton (chlorophyll-*a*), carbonaceous biochemical oxygen demand, dissolved oxygen, and fecal coliform.

Given the initial conditions or calculated concentration fields at the slack-before-ebb (SBE) that initiates a tidal cycle, the calculation of the concentrations at the succeeding SBE is performed in two steps. First, the concentration fields are calculated assuming that only the physical transport processes are in action. Second, the calculated concentration fields are adjusted for the relevant chemical and biological processes.

2.2.3 Complex Models

This category includes computerized one-dimensional (1-D) models, quasi-2-D models, and a variety of 2-D intratidal models that simulate variations in tidal height and velocity throughout each tidal cycle. The 2-D models may be further divided into two broad categories, 2-D vertically averaged (x-y) and 2-D laterally averaged (x-z).

Although many 2-D vertically averaged, finite-difference or finite-element hydrodynamic programs exist, relatively few contain a water quality program that simulates constituents other than salinity and/or temperature (Blumberg, 1975; Hamilton, 1975; Elliot, 1976). Examples of finite-element models, often preferred for complex coastlines, are the CAFEI/DISPERI and TEA/ELA hydrodynamic and transport models and a water quality model developed by Chen (1978). The first two models can simulate only mass transport of a nonconservative constituent, whereas Chen's model is capable of representing most major water quality processes.

A number of 2-D, laterally averaged models (longitudinal and vertical transport simulations) treat mass transport of salt and temperature, but very few include nonconservative constituents or water quality routines. Models in this category simulate vertical stratification but neglect lateral effects, including Coriolis effects. The Waterways Experiment Station (WES) CE-QUAL-W2 model (WES, 1986) is included in this category.

The complex models are generally composed of separate but compatible hydrodynamic and water quality models. These two models are run sequentially, and the output of the hydrodynamic model becomes part of the input to the water quality model. These models enable the characterization of phenomena rapidly varying within each tidal cycle, such as pollutant spills, stormwater runoff, and batch discharges. Complex models also are deemed appropriate for systems where the tidal boundary impact, as a function of the hydrodynamics and water quality, is important to the modeled system within a tidal period.

In using complex models, one must decide whether a simple 1-D link-node longitudinal system is sufficient or whether a quasi-2-D model with branching networks or triangular/rectangular configuration is required to model the longitudinal and lateral variations in a proposed marina. The length of model segments or links depends on the resolution required. The length and position of segments depend on the physical properties of the marina. Homogeneity of physical characteristics should be the basis for defining segments. Where bends, constrictions, or other changes occur, smaller segments are generally defined to improve resolution.

The quasi-2-D model is applicable where there is a need to project lateral differences in water quality. However, the quasi-2-D model, which uses 1-D equations of motion, cannot estimate longitudinal and lateral dispersion as effectively as the true 2-D model. Although the quasi-2-D and the true 2-D model both assume that the marina is vertically well mixed, the true 2-D model can effectively represent lateral variation in velocity and constituent concentration for embayments with nonuniform cross-sections and branching channels. The 2-D model also can account for the effect of Coriolis force and wind circulation.

In their treatment of conventional pollutants, complex models deal mainly with biochemical processes. All complex models considered here can simulate simple BOD-DO interactions. Most of these models also are formulated to simulate the reactions and interactions of organic phosphorus and orthophosphorus; organic nitrogen, ammonia, nitrite and nitrate; algal growth and respiration; and DO. These models also include settling rates and benthic flux rates for several different constituents such as phosphorus, nitrogen, and sediment oxygen demand.

2.2.3.1 Water Quality Analysis Simulation Program, WASP4

The Water Quality Analysis Simulation Program (WASP4) is a dynamic compartment modeling system that can be used to analyze a variety of water quality problems in one, two, or three dimensions. WASP4 simulates the transport and transformation of conventional and toxic pollutants in the water column and benthos of ponds, streams, lakes, reservoirs, rivers, estuaries, and coastal waters. The WASP4 modeling system covers four major subjects: hydrodynamics, conservative mass transport, eutrophication-dissolved oxygen kinetics, and toxic chemical-sediment dynamics. The modeling system also includes a stand-alone link-node hydrodynamic program, DYNHYD4, that simulates the movement of water.

WASP4 contains two separate kinetic submodels, EUTRO4 and TOXI4, each of which serves a distinct purpose. EUTRO4 is a simplified version of the Potomac Eutrophication Model (PEM) and is designed to simulate most conventional pollutant problems. EUTRO4 can simulate up to eight state variables: ammonia nitrogen, nitrate nitrogen, inorganic phosphorus, phytoplankton carbon, carbonaceous BOD, dissolved oxygen, organic nitrogen, and organic phosphorus. TOXI4 simulates organic chemicals, metals, and sediment in the water column and underlying bed. TOXI4, EUTRO4, and DYNHYD4 can be obtained from the Center for Exposure Assessment Modeling, Athens, Georgia.

DYNHYD4 is a link-node model that may be driven by either constantly repetitive or variable tides. Unsteady inflows may be specified, as well as wind that varies in speed and direction. DYNHYD4 produces an output file of flows and volumes that is read by WASP4 during the water quality simulation.

Typically, the hydrodynamic submodel (DYNHYD4) is calibrated to measure tides and velocities in the water body. However, this is not possible for a proposed marina. Instead, a 2-D hydrodynamic model (i.e., CAFE-1 and/or TEA) is applied and calibrated for the proposed marina. Calibration of DYNHYD4 is accomplished through successive adjustment of channel roughness and channel geometry (hydraulic radius and width) until the velocities in the DYNHYD4 model channels match those from the 2-D model. This approach was successfully applied to a proposed recreational boat canal in Florida. Appendix E of this report demonstrates in further detail the appropriateness of this approach.

The WASP4 model system is supported by EPA and has been applied to many aquatic environments (e.g., Tetra Tech, 1990). The water quality component is set up for a wide range of pollutants; however, the hydrodynamic component is rather simplistic. The WASP4 model, though weak in the hydrodynamic component (DYNHYD4), is a full approach to water quality and is relatively complete. The WASP4 model can be used in 1-D, 2-D, or 3-D problems although it is difficult to use because it requires a large number of constants. The use of WASP4 as a water quality component with the 2-D or 3-D hydrodynamic models is also a potential solution for complex multidimensional problems.

2.2.3.2 Dynamic Estuary Model, DEM

DEM is a quasi-2-D model that represents tidal flow in the lateral and longitudinal directions with a branching link-node network (Genet et al., 1974). The model can be linked to the Tidal Temperature Model (TTM) for heat budgets. Several versions of the hydrodynamic component of DEM exist. One version is limited to steady inflows and constantly repetitive tide. The steady inflow version cannot explicitly handle short-term stochastic transients such as wind stress or large storm flushing and has difficulty in predicting long-term patterns such as the 2-week spring neap tide cycle or the seasonal freshwater inflow pattern. Consequently, this version is most reliable when predicting high and low values for diurnal or tidal cycles, or both, averaged over a relatively steady 2-week period (Ambrose and Roesch, 1982). Real-time simulations of water quality are possible with the steady inflow version of DEM, but with some inaccuracies. Newer hydrodynamic versions of the model can handle variable inflows and can thus generate a more accurate real-time prediction of water quality.

Several water quality submodels also have been used with DEM. All versions include nutrient modeling and algal growth, photosynthesis, and respiration. The following is a brief description of the versions of DEM currently available.

DEM, Chen-Orlob version, is the most comprehensive version of the model currently available (Chen and Orlob, 1972). The model has the capability of representing 22 coupled biotic and abiotic constituents including temperature, pesticides, heavy metals, carbonaceous biochemical oxygen demand (CBOD), DO, phosphate, ammonia, nitrite, nitrate, total dissolved solids, alkalinity, pH, carbon dioxide, phytoplankton, zooplankton, fish, benthic animals, suspended detritus, and sediment detritus.

DEM, Potomac version, is documented as handling only steady inflows and constantly repetitive tide, but a newer version that is capable of handling variable inflows is available (Roesch et al., 1979). The model simulates CBOD, DO, ammonia, nitrate, phosphate, and chlorophyll-*a*.

The overall two-dimensional DEM model is composed of three separate components—a hydrodynamic model (HYD1), a dynamic quality model (DQUAL), and a steady-state quality model (AQUAL). The first uses the equation of motion and continuity to calculate channel flows and nodal volume changes in response to wind and tidal boundary fluctuations. Dynamic and/or steady-state results, averaged over a complete tidal cycle, are stored on disk files to be used repeatedly in the calibration of the quality models. Once the physical transport mechanisms of water flow and velocities are determined, the biological and chemical reactions can be superimposed to calculate water quality at any location and time.

DQUAL and AQUAL can be used to simulate any combination of the following nine constituents and have the capability to include up to four additional user-specified conservative constituents: salinity (chloride), total nitrogen, total phosphorus, total coliform bacteria, fecal coliform bacteria, carbonaceous BOD, TKN, dissolved oxygen, and temperature.

2.2.3.3 M.I.T. Dynamic Network Model, MITDNM

MITDNM is a one-dimensional model that uses a finite element, branching network to simulate the flow regime of an estuary with unsteady tidal elevation and upstream flow (Harleman et al., 1977). The model was originally developed for aerobic, nitrogen-limited systems and includes detailed simulation of the nitrogen cycle, which includes ammonia, nitrite, nitrate, phytoplankton-N, zooplankton-N, particulate organic-N, and dissolved organic-N, as well as salinity, temperature, CBOD, DO, and fecal coliform. The model solves the one-dimensional continuity and momentum equations to generate the temporal and spatial variations in the tidal discharges and elevations. This information is used in the solution of the conservation-of-mass equations for the water quality variables (Najarian and Harleman, 1975).

2.2.3.4 Waterways Experiment Station Model, CE-QUAL-W2

CE-QUAL-W2 is a dynamic 2-D (x-z) model developed for stratified water bodies (WES, 1986). This model is a Corps of Engineers modification of the Laterally Averaged Reservoir Model (Edinger and Buchak, 1983; Buchak and Edinger, 1984a, 1984b). CE-QUAL-W2 consists of directly coupled hydrodynamic and water quality transport models. Hydrodynamic computations are influenced by variable water density caused by temperature, salinity, and dissolved and suspended solids. Developed for reservoirs and narrow, stratified estuaries, CE-QUAL-W2 can handle a branched and/or looped system with flow and/or head boundary conditions. With two dimensions depicted, point and nonpoint loadings can be spatially distributed. Relative to other 2-D models, CE-QUAL-W2 is more efficient and cost-effective.

In addition to temperature, CE-QUAL-W2 simulates as many as 20 other water quality variables. Primary physical processes included are surface heat transfer, shortwave and longwave radiation and penetration, convective mixing, wind- and flow-induced mixing, entrainment of ambient water by pumped-storage inflows, inflow density current placement, selective withdrawal, and density stratification as impacted by temperature and dissolved and suspended solids. Major chemical and biological processes in CE-QUAL-W2 include the effects on DO of atmospheric exchange, photosynthesis, respiration, organic matter decomposition, nitrification,and chemical oxidation of reduced substances; uptake, excretion, and regeneration of phosphorus and nitrogen and nitrification/denitrification under aerobic and anaerobic conditions; carbon cycling and alkalinity-pH-CO_2 interactions; trophic relationships for total phytoplankton; accumulation and decomposition of detritus and organic sediment; and coliform bacteria mortality.

2.2.3.5 H.S. Chen Water Quality Model, WQM2D

The H.S. Chen model (WQM2D) is a real-time 2-D (x-y) model that simulates conventional pollutants (Chen, 1978). The hydrodynamic submodel considers inertial force, convective forces, hydrostatic pressure, wind forces, Coriolis forces, bottom friction, and internal water column forces due to eddies. The parameters simulated by the model include the following: conservatives, salinity, coliform bacteria, chlorophyll-*a*, organic nitrogen, ammonia nitrogen, nitrite-nitrate nitrogen, organic phosphorus, inorganic phosphorus, CBOD, DO, and DO deficit. Algal growth, photosynthesis, and respiration are represented in the model, as well as benthic oxygen demand and bottom releases of ammonia and inorganic phosphorus. Equations are solved by a finite element technique.

2.2.3.6 M.I.T. Tidal Embayment Analysis and Eulerian-Lagrangian Transport Models, TEA/ELA

The Tidal Embayment Analysis is a 2-D depth-averaged finite element circulation model (Westerink et al., 1985). The model computes the spatial variation of surface elevation and current velocity at nodal points on a finite element triangular grid representing the solution field. The triangular elements provide a high degree of flexibility for fitting the solution grid to the complex geometry of many tidal embayments. TEA takes advantage of the periodic nature of the tidal phenomenon and operates in the frequency domain rather than the time domain. As a result, TEA is more efficient in terms of computer time than time-stepping models (e.g., CAFE-1, Wang and Conor, 1975) for predominantly tidal flow.

ELA is a 2-D, Eulerian-Lagrangian finite element transport model (Kossik et al., 1987). ELA is driven by hydrodynamic circulation. ELA is presently configured to accept circulation input as provided by TEA. Other circulation input could be used with ELA with only slight modification of the code. ELA numerically solves the depth-averaged form of the advection-diffusion equation.

The TEA/ELA model system is based on a harmonic solution to the governing equations. The linear version has been used in most applications to date.

2.2.3.7 M.I.T. CAFE-1 and DISPER-1 Models

CAFE-1 is a two-dimensional, depth-averaged finite element circulation model, and DISPER-1 is a 2-D, depth-averaged finite element dispersion model (Wang and Conor, 1975). DISPER-1 is presently configured to accept circulation input as provided by CAFE-1. This set of models, originally developed at the Massachusetts Institute of Technology (M.I.T.), has a substantial history of successful application. A two-layer version of the model is also available (Christodoulou et al., 1976). The model predicts contaminant concentration at the nodal points of a two-dimensional finite element grid representing the solution field.

2.2.3.8 Waterways Experiment Station Open-Channel Flow and Sedimentation Model, TABS-2

TABS-2 is a generalized numerical modeling system for open-channel flows, sedimentation, and constituent transport developed and supported by the U.S. Army Corps of Engineers, Waterways Experiment Station, Hydraulics Laboratory (Thomas and McAnally, 1985). It consists of more than 40 computer programs to perform modeling and related tasks. The major modeling components, RHA-2V, STUDH, and RMA-4, calculate two-dimensional, depth-averaged flows, sedimentation, and dispersive transport, respectively. The other programs in the system perform digitizing, mesh generation, data management, graphical display, output analysis, and model interfacing tasks. Utilities include file management and automatic generation of computer job control instructions. TABS-2 has been applied to a variety of waterways, including rivers, estuaries, bays, and marshes. It is designed for use by engineers and scientists who may not have a computer background.

Transport calculations with RMA-4 are made using a form of the convection-diffusion equation that has general source-sink terms. Up to seven conservative substances or substances requiring a decay term can be routed. The code uses the same grid mesh as RMA-2V. Recently, an improved two-layer version has been developed to improve the predictive capability for estuarine circulation (Jin and Raney, 1990).

2.2.3.9 Waterways Experiment Station Implicit Flooding Model, WIFM

WIFM-SAL is a two-dimensional, depth-averaged (x-y) finite difference model that generates time-varying water surface elevations, velocities, and constituent fields over a space-staggered grid (Schmalz, 1985). This model was developed by the U.S. Army Corps of Engineers, Waterways Experiment Station. Units of measure are expressed in the English system (slug-ft-second). Results computed on a global grid may be employed as boundary conditions on a more spatially limited refined grid concentrated around the area of interest. In addition, the user may select either of two distinct transport schemes. Scheme 1 is a flux-corrected transport scheme capable of resolving sharp front without oscillation; Scheme 2 is a full three-time-level scheme directly compatible with the three-time-level hydrodynamics. The telescoping grid capability, in conjunction with the user-selectable constituent transport scheme, is a powerful concept in practical transport problem solving.

2.2.3.10 Solute Transport Model for Tidal Canal Networks, CANNET3

CANNET3 is a three-dimensional (x-y-z) time-varying model. This model was developed by Morris et al. (1977) to investigate solute fate and transport in tidal canal networks. Water quality variables (e.g., DO) are not considered in the current version (Christensen, 1990).

2.2.3.11 Waterways Experiment Station Three-Dimensional Models, CH3-D and CBWQM

The most advanced complex models are the 3-D hydrodynamic and water quality models, which allow for most physical processes to be included. Models in this category include the CH3-D and CBWQM models of the USACOE (Cerco and Cole, 1989). These models simulate hydrodynamics, transport of salt, temperature, and other conservative and water quality constituents. However, fully 3-D models that can predict longitudinal, lateral, and vertical transport are the most complex and expensive to set up and run. Because of their cost and complexity, these models have not been widely used. A recent modeling strategy is to drive a compartment model that has been configured in two or three dimensions with flows and volumes from a 2-D or 3-D hydrodynamic model. This strategy attempts to combine the transport rigor of complex models with the convenience, flexibility, and cost efficiency of compartment models. Examples include recent studies of the Patuxent estuary with a 2-D vertically averaged model linked to a version of WASP4 and studies of the Chesapeake Bay with the Sheng model linked to another specially adapted version of WASP4. Plans for CH3-D and CBWQM models are to generalize the models for any area and eventually to provide a microcomputer version.

2.3 Short-listed Models

2.3.1 Selection Criteria

This section presents the short-listed marina water quality models selected from the many models and methods described in previous sections. The short list of models that can adequately describe marina water conditions is given in Table 2-2 for the simple, mid-range, and complex categories. The selection criteria for including a model on the short list are as follows:

1. Public domain model
2. Ease of application
3. Documentation
4. Constituents modeled
5. Hydrodynamic capabilities
6. Applicability to small systems (i.e., marinas)

2.3.2 Models Selected

Simple marina models are desktop screening methodologies that calculate mean pollutant concentrations based on steady-state conditions. These models are in the public domain, are easy to apply, and are well documented (USEPA, 1982 and 1985). The hydrodynamics of simple models are represented as user-supplied velocity and flow data. These models can be easily applied to marinas to calculate DO and fecal coliform concentrations.

Marina mid-range models consist of the NCDEM DO Model and the Tidal Prism Model of Kuo and Neilson (1988). Both models are in the public domain, are easy to apply, and are supported with good documentation. The NCDEM Model is a steady-state program that is capable only of predicting DO concentrations. On the other hand, the Tidal Prism Model is a steady-state model that is capable of simulating up to 10 water quality variables. The nonconservative substances considered in the model include organic nitrogen, ammonia nitrogen, nitrate-nitrite nitrogen, organic phosphorus, inorganic phosphorus, phytoplankton (chlorophyll-*a*), carbonaceous biochemical oxygen demand, dissolved oxygen, and fecal coliform. The user's manual is well written and includes input/output examples as well as guidance on how to calibrate the model.

Complex marina models consist of two components—hydrodynamics and water quality. In this category, hydrodynamics may be represented by numerical solution of the 1-D (i.e., WASP4, DEM) or the full 2-D (i.e., CE-QUAL-W2 and WQM2-D) equations of motion and continuity. Water quality conservation-of-mass equations are executed using the hydrodynamic output of water volumes and flows. The water quality component of the model calculates pollutant dispersion and transformation or decay, giving resultant concentrations over time. All water quality models discussed in this category are in the public domain and are supported by public agencies. These models are very complex and require an extensive effort for a specific application. Table 2-3 summarizes the capabilities of the short-listed models with respect to the selection criteria.

TABLE 2-2. Short-listed Marina Water Quality Models

Simple Models	Mid-range Models	Complex Models
Tidal Prism Analysis Flushing Characteristics Diagram	NCDEM DO Model Tidal Prism Model	WASP4 DEM MITDNM CE-QUAL-W2 WQM2-D

TABLE 2-3. Capabilities of Short-listed Marina Water Quality Models

				Constituent Modeled					Hydrodynamic Capabilities			
	Public Domain	Ease of Application	Documentation	Conservative	Non-Conservative	Oxygen	Nutrients	Metals	User's Supplied	Timescale	Spatial Dimension	Applicability to Small Systems
Tidal Prism Analysis	*	S	E	△	△	△			□			▲
Flushing Characteristics Diagram	*	S	G	△					□			▲
NCDEM DO Model	*	M	G			△				SS	X	▲
Tidal Prism Model	*	M	E	△	△	△	△			SS	X	▲
WASP	*	C	E	△	△	△	△	△		D	XX	▲
DEM	*	C	E	△	△	△	△			D	XX	▲
MITDNM	*	C	E	△	△	△	△	△		D	X	▲
CE-QUAL-W2	*	C	E	△	△	△	△			D	XZ	▲
WQM2D	*	C	F	△	△	△	△			D	XY	▲

E Excellent
G Good
F Fair
P Poor

S Simple
M Mid-range
C Complexr

SS Steady state
D Dynamic

X X-direction
XX Link-node network
XY Horizontial direction
XZ Longitudinal and vertical dimension

3. MODEL CAPABILITIES

The purpose of Chapter 3 is to compare the capabilities of the various water quality models applicable to coastal marinas and to select the best qualified simple, mid-range, and complex models. The best simple model is the Tidal Prism Analysis presented in Chapter 4 of the *Coastal Marina Assessment Handbook* (USEPA, 1985). The best mid-range model is the Tidal Prism Model developed at the Virginia Institute of Marine Science (Kuo, 1976). The complex model chosen as most applicable for marina water quality assessment is the WASP4 model developed and supported by EPA's Athens Research Laboratory (Ambrose et al., 1987). The reasons for selecting the above methodologies are presented in greater detail in the remaining sections of this chapter.

Chapter 3 is divided into three sections. Section 3.1 presents data requirements and the associated model application costs for applying the short-listed models selected in Section 3.2. Section 3.2 discusses each model's capabilities and applicability to various marina types with respect to the typical water quality constituents of interest in marina assessments. Section 3.3 discusses the criteria for selecting the best qualified models. The section includes recommendations of models appropriate for application to coastal marinas along with a discussion of the strengths and limitations of each model.

Computer models may be used to predict water quality through the simulation of the physical and chemical processes of an aquatic system. In this report, the term *model*, following commonly used terminology, is used to describe a computer program that simulates water quality processes. However, strictly speaking, a computer program is not a model until the user structures it with the geometry, hydrology, loading rates, and rate factors that are representative of the particular system being analyzed. It is only when this is done that a computer program can be considered a mathematical model of a particular system.

3.1 Model Overview

This section focuses on describing the input data requirements for marina water quality models. In general, all mid-range and complex models, except the NCDEM DO model, are written in FORTRAN 77 and most are machine independent. In addition, mid-range and complex models can print results of the model simulation and the input data.

As a common rule, storage requirements for marina water quality models increase with program complexity. For example, input data requirements for simple and NCDEM models are similar and include such parameters as tide range, marina surface area, depths, channel geometry, freshwater inflow, and salinity. These parameters are generally available from federal, state, or private agencies. On the other hand, complex models are composed of two components: a hydrodynamic model to predict the circulation patterns and a water quality model that uses those patterns along with biochemical kinetics to predict concentrations of various water quality parameters. Since there is no feedback from the water quality model to the hydrodynamic model, all complex models require scratch disks or tapes for storing intermediate results. These tapes or disks are subsequently used in the water quality submodels or for storing information to be plotted.

3.1.1 Data Requirements

In the application of most models, there are two fundamental types of data requirements. First, there are the data needed simply to make the model function, that is, input parameters and time series data for the model. These data typically include freshwater input, tides, and other meteorological information. The second type of information, required for the calibration of more complex models, is measured water quality data with which to test the model.

All marina water quality models require data for input and for calibration. It is best if model selection is not restricted by availability of data and the decision to acquire the specific type of data required for the model. However, if data availability is a constraint, selection of a less sophisticated model than would be warranted on technical grounds may be appropriate.

Table 3-1 summarizes input data requirements for each of the short-listed water quality models. Input data requirements increase with the complexity of the hydraulics and water quality mathematical formulations of the system modeled. For example, simple models assume steady state, which then requires specification of freshwater inflows and average depth at high and low tide. The more complex models, such as WASP4 and CE-QUAL-W2, solve a form of the momentum equation, which requires more detailed characterization of the system geometry and roughness. Similarly, the data required to simulate the nonlinear nutrient-algal-DO linkage are extensive. The water quality data required, beyond those needed to quantify transport, will vary depending on how the variables will be used and the anticipated impacts of the system to changes in the value of the variables. Data requirements will vary if the analysis is intended for dissolved oxygen, eutrophication, or toxics. For example, variables critical to an analysis of toxicity, such as pH for ammonia and metals, may not be required if the parameter of interest is DO. If the response time of the system or the period of interest is less than the rate of change of a variable, such as bottom demand, then measurement of that variable may be sufficient. However, if the response time or period of interest is greater than the variable's rate of change, then it may be necessary to model factors affecting that variable, requiring collection of supporting data.

3.1.2 Operating Costs

For each modeling study several steps are applied in an iterative process. The first involves data review and model identification and/or selection. The second step is initial calibration of the model to existing data. As more data become available, the calibrated model is tested and refined. After some effort at recalibration and testing, the modeler/analyst decides

TABLE 3-1. Data Requirements

	Geometric	Meteorologic	Hydraulic/Hydrologic	Water Quality
Tidal Prism Analysis	surface area and depth	NA	non-tidal freshwater inflow, volume of tidal prism, and return ratio	ambient/initial concentration of pollutant, mass of pollutant discharged into basin, and rate coefficients for kinetic reactions
Flushing Characteristics Diagram	surface area, depth, total length of shoreline inverse bankslope	wind speed and direction	non-tidal freshwater and groundwater inflow, tidal amplitude, and return ratio	initial concentration of pollutant
NCDEM DO Model	segment and channel surface area and depth	NA	tidal amplitude, and return ratio	ambient and saturation DO concentration, sediment oxygen demand, channel and marina boat activities, reaeration and decay coefficient
Tidal Prism Model	transect distance from mouth of river, connection scheme, and segment mean depth	NA	freshwater inflow, tidal prism volume per segment, return ratio	inflow concentration, temperature, initial and boundary conditions for all modeled state variables expressed as daily average for time varying application, and reaction rates
WASP4	channel length, width and direction, connection scheme, segment surface area, and depth	time series of solar radiation, wind speed and direction, photoperiod, and temperature	coefficients for velocity flow regression (steady-state), time series of segment volume, flow, and bottom roughness (Manning's n), time series of headwater and tributary inflows and tides	inflow concentration, temperature, initial and boundary conditions for all modeled state variables (time series) and rate coefficients for kinetic reactions
DEM	channel length, width and direction, connection scheme, segment surface area, and depth	time varying meteorological and climatological data, including cloud cover, dry and wet bulb air temperature, atmospheric pressure, wind speed and direction, precipitation and photoperiod	tributary and ground water inflows, time varying tidal stage and currents. time series of segment volume, flow, and bottom roughness rating curves and/or stage/routing	initial in situ water quality parameters concentration, time-varying water quality variables at boundaries, tributary inflows and waste discharges, time-varying stormwater inflow and quality characteristics, rate coefficients for kinetic reactions
MITDNM	side and bottom slope of channel, length of reach, cross-section area, connection scheme and bottom elevation	time varying of ambient temperature, relative humidity, wind speed, net solar flux, net atmospheric flux, atmospheric pressure, and solar radiation	time series of headwater and tributary inflow, Chezy coefficient, and tidal elevation	initial in situ water quality parameters concentration, time-varying water quality concentration at boundaries, inflow concentration of water quality variables, and rate coefficients for kinetic reactions
CE-QUAL-W2	segment length, width and depth, and layer thickness for main channel and branches	time varying meteorological data including wind speed, coefficient of surface heat exchange, equilibrium temperature, solar radiation, and attenuation coefficient	time series of headwater and tributary inflows, Manning's n, and tidal elevation	inflow concentration, temperature, nonpoint inflows, and rate coefficients for kinetic reactions
WQM2-D	element surface area and depth	wind speed and direction	time series of headwater and tributary inflows, Manning's n, and tidal elevation	inflow concentration, temperature, initial and boundary conditions for all modeled state variables (time series), and rate coefficients for kinetic reactions

either that the model is sufficiently reliable to produce sound results or that available time and resources do not permit continued refinement. Since these iterative processes are problem dependent, it is difficult to estimate overall costs involved in a model application. Each application differs in scope and complexity, and the ability to solve or avoid certain problems is very dependent on the experience and technical background of the analysts involved. However, machine requirements and costs associated with typical runs are usually estimated in the program documentation. As a rule, the simpler the model, the less expensive it is to apply. Also, it is essential that the support agency and other experienced professionals be contacted for information or assistance.

Information presented in Table 3-2 is primarily nontechnical and is related to operational features of the short-listed models. This information is provided to evaluate the cost associated with and the ease of acquiring the model, getting the model running on the system, calibrating the model, and finally applying the model. The information provided in Table 3-2 is primarily qualitative and sufficient to determine whether a model may be suitable for a practical application. For complete information the potential user must consult the appropriate user's manuals and other supporting documentation. The Center for Exposure Assessment Modeling (CEAM), EPA Environmental Research Laboratory, Athens, Georgia (Mr. Thomas O. Barnwell) is a good source of information and technical support.

TABLE 3-2. Approximate Operating Costs

Dimensionality	Water-Quality Problem	Approximate Level of Effort
1-D steady state	DO,BOD, nutrient	1-2 person-months
1-D, 2-D steady state	DO, BOD, nutrient, phytoplankton, toxics	1-4 person-months
2-D, 3-D time variable	DO, BOD, nutrient, phytoplankton, toxics	3-12 person-months

3.2 Model Appropriateness

Table 3-3 presents the short-listed models that can adequately describe marina water quality conditions and summarizes the water quality constituents that can be simulated by these models. With the exception of the NCDEM Model, all mid-range and complex models address salinity and bacteria either explicitly or by specifying the appropriate first-order decay constant for another state variable. This table compares the short-listed models with respect to the constituents simulated. The models vary significantly in terms of the number and constituents for which calculations are performed. The number of constituents analyzed usually reflects the number and complexity of biochemical processes simulated. For example, NCDEM is limited to steady-state DO analyses, while WASP4 and other complex models can be used for dissolved

TABLE 3-3. Constituents Included in Model

	Coliform Bacteria	DO	CBOD or total BOD	NBOD	SOD	Temp	Tot P	Org P	PO_4	Tot N	Org N	NH_3	NO_2	NO_3	Carbon	Algae or Chl-a	Zoo-plankton	Salinity Conservative	pH	Alk	TDS
Tidal Prism Analysis	X	X																X			
Flushing Characteristic Diagram																		X			
NCDEM DO Model		X																			
Tidal Prism Model	X	X	X			●	X	X			X	X	X	X		X		X			
WASP4		X	X	▲	●	●	X	X	X	X	X	X		X		X	●	X			
DEM	X	X	X	X	●	X	X	X	X	X			X	X		X		X			
MITDNM	X	X	X			X	X			X	X	X	X	X		X	X	X			
CE-QUAL-W2	X	X	X			X	X		X			X		X	X	X		X	X	X	X
WQM2-D	X	X	X		X	●					X	X				X		X			

● specified by model users
▲ NBOD simulated as nitrification of ammonia

oxygen analyses as well as eutrophication analyses. The later models simulate the effects of photosynthesis, respiration, and temperature on diurnal variations of dissolved oxygen. Complex models are truly dynamic since they simulate continuous temporal variations in systems hydraulics and waste loadings. The Tidal Prism Model assumes that these features remain constant but allows water quality conditions to vary (quasi-dynamic). The following sections discuss model capabilities when applied to a variety of marina types (including one-segment, two-segment, open-water, and flow-through marinas) and the usefulness of each model for determining water quality impacts.

3.2.1 Marina Type

Table 3-4 presents the appropriateness of each of the short-listed models when applied to each marina type considered in this study. Mid-range models are not applicable to flow-through marina types. However, the Tidal Prism Model is capable of addressing all water quality problems in open and semi-enclosed marina types.

TABLE 3-4. Applicability of Short-listed Models to Marina Type

	Open Water		Semi-Enclosed					
			One-Segment		Two-Segment		Flow-Through	
	Conservative	Non-conservative	Conservative	Non-conservative	Conservative	Non-conservative	Conservative	Non-conservative
Tidal Prism Analysis	X	NA	X	X	NA	NA	NA	NA
Flushing Characteristics Diagram	X	NA	X	NA	X	NA	X	NA
NCDEM DO Model	NA	•	NA	•	NA	•	NA	NA
Tidal Prism Model	X	X	X	X	X	X	NA	NA
WASP4	X	X	X	X	X	X	X	X
DEM	X	X	X	X	X	X	X	X
MITDNM	X	X	X	X	X	X	X	X
CE-QUAL-W2	X	X	X	X	X	X	X	X
WQM2-D	X	X	X	X	X	X	X	X

• DO only
X other water quality constituents in addition to DO
NA Not Applicable

All complex models are applicable to all marina types considered in this study (i.e., open water, one-segment, two-segment, and flow-through marinas). Data management and meeting data requirements, as well as the level of effort involved to set up, run, calibrate, and apply these models, are formidable tasks for the inexperienced analyst. Good, defensible model results are dependent on a careful, detailed application of the model to the specific site.

3.2.2 Constituents Modeled

The purpose of this section is to evaluate the usefulness of each short-listed model for determining water quality degradation (e.g., how well the model can predict dissolved oxygen variations or fecal coliform bacteria).

3.2.2.1 Dissolved Oxygen

Adequate sustained DO concentrations are required for the survival of most aquatic organisms. Seasonal or diurnal depletion of dissolved oxygen disrupts or displaces aquatic communities. Ambient DO levels are affected by many natural processes, such as oxidation of organic material, nitrification, reaeration, decay, settling of CBOD, and photosynthesis/respiration. The natural balance can be disrupted by excessive wastewater loads of organic material, ammonia, and nutrients. Other sources of nutrients, such as runoff from agricultural, residential, and urban lands and atmospheric deposition, also can disrupt the DO balance. Excessive heat input from power plants can aggravate existing problems. Because of its intrinsic importance, and because it is affected by so many natural and human-influenced processes, DO has been selected as the best indicator of water quality problems in coastal marinas.

Dissolved oxygen dynamics depend on the interactions of several constituents and processes. The constituents include dissolved oxygen, carbonaceous BOD, nitrogenous BOD (ammonia and nitrite), temperature, and in some cases phytoplankton, periphyton, and aquatic plants. The major processes include (Figure 3-1):

- Reaeration;
- BOD reactions;
- Sediment oxygen demand (SOD);
- Photosynthesis, respiration; and
- Nitrification.

Reaeration

Atmospheric reaeration is the process of mass exchange of oxygen between the atmosphere and the surface layer of the water column. Typically, the net transfer of oxygen is from the atmosphere into the water since the oxygen levels in the water are usually less than the saturated concentration. The mass flux of exchange of oxygen across the air-water interface

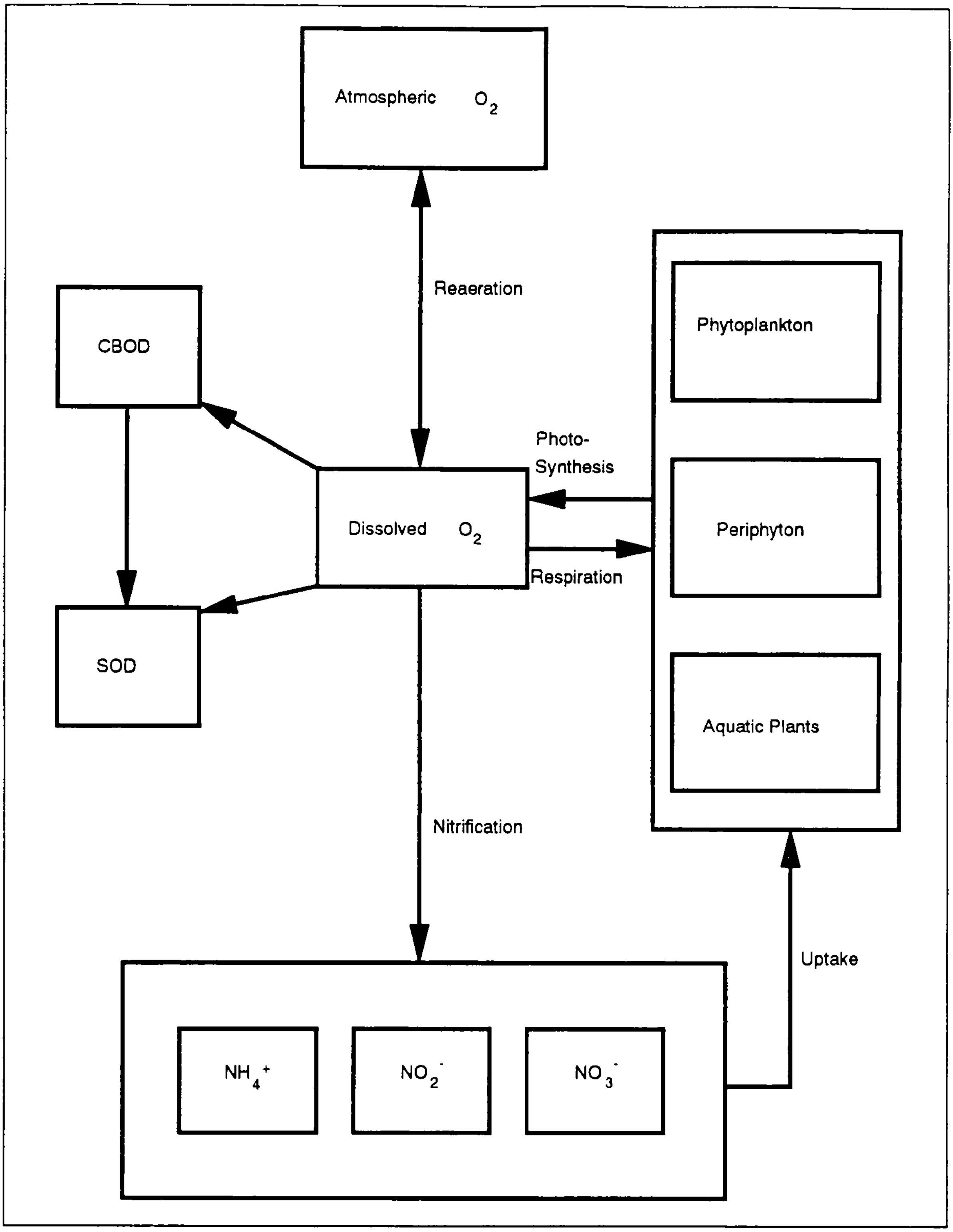

Figure 3-1. Processes Affecting Dissolved Oxygen.

is modeled as a first-order kinetic process that is dependent on the oxygen mass transfer coefficient, the local oxygen concentration in the water, and the saturation concentration of oxygen. Table 3-5 presents model capabilities with respect to reaeration formulation. Most marina water quality models permit direct input of the reaeration coefficient or selection from several commonly used correlations or methods. For example, simple and mid-range models permit only direct input of the reaeration coefficient. On the other hand, WASP4 allows the user to choose from five options of the reaeration coefficient.

TABLE 3-5. Model Capabilities: Reaeration Formulations

Model	Options
Tidal Prism Analysis	One option. input directly
Flushing Characteristics Diagram	NA
NCDEM DO Model	One option: input directly
Tidal Prism Model	Two options: input directly, calculated as a function of velocity and depth (O'Connor and Dobbins, 1958)
WASP4	Five options: Churchill, et al., O'Connor and Dobbins, Owens et al., Covar's, and wind-dependent reaeration for lakes and estuaries
DEM	One option: input directly
MITDNM	Two options: input directly, calculated as a function of channel velocity and geometry
CE-QUAL-W2	No reaeration coefficient: instead the model calculates interfacial exchange rate (wind speed dependent) according to Kanwisher's (1963) or Mackay's (1980) formulation
WQM2-D	One option

BOD Reactions

Biochemical oxygen demand (BOD) is a measure of the biodegradable material oxidized in a stream or a sample of the stream water. Both carbonaceous organic and nitrogenous compounds are oxidized. These forms of BOD are distinguish as CBOD and NBOD. All nitrogenous oxygen demand is labeled NBOD. NBOD is determined from the Kjeldahl nitrogen (organic plus ammonia nitrogen) measurements of the water.

In the past, models have simulated both NBOD and BOD (total), but these demands were difficult to calibrate reliably and did not result in well-calibrated predictive models. Modeling NBOD and CBOD as separate demands has been more reliable than modeling total BOD; however, this approach is not as accurate as modeling CBOD, ammonia, nitrite, and nitrate separately. Some of the early total BOD models ignored sediment oxygen demand (SOD) by combining these effects with simulations of total BOD. These models could be calibrated with some difficulty (i.e., the BOD decay rate coefficient was selected so simulations matched measurements of BOD) when SOD was a small effect, but these calibrations lacked predictive validity. Recently water quality models (e.g., MITDNM and WASP4) tend to represent carbonaceous oxygen-demanding materials as CBOD and nitrogenous materials as the various species of the nitrogen cycle (i.e., organic nitrogen, ammonia, nitrite, and nitrate) rather than the traditional NBOD.

Sediment Oxygen Demand (SOD)

Chemical reduction and bacterial respiration of organic matter that occur in sediments create a demand for oxygen from overlying waters. This sediment oxygen demand (SOD) can strongly influence oxygen conditions in a water column; therefore, SOD is an important component of models that predict oxygen concentrations. Decomposition of organic matter and respiration of resident invertebrates form the major oxygen demands from the sediment. Although these processes are distinct, they are typically modeled together since in situ forms of measurement combine oxygen uptake and separation would result in additional model complexity.

SOD rates are highly site-specific and are influenced by substrate composition, sediment organic content, and environmental factors such as temperature (Hatcher, 1986). For example, SOD rates were an essential component of the NCDEM DO model used to evaluate DO changes due to coastal marinas (NCDEM, 1990). However, data collected during this study were insufficient to determine whether the observed rates were typical or what the expected range of SOD rates might be for coastal marinas. Therefore, marina water quality models should use site-specific SOD rates as actual estimates can range over several orders of magnitude (Bowie et al., 1985; NCDEM, 1990). Although often of critical importance, the predictive capability of most presently available models of sediment interactions is limited. In most models description of these impacts is often reduced to field measurements followed by use of zeroth order rate to describe sediment interactions and their effects on other variables and processes. For example, WASP4, WQM2-D, and DEM are the only complex models that account for SOD rates.

Photosynthesis and Respiration

Through the biological processes of photosynthesis and respiration, phytoplankton, periphyton, and rooted aquatic plants (macrophytes) can exert a significant influence on dissolved oxygen levels. The mass flux source and sink of dissolved oxygen from photosynthesis and respiration of aquatic plants in a system are dependent on plant biomass, water temperature, saturated growth rate, the availability of light in the water column and benthos, and the respiration rate. All complex models account for the effects of photosynthesis and respiration on dissolved oxygen concentration in a marina.

Nitrification

In natural waters, nitrogen consists of organic constituents (dissolved and particulate) and inorganic dissolved constituents (ammonia, nitrite, nitrate) and nitrogen gas. The species of nitrogen undergo a sequence of chemical (hydrolysis) and bacterially mediated (nitrification and denitrification) reactions that result in the sequential transformation of the various species of nitrogen. Organic nitrogen is initially hydrolyzed to ammonia. Through the bacterially mediated aerobic two-stage process of nitrification, ammonia is first transformed to nitrite and nitrite is then converted to nitrate. Under anaerobic conditions in either the sediments or the water column, the bacterially mediated process of denitrification converts nitrate to nitrogen gas. The gaseous form of nitrogen is then lost across the air-water interface to the atmosphere. Some short-listed marina models (i.e., DEM, CE-QUAL-W2, and WQM2-D) account for a segment or a fraction of the nitrogen cycle, while others (i.e., WASP4 and MITDNM) are capable of modeling all major constituents in the nitrogen cycle. The mass flux reduction of organic nitrogen and ammonia in a marina is modeled as a first-order kinetic process that is dependent on the organic nitrogen hydrolysis rate, the organic nitrogen settling/removal rate, nitrification, the local organic nitrogen and ammonia concentrations in the water, and the local water temperature.

3.2.2.2 Fecal Coliform Bacteria

The abundance of coliform bacteria has traditionally been used as an indicator of pathogen contamination. Standards and criteria have been formulated and promulgated based on coliform concentrations to indicate the safety of water for drinking or recreational purposes. The discharge of sanitary waste from boats in the vicinity of marinas has the potential to contaminate adjacent shellfish beds and to pose a serious public health risk if the shellfish are harvested for human consumption. The potential for pathogenic contamination of shellfish-producing water bodies can be assessed by determining the concentration of total coliform or fecal coliform organisms in the water body. Predictions of coliform bacteria are, therefore, important because of their impact on project purposes such as recreation and water supply.

With the exception of the Flushing Characteristics Diagram and NCDEM DO models, all short-listed models are capable of calculating fecal coliform concentrations in a coastal marina.

4. RECOMMENDED MODELS

4.1 Selection Criteria

Marina areas contribute pollutants from the sanitary wastes of their human occupants, as well as from materials leaching from hulls or discharging with engine exhausts. These wastes pose a variety of potential problems for water quality including microbiological contamination of adjacent shellfish and swimming areas, depletion of dissolved oxygen in the water column or sediments, and toxic effects on estuarine biological resources. The use of an area for a marina may infringe or preclude other uses of the resources, and it is this potential conflict that must be evaluated through the use of a water quality model.

To understand what is required of a model, it is essential to focus on the physical, chemical, and biological processes that move water into and out of the marina area, control mixing with adjacent waters, regulate chemical reactions in the water and sediments, and facilitate biological growth and decay (die-off). A variable combination of winds, tides, currents, and density differences is responsible for the physical movement of water volumes and pollutants. Numerous references are available which describe these processes and the relationships between the physical processes and the changes in concentrations of dissolved or suspended particulate materials (Officer, 1976; Thomann and Mueller, 1987; Moffatt and Nichol, 1989; and Biswas, 1981). The geometry of a site can also have a major effect on flushing and dispersion and is an important issue in selecting the model, collecting the data, and attaining the required water quality standards (Tetra Tech, 1988).

Biodegradation of organic material, growth and decay of bacteria and other organisms, nutrient uptake, and chemical transformations of various kinds are typical of biochemical processes affecting the contaminants of interest. The capability of various models to describe these reactions, which are termed nonconservative processes, ranges from a first-order decay term added to the basic hydrodynamic equations for the simplest models to complex kinetic expressions for the most advanced models (Thomann and Mueller, 1987; Mills et al., 1985).

Physical, chemical, and biological processes must be combined to form a conceptual model of the site and its consequent contaminant assimilation potential. After the site in question has been conceptualized, the next step is to choose a model that incorporates the appropriate physical processes and biochemistry to predict water quality. Depending on the sophistication level at which the assessment is taking place, the model selected may be a simple screening calculation (e.g., Tidal Prism Analysis) or a multidimensional numerical model (e.g., WASP4, DEM, and WQM2D). This approach guides the user to the models that are most appropriate under various situations; for example, tidal prism model where tide level changes are the predominant mode of material exchange, a freshwater fraction model where upstream inflow and density differences are dominant, and so on.

The short-listed models discussed in Chapter 3 are capable of simulating water quality constituent variations in a coastal marina. These models have been selected for the following reasons:

- They are in the public domain.
- They are available at a minimal cost from various public agencies.
- They are supported to a varying extent by federal and/or state agencies. The form of support is generally telephone contact with a staff of engineers and programmers who have experience with the model and provide guidance (usually free of charge).
- They have been used extensively for various purposes and are generally accepted by the profession.
- Together they form a sequence of increasingly more technically complex models; i.e., each model takes additional phenomena into account in a more detailed manner than the preceding model.

Selection from among these models is made on the basis of the needed model capabilities.

In addition to model capabilities, the two most important factors in the selection of a model are the adequacy of the documentation and the adequacy of the support available. The documentation should state the theory and assumptions in adequate detail, describe the program organization, and clearly present the input data requirements and format. A well-organized data scheme is essential. The support provided by the support agency should include user access via telephone to programmers and engineers familiar with the model. It may be possible that special support (including short courses or informational or personnel exchanges) is available under existing intra-agency or interagency agreements or otherwise could be made available to the potential user. The support agency may also be able to provide the potential user with a list of local users who could be contacted for information regarding their past or current experience with the computer program. Table 4-1 presents documentation and user's support available for the short-listed models.

In addition to having adequate documentation and user's support, the selected model must address all marina water quality problems of concern. For example, for the Flushing Characteristics Diagram, Christensen (1989) stated the theory and the assumptions made in his model in adequate detail. However, the model is not capable of simulating water quality variables such as DO or fecal coliform and therefore was excluded from further consideration.

The following section provides an overview of the best qualified marina water quality model in each of the selected categories. These models are listed in Table 4-2, which provides information related to the operational features of the models. This information is provided to evaluate the estimated cost associated with and the ease of acquiring the model, getting the model running on the user's system, calibrating the model, and finally applying the model.

TABLE 4-1. Ease of Application: Sources, Support, and Documentation

Model	Source(s) of Model	Nature of Support	Reference	Adequacy of Documentation
Tidal Prism Analysis	NA	NA	EPA (1985) Mills et al. (1985)	Excellent documentation with example application
Flushing Characteristics Diagram	NA	NA	Christensen (1989)	Good illustrations with numerical example application
NCDEM DO Model	North Carolina Dept. of Environmental Health and Natural Resources, Division of Environmental Management (919) 733-6510	Telephone contact	NCDEHNR (1990)	Good documentation with several applications
Tidal Prism Model	Virginia Institute of Marine Science, Gloucester Point, VA 23062 (804) 642-7212	Telephone contact	Diana et al. (1987)	Excellent documentation of theory and assumptions; excellent user's guide with input and output information
WASP4	Center for Exposure Assessment Modeling, U.S. Environmental Protection Agency, Athens, GA 30613 (404) 546-3585	Software maintenance, workshop technical assistance through EPA channels	Ambrose et al. (1987)	Excellent documentation of theory and assumptions, excellent user's guide with input and output information
DEM		None	Roesch et al. (1979) Genet et al. (1974) Chen and Orlob (1972)	Excellent documentation of theory and assumptions; excellent user's guide with input and output information
MITDNM		None	Najarian and Harleman (1975) Harleman et al. (1977) USEPA (1977) Thatcher et al. (1975)	Excellent documentation of theory and assumptions; excellent user's guide with input and output information
CE-QUAL-W2	U.S. Army Engineer Waterways Experiment Station, Environmental and Hydraulics Laboratories, P.O. Box 631, Vicksburg, MS 39180-0631 (601) 634-5069	Telephone contact	Waterways Experiment Station (1986)	Excellent documentation of theory and assumptions; excellent user's guide with input and output information
WQM2-D	Virginia Institute of Marine Science, Gloucester Point, VA 23062 (804) 642-7212	None	Chen et al. (1979) Chen et al (1978)	Good documentation of theory and application with the user's guide almost nonexistent

TABLE 4-2. Approximate Operating Costs for Best Qualified Models

Complexity	Model	Water Quality Problem	Approximate Level of Effort
Simple	Tidal Prism Analysis	DO, fecal coliform	1-2 Days
Mid-range	Tidal Prism Model	DO, BOD, nutrient, phytoplankton, fecal coliform	3-7 Days
Mid-range	NCDEM DO	DO	1-2 Days
Complex	WASP4	DO, BOD, nutrient, phytoplankton, toxics, fecal coliform	3-4 Weeks

4.2 Models Selected

The most rigorous tools that can be used for assessing marina impacts on water quality are numerical models. Models range in complexity from simple desktop calculations to full three-dimensional models that simulate physical and chemical processes by solving equations of motion and rate equations for chemical processes.

Model complexity will determine the degree of resolution in the results. For example, in an early part of a study the Tidal Prism Analysis strategy is used to obtain a general understanding of potential impacts caused by pollutant discharged from a proposed marina. It is likely that the simplified strategy will predict substantial impacts to the environment. Therefore, an advanced model is required to conduct further detailed analyses. The mid-range model is used in situations where steady-state conditions may be assumed and tidal flushing is the predominant mode of flushing. The complex model is used in dynamic environments subject to estuarine circulation and full biochemical kinetics with sources and sinks for all dissolved constituents and for proposed marinas.

4.2.1 Simple Model

The methods listed here include desktop screening methodologies that calculate seasonal or annual mean pollutant concentrations based on steady-state conditions and simplified flushing time estimates. These models are designed to examine and isolate trouble spots for more detailed analyses. They should be used to highlight major water quality issues and important data gaps in the early stage of a study.

The impact assessment methods presented in Chapter 4 of the *Coastal Marina Assessment Handbook* (USEPA, 1985) are appropriate screening tools. Methods presented in this chapter, particularly some of the mathematical descriptions, are simplifications of more sophisticated techniques. These techniques, as presented, can provide reasonable approximations for screening potential impact problems when site-specific data are not available. *Water Quality Assessment: A Screening Procedure for Toxic and Conventional Pollutants* (Mills et al., 1985) provides additional and more detailed descriptions of screening methodologies. The Tidal Prism Analysis was selected as the method of choice in this category. This method is capable of addressing all marina water quality issues of concern (e.g., DO and fecal coliform) and comes with an excellent source of documentation. The primary strengths and advantages of the EPA screening procedures are as follows:

1. Excellent user documentation and guidance.
2. No computer requirements since the procedures can be preformed on hand calculators.
3. Relatively simple procedures with minimal data requirements that can be satisfied from the user's manual when site-specific data are lacking.

The Tidal Prism Analysis procedures can be easily implemented in a computer program. This will allow the user to test model sensitivity and determine the range of potential water quality impacts from a proposed marina quickly and efficiently.

4.2.2 Mid-range Models

The recommended marina mid-range models are the Tidal Prism Model and the NCDEM DO Model. Both models are in the public domain, are easy to apply, and are supported with good documentation.

4.2.2.1 Tidal Prism Model

The Tidal Prism Model is a steady-state model that is capable of simulating up to 10 water quality variables including dissolved oxygen and fecal coliform. The user's manual is well written and includes input/output examples as well as guidance on how to calibrate and apply the model. Based on constituents modeled, the Tidal Prism Model is recommended as the best qualified marina mid-range model. The primary strengths and advantages of the Tidal Prism Model are as follows:

1. Excellent user documentation and guidance.
2. Minimal computer storage requirements.
3. Relatively simple procedures with data requirements that can be satisfied from existing data when site-specific time series data are lacking.

The Tidal Prism Model is applicable only to marinas where tidal forces are predominant with oscillating flow (e.g., an estuary or a tidal river). Therefore, the Tidal Prism Model can not be applied to marinas located on a sound or an open sea. Since the Tidal Prism Model is not applicable to the majority of marina situations, the NCDEM DO model is recommended as an alternative best qualified model for mid-range applications when the Tidal Prism Model can not be applied.

4.2.2.2 NCDEM DO Model

The NCDEM DO model is a steady-state program that is only capable of predicting DO concentrations. The NCDEM DO model is applicable to one-, two-, and three-segment marinas. Model theory, assumptions, and input parameters are presented in adequate detail (NCDEM, 1990). Model documentation includes input and output examples of several applications as well as a listing of the model code. The model code is written in BASIC.

The NCDEM DO model incrementally mixes the ambient and marina waters as a function of the average lunar tides. The tidal variation is assumed to follow a sinusoidal distribution. For simplicity, a 12-hour tidal cycle is used. By running this time-variable model through a sufficient number of tidal cycles, the average marina basin DO value will approach a steady-state value.

4.2.3 Complex Model

Complex models consist of two components: hydrodynamics and water quality. In this model category, hydrodynamics may be represented by numerical solution of the 1-D or the full 2-D equations of motion and continuity. Water quality conservation-of-mass equations are executed using the hydrodynamic output of water volumes and flows. The water quality component of the model calculates pollutant dispersion and transformation or decay, giving resultant concentrations over time. These models are very complex and require an extensive effort for specific applications.

Complex models can be further divided into two categories according to number of dimensions. The first group is the 1-D or quasi-2-D models, which include WASP4, DEM, and MIT DNM. The second group, the full 2-D models, includes CE-QUAL-W2 and WQM2D. WQM2D is a real-time 2-D model that simulates conventional pollutants such as dissolved oxygen and fecal coliform (Chen, 1978). This model was originally developed for EPA, but the model is not currently supported by any state or federal agencies. In addition, the existing documentation for the model does not include a user's manual; therefore, WQM2D is excluded from the final list of recommended models.

CE-QUAL-W2 is a dynamic 2-D model developed for stratified waterbodies (WES, 1986). This model consists of directly coupled hydrodynamic and water quality transport models. Hydrodynamic computations are influenced by variable water density caused by temperature, salinity, and dissolved and suspended solids. The CE-QUAL-W2 model can handle a branched and/or looped system with flow and/or head boundary conditions. With two dimensions depicted, point and nonpoint, loadings can be spatially distributed. In addition to temperature, CE-QUAL-W2 simulates as many as 20 other water quality variables including dissolved oxygen and fecal coliform. Relative to other 2-D models, CE-QUAL-W2 is efficient and cost-effective. The existing documentation includes a user's manual, which contains an explanation of theory and numerical procedures, data needs, data input format, and a description of the associated software. However, user support is almost nonexistent, and therefore CE-QUAL-W2 is excluded from the final list of recommended marina models.

DEM is a quasi-2-D model that represents tidal flow in the lateral and longitudinal directions with a branching link-node network (Genet et al., 1974). The overall two-dimensional DEM model is composed of three separate components: a hydrodynamic model (HYD1), a dynamic quality model (DQUAL), and a steady-state quality model (AQUAL). The first uses the equation of motion and continuity to calculate channel flows and nodal volume changes in response to wind and tidal boundary fluctuations. Dynamic and/or steady-state results, averaged over a complete tidal cycle, are stored on disk files to be used repeatedly in the calibration of the quality models. Once the physical transport mechanisms of water flow and velocities are determined, the biological and chemical reactions can be superimposed to calculate water quality at any location and time. The DEM model can be used to simulate up to nine water quality parameters including fecal coliform bacteria and dissolved oxygen in a coastal marina. The documentation, which includes a user's manual, is an excellent source of information. On the other hand, no user's support is currently available for the DEM model, and consequently, the model is excluded from the final list of recommended marina models.

MITDNM is a one-dimensional model that uses a finite-element, branching network to simulate the flow regime of an estuary with unsteady tidal elevation and upstream flow (Harleman et al., 1977). The model was originally developed for aerobic, nitrogen-limited systems and includes detailed simulation of the nitrogen cycle, as well as dissolved oxygen and fecal coliform. The model solves the one-dimensional continuity and momentum equations to generate the temporal and spatial variations in the tidal discharges and elevations. This information is used in the solution of the conservation-of-mass equations for the water quality variables (Najarian and Harleman, 1975). As is the case for most models considered in this section, the MITDNM user's guide is an excellent source of information, but currently no user's support is available. Hence, the MITDNM is also excluded from the final list of recommended marina models.

The final model in this category is the Water Quality Analysis Simulation Program, WASP4 (Ambrose et al., 1987). This program is a dynamic compartment modeling system that can be used to analyze a variety of water quality problems in one, two, or three dimensions. WASP4 simulates the transport and transformation of conventional and toxic pollutants in the water column and benthos of ponds, streams, lakes, reservoirs, rivers, estuaries, and coastal waters. The WASP4 modeling system covers four major subjects: hydrodynamics, conservative mass transport, eutrophication-dissolved oxygen kinetics, and toxic chemical-sediment dynamics. The modeling system also includes a stand-alone hydrodynamic program, DYNHYD4, that simulates the movement of water. DYNHYD4 is a link-node model that may be driven by either constantly repetitive or variable tides. Unsteady inflows may be specified, as well as wind that varies in speed and direction. DYNHYD4 produces an output file of flows and volumes that can be read by WASP4 during the water quality simulation. WASP4 contains two separate kinetic submodels, EUTRO4 and TOXI4. EUTRO4 is a simplified version of the Potomac Eutrophication Model (PEM) and is designed to simulate most conventional pollutant problems. EUTRO4 can simulate up to eight state variables including dissolved oxygen and fecal coliform. TOXI4 simulates organic chemicals, metals, and sediment in the water column and underlying bed.

The WASP4 model system is supported by the U.S. EPA Center for Exposure Assessment Modeling (CEAM), Athens, Georgia, and has been applied to many aquatic environments. The WASP4 model may be obtained over the CEAM electronic bulletin board system, or by mailing the appropriate number of diskettes to CEAM. The water quality component is set up for a wide range of pollutants and the model is the most versatile and most widely applicable of all models considered in this study. For these reasons WASP4 is the model of choice in this category. The primary strengths and advantages of the WASP4 model are as follows:

1. Documentation: WASP4 has excellent user documentation and guidance. Theory and assumptions are presented in adequate detail; program organization and input data requirements and format are clearly presented.

2. Support: User access is available via telephone to programmers and engineers familiar with the model. Occasional workshops, sponsored by the EPA Center for Exposure Assessment Modeling, Athens, Georgia, are available. The support agency can provide the potential user with a list of local users who could be contacted for information regarding their past or current experience with the computer program.

3. Flexibility: Model users can add their own subroutines to model other constituents that may be more important to the specific application with minimum or virtually no programming effort required. WASP4 can be operated by the user at various levels of complexity to simulate some or all of these variables and interactions.

The Center for Exposure Assessment Modeling maintains and updates software for WASP4 and the associated programs. Continuing model development and testing within the CEAM community will likely lead to further enhancements and developments of the WASP4 modeling system. In fact, USEPA CEAM is currently supporting the development of a 3-D hydrodynamic model that will be linked to the WASP4 model.

5. DATA COLLECTION PLAN

The two main purposes of this section are (1) to help water quality specialists design a monitoring plan to support modeling activities for a proposed coastal marina and (2) to assist in the design of a monitoring plan for an existing coastal marina. The planner is guided through the data collection process so that the models used for marina water quality analysis can be applied to critical design conditions.

For a number of aspects of water quality sampling, significant reference material already exists, including equipment requirements, personnel requirements, collection of water quality samples, and laboratory analytical techniques for analyzing samples. These facets will not be discussed further in this report.

A secondary purpose of this section is to educate field personnel on the relationship between sampling requirements and water quality modeling needs. Field personnel may sometimes not fully understand why historical data are not adequate to meet study objectives, why specially designed surveys are required to generate the data, and what the rationale is for selecting certain sampling locations and parameters. By understanding these factors, field personnel are more likely to perform their tasks more effectively. Moreover, when unforeseen field conditions indicate the necessity for a change in sampling strategy, they have a better basis for deciding how to modify the sampling program design.

Planning a monitoring study should be a collaborative effort of participants involved in field collection, analysis, data processing, quality assurance, data management, modeling, and budgeting activities. Close collaboration ensures that the fundamental design elements are properly stated so that the available resources are used in an efficient manner.

5.1 General Considerations

The level of sampling effort is proportionate to the complexity of the model used. For example, the Tidal Prism Analysis calculations and the NCDEM DO model require only summary data, while WASP4 needs detailed bathymetry and time series data for both physical and water quality parameters.

The type and amount of data will depend largely on the following: (1) study objectives, (2) system characteristics, (3) data presently available, (4) modeling approach selected, (5) degree of confidence required for the modeling results, (6) project resources, and (7) whether the marina site is an existing or a proposed site. Each of these factors should be considered in the planning stage of the sampling effort in order to formulate fundamental questions that can be used in the data collection design.

5.1.1 Study Objectives

The study objectives will often determine the degree of effort required for data collection. The objectives should be clearly defined and well known prior to the planning of any monitoring study. Obviously, the purpose of such a study will be to assess the potential impacts of a proposed marina on coastal water quality. For an existing marina, the objective of the monitoring program is to determine compliance with water quality standards inside and outside a coastal marina. For example, the monitoring program must be of much higher resolution if the main objective is to define hourly variations than if the objective is to determine the mean or overall effect of an existing or proposed marina on the adjacent water body. Until all objectives are defined it will be difficult to establish the basic criteria for a monitoring study.

5.1.2 System Characteristics

Each marina site is unique, and the scope of the sampling effort should be related to the problems and characteristics of that particular system. The particular advantages of models are that they can be used to interpolate between known events and to extrapolate to conditions for which data are not available. The kind of data required is determined by the characteristics of the system, the dominant processes controlling the constituent investigated, and the time and space scales of interest. The selection of modeled processes and degree of resolution will be the driving force in determining the sampling required. Water quality model results are limited by the data used to calibrate the hydrodynamic submodel and the kinetic rate coefficients. If data are collected during a major storm, then the model may provide valid results only during storm events.

5.1.3 Data Availability

Some data must be available to make initial judgments as to the location and frequency of sampling as well as to make decisions concerning the selection and application of the marina model. Where data are not available for the constituents of interest, it may be necessary to use some alternative surrogate parameters for these initial judgments, such as, possibly, suspended solids for strongly sorbed constituents. Reconnaissance surveys may be required to provide a sufficient data base for planning where only limited data are available.

5.1.4 Model Selection

Data collection requirements for water quality modeling depend to some extent on the particular model or the calculation procedure selected and the detail required in the modeling analysis. The modeling approach should be selected prior to the monitoring study based on historical data and reconnaissance surveys. Ideally, preliminary model applications should be conducted to assess available data, define data gaps, and provide guidance on monitoring requirements. Critical examination of the model input data requirements and studies of the model's sensitivity to parameters and processes should aid in the development of monitoring strategies. Several iterative cycles of data collection and model application optimize both monitoring and modeling efforts.

5.1.5 Confidence

To a large degree the quantity and quality of the data determine the confidence that can be placed in the model application. Without data, it is impossible to determine the uncertainties associated with model predictions. Uncertainties in the driving forces for the model (i.e., loadings, wind, tide) will be propagated in model predictions. The greater the uncertainty (spatial, temporal, or analytical) associated with data used in model forcing functions, estimation of model parameters, or evaluation of model predictions, the greater the resulting uncertainty associated with those predictions. One fundamental question that may impact monitoring studies is the acceptable degree of uncertainty in both data and model predictions.

Quantitative measurements of the error limits and confidence intervals should be made for all collected data so that the gains or losses in model accuracy and precision can be determined. Accuracy can be lost in a number of ways. For example, accuracy can be affected by improper field procedures such as faulty sample labeling, insufficient instrument calibration, instrument breakdown, and poor training of field personnel. Even if high-quality data are collected the data must also reflect the processes being modeled in order to provide a rational aid for making decisions governing the sampling plan. For example, if study objectives require that boundary conditions must be sampled with 95 percent confidence, then there are established quantitative methods available to estimate the sampling effort required (e.g., Cochran, 1977; Whitefield, 1982).

5.1.6 Resources

The major factors usually limiting sampling programs are budget and time constraints. Complex models such as WASP4 require large amounts of data and the corresponding expenditure of trained personnel, instrumentation, and ship time. Such an expenditure may not be feasible in many circumstances. In cases of limited funding and time, the Tidal Prism Model may be more appropriate due to its less stringent data requirements. It should be noted, though, that the quality of the model result is related to the complexity of the model employed.

5.1.7 Existing Versus Proposed Marina

The number and location of sampling stations and the level of sampling effort depend to a large extent on the physical status of the marina site (i.e., existing versus proposed marina). Since sampling resources are generally limited, it is important to locate the stations in places that will provide the most information. In general, fewer stations will be available to sample for a proposed marina since stations within the proposed marina do not exist and therefore, cannot be sampled. This factor will affect the level of effort in the monitoring program. For a proposed marina, it is more important to perform sensitivity analysis under wide range of conditions, especially where water quality standards are more likely to be violated, and to establish a concentration range for the water quality constituent of concern. Most model coefficients and reaction rates are site-specific; therefore, sensitivity analysis must be a fundamental component of water quality assessment at a proposed marina.

5.2 Types of Data

In general, the simpler the model, the fewer the data requirements. Tidal Prism Analysis calculations require only bathymetry, tidal range, and estimates of pollutant discharge rates. In addition to these data, the WASP4 model requires meteorological data, currents, salinity, temperature, and SOD measurements, as well as other data. These data are used to calculate rate coefficients, to determine boundary and forcing conditions, and to judge the accuracy of the model results. The general types of data required are discussed in further detail in the following section.

5.2.1 Reconnaissance and/or Historical Data

The amount and types of historical data available determine which level of model (simple, mid-range, or complex) can be initially applied to a marina site. Historical data sources should always be surveyed, but where historical data are not available it may be necessary to perform reconnaissance surveys to obtain sufficient data for model selection. Additional reconnaissance surveys may be required particularly in areas where the greatest uncertainties exist. The data required at this stage includes system geometry, bathymetry, and tidal range, to evaluate the flushing characteristics and to estimate typical dissolved oxygen and fecal coliform concentration. Initial Tidal Prism Analysis calculations should be carried out so that any potential water quality problems can be identified.

A sensitivity analysis is useful when applied to a preliminary calibration or an application of a simple model using historic or estimated conditions. In this case, the sensitivity analysis results can be used to determine which coefficients and parameters should be measured and which can be estimated. For example, if the model is sensitive to SOD rates, then these should be measured rather estimated. If other parameters such as the wind speed function have little influence, then very little effort should be expended to measure their exact form.

The data needs for the WASP4 and Tidal Prism models are not likely to be fulfilled through historical and/or reconnaissance surveys because of the extensive data requirements of these models. However, information such as wind, tide, and geometry may be available in sufficient amounts to calibrate the hydrodynamic submodels, and such data may not need to be collected.

5.2.2 Boundary Condition Data

Boundary condition data are external to the model domain and are driving forces for model simulations. For example, tides, atmospheric temperature, solar radiation, and wind speeds are not calculated but are specified to the model as boundary conditions to drive modeled processes such as mixing, heat transfer, algal growth, reaeration, photolysis, volatilization, etc. Nonpoint and point source loadings as well as fresh water inflows are model boundary input for both the Tidal Prism and the WASP4 models. Therefore, boundary condition data (i.e., water surface elevation and flows) must be collected for the WASP4 and Tidal Prism models. Data collection at boundary areas should be done at a higher frequency than other sampling due to its critical nature.

Boundary conditions for either Tidal Prism Analysis or the NCDEM DO model requires only the average dissolved oxygen concentration in the adjacent water, a single point. In addition, the NCDEM DO model requires tidal information, which is available through NOAA's tide tables.

5.2.3 Initial Condition Data

Generally, initial conditions are not required for internal flows or velocities. However, for water quality constituents in both the Tidal Prism Model and the WASP4 model initial conditions are required where the simulated period of interest is less than the required time for these initial conditions to be "flushed out." For example, if the model is run to a steady state, then by definition initial conditions are not required. If, however, simulations are conducted over "short" periods of time, then proper initial conditions may be critical in order to ensure that model calculations have reached equilibrium.

Initial conditions are generally not required for flows in the WASP4 hydrodynamic submodel. Generally, velocity fields are set up within relatively few model time steps. However, initial conditions are required for materials such as tracers, salinity, or temperature used to calibrate the transport predictions. An exception is where the initial conditions are rapidly flushed out, or the flushing period is short in comparison to the simulation period. In this case, it is often reasonable to run the model to a steady state, using the initial boundary conditions, and to use the results of steady-state simulations as the initial conditions for subsequent simulations.

5.2.4 Calibration/Evaluation Data

The Tidal Prism and WASP4 models are general in that they can be applied to a variety of sites and situations. However, the values of water quality coefficients must be selected on a site-specific basis, within some acceptable range. The process of adjusting the model parameters to fit site-specific information is known as model calibration, and it requires that sufficient data be available for estimation of coefficients. Calibration applies only to existing marinas since calibration data cannot be collected from a non-existing marina. While resources often limit the extent of the calibration data, more than one set of data describing a range of conditions is desirable. Ideally, the calibration data should reflect the entire range of conditions that are normally found at the marina site.

It is always wise to calibrate either model with one or more independent data sets to ensure that the model accurately describes the system. Evaluation conditions should be sufficiently different from calibration conditions to test model assumptions without violating them. For example, if the rate of sediment oxygen demand is assumed not to change (i.e., is specified as a zero order rate), then the model obviously would not predict well under situations where the sediment oxygen demand was drastically different because of a storm event.

The calibration of the hydrodynamic model may require an iterative effort in conjunction with the application of the water quality models for the constituent of interest (e.g., dissolved oxygen). However, initial calibration is usually conducted against materials such as conservative tracers, salinity, or temperature. Salinity, temperature, and suspended solids concentrations will impact density, which will in turn affect computed velocity distributions. The transport of at least salinity, and possibly temperature and suspended solids, should generally be directly linked to hydrodynamic predictions. Continuous dye discharges may be used to estimate lateral mixing and flushing characteristics.

Dye tracer studies are one of the better means of calibration. The spread of the dye will aid in estimation of dispersion coefficient, and the movement of its centroid can help to estimate net flows.

5.2.5 Post-Audit Data

One type of data that is often ignored is post-audit data. Models will usually be calibrated and applied to produce predictions for the various water quality processes under investigation for a time period of interest. These results are then used for making regulatory decisions that may affect the design of the marina modeled (Tetra Tech, 1988). This is often the end of most modeling and monitoring studies. Post-audit data for the water quality parameters must also be collected to provide a direct comparison between model predictions and observed data. There are relatively few cases where studies are conducted after the implementation of management decisions to determine whether the model predictions were accurate and the decisions were appropriate. Without a follow-up investigation, the overall success or failure of a modeling study often cannot be determined. An example where post-audit data were used to verify model results is the Wexford Marina study (EPA, 1986).

5.3 <u>Model Data Requirements</u>

5.3.1 Bathymetry Data

Bathymetry data are always required to determine model morphometry. Marine morphometry controls tidal flushing and subsequently DO and fecal coliform concentrations. All models require essentially the same types of information to define the geometric characteristics of the marina and the adjacent water. The basic types of data required for each segment include:

- Segment length;
- Variation of channel width and cross-sectional area with depth;
- Bottom slope (or bed elevations);
- Variation of wetted perimeter or hydraulic radius with depth; and
- Bottom roughness coefficient (Manning's n).

Length and average slope over long distances can be determined from topographic maps, while the other variables usually require field surveys. The first two data types, length and cross-sectional area, are fundamental to any modeling study since they are necessary in the transport calculations. The remaining information may or may not be required, depending on the type of hydraulic computations used in the model. WASP4 internally computes the cross-sectional area as a function of depth based on idealized representations of the channel shape. On the other hand, the Tidal Prism Analysis procedures require the average depth and the marina surface area. Table 5-1 lists the geometric and bathymetric data requirements for the recommended marina models. Bathymetry data are available for most estuaries and coastal areas from U.S. Coastal and Geodetic Navigation Charts and Boat Sheets or from sounding studies conducted by the U.S. Army Corps of Engineers. The charts tend to slightly underestimate depths in navigation channels to allow for siltation. Bathymetric charts may be sufficient enough to provide all information needed for the Tidal Prism Model geometry. If these charts do not provide the required geometric data, then bathymetric survey of the existing marina should be included in the data sampling plan.

TABLE 5-1. Geometric and Bathymetric Data Requirements for Recommended Marina Models

Model	Parameters
Tidal Prism Analysis	Surface area Average depth at high and low tide
NCDEM DO Model	Marina and channel Surface area Average depth at high and low tide
Tidal Prism Model	Distance to transect from mouth Segment volume at low and high tide
WASP4 Model	Channel length and width Segment depth and surface area

5.3.2 Transport/Hydraulic Data

Either direct observation or the prediction of transport is essential to assess potential water quality impacts from coastal marinas. All marina water quality models are based on mass balance principles, and both concentrations and flows are required to compute mass rates of change. Essential physical data required for prediction or description of transport for the recommended marina models are outlined in Tables 5-2 and 5-3. Table 5-2 lists essential data types required to model transport and dispersion and Table 5-3 provides required input data for the recommended models.

TABLE 5-2. Essential Transport Data

Data Type	Parameters
Morphometic	Segment geometry
Hydrodynamic	Water surface elevations Current speed and direction Point and distributed flows
Meteorological	Solar radiation Air temperature Precipitation Wind speed and direction
Physical	Salinity Water temperature Suspended sediments Dye studies

TABLE 5-3. Transport/Hydraulic Data Requirements for Recommended Marina Models

Model	Parameters
Tidal Prism Analysis	Freshwater inflow Marina tidal prism volume
NCDEM DO Model	Tidal amplitude
Tidal Prism Model	Average solar radiation during simulation period Freshwater inflows Tributary inflows Tidal prism volume per segment
WASP4 Model	Precipitation rate Wind speed and direction Average solar radiation Air temperature Cloud cover Time series of headwater Time series of tide

The type of data used to quantify transport depends on the model selected and the characteristics of the system. For example, geometry, freshwater flow, tidal range, salinity distribution, and boundary concentrations representative of conditions being analyzed are necessary input for applications involving the WASP4 and Tidal Prism models.

For complex marinas, time-varying flows, depths, and cross-sections will make estimation of flows and dispersion from field data difficult. In these cases the flows have to be measured either by dye studies or by current meters. No matter how these parameters are determined, they must adequately reflect the flushing characteristics of the system.

An intensive data collection program that includes concurrent water surface elevation, velocity, and dye dispersion or salinity gradient studies provides the most complete set of data for calibration of hydrodynamics for the WASP4 and the Tidal Prism models.

Hydrodynamic boundary conditions for the WASP4 model consist of flows or heads. Head refers to the elevation of the water surface above some datums. Generally, flow information is provided for tributary and point sources and water surface elevations provided at the channel entrance boundary.

Water surface elevation information is often available from tide gauge records or from the Coast and Geodetic Survey tide tables published annually by NOAA. These tide tables do not include the day-to-day variations in sea level caused by changes in wind or barometric conditions, nor do they account for unusual changes in freshwater conditions. All of these conditions will cause the tide to be higher or lower than predicted in the tables. Where possible, water surface elevation gauges should be placed at the model boundaries as part of the monitoring program for use with the WASP4 model application. Tide information obtained from NOAA's tide table is sufficient for both the Tidal Prism Analysis calculations and the Tidal Prism Model.

5.3.3 Meteorological Data

Meteorological data, including precipitation, wind speed, and direction, are required to compute surface shear, vertical mixing, and pressure gradients. Meteorological data are often available for nearby National Weather Service stations from the National Climatic Center in Asheville, North Carolina.

Different meteorological parameters are required for the various models. Tidal Prism Analysis does not utilize this type of data and thus biochemical reaction rates cannot be extensively varied. The Tidal Prism Model requires only the average solar radiation for the time period being modeled. The meteorological data requirements of WASP4 for each submodel are outlined in Table 5-4. Wind speed and direction are important input data for the WASP4 model application since wind data are included in the hydrodynamic and the dissolved oxygen calculation (reaeration rate). Measured wind speed and direction for the WASP4 model application are good to have for realistic predictions at a marina site.

TABLE 5-4. Meteorological Data Requirements for WASP4 Submodels

WASP4 Submodel	Parameters
Hydrodynamic	Wind speed and direction
Water Quality (Dissolved Oxygen)	Instantaneous and average solar radiation Temperature Wind speed
Toxic Chemical	Wind speed Solar radiation Cloud cover

5.3.4 Water Quality Data

Given the semi-empirical nature of water quality models, water quality data are necessary to set up, calibrate, and verify any water quality model. Input data are needed for all parameters that will be simulated. For models that simulate conventional pollutants, data may include water temperature, dissolved oxygen, carbonaceous BOD, phosphorus, nitrogen (ammonia, nitrite, and nitrate), fecal coliform bacteria, chlorophyll-*a* or phytoplankton dry weight biomass, and conservative constituents such as total dissolved solids. The WASP4 model also includes additional constituents such as total inorganic carbon, alkalinity, pH, inorganic suspended solids, suspended organic detritus, periphyton, and zooplankton grazing rates.

Data requirements for WASP4 will vary if the application is intended for dissolved oxygen, fecal coliform, or toxics. Variables critical for an analysis of toxicity, such as pH for ammonia and metals, may not be required if the parameter of interest is DO. If pollutants are not expected to impact particular variables, such as pH, then it may be sufficient to use available data to determine their effects. If, however, data are not available for conditions of interest or if the variable is expected to change, either directly or indirectly, in response to marina wastes, then modeling will require collection of additional supporting data. When simulating dissolved oxygen with the WASP4 model, diurnal DO data is very helpful for calibrating the phytoplankton growth rate, death rate, and respriation coefficients. The diurnal DO data collection period should span at least one complete diurnal tide cycle (i.e., at least 25 hours) to ensure that both the daily maximum and minimum DO are measured. Ideally, sampling begins at 6:00 am and continues to 7:00 am the following day to cover two daily minimums.

Table 5-5 provides an overview of some commonly measured water quality variables, their problem context, and an indication of the processes they impact. The specific type of data for a particular application will vary depending on the factors listed in Section 5.1. Concentrations for all pertinent water quality variables should be provided at the model boundaries, providing the driving forces for model predictions, as well as at stations within the model system to provide a basis for estimating model parameters and evaluating model predictions. The user's manuals for the Tidal Prism and WASP4 models should be consulted for the exact data requirements for each application.

TABLE 5-5. Water Quality Variables

Constituent	Problem Context	Effects
Salinity	All	Transport, dissolved oxygen
Temperature	All	Transport, kinetics, dissolved oxygen
Dissolved oxygen	All	Indicator, toxicity, sediment release
BOD-5	DO	Dissolved oxygen
NBOD	DO	Dissolved oxygen
Bottom demand	DO	Dissolved oxygen, nutrient release
Total phosphorus	DO	Algae
Soluble reactive phosphorus	DO	Dissolved oxygen, algae
Total Kjeldahl nitrogen	DO	Dissolved oxygen, algae
Ammonia-nitrogen	DO, Toxicity	Dissolved oxygen, toxicity, algae
Nitrite-nitrogen	DO	Dissolved oxygen, algae
Nitrate-nitrogen	DO	Dissolved oxygen, algae
Dissolved available silica	DO	Algae
Chlorophyll-*a* and phaeophyton	DO	Algal indicator
Phytoplankton (major groups)	DO	Dissolved oxygen, nutrient cycles, pH
Meteorologic data (wind, temperature, etc.)	All	Gas transfer, reaction rates
Fecal coliform bacteria	Shellfishery areas Recreational contact	Decay rates

In the WASP4 model, five state variables participate in the DO balance: phytoplankton carbon, ammonia, nitrate, carbonaceous biochemical oxygen demand, and dissolved oxygen. A summary is illustrated in Figure 5-1. The reduction of dissolved oxygen is a consequence of the aerobic respiratory processes in the water column and the anaerobic processes in the underlying sediments. Table 5-6 lists water quality data requirements for the recommended marina models.

TABLE 5-6. Water Quality Data Requirements for the Recommended Marina Models

MODEL	Fecal Coli.	DO	BOD	SOD	Temp.	NH_3	Algae	Zoo.	Salinity
Tidal Prism Analysis	X	X	X	X					
NCDEM DO Model		X		X					
Tidal Prism Model	X	X	X	X	X	X	X		X
WASP4 Model	X	X	X	X	X	X	X	X	X

5.4 Sampling Guidelines for Existing Marinas

General guidance is presented to develop the framework for a site-specific water quality sampling program suitable for an *existing* marina. A monitoring study at an existing marina may be required by regulatory agencies if it is suspected that the marina is causing degradation of water quality standards. As shown in Figure 5-2, the overall monitoring program can consist of three phases or levels. In Level 1, preliminary screening is conducted to gather baseline information on the marina. If historical data are available on the marina, then this level may not be required or the quantity of data needed may be reduced. Based on the historical and/or Level 1 data, if it is established that the marina may be causing impacts on water quality, then Level 2 sampling which incorporates additional sampling of the receiving waters, would commence. If evaluation of Level 2 data also indicates that the marina is impacting water quality, then marina design changes may be recommended and eventually implemented. Level 3 sampling would be initiated to evaluate the performance of any implemented marina design changes. Examples of potential marina design changes include removal of sills, which tend to trap water in the lower depths of a marina, and improvement of flushing by altering sharp corners within the marina or by enlarging the marina entrance.

5.4.1 Spatial Coverage

An intensive spatial coverage of the marina and the adjacent water body for some indicator or surrogate water quality parameter, such as salinity or turbidity, is generally needed to estimate spatial variability and to determine the model type and the segmentation required.

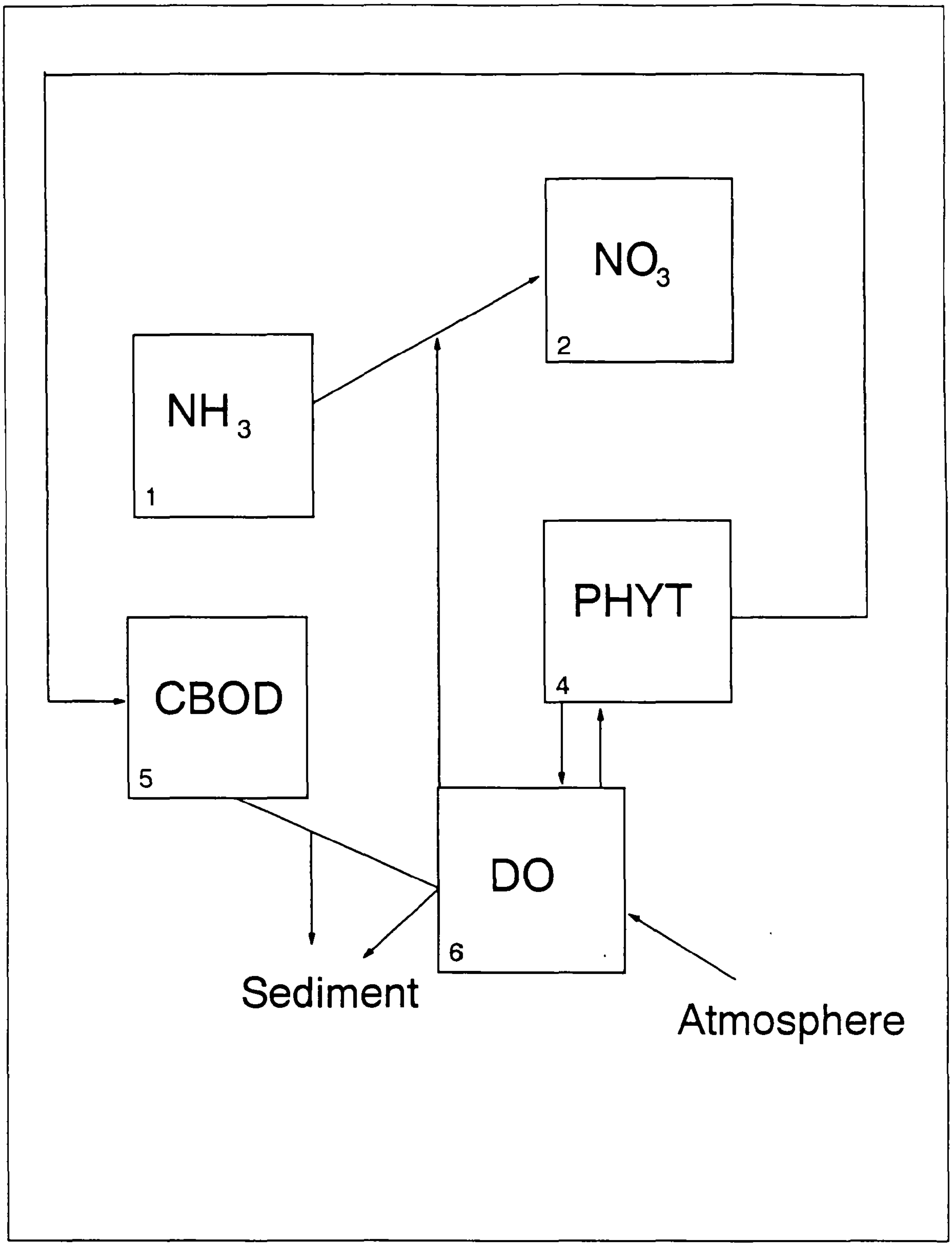

Figure 5-1. Oxygen balance.

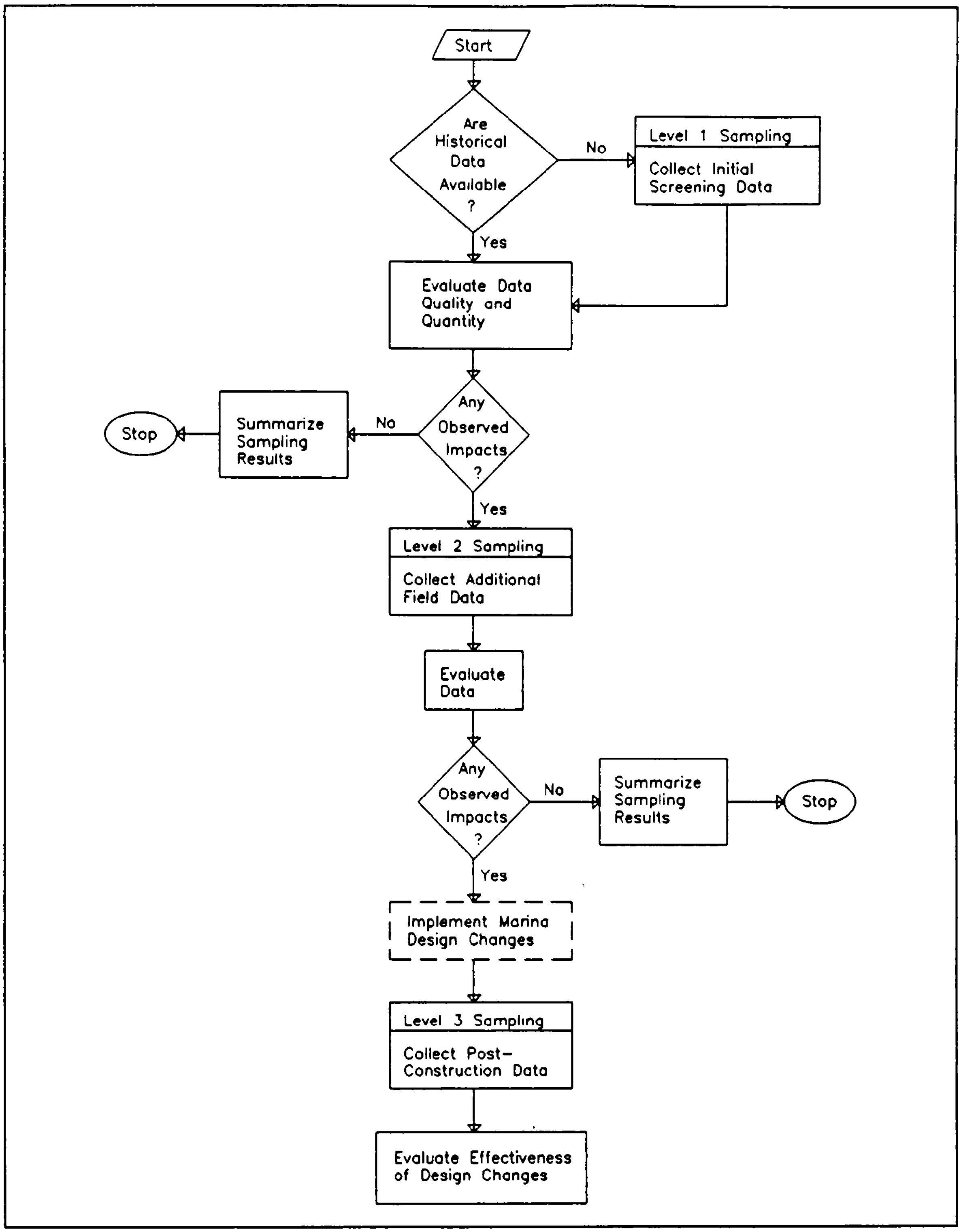

Figure 5-2. Sampling Scheme for Existing Marina.

Generally, the spatial coverage of the modeled marina should extend away from the marina site to the extent that normal background levels for DO are encountered. At this location, model boundary conditions (i.e., surface elevations or current velocities) can be established. In this manner the total effect of the marina can be measured.

The preceding approach is appropriate when using the WASP4 model. Sampling stations for the WASP4 model should be spaced throughout the model grid system with the spatial coverage being governed by the gradients in velocities and water quality constituents. For existing marinas, the adjacent water bodies are divided into a series of reaches for WASP4 model application, with each reach described by a specific set of channel geometry dimensions (i.e., cross-sectional dimensions) and flow characteristics (i.e., flow rates, tidal range, velocities and biochemical processes). The model assumes that these conditions are uniform within each reach. Each reach is in turn divided into a series of model segments or computational elements in order to provide spatial variation for the water quality analysis. Each segment is represented by a grid point in the model where all water quality variables are computed. For the WASP4 model, the segment length is dependent on the degree of resolution desired and the natural variability in the system. Enough detail should be provided to characterize anticipated spatial variation in water quality.

The hydrodynamics of the Tidal Prism Model are based on the tidal prism volume at each segment. Therefore, the spatial coverage of a marina, using the Tidal Prism Model, will include the entire estuary/river where the marina is located (Kuo et al., 1989). The length of each segment is defined by the tidal excursion, the average distance traveled by a water particle on the flood tide, since this is the maximum length over which complete mixing can be assumed.

A sampling station for each model segment is the minimum requirement to calibrate the returning ratios of the Tidal Prism Model. Sampling stations should generally be located along the length of the estuary and in the main channel. The returning ratio is defined as the percentage of tidal prism that was previously flushed from the marina on the outgoing tide. More information concerning the Tidal Prism Model returning ratio calibration is provided in a later section of this report.

5.4.2 Constituents Sampled

The specific constituents that must be sampled, as well as the sampling frequency, depend to some extent on the particular modeling framework to be used in the analysis. The selected model should include all of the processes that are significant in the area under investigation without the unnecessary complexity of processes that are insignificant. A few preliminary measurements may be useful to define which processes are important.

The minimum sampling requirements for all dissolved oxygen studies should include dissolved oxygen, temperature, CBOD, and total Kjeldahl nitrogen since these parameters are fundamental to any dissolved oxygen analysis. Biochemical oxygen demand (BOD) is typically measured as a 5-day BOD, but a few measurements of long-term BOD are also necessary. The

Tidal Prism Model considers only the CBOD component, and therefore the model should be used only in situations where the nitrogenous components are known to be unimportant.

In addition to total Kjeldahl nitrogen (TKN), ammonia and nitrate (or nitrite plus nitrate) should be measured for dissolved oxygen investigations for both the Tidal Prism and WASP4 models. Even if they are not modeled, ammonia, nitrate, and nitrite data are useful for estimating the nitrogenous BOD decay rate or ammonia oxidation rate.

Concentrations of algal dry weight biomass or chlorophyll-*a* should be measured because both WASP4 and the Tidal Prism Model simulate algae growth for dissolved oxygen analysis. Light extinction coefficients (or Secchi depths) will also be needed for the algal growth computations in dissolved oxygen analysis if the WASP4 model is used.

In situ sediment oxygen demand (SOD) should be measured in situations where it is expected to be a significant component of the oxygen budget. This is most likely to occur in shallow areas where the organic content of the sediments is high or in deep marina basins where flushing is minimal (NCDEM, 1990). In developing a strategy for SOD measurement, it is logical to assume that those factors important in establishing model reaches or segments are also relevant to selecting SOD measurement sites. The more important of these factors are:

- Geometric - depth and width;
- Hydraulic - velocity, slope, flow, and bottom roughness; and
- Water quality - location of: point sources, nonpoint source runoff, and abrupt changes in DO/SOD concentrations.

The most important factor for SOD is likely to be the location of abrupt changes in DO/BOD concentrations such as surrounding the entrance channels of marinas and in the marina basin proper (NCDEM, 1990). The final point to consider is that SOD may vary with season. This observation is particularly relevant to marinas and adjacent areas dominated by algal activity and/or oxidation of organic and inorganic nutrients by benthic microorganisms, both of which may occur seasonally. The modeler should thus be aware of this potential concern and structure the SOD measurement times accordingly.

In addition to sampling for the constituents to be simulated, measurements are also necessary to help quantify the various coefficients and parameters included in the model equations. Coefficient values can be obtained in four ways: (1) direct measurement, (2) estimation from field data, (3) literature values, and (4) model calibration. Model calibration is usually required regardless of the selected approach. However, coefficients that tend to be site specific or that can take on a wide range of values should either be measured directly or estimated from field samples. This could include the following parameters:

- Carbonaceous BOD decay rate;
- Carbonaceous BOD settling rate;
- Ammonia oxidation rate (nitrogenous BOD decay rate); and
- Sediment oxygen demand.

In addition to the above model parameters, which are determined primarily from the results of field sampling surveys, several other rate coefficients can be measured in the field. For example, stream reaeration rates for the WASP4 model, and returning ratios for the Tidal Prism Model, can be measured using tracer techniques. WASP4 provides several options for the reaeration rate equation since many of the equations are applicable only over certain ranges of depth and velocity.

5.4.3 Sampling Locations

Water quality data should be collected at the downstream boundary of the study area for model calibration. While a single downstream station is the minimum requirement for short channel sections, additional sampling stations are desirable to provide more spatial data for calibrating the model. Logical locations for additional stations are sharp corners and deadend segments in the marina basin proper. If the marina is segmented for a WASP4 model application, then each segment must be sampled. Additionally, adjacent waters both upstream and downstream must also be sampled to determine background concentration of water quality constituents. However, an NCDEM study at 11 marina sites indicated that water quality variations are negligible at stations located upstream and downstream immediately outside those marinas (NCDEM, 1990).

In the Tidal Prism Model, water quality is assumed to be well-mixed and uniform over each segment of the stream. Therefore, samples taken immediately downstream of the marina would probably not match conditions in the model unless they were taken far enough downstream for complete cross-sectional mixing to occur. In general, increased sampling should be allocated to those areas of the marina and the adjacent water that have the most impact (i.e., along the shoreline). In general, all of the major water quality parameters of interest (DO, CBOD, TKN, NH_3, NO_3, fecal coliform, temperature, etc.) should be measured at each station in the sampling network.

Rate coefficients and model parameters can be estimated from literature values before site-specific measurements are available. For important parameters such as the BOD decay rate, sensitivity analyses can be performed to evaluate the effects of different coefficient values in formulating DO concentrations. These analyses should provide enough information so that sampling stations can be located in critical areas.

5.4.4 Sampling Time and Frequency

The duration and frequency of water quality sampling depend to a large extent on whether the Tidal Prism or the WASP4 model will be used. The Tidal Prism Model computes water quality conditions only at slack before ebb; thus, sampling at a higher rate is not necessary. The WASP4 model has a user-specified time step, which means that sampling must be greater for shorter time steps.

Since the Tidal Prism Model assumes that conditions remain constant with time, it is important to conduct the sampling program during a period when this assumption is valid.

Synoptic surveys (e.g., sampling all stations over 2 to 3 days) should be conducted to the extent possible so that water quality conditions at different locations are not affected significantly by changes in the weather or variations in the marina discharge that are not accounted for in the model. However, since temperature varies diurnally and temperature influences the process rates of most biological and chemical reactions, some variability will be inevitable in the sampling results. It should be noted that the Tidal Prism Model uses the first day of field data as initial and boundary condition input to the model. Field data from succeeding cycles are then used to compare the output simulations at the same cycle.

The WASP4 model computes the continuous changes that occur over time due to variations in stream flow, temperature, nonpoint and point source loadings, meteorology, and processes occurring within a marina and its adjacent waters. In the WASP4 model, all of the factors that are assumed constant for a Tidal Prism analysis are free to vary continuously with time. This allows an analysis of diurnal variations in temperature and water quality, as well as continuous prediction of daily variations or even seasonal variations in water quality.

WASP4 generally requires a much more detailed sampling program than that required by the Tidal Prism Model. Enough data must be collected to define the temporal variations in water quality throughout the simulation period at the model boundary conditions. Therefore, more frequent data collection must be conducted at the model boundary condition. The WASP4 model excels in investigating the temporal variations in dissolved oxygen and fecal coliform bacteria. To achieve this resolution, intensive surveys should be mixed with long-term trend monitoring. The significance of the temporal variations depends on the context of the problem. For example, if the daily average dissolved oxygen concentration is around 5 mg/L or less, then a diurnal variation of less than 1 mg/L could be very important with respect to meeting water quality standards, while if the average dissolved oxygen concentration is around 10 mg/L, then diurnal variations of 2 or 3 mg/L may not matter. If preliminary sampling indicates diurnal variations are important, then the sampling program should include 2 or 3 days of intensive sampling for dissolved oxygen and temperature at all of the key stations. As a minimum, these stations would include the stations designated as the model boundary, as well as the stations surrounding the marina and adjacent waters and stations within the marina. These locations satisfy the minimum requirements of defining the boundary and loading conditions plus a few calibration stations in the critical areas for DO, SOD, and fecal coliform.

Long-term dynamic simulations of seasonal variations in stream water quality may be impractical. Where seasonal variation is of interest, the typical practice is to run the Tidal Prism Model or the WASP4 model (with short-term simulations) several times for different sets of conditions that represent the full spectrum of conditions expected over the period of interest. Enough data should be collected to characterize the seasonal variations, and to provide adequate data for calibrating and applying the model. If possible, enough data should be collected to cover the full range of conditions of the model analysis. As a minimum, this should include conditions during the critical season for the water quality variable of interest. For dissolved oxygen, the critical season occurs during the hot summer months (July through September).

Two general types of studies can be defined—those used to identify short-term variations in water quality (i.e., intensive surveys) and those used to estimate trends or mean values (i.e., trend monitoring). Intensive surveys are intended to identify intertidal variations or variations that occur due to a particular event in order to make short-term forecasts. Intensive surveys should encompass at least four full tidal cycles (Brown and Ecker, 1978). Intensive surveys should usually be conducted regardless of the type of modeling study being conducted. Wherever possible, all stations and depths should be sampled synoptically. Boundary conditions should be measured concurrently with the monitoring of the marina basin and the adjacent water. A record of all point source waste loads, located near the marina site, during the week prior to the survey is recommended. Variables that should be sampled during the intensive surveys include tide, current velocity, salinity, DO, fecal coliform, nitrogen, and phosphorus measured hourly.

Trend monitoring is conducted to establish seasonal and long-term trends in water quality. Trend sampling may take place on a biweekly or monthly basis for a year at a time. Stations should be sampled at a consistent phase of the tide and time of day to minimize tidal and diurnal influences on water quality variations (Ambrose, 1983). Some stations may be selected for more detailed evaluation during the intensive survey. Long-term trend monitoring should also be considered as a way to track changes in water quality between the intensive surveys (Brown and Ecker, 1978).

Most states have water quality standards for the 24-hour average concentration and the instantaneous minimum concentration of dissolved oxygen. Therefore, it is important to collect dissolved oxygen data throughout a complete cycle, i.e., from the high value, which normally occurs at mid-afternoon, to the low value, which usually occurs at dawn. This will allow the DO range in the model to be calibrated to specific field conditions. If the water body is stratified, then samples should be collected at the surface, mid-depth, and bottom. In general, it is necessary to collect samples at a 2-hour frequency over a 24-hour period in order to adequately define the daily average and the minimum DO concentrations.

5.5 Sampling Guidelines for Proposed Marina

This subsection presents general guidance to develop a framework for a site-specific water quality sampling program suitable for a *proposed* marina. Regulatory agencies require that it should be demonstrated (i.e., modeled) that a proposed marina will not adversely impact water quality. The sampling guidelines outlined here provide the procedure for collecting information necessary to develop a water quality model of the proposed marina. The overall monitoring program consists of three levels (Figure 5-3). Initially, a preliminary investigation is conducted to determine the site characteristics necessary to properly design a monitoring program. Required information includes the locations of any nearby point source discharges (including flow rates and concentrations of effluent constituents) that could potentially be transported inside the marina. Any past studies of the area can also provide useful information and should be collected during the preliminary investigation. If adequate historical information is not available, then Level 1 sampling should be conducted to gather the initial screening data

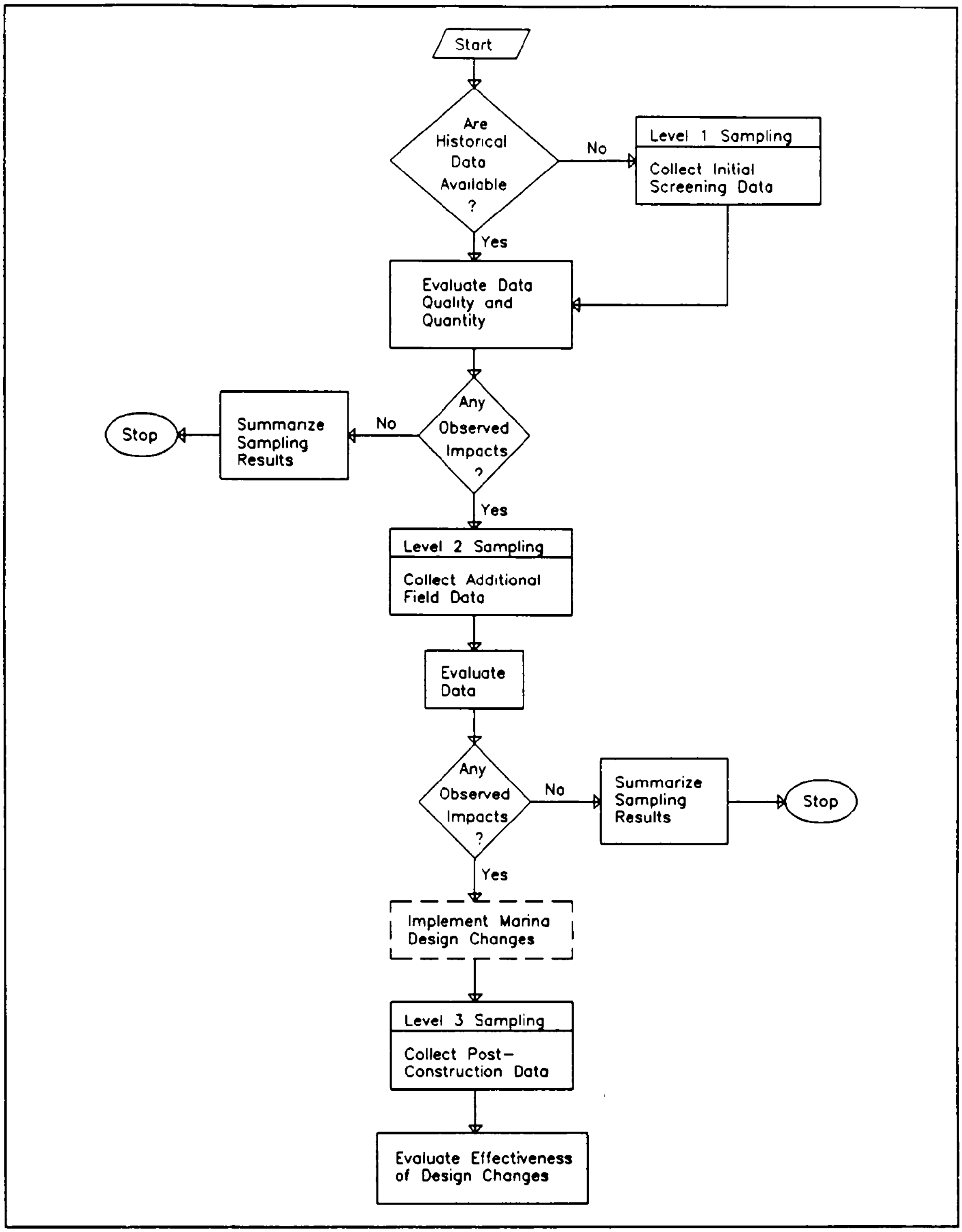

Figure 5-3. Sampling Scheme for a Proposed Marina.

necessary to develop a simple model (i.e., the Tidal Prism Analysis method or NCDEM DO Model). If application of the simple model to the proposed marina indicates that water quality is marginal or will be degraded, then Level 2 sampling is initiated to collect field data necessary to apply the more complex Tidal Prism Model or WASP4 model. After the marina has been permitted and constructed, Level 3 sampling may be required to determine compliance with water quality standards.

5.5.1 Spatial Coverage

An intensive spatial coverage of the proposed marina site and the adjacent water body, for some indicator or surrogate water quality parameter, such as salinity or turbidity, is generally needed in order to estimate spatial variability. As discussed earlier in this chapter, the hydrodynamics of the Tidal Prism Model are based on the tidal prism volume at each segment. Therefore, the spatial coverage of a proposed marina, using the Tidal Prism Model, will include the entire estuary/river where the marina is located (Kuo et al., 1989). The proposed marina is treated as a single-segment tributary with no freshwater input. A sampling station for each model segment is the minimum requirement to calibrate the returning ratios of the Tidal Prism Model. Sampling stations should be located along the length of the estuary and in the main channel. Model segmentation is explained in further detail in Chapter 6.

Sampling stations, for the WASP4 model, should be spaced throughout the model grid. A sampling station for each model segment is the minimum requirement to calibrate the WASP4 model. However, for a proposed marina the model cannot be calibrated or verified based on field data. Instead, the link-node hydrodynamic model may be calibrated against hydrodynamic results obtained from a two-dimensional model application to the proposed marina site (see Appendix E for more detail).

5.5.2 Constituents Sampled

The specific constituents that must be sampled, as well as the sampling frequency, depend to some extent on the particular modeling framework that will be used in the analysis. The selected model should include all of the processes that are significant at the proposed site. Since the system does not yet exist, neither WASP4 nor the Tidal Prism Model can be calibrated. Instead, a base condition consisting of average typical values of the various rate coefficients for the kinetic reaction terms and source/sink terms should be defined. A model sensitivity analysis is then performed by varying the rate coefficients about their typical ranges, and the effect on water quality constituents is documented. Water quality impacts of the proposed system can then be estimated from the sensitivity analysis.

At the proposed marina site, concentrations of algal dry weight biomass or chlorophyll-*a* should be measured because both WASP4 and the Tidal Prism Model simulate algae growth for dissolved oxygen analysis. Light extinction coefficients are also needed for the algal growth computations in dissolved oxygen analysis if the WASP4 model is used. In addition, in situ sediment oxygen demand (SOD) and other water quality variables (e.g., BOD) should be measured.

5.5.3 Sampling Locations

Water quality data should be collected at or near the proposed marina site. While a single downstream station is the minimum requirement for short channel sections with no major tributaries, additional sampling stations are desirable to provide more spatial data for calibrating the model. Additional stations should logically be located at biologically sensitive areas (e.g., shellfish harvesting areas). Water quality, in the Tidal Prism Model, is assumed to be well-mixed and uniform over each segment of the stream, requiring a sampling station in each segment along the length of the estuary in the main channel.

In general all of the major water quality parameters of interest (DO, CBOD, TKN, NH_3, NO_3, fecal coliform, temperature, etc.) should be measured at each station in the sampling network. Sampling locations for a proposed marina are limited since the proposed marina does not yet exist. Sampling stations are located in the adjacent waterways to determine existing water quality conditions and model boundary conditions. Figure 5-4 illustrates potential monitoring sites for *proposed and existing* open marinas and various types of *existing* enclosed marinas. For *proposed* enclosed marinas, monitoring stations should be positioned at the ambient water locations shown in Figure 5-4. If a nearby marina exists, then water quality parameters can be measured at the existing marina and extrapolated to the proposed marina.

When analyzing dissolved oxygen problems at a proposed marina site with several nearby marinas, more of the sampling effort should be allocated to areas where water quality standards are most likely to be violated. Areas where large water quality gradients exist should be sampled more thoroughly.

The Tidal Prism Model treats the proposed marina as a single-segment tributary, therefore, complicated marina design cannot be simulated. The WASP4 model, however, is capable of handling any complicated design as long as the model is calibrated with a two-dimensional hydrodynamic application to the proposed marina site.

5.5.4 Sampling Time and Frequency

The duration and frequency of water quality sampling depend to a large extent on the selected model. For example, since the Tidal Prism Model computes water quality conditions only at slack before ebb, sampling at a higher rate is not necessary. An intensive survey of the entire estuary (2 or 3 days) is required for the calibration of the Tidal Prism Model.

Sampling time and frequency are not affected by whether the marina exists or not and therefore issues discussed under Section 5.4.4 for an existing marina are also applicable to a proposed marina.

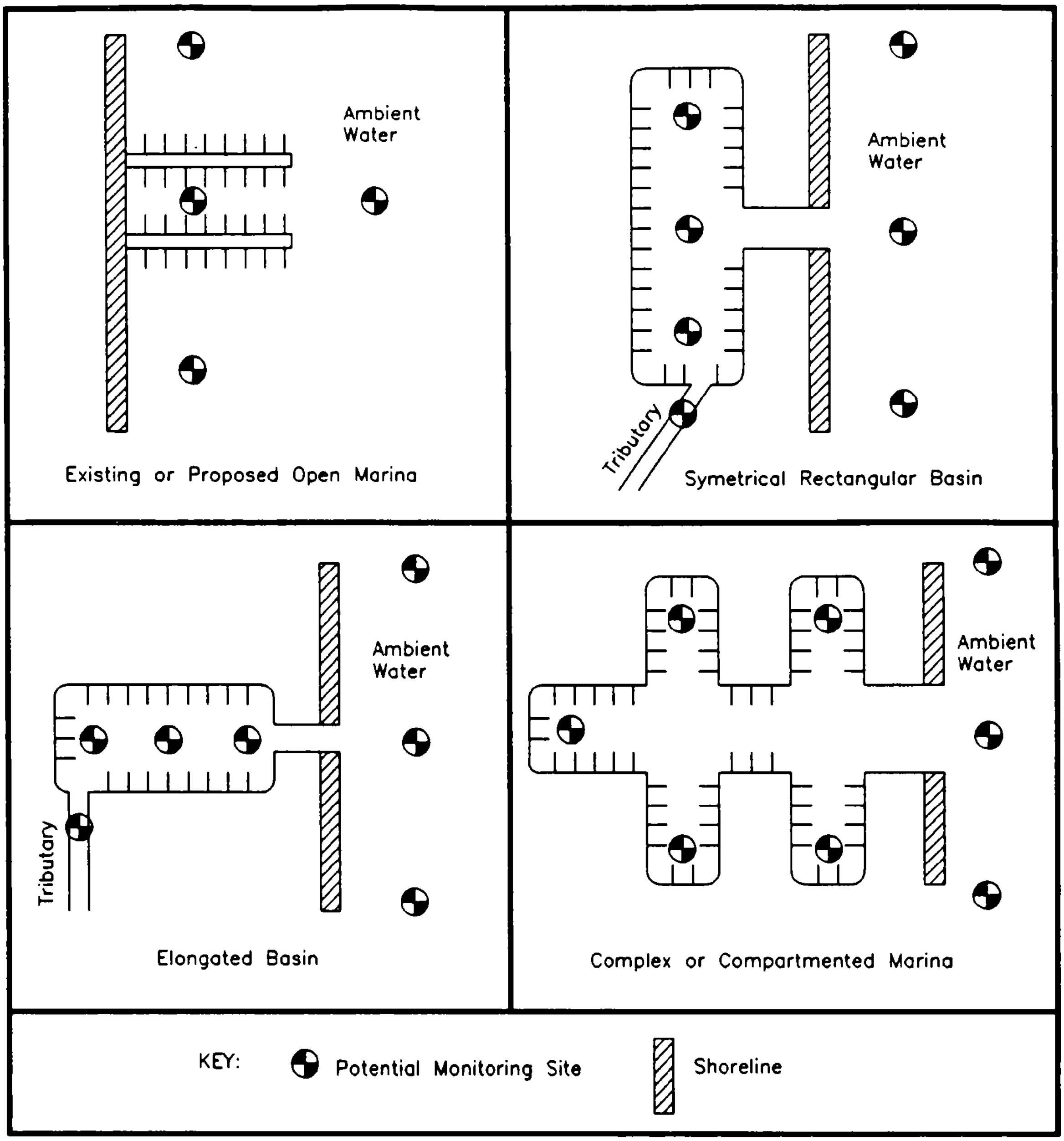

Figure 5-4. Potential Monitoring Sites for Proposed and Existing Marinas.

6. MODEL APPLICATION AND EVALUATION

Chapter 6 presents, in summary form, the findings of three modeling studies conducted at the Indian Hills canal/marina development in Boca Raton, Florida; Beacons Reach marina, in Carteret County, North Carolina; and Gull Harbor marina in Carteret County, North Carolina. Field studies and data collection for all these marinas were performed by the staffs of the U.S. EPA Region IV Environmental Services Division (ESD) and the Florida Department of Environmental Regulation (FL-DER).

In this chapter, data collected during the intensive surveys are used to calibrate and to apply the best qualified simple, mid-range, and complex marina models. Descriptions of existing water quality conditions during the intensive surveys are presented as well as model applications to the selected marinas.

6.1 Marina Description

6.1.1 Indian Hills Marina

The Indian Hills Yacht Club in Boca Raton, Florida, features a flow-through waterway system that is cross-connected by a canal near its midpoint and has a non-navigable cross-connecting circulation channel at its landward extreme. East of the cross-connecting midpoint canal, a mangrove forest remains intact and borders the Intracoastal Waterway. East to west the system spans approximately 1300 feet; the north-to-south dimension is approximately 900 feet (Figure 6-1).

The Indian Hills system was characterized chemically, hydrographically, and biologically during July 1984 and January 1985. Hydrographic investigations consisted of depth profiles and centerline traces, tidal dynamics, and current velocities. In conjunction with this data collection, circulation studies were accomplished through the use of dye-tracing techniques.

Water quality sampling occurred over a 27-hour period with the primary focus on dissolved oxygen, temperature, and salinity measurements, as well as slack tide water sample collection for chemical analysis. The laboratory analysis included ammonia, nitrite-nitrate, and total Kjeldahl nitrogen, as well as phosphorus, total organic carbon (TOC), and biochemical oxygen demand (BOD). Water quality data are summarized in Table 6-1.

Water level instruments were placed at the north entrance and near the circulation channel at Indian Hills. No notable differences were observed between these records in both water level heights and phases. Mean high water during the July study period was 1.28 feet above mean tidal level (MTL). During the winter study, water level recorders were placed within the Indian Hills marina near the circulation channel and also in a mosquito ditch within the mangrove area.

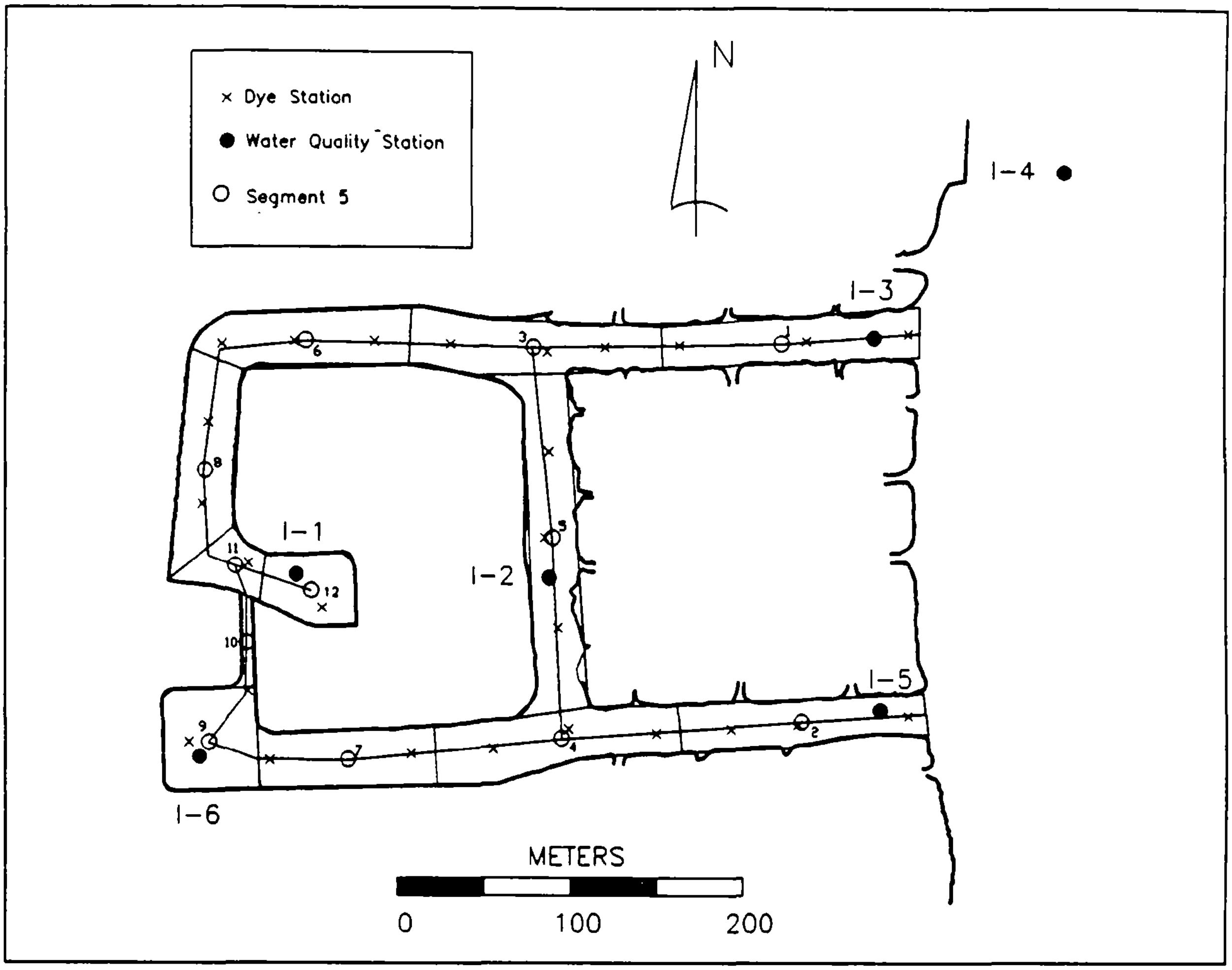

Figure 6-1. Indian Hills Marina.

TABLE 6-1. Indian Hills Marina Water Quality Summary

Parameter	Mean of Data Observed on July 12-13, 1984					
	Ambient Sta I-4	Sta I-1	Sta I-2	Sta I-3	Sta I-5	Sta I-6
DO (mg/L)	4 94	4 59	4.86	4.74	4.69	4.34
Salinity (ppt)	27 56	26 17	26.45	26.76	26.38	25.97
Temperature (deg C)	31.00	31 06	31 04	30.91	31.03	30.98
CBOD 20-day (mg/L)	2.4	3.3	3.4	3.0	3 1	3.6
Ammonia (mg/L)	0.07	0.07	0.06	0.06	0.06	0.07
Total Kieldahl N (mg/L)	<0.10	0.53	0.44	0 35	0.16	0.19
Nitrate+nitrite (mg/L)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Total phosphorus (mg/L)	0.12	0.13	0.14	0.11	0.11	0.13

Circulation studies were used to measure mixing within the system as well as determinations of water exchange (flushing) rates. During phase I, a dye tracer (Rhodamine WT) was introduced into the basin in a slug fashion. The dye cloud configuration was then monitored by means of a boat-mounted fluorometer and a pump fashioned in a flow-through mode. One liter of dye was introduced into the Indian Hills Canal at station 13 (Figure 6-1) at 1715 hours on July 12, 1984.

Water quality sampling was accomplished in conjunction with diel monitoring of dissolved oxygen, salinity, and temperature (DST) during both study phases. During the course of the diel monitoring, and corresponding as closely as possible to low and high slack tide, mid-depth 500-ml water samples were collected for chemical analysis of NH_3 NO_2-NO_3, TKN, T-P, and TOC in the ESD laboratory. In addition, BOD samples were also collected.

6.1.2 Beacons Reach Marina

Beacons Reach is located on the south side of Bogue Sound near Pine Knoll Shores, Carteret County, North Carolina. Also called Westport Marina, it is part of a larger development owned by the Beacons Reach Master Association. The marina is densely surrounded by condominiums that are most highly occupied during the summer.

The boat basin, constructed around 1978, consists of approximately 58 slips. The surface area of the marina basin is 2.3 acres. There are no pumpout facilities. A boat ramp is provided for residents. The number of boats observed during sampling ranged from 11 to 35, with both powerboats and sailboats present. Average depths measured in the basin ranged from 1.0 to 2.0 meters. Adjacent ambient waters were of about the same depth.

Water quality data are summarized in Table 6-2. Statistical analysis revealed that the average summer DO was significantly higher at the ambient stations than at either the basin or channel stations. SOD rates were approximately equal in ambient and basin waters, but greater residence time may allow SOD to exert a stronger effect on overlying oxygen concentrations in the basin compared to ambient waters, resulting in lower basin DO (NCDEM, 1990). Sampling stations for the Beacons Reach marina are shown in Figure 6-2.

NCDEM (1990) reported that both basin and ambient DO values were less than 5.0 mg/L on July 21, 1988. On that date, the Bogue Sound marinas were sampled during an unusually low tide, and DO values were low throughout the sound. Aside from this one episode, wind and tidal stage had no observable effect on DO. Dissolved oxygen in Beacons Reach never fell below 1.5 mg/L at any depth. Throughout the summer, the water column was well mixed. Although DO profiles were not stratified, values were depressed immediately above the sediment during the two August sampling events. Four of the 10 fecal coliform samples collected in the marina basin were greater than 14 fecal coliform/100 mL. A maximum value of 50/100 mL was found on May 26 at BR-6. Although some individual observations exceeded the North Carolina State criterion of 70/100 mL for shellfish, the median value was 10/100 mL for the basin.

TABLE 6-2. Beacons Reach Marina Water Quality Summary

Parameter	Summer Mean	
	Ambient	Basin
Column DO (mg/L)	6.3	5.0
Surface DO (mg/L)	6.3	5.3
Photic zone DO (mg/L)	6.3	5.1
Fecal coliform/100 mL	< 10[a]	10[a]
Turbidity (NTU)	8.3	7.0
Chlorophyll-*a* (μg/L)	12	15
Ammonia (mg/L)	0.04	0.07
Total Kieldahl N (mg/L)	0.4	0.4
Nitrate-nitrite (mg/L)	<.01	0.02
Total phosphorus (mg/L)	0.05	0.07

[a] Median

Therefore, these waters did not violate the state standard for class SA waters (14/100 mL median value). All eight of the fecal coliform samples collected in ambient waters were below the laboratory detection limit of 10/100 mL. A station at the mouth of Beacons Reach Marina was sampled once during the study period by the Division of Health Services Shellfish Sanitation Branch. Collected on May 26, this sample contained 79 fecal coliform/100 mL.

Turbidity and chlorophyll-*a* values were all within state standards. Nutrients were slightly higher in the basin than in ambient waters. One long-term BOD sample was collected at station BR-4 on September 8. The 5-day BOD value for this sample was 2.47 mg/L. After 81 days, 7.23 mg/L of oxygen had been consumed (NCDEM, 1990).

6.1.3 Gull Harbor Marina

Gull Harbor Marina is located on the northern shore of Bogue Sound in Carteret County, North Carolina, about 6.5 miles west of Morehead City. Gull Harbor Marina basin contains approximately 32 slips, and the surface area is 1.4 acres. The average depth measured in the basin ranged from 1.0 to 1.8 meters. Both sailboats and powerboats were docked in the marina during the dye study, and the number of boats observed ranged from 16 to 28. Sampling stations are indicted on the marina map (Figure 6-3). Gull Harbor shared ambient stations with Brandywine Bay Marina (BB-1UPS and DS). These ambient stations were located in the Intracoastal Waterway on either side of the two marinas.

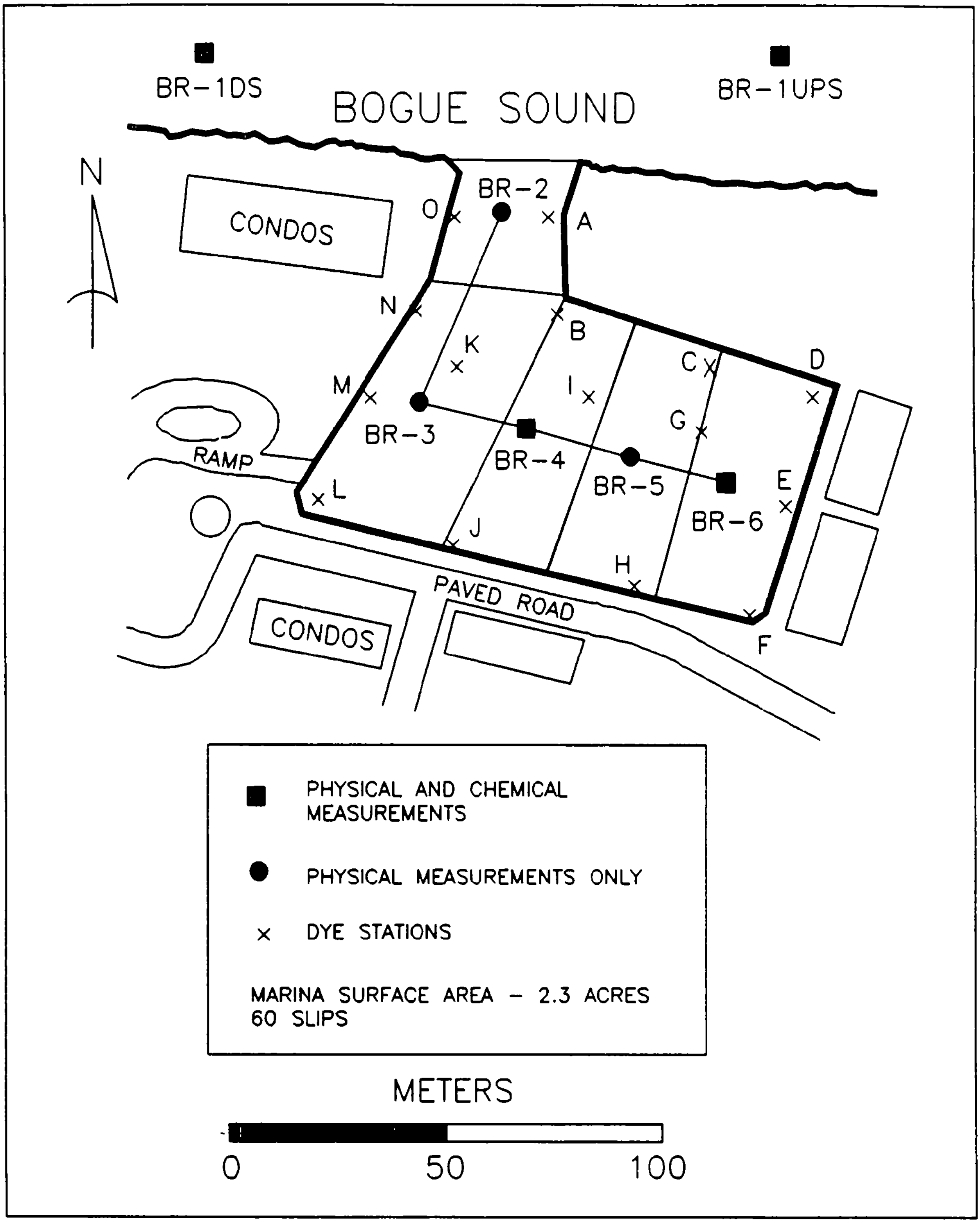

Figure 6-2. Sampling Stations and WASP Model Application to the Beacons Reach Marina.

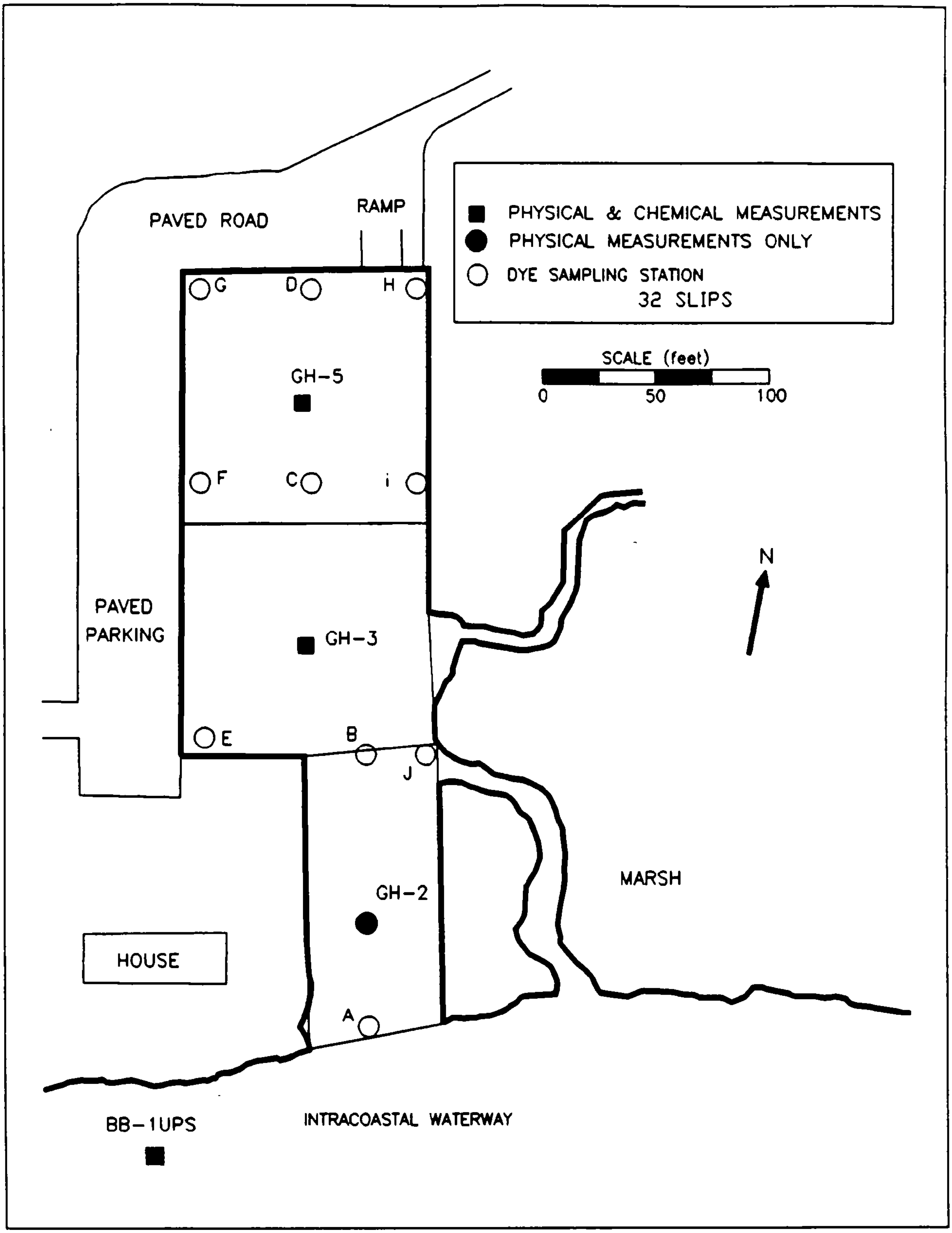

Figure 6-3. Sampling Station and WASP Model Application to the Gull Harbor Marina

The marina is surrounded by a residential development of large single-family houses. Stormwater runoff from adjacent roads enters the basin via the boat ramp and a roadside culvert. In addition, a small drainpipe discharges water from a well-water, once-through heat pump into the marina. Drainage also enters the marina though a small marsh, which borders on the eastern edge of the marina channel (adjacent to station GH-2).

Gull Harbor is one of three marinas where intensive work was done to determine sediment oxygen demand (SOD) and marina flushing characteristics. Gull Harbor is a semi-enclosed marina with distinct basin and channel sections (i.e., two-segment marina). The channel, however, is relatively wide compared to the basin. Adjacent areas outside the marina are similar in depth to the basin. However, a well-defined boat channel has been dredged between the Waterway and the marina inlet. Measurements indicate that while the basin is slightly deeper than the inlet channel, both are much shallower than the Intracoastal Waterway. The dye tracer study performed at this marina confirmed that this design, coupled with the tidal amplitude of the area, results in rapid flushing of Gull Harbor Marina.

Water quality data are summarized in Table 6-3. The marina basin was never anoxic, but oxygen profiles were weakly stratified during half of the sampling events. Minimum basin dissolved oxygen values of 2.6 mg/L were measured just above the bottom sediments during the August sampling events.

Statistical analysis revealed that the average summer DO was significantly higher at the ambient stations than at either the basin stations or the channel stations (NCDEM, 1990). Both basin and ambient DO values were less than 5.0 mg/L on July 21, 1988. On that date, the Bogue Sound marinas were sampled during an unusually low tide, and DO values were low throughout the sound. Aside from this one episode, wind and tidal variations had no observable effect on DO.

All metals values were below laboratory reporting levels. Turbidity levels were low as well, with no values exceeding the state standard (25 NTU). One chlorophyll-*a* value of 10 in the marina basin was above the state standard of 40 μg/L (50 μg/L on August 3 at GH-5). Nitrogen fractions were similar in ambient and basin waters, but total phosphorus was slightly higher in the basin. One long-term BOD sample was collected at station GH-5 on September 8, 1988. The 5-day BOD value for this sample was 2.15 mg/L. After 81 days, 6.01 mg/L of oxygen had been consumed.

Station GH-5 was sampled on August 18 for pesticides and organics analyses. Pesticide extractions and analyses detected one identified peak by the gas chromatograph/electron capture sector method. Acid herbicide extraction and analyses detected three unidentified peaks by the gas chromatograph/electron capture method (NCDEM, 1990). None of these results represent violation of state pesticide or organics standards.

TABLE 6-3. Gull Harbor Marina Water Quality Summary

Parameter	Summer Mean	
	Ambient	Basin
Column DO (mg/L)	6.0	4.0
Surface DO (mg/L)	6.1	4.6
Photic zone DO (mg/L)	6.0	4.2
Fecal coliform/100 mL	< 10[a]	15[a]
Turbidity (NTU)	6.3	7.4
Chlorophyll-*a* (μg/L)	8.3	19
Ammonia (mg/L)	0.04	0.06
Total Kjeldahl N (mg/L)	0.3	0.4
Nitrate-nitrite (mg/L)	<.01	<.01
Total phosphorus (mg/L)	0.04	0.06

[a] Median.

6.2 Marina Data Review

The purpose of this section is to summarize the marina data received from the U.S. EPA and other sources for use in calibrating the marina water quality models chosen for this study. Data were received from a number of sources including the EPA-Athens Laboratory, the North Carolina Department of Environmental Management (NCDEM), and the Delaware Department of Natural Resources and Environmental Control (DNREC). EPA-Athens Laboratory provided a data set on the Indian Hills Yacht Club canal in Boca Raton, Florida. NCDEM provided the *North Carolina Coastal Marinas: Water Quality Assessment* (1990) report, which provided data collected at 11 coastal marinas in that state. The Delaware DNREC recently conducted flushing time characteristics studies at two coastal marinas; however, the final reports of those studies are not yet available.

Based on the three levels of water quality models chosen for application to coastal marinas, the following marina data sets were selected:

Indian Hills Yacht Club, Boca Raton, Florida
Beacons Reach Marina, Bogue Sound, Pine Knoll Shores, North Carolina
Gull Harbor Marina, Bogue Sound, North Carolina

Descriptions of the available data for the above marinas and data gaps related to model application are provided in the following subsections.

6.2.1 Indian Hills Marina

Data for this marina were provided by Mr. Tom Cavinder at USEPA Athens Laboratory. The Indian Hills facility is a flow-through canal rather than a typical marina design; from a data standpoint, however, this facility was one of the best choices because of the amount of water quality information available on the system. Data were collected in the canal system during 1984 and 1985 and included the following parameters:

Tide range
Current velocity
Dye tracer data
Sediment oxygen demand
Sediment core characterizations
Water temperature
Salinity
Dissolved oxygen
Light transmissivity
Ammonia (NH_3)
Nitrate+nitrite (NO_2+NO_3)
Total Kjeldahl nitrogen (TKN)
Total phosphorus
Total organic carbon
Carbonaceous Biochemical Oxygen Demand (CBOD)

Data Gaps

The following information was not available for the Indian Hills system:

Meteorological data (air temperature, wind speed, wind direction)
Coliform bacteria data
Number of boats and boat slips

Lack of meteorological data may bias the reaeration used in the WASP4 model since wind speed is used in the calculation of hydrodynamic current velocities and in the reaeration formulas themselves. It is not anticipated that the lack of wind data will have a large impact on calibration of the WASP4 model at the Indian Hills canal.

Since no coliform data are available, it is not possible to calibrate any of the models to this parameter. Also, the number of boats and number of boat slips in this facility were not documented. Information on the number of boats in a marina can be used to estimate potential coliform loading (USEPA, 1985).

6.2.2 Beacons Reach Marina

Data for this coastal marina were received from NCDEM. The marina is located on Bogue Sound near Pine Knoll Shores, North Carolina, and is an example of the classic two-segment coastal marina design showing distinct basin and channel segments. This marina was chosen because of its classical design configuration and because the data included a dye study. Data were collected during the summer of 1988 and included the following parameters:

Tide range
Dye tracer data
Sediment oxygen demand
Water temperature
Salinity
Dissolved oxygen
Turbidity (NTU)
Chlorophyll-*a*
Ammonia (NH_3)
Nitrate+nitrite (NO_2+NO_3)
Total Kjeldahl nitrogen (TKN)
Total phosphorus
Fecal coliform
BOD
Metals (chromium, arsenic)
Pesticides and organics
Number of boats and boat slips

Data Gaps

The following information was not available for the Beacons Reach Marina:

Current velocities
Meteorological data (air temperature, wind speed, and wind direction)

6.2.3 Gull Harbor Marina

Data for this coastal marina were received from NCDEM. The marina is located on the northern shore of Bogue Sound in Carteret County, North Carolina, and is a two-segment coastal marina having a main basin segment and a channel entrance segment. This marina was chosen because of its classical design and because the data included a dye study. Data at the Gull Harbor Marina were collected in 1988 and include the following parameters:

Tide range
Sediment oxygen demand
Dissolved oxygen
Turbidity (NTU)

Chlorophyll-*a*
Ammonia (NH_3)
Nitrate+nitrite (NO_2+NO_3)
Total Kjeldahl nitrogen (TKN)
Total phosphorus
Fecal coliform
BOD
Metals (chromium, arsenic)
Pesticides and organics
Number of boats and boat slips

Data Gaps

The following information was not available for the Gull Harbor Marina:

Water temperature and salinity
Current velocities
Meteorological data (air temperature, wind speed, and wind direction)

6.3 Model Application

6.3.1 Simple Model

The Tidal Prism Analysis was selected as the method of choice in the simple model category. This technique, as presented, can provide reasonable approximations for screening potential impact problems when site-specific data are not available. This method is capable of addressing all marina water quality issues of concern (e.g., DO and fecal coliform) and comes with excellent documentation.

To assess the water quality impacts of marina-derived pollutants on the environment using the methods discussed in this section, certain pollutant loading values must be available for use. If actual values for various loadings are not available, estimations can be made using Table 6-4. The loadings shown in Table 6-4 are based on the following assumptions (Carstea et al., 1975):

- Average number of persons per boat is three.
- Average per capita discharges of coliform bacteria and BOD are 2 billion MPN and 75.6 g, respectively.
- Half of the people on board contribute fecal material in 24 hours.
- Coliform bacteria populations do not increase.
- A boat in use spends 1 hour in the marina.
- 25 to 40 percent of boats present are in use and evenly distributed.
- An average boat has a 2-cycle 30-hp outboard motor, consumes 4.458 liters of gasoline per hour, and operates at 1000 rpm; the fuel has a gasoline-to-oil ratio of 50:1.

TABLE 6-4. Estimated Pollutant Contribution from Boats

Boats Total	Boats in Use	BOD (g/hr)	Coliform Bacteria (billions/hr)	Nonvolatile Oil (g/hr)	Volatile Oil (g/hr)	Phenol (g/hr)	Lead (g/hr)
1	1	4.54	0.13	66.7	37.8	0.8	0.4
5	2	9.08	0.25	133.5	75.6	1.6	0.8
10	3	13.62	0.38	200.1	113.4	2.4	1.2
20	5	22.70	0.63	333.5	189.0	4.0	2.0

Density of waste fuels is 0.7 g/ml.
Source: Carstea et al., 1975.

Fecal coliform bacteria loadings for all marinas were estimated using the values reported in Table 6-4, as will be shown later in this section.

Flushing Time

Flushing time for Beacons Reach, Indian Hills, and Gull Harbor is estimated using Equation 2-3 (USEPA, 1985). This equation represents a simplified approach to estimate flushing time assuming that:

- The majority of flushing is due to tidal flow.
- The tidal prism volume completely mixes with basin waters.
- The pollutant concentration decreases with each tidal dilution but will never completely flush.
- The influx of pollutant by nontidal fresh water is small in comparison to the mass of pollutant in the low tide water and return tidewater volumes.
- The concentration of the pollutant in ambient waters outside the marina is very small.

The parameter b in Equation 2-3 represents the returning ratio (the percentage of the tidal prism that was previously flushed from the marina on the outgoing tide) and is expressed as a decimal fraction. For example, if a river had a relatively low flow rate, water discharged from the marina at the completion of one tidal cycle may still exist in proximity to the marina inlet and portions may flow back into the marina on the incoming tide.

In using Equation 2-3, the return flow factor (b) may be the most difficult parameter to determine. This value may be estimated based on the circulation characteristics of the affected water bodies. Without definitive field data, subjective estimations would have to be made. The return flow factor (b) is assumed to be zero in calculating flushing time at both marinas.

In using Equation 2-3, the value for D should be chosen depending on the amount of flushing desired. If complete flushing is desired, a very low value of D can be selected, such as 0.01. Since the remaining pollutant concentration will be diluted by each tidal cycle, complete flushing will be approached asymptotically, so a reasonable cutoff value for dilution must be chosen (USEPA, 1985). For most cases it is satisfactory to achieve the desired dilution (D) within a 2- to 4-day flushing time. Longer flushing times may not be acceptable (Boozer, 1979).

Fecal Coliform Bacteria

Marina sites in the vicinity of harvestable shellfish beds represent potential sources for bacterial contamination of the shellfish. Therefore, issues related to the potential for contravention of state water quality standards in waters classified as suitable for shellfish propagation and harvesting may arise. The following methods available for predicting impacts from boat wastes may not be conclusive because coliform counts vary with temperature, turbidity, boat densities, tides, day of the week, season of the year, and the number of persons aboard each boat. The contribution of boats to fecal coliform pollution of the water can be estimated by methods used by FWPCA (1967), USFDA (1972), Faust (1982), Furfari (1968), and SCDHHS (1982). Many of these studies were directed toward estimating the number of boats allowable in a shellfishing area.

For a continuous discharge of a nonconservative pollutant into a marina basin, an estimate of long-term concentrations may be obtained by Equation 2-7 (USEPA, 1985). In Equation 2-7, it is assumed that the pollutants remain in solution and loss by sedimentation is minimal. The result of these assumptions is that concentrations obtained would probably exceed actual concentrations measured (USEPA, 1985). It is also assumed that the pollutant decay is first order. Values for the reaction rate K are critical for accurate estimates. Therefore, the K values in Table 6-5 should be used only if actual values cannot be obtained for the site under consideration. These values are generally determined empirically and are specific to a temperature of 20°C and the set of physical conditions existing at the time of measurement. Additional K values for bacteria may be obtained from Thomann and Mueller (1987). Another reference for K values, including procedures to estimate K, is USEPA (1985). The first order decay coefficient is temperature dependent according to the following equation:

$$K_{(T)} = K_{(20)}\ \Theta^{(T-20)} \qquad \textbf{(6-1)}$$

where:

K = first order rate coefficient (0.5 - 1.0 day^{-1})
T = water temperature in °C
Θ = 1.02 for coliform decay coefficient

Dissolved Oxygen

Low dissolved oxygen levels are being recognized as a serious water quality impact that may result from poorly designed and maintained marinas. The assessment of DO levels is complicated because the kinetics of dissolved oxygen are very complex. Dissolved oxygen concentrations can vary greatly over short periods of time as a function of teh following (Thomann and Mueller, 1987):

- Reaeration from the atmosphere;
- Photosynthetic oxygen production;
- Dissolved oxygen inputs by tidal flow and tributaries;
- Sediment oxygen demands;
- Biochemical oxygen demands; and
- Oxygen use by aquatic organisms.

The best way to assess marina impacts on water quality is to design a sampling strategy and physically measure dissolved oxygen values. During the sampling, sediment oxygen demand and other data can be collected. These data may be used to estimate future dissolved oxygen levels using mathematical modeling procedures described in the *North Carolina Coastal Marinas Water Quality Assessment* (NCDEM, 1990) and the *Technical Guidance Manual for Performing Wasteload Allocations* (USEPA, 1989). Prior to data collection, screening procedures such as Equation 2-8 should be used to identify trouble spots. Equations 2-8a and 2-8b should be used to successively estimate dissolved oxygen concentrations at high and low tide in a semi-enclosed marina. Equations 2-8a and 2-8b are based on a mass balance of the following dissolved oxygen sources and sinks:

- Tidal inflow;
- Reaeration;
- Biochemical oxygen demand;
- Sediment oxygen demand;
- Low tide dissolved oxygen; and
- Freshwater inflow.

It is assumed that there is no increase in oxygen levels within the basin due to biological activity, that dissolved oxygen carried in by tidal flushing is retained within the basin, and that benthic oxygen demand is uniform throughout the basin.

Values for K_a should be determined for the specific site considered. Thomann and Mueller (1987) and USEPA (1985) describe procedures to estimate K_a. If site-specific values are not available, an estimate can be obtained using the K values shown in Table 6-5.

Dissolved oxygen concentrations at saturation can be obtained from solubility tables (APHA, 1985), which provide DO_S values for water-saturated air at standard pressure given various chloride concentrations. For dissolved oxygen calculations, chloride concentrations are typically set equal to chlorinity, the chlorine equivalent of the total halide concentration in the seawater. The following equation relates chlorinity and salinity (USEPA, 1985):

$$\textbf{Salinity, ppt} = 0.03 + (0.001805)\ (\textbf{chlorinity, mg/L}) \qquad (6\text{-}2)$$

TABLE 6-5. Representative Reaction Coefficients

Pollutant	Typical K (day^{-1})	Typical Range (day^{-1})
K_1, Oxidation Rate (1/day)	0.25	0.10 - 0.30
SOD, Sediment Oxygen Demand Rate ($g/m^2/day$)	0.10	0.00 - 5.00
K_a, Reaeration Rate (1/day)	0.12	0.05 - 3.00
K_x, Fecal Coliform (1/day)	1.20	0.30 - 1.20

Source: USEPA, 1978.

6.3.1.1 TPA Application to Indian Hills Marina

Flushing Time

A dye study was conducted at the Indian Hills marina during phase I. The tracer was quickly mixed within the Indian Hills waterways and within 42 hours, 90 percent of the dye had been flushed from this system. Accordingly, for a 0.10 dilution factor the observed flushing time at the Indian Hills marina is 42 hours (3.36 tidal cycles).

Input parameters used in Equation 2-2 to estimate the flushing time for Indian Hills marina are listed in Table 6-6. The observed tidal range at Indian Hills marina is 0.8 meter. Depths at the Indian Hills marina are relatively uniform, averaging 2.0 meters at Mean Tide Level. Predicted and observed flushing times of the Indian Hills marina are listed in Table 6-7.

Fecal Coliform Bacteria

Estimates of fecal coliform contribution from boats in Indian Hills were calculated based on Carstea et al., (1975). Available data for Indian Hills marina did not include the number of boat slips available at this site. It was decided that representative data from Table 6-4 would be used (Cavinder, 1991). Table 6-4 assumes that for every 20 boats available 5 boats are in use. Loading rates of fecal coliform, for both marinas, are estimated as follow:

$$\mathbf{Mr = ((20/20) \times 0.25) \times 0.63x10^{9} \times 24\ hours = 0.38x10^{10}\ organisms/day}$$

TABLE 6-6. Input Data Used to Estimate Flushing Time (TPA)

Parameter		units	Beacons Reach	Indian Hills	Gull Harbor
T_C	Tidal cycle	hours	12.5	12.5	12.5
A	Surface area of marina	m^2	9448	34355	5360
D	Desired dilution factor	dimensionless	0.1	0.1	0.1
R	Range of tide	m	0.6	0.8	0.6
b	Return flow factor	dimensionless	0.0	0.0	0.0
I	Non-tidal freshwater inflow	m^3/hour	0.0	0.0	0.0
L	Average depth at low tide	m	1.8	1.6	1.2
H	Average depth at high tide	m	2.4	2.4	1.8
V_L	Volume of marina at low tide	m^3	17006	54968	8040
V_H	Volume of marina at high tide	m^3	22675	82452	11256
V_p	Volume of marina tidal prism (V_H - V_L)	m^3	5669	27484	3216

TABLE 6-7. Observed and Predicted Flushing Time Using TPA

Marina Site	Dilution Factor (D) (dimensionless)	Predicted Flushing Time Equation 2-3 (tidal cycles)	Observed Flushing Time Dye Study (tidal cycles)
Beacons Reach	0.25 0.10	4.8 8.0	3.8 7.2[a]
Indian Hills	0.10	5.7	3.4
Gull Harbor	0.10	5.7	1.5

[a] Extrapolated from observed data.

Since the number of boat slips at the Indian Hill marina during the study was not reported, it was assumed that 20 boats were present during the study period. The assumed 20-boat value is used thereafter to estimate fecal coliform loadings at the Indian Hills marina. Fecal coliform loading for the Indian Hills marina is estimated at 0.38 E10 organisms/day. Predicted and observed fecal coliform concentrations for the Indian Hills marina, over the observed flushing time of 42 hours, are also listed in Table 6-8. Fecal coliform predictions are calculated for illustrative purposes, and no further conclusions should be made with regard to model predictions at this marina site.

Dissolved Oxygen

Equation 2-8 was used to estimate DO levels at Indian Hills marina. For the Indian Hills marina the averaged CBOD was 3.15 mg/L. The oxidation coefficient for BOD, k_1, will vary depending on sedimentation rates, waste characteristics, water depth, temperature, and other values. Table 6-9 lists default values for K_1 used at the Indian Hill marina. An oxidation rate of 0.33 was used in Equation 2-8 for Indian Hills marina. The value for k_a used in Equation 2-8 is 0.70 per day for Indian Hills marina (0.70 was obtained from the Indian Hills WASP4 model run).

Chemical reduction and bacterial respiration of organic matter that occur in sediments create a demand for oxygen from overlying waters. This sediment oxygen demand (SOD) can strongly influence oxygen conditions in a water column; therefore, SOD is an important component of models that predict oxygen concentrations. SOD rates are highly site-specific and are influenced by substrate composition, sediment organic content, and environmental factors such as temperature (Hatcher, 1986). SOD rates were measured once at Indian Hills marina. After correcting for water column respiration, results from replicate chambers were averaged to determine one SOD value. The Indian Hills marina basin SOD rate is 3.99 $g/m^2/day$.

Observed DO values at station I-4, Figure 6-1, were used to calculate DO_A in Equation 2-8. The ambient DO_A used in the calibration runs was based on whole-column averages of all DO_A values sampled adjacent to each marina during the study. The DO_S saturation value was based on similar averages of temperature and salinity. The DO_S value used in Equation 2-8 for Indian Hills marina is 4.94 mg/L. Results obtained from Equation 2-8 were compared to similar whole-column averages of all inlet channel and marina basin DO values sampled at the marina during the study. It was assumed that these values were approximately equivalent to average summer conditions.

TABLE 6-8. Predicted and Observed Fecal Coliform Using TPA

Marina Site	Summer Temperature (°C)	K_x day^{-1}	Predicted per/100mL	Observed per/100 mL
Beacons Reach Average Summer Conditions	20 20 29 29	0.5 1.0 0.6 1.2	45 27 41 22	> 50 - - < 10
Beacons Reach May 26	20.5 20.5	0.5 1.0	45 27	50 79[a]
Indian Hills[a] Average Summer Conditions	27.5 27.5	0.6 1.16	<10 <10	- -
Gull Harbor Average summer conditions	20 20 29 29	0.5 1.0 0.6 1.2	51 32 46 27	15 - 140 15 - 140 15 - 140 15 - 140

[a] Fecal coliform loadings are based on estimates of number of slips at this site.

TABLE 6-9. TPA Input Parameters Used to Estimate DO Levels

Marina Site	DO_A mg/L	DO_S mg/L	DO_1 mg/L	K_a day^{-1}	K_1 day^{-1}	B $g/m^2/day$	C_b mg/L
Beacons Reach	6.30	6.90	6.30	0.30	0.10	2.68	7.23
Indian Hills	4.94	6.40	4.94	0.70	0.10	3.99	3.15
Gull Harbor	6.00	7.00	6.00	0.30	0.10	3.00	6.01

6.3.1.2 TPA Application to Beacons Reach Marina

Flushing Time

A dye study was conducted at the Beacons Reach marina site. The purpose of the dye study was to provide data on the flushing characteristics of the marina by tracing Rhodamine WT dye through consecutive tidal cycles until 90 percent of the average dye concentration had flushed out from the marina (D=0.1). Table 6-10 lists average dye concentration at Beacons Reach during the study period. A reduction of 74.3 percent of the initial dye concentration was achieved at the end of 48 hours (D=0.25). Therefore, the observed flushing time at Beacons Reach marina is 48 hours (3.84 tidal cycles) for a 0.25 dilution factor.

Equation 2-3 was used to estimate the flushing time at Beacons Reach marina. Input parameters used in Equation 2-3 to estimate the flushing time for Beacons Reach marina are listed in Table 6-8. The observed tidal range at Beacons Reach marina was 0.6 meter. Depths at Beacons Reach marina are relatively uniform averaging 2.1 meters at Mean Tide Level. Predicted and observed flushing times at Beacons Reach marina are listed in Table 6-7.

Fecal Coliform Bacteria

Results of whole column averaging of all temperature values sampled adjacent to each marina during the study were used to estimate the k values used in Equation 2-7. It was assumed that these values were representative of typical conditions at these sites. Adjacent temperatures at Beacons Reach marina ranged from 20°C to 29°C during the study period. High and low ambient temperatures were used in Equation 2-7 to estimate decay rate coefficient. The $k_{(x)}$ values were 0.5 and 1.2 for the temperature range observed during the study period at Beacons Reach marina. Equation 2-7 was then used to calculate fecal coliform concentrations.

Estimates of fecal coliform contribution from boats in Beacons Reach were calculated based on Carstea et al. (1975). Table 6-4 provides estimates of the contaminant loading rate, Mr, appearing in Equation 2-7. Beacons Reach marina has 58 available slips. Loading rates of fecal coliform at Beacons Reach marina are estimated as follow:

$$\mathbf{Mr = ((58/20) \times 0.25) \times 0.63x10^{9} \times 24\ hours = 1.10x10^{10}\ organisms/day}$$

According to the NCDEM monitoring study, 4 of the 10 fecal coliform samples collected at stations BR-4 and BR-6 within the Beacons Reach marina basin were greater than 14 fecal coliform/100 mL. Although some individual observations exceeded the criterion, the median of the basin value was 10/100. A maximum value of 50/100 mL was found on May 26 at station BR-6 (Figure 6-2). In addition, a station at the mouth of Beacons Reach marina was sampled once during the study period by the Division of Health Services, Shellfish Sanitation Branch. Collected on May 26, this sample contained 79 fecal coliform/100 mL. During May, the average temperature at Station BR-1 (Figure 6-2) was 20.5°C. This value was then used to estimate fecal coliform concentrations at Beacons Reach marina for the same month. Predicted and observed values of fecal coliform for Beacons Reach marina are listed in Table 6-8.

TABLE 6-10. Averaged Dye Concentration at Beacons Reach Marina During the Study Period

Hour after Dye Release	Average Dye Conc. (ppb)
6	95.3
12	78.6
18	57.5
24	35.6
30	29.9
36	28.4
42	26.2
48	24.5

Dissolved Oxygen

Equation 2-8 was used to estimate DO levels at Beacons Reach marina. Initially, the value of DO_L was set equal to DO_A, which is assumed constant over the period of analysis. The DO_A value used in Equation 2-8 for Beacons Reach marina was 6.3 mg/L. Values for K_a should be determined for the specific site considered. Since site-specific values were not available, a K_a value of 0.30 per day was used in Equation 2-8 for Beacons Reach marina.

Values of C_B will decrease as biochemical oxygen demand (BOD) is consumed. For screening purposes a steady state BOD concentration may be calculated for C_B by using several techniques provided in USEPA (1985). One long-term BOD sample was collected at Beacons Reach on September 8, 1988. The 5-day value for this sample was 2.47 mg/L. After 81 days, 7.23 mg/L of oxygen had been consumed. The long-term BOD value of 7.23 mg/L is used in the analysis. SOD rates were measured once at Beacons Reach marina. After correcting for water column respiration, results from replicate chambers were averaged to determine one SOD value. The Beacons Reach marina basin SOD rate is 2.60 $g/m^2/day$.

Observed DO values at station BR-1 (Figure 6-2) were used to calculate DO_A in Equation 2-8. The ambient DO_A used in the calibration runs was based on whole-column averages of all DO_A values sampled adjacent to Beacons Reach marina during the study. The DO_S saturation value was based on similar averages of temperature and salinity. The DO_S value used in Equation 2-8 for Beacons Reach is 6.9 mg/L. Results obtained from Equation 2-8 were compared to similar whole-column averages of all inlet channel and marina basin DO values sampled at the marina during the study. It was assumed that these values were approximately equivalent to average summer conditions. Whole-column averages were used because the equation assumes a completely mixed inlet channel and a completely mixed basin.

6.3.1.3 TPA Application to Gull Harbor Marina

Flushing Time

A dye study was conducted in the Gull Harbor Marina near Morehead City on October 24-26, 1988. The purpose of the study was to provide data on the flushing characteristics of the marina by tracing Rhodamine WT dye through consecutive tidal cycles until 90 percent of the average dye concentration had flushed from the marina.

The study consisted of pouring, in a south-to-north pattern, 4 liters of Rhodamine WT dye from a boat into the surface waters of the marina and then mixing the dye by running the boat through the dye cloud several times. Dye samples were then collected by hand from piers and by boat at 10 selected sites (stations A through J in Figure 6-3). Samples were taken with a depth-integrating sampler and represent an average of the water column.

The dye was placed in the marina 30 minutes after low tide, which occurred at approximately 1630 October 24. The dye sampling was done at high tide and low tide for 3 1/2 tidal cycles staring at the high tide after the dye dose.

The average initial dye concentration at the first high tide sampling run was 75.8 ppb, and on the next low tide sampling run it was 9.23 ppb, an 88 percent reduction. The second high tide run showed an average dye concentration of 3.42 ppb, a 95.5 percent reduction, and the remaining sampling runs had concentrations of 5.0 ppb (low tide) and 3.1 ppb (high tide). This marina almost attained the 90 percent reduction goal on the first tidal period, which is a quicker flushing time than those of the other marinas studied. It is also of interest that the dye concentration in this marina seemed to reach a certain concentration (3-5 ppb) and then stay at that concentration, almost as if it had reached equilibrium.

Equation 2-3 was used to estimate the flushing time at Gull Harbor marina. Input parameters used in Equation 2-3 to calculate flushing time for Gull Harbor marina are listed in Table 6-6. Observed tidal range was assumed 0.6 meter (similar to Beacons Reach marina) and depths are relatively uniform, averaging 1.5 meters at Mean Tide Level. Predicted and observed flushing times at Gull Harbor marina are listed in Table 6-7.

Fecal Coliform Bacteria

Water temperatures adjacent to Gull Harbor marina were not available during the study period. Therefore, high and low ambient temperatures at Beacons Reach were used in Equation 2-7 to estimate the decay rate coefficient for the Gull Harbor marina. Both marinas are located on the Bogue Sound, and minimum and maximum temperatures should be very similar. The $K_{(x)}$ values used were 0.6 and 1.2 for the temperature range at Gull Harbor marina. Equation 2-7 was then used to calculate fecal coliform concentrations.

At the Gull Harbor marina, 32 slips are available; therefore, loading rates of fecal coliform are estimated as follows:

$$\mathbf{Mr = ((32/20) \times 0.25) \times 0.63x10^9 \times 24\ hours = 0.60x10^{10}\ organisms/day}$$

According to the NCDEM monitoring study, five of ten fecal coliform samples collected in the marina basin were greater than 14/100 mL. A maximum value of 140/100 mL was found on September 8 at GH-3. The median of the individual basin observations was 15/100 mL, which exceeds that state standard of 14/100 mL. One high value (less than 600/100 mL) was found in ambient waters, but the median (less than 10/100 mL) was below the state standard. Gull Harbor Marina was sampled twice during the study period by the Division of Health Services, Shellfish Sanitation Branch. On both sampling dates, values of 49/100 mL were found at the mouth of the marina. A station in the Intracoastal Waterway just outside of the marina was sampled four times. One value (17/100 mL) above the standard was found on June 20.

Dissolved Oxygen

Equation 2-8 was used to estimate DO levels at Gull Harbor marina. Initially, the value of DO_L was set equal to DO_A, which is assumed constant over the period of analysis. DO_A value used in Equation (2-8) for Gull Harbor marina was 6.0 mg/L. Values for k_a should be determined for the specific site considered. Since site-specific values were not available, a k_a value of 0.30 per day was used in Equation 2-8.

One long-term BOD sample was collected at station GH-5 on September 8. The 5-day value for this sample was 2.15 mg/L. After 81 days, 6.01 mg/L of oxygen had been consumed. The long-term BOD value of 6.01 mg/L was used in the analysis.

The widest variation in SOD values was obtained at the Gull Harbor marina. Two relatively low values were obtained out of a total of five; however, these values occurred on substrate that was not representative of the average bottom condition (NCDEM, 1990). The Gull Harbor marina basin SOD rate used was 3.0 $g/m^2/day$ as suggested in NCDEM (1990).

Observed summer DO values at ambient stations were used to calculate DO_A in Equation 2-8. The ambient DO_A used in the calibration runs was based on whole column averages of all DO_A values sampled adjacent to Gull Harbor marina during the study. The DO_S saturation value was based on similar averages of temperature and salinity. The DO_S value used in Equation 2-8 for Gull Harbor was 7.0 mg/L. Results obtained from Equation 2-8 were compared to similar whole-column averages of all inlet channel and marina basin DO values sampled at the marina during the study. It was assumed that these values were approximately equivalent to average summer conditions. Whole-column averages were used because the equation assumes a completely mixed inlet channel and a completely mixed basin.

6.3.1.4 Summary of Simple-Methods Model Results

Flushing Time

Equation 2-3 over predicted flushing times at all marina sites. The smallest discrepancy between observed and predicted flushing time is found at the Beacons Reach marina (approximately 20 percent deviation from observed flushing time), while the highest discrepancy is found at the Gull Harbor marina (approximately four times the observed flushing time). An average deviation of approximately 68 percent from observed flushing time is found at the Indian Hills marina. It should be noted that the Indian Hills marina is a flow-through type marina with a network of canals. These channels increase water exchanges between the water inside the marina basin and the water outside the marina, resulting in a much shorter flushing time. Equation 2-3 does not take into account the added water exchange, through the existence of several openings/canals, with the adjacent water. In addition, Equation 2-3 is a simple tool that calculates flushing time based on tidal prism volume at a site. Tidal prism, in turn, depends on the surface area of a site and the averaged depth for high and low waters.

The Gull Harbor marina is a two-segment marina (not a flow-through type); however, as illustrated in Figure 6-3, the marina basin is connected to two canals. The first canal is directly connected to the main water body outside the marina, while the second canal is connected to a marsh area bordering the eastern side of the marina. As stated earlier, Equation 2-3 does not account for added water exchanges through existing openings (exchange canals) and therefore a discrepancy arises in predicting flushing time at Gull Harbor marina.

Fecal Coliform Bacteria

Fecal coliform values predicted using Equation 2-7 are in good agreement with observed data (Table 6-8). In general, predicted values fell within the range of fecal coliform levels found during the summer. According to both observed and predicted fecal coliform counts, conditions at the Gull Harbor marina are consistently above the standard of 14mL/100mL.

Dissolved Oxygen

TPA model results are in good agreement with observed DO levels at the three marina considered for this study. TPA procedure over predicted DO at Indian Hills and Gull Harbor marinas and under predicted DO at Beacons Reach marina. The comparison between predicted and actual values of DO is summarized in Table 6-11. The highest deviation between predicted and observed DO levels is found at the Gull Harbor marina (approximately 38 percent deviation from observed value), and the lowest discrepancy is found at the Beacons Reach marina (approximately 5 percent deviation from observed value). It should be noted that according to TPA model results at all three marinas are consistently above 5 mg/L (i.e. all three marinas are in compliance with State water quality standard for dissolved oxygen). However, observed DO levels at Indian Hills and Gull Harbor marinas indicate otherwise.

TABLE 6-11. Observed and Predicted DO levels (TPA)

Marina Site	Predicted mg/L	Observed mg/L
Beacons Reach	5.34	5.60
Indian Hills	5.06	4.64
Gull Harbor	5.54	4.0[a]

[a] Summer Mean.

6.3.2 Mid-range Model

The recommended marina mid-range models are the Tidal Prism Model and the NCDEM DO model. Both models are in the public domain, are easy to apply, and are supported by good documentation.

6.3.2.1 Tidal Prism Model (TPM)

The Tidal Prism Model is a steady-state model that is capable of simulating up to 10 water quality variables including dissolved oxygen and fecal coliform. The Tidal Prism Model should be used to corroborate the results of the simplified methods in the previous section when the simplified methods indicate adverse water quality impacts.

Based on constituents modeled, the Tidal Prism Model was selected as the best qualified marina mid-range model. The Tidal Prism Model predicts the longitudinal distribution of conservative and nonconservative dissolved constituents at high slackwater (slack-before-ebb). The rise and fall of the tide at the mouth of a marina causes an exchange of water masses through the entrance. This results in the temporary storage of large amounts of bay or river water in the marina during flood tide and the drainage of this water during ebb tide. This volume of water is known as the tidal prism. Since water brought into the marina on flood tides mixes with the creek water, a portion of the pollutant mass in the marina is flushed out on ebb tides. This flushing mechanism due to the rise and fall of the tide is called tidal flushing.

The model is based on the division of the adjacent water body into segments, each of which is considered to be completely mixed at high tide. The length of each segment is defined by the local tidal excursion, the average distance traveled by a water particle on the flood tide, since this is the maximum length over which complete mixing can be assumed. Instead of starting the segmentation from the landward end with freshwater discharge and tidal prism as two non-zero parameters, the modified model subdivides the water body starting from the seaward end with the difference between tidal prism and freshwater discharge as a single parameter. The mass balance within each segment is formulated by considering the exchange of water with its neighboring segments due to the flushing of freshwater discharge, as well as the tidal prism on ebb cycle, and to the mixing of the tidal prism on flood tide. This results in an algebraic equation that may be solved for concentration in each segment by successive substitution. For a nonconservative substance, the biochemical reaction terms are then added to the algebraic equation without complicating the solution scheme. The model has been successfully applied to a number of tidal creeks and coastal embayments (Kuo, 1989).

Given the initial conditions or calculated concentration fields at the slack-before-ebb (SBE) that initiates a tidal cycle, the calculation of the concentrations at the succeeding SBE is performed in two steps. First, the concentration fields are calculated assuming that only the physical transport processes are in action. Second, the calculated concentration fields are adjusted for the relevant chemical and biological processes.

To properly apply the mid-range Tidal Prism Model, salinity data from the mouth of adjacent water to the head of tide are needed. In lieu of salinity data, dye tracer data from the mouth to the head of tide can be used to calibrate the Tidal Prism Model. The freshwater inflow at the upstream end of the adjacent river/creek is also required for the Tidal Prism Model. Since not all data were available for proper application of this mid-range model, a hypothetical case study will be used.

TPM Model Application

The first step in applying the model is segmentation of the water body. Geometrical data are needed regarding river/creek and marina geometry, volume, and tidal prism. Figure 6-4 shows for a hypothetical tidal creek the accumulated low tide volume, Vol(x), and the difference between the tidal prism and the river flow upstream of a point, [P(x) - R(x)], plotted as a function of x, the distance from the mouth. Vol(x) is defined as the accumulated low tide volume of the mainstem from the mouth to any distance x. P(x) is defined as the intertidal volume, including the volumes of the tributaries and marinas, upstream of a transect located at x. R(x) is defined as the freshwater input, summed over a half tidal cycle, which enters the creek upstream of a transect located at x. The volume P(1) is the intertidal volume of the entire creek. R(1) is the total freshwater input to the creek: river flow, waste flows (point sources), and lateral inputs (surface runoff). The volume V(1) is defined as a dummy volume located outside the creek mouth. The first volume within the creek is defined as V(2). For the assumption of complete mixing within each segment to be valid, segment lengths must be less than or equal to the local tidal excursions. Therefore, the low tide volume of the first segment within the river should equal the intertidal volume, minus the river flow, upstream of the landward boundary of the segment. In a segment where a tributary and/or marina comes in, segment 4 in Figure 6-4, the tidal prism of the tributary/marina should be included in determining the segment volume. Therefore the curve Pr(x) - Ri(x) needs to be extrapolated from the tributary junction to the landward transect of the segment.

As an example of application, consider a freshwater creek, shown in Figure 6-5, located along the border of Fairfax County and Alexandria, Virginia. Hunting Creek drains a largely urban area (approximately 44 mi^2) and consists of a creek-like reach with upland and tidal sections, which join to a small embayment of the Potomac.

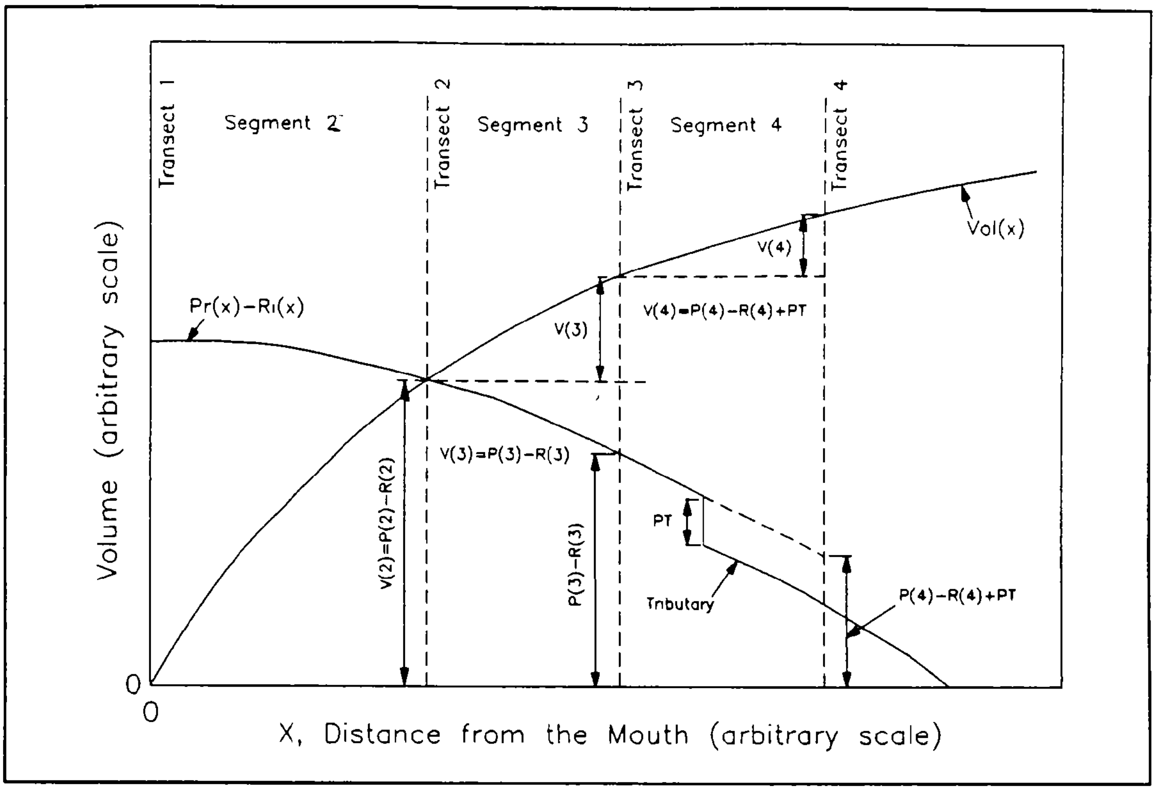

Figure 6-4. Graphical Method of Segmentation of a Water Body.

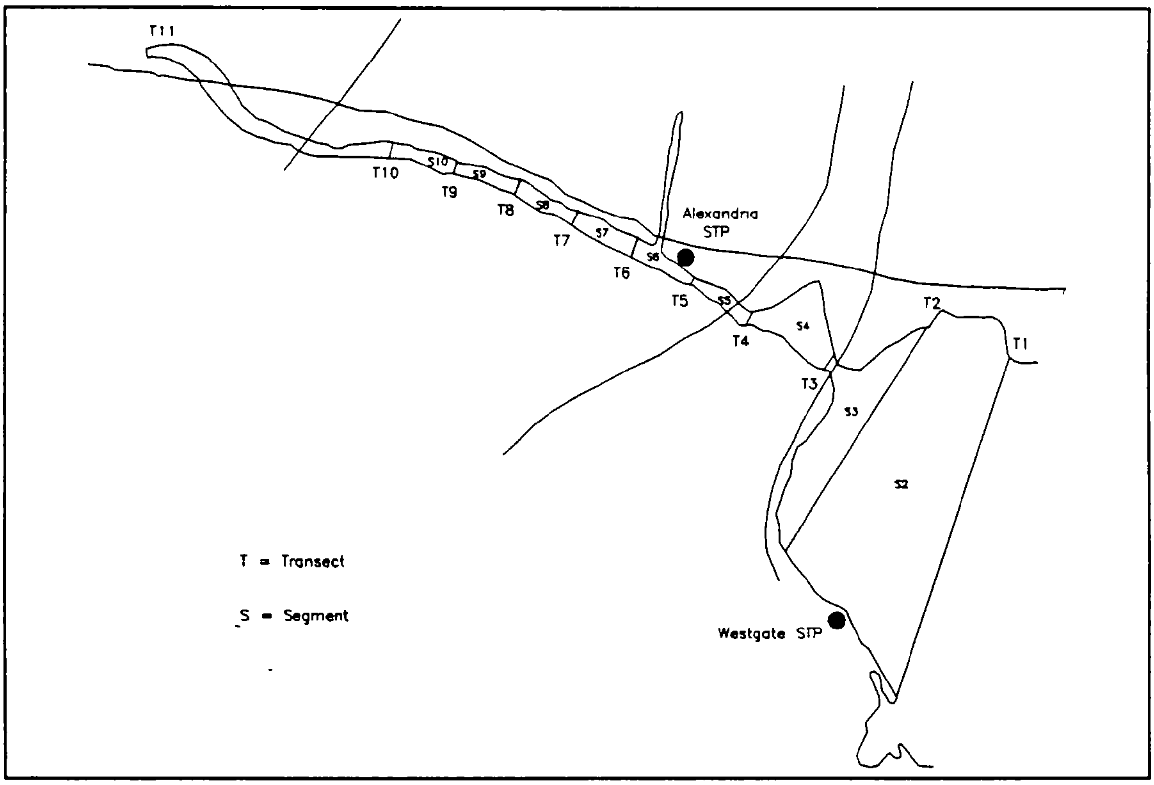

Figure 6-5. Hunting Creek Showing Model Segments.

The hydrodynamic regime in Hunting Creek is dominated by tidal transport. During a typical 12.4-hour tidal cycle, 29 million cubic feet of water is exchanged between the creek and the Potomac River as the result of tidal flushing. During the same period, only about 1 million cubic feet of fresh water enters the system. Thus a model based on substance transport by tidal mixing is appropriate. The creek has no tributaries and is divided into 11 segments. It has two point sources of pollution as well as upstream freshwater runoff.

If, during a flood tide, a particle at A can move only to B, and B only to C, then everything between A and B will be contained at high tide within B and C (Figure 6-6). This must be the value of the tidal prism above D, not counting mass inputs above B (runoff, etc.); that is,

$$P(x) - R(x) = V(x) \qquad \textit{at B}$$

For segment 2, the position B must be found such that between it and the mouth the volume equals P(B)-R(B) (i.e., $P(T_2)$-$R(T_2)$). Volumes from the mouth to X will be less than P(x)-R(x) until a distance has been reached equal to the local particle excursion since the prism at any point in between includes particles entering from below (seaward of) the mouth.

Point B is the position of transect #2 (transect #1 is at the mouth) and V2 is contained between the curves of P(x)-R(x) and accumulated volume versus cross section at B. For the third segment, move from B upriver until the total volume less V(2) equals P(x)-R(x). This is the position of transect #3. For the fourth segment, move from transect #3 upriver until the total volume less V(2) and V(3) equals P(x)-R(x); this is transect #4. Segmentation continues in this manner until the cut-off guideline is approached (i.e., when the width of a segment exceeds its length. Each of the tributaries/marinas may be segmented in the same way as that of the mainstem. For segments landward of the transect at which P(n) = R(n), the creek behaves as a fluvial stream and no water is transported landward during flood tide. The total volume of water flowing through a transect during a tidal cycle is 2R(n).

In Figure 6-6, the accumulated low-tide volume vs. tidal prism (less runoff) is shown for Hunting Creek. Accumulated (summed from the mouth to points upstream) low-tide volume is used for graphical segment determination. The prism is summed from the head to points downstream. Volumes are with regard to the bathymetric transects at this point since the model segments have not yet been determined.

Table 6-12 shows the local (not accumulated) high-tide volume of the model segments, which is the "volume" input to the model, and the prism above each transect, which is the "prism" input to the model for the Hunting Creek example.

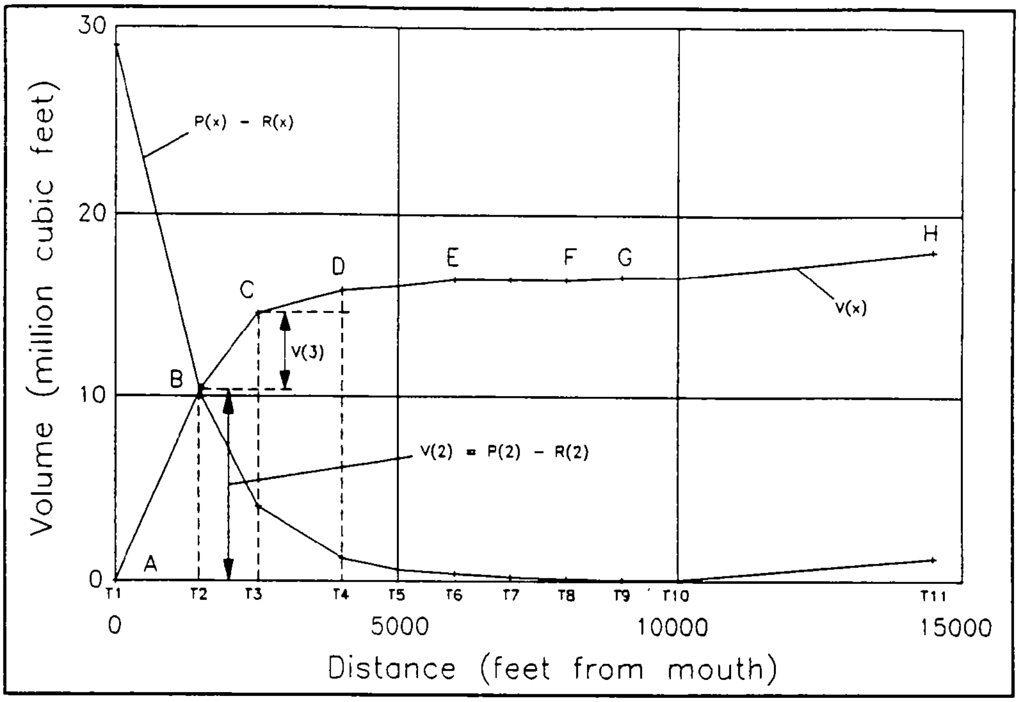

Figure 6-6. Graphical Representation of Hunting Creek Segmentation.

TABLE 6-12. Model Parameters for Hunting Creek Model Geometry

Transect	Segment	Distance from Mouth (mi)	Local High Tide Volume (1000 cf)	Tidal Prism above Transect (1000 cf)	Average Depth (ft)	Return Ratio
1	1	0.00	0.00	28.97	3.1	0.0
2	2	0.33	27.61	11.59	4.5	0.0
3	3	0.50	10.68	4 96	7.1	0.6
4	4	0.76	3.20	2.98	3.2	0.0
5	5	0.95	0 90	2.44	2.9	0 0
6	6	1.14	0.81	1.91	2 4	0.0
7	7	1.33	0.69	1.40	2.0	0 0
8	8	1 52	0 56	0.94	1.7	0.0
9	9	1 70	0.49	0.54	1.4	0.0
10	10	1.89	0.32	0.24	1.2	0 0
11	11	2.75	1.95	0 00	0.5	0.0
Upstream and point source inputs, August 1 Flow (cfs)						
Segment 11 Upstream 1.7 cfs			Segment 6 Alexandria STP 36 5 cfs	Segment 2 Westgate STP 13.2 cfs		

TPM Model Calibration

The first step in model calibration is to simulate conservative substances, such as salt, since the distribution of these substances is solely the result of physical processes. That is, the variations in salinity in the estuary are the result of bay-derived salty water being transported and mixed with land-derived fresh water. The calibration process is accomplished through the calibration of the returning ratios against a dye study or salinity measurements. Low returning ratios result in vigorous mixing, while a returning ratio of one has the physical meaning that absolutely no mixing has occurred. For example, transects in areas where the depth suddenly increases may be found to have much larger returning ratios, because mixing throughout the larger volume takes longer and more of the old, unmixed water is left to return.

It is assumed that all substances will be transported and dispersed in a similar manner, but that nonconservative substances will experience biochemical transformations during the process. Therefore, the second stage of calibration is to simulate the concentration field of nonconservative substances. Normally the fecal coliform submodel would be calibrated next since it is simple, having essentially no interactions with other components.

Calibration of the nutrient cycle is complicated and difficult since numerous elements and rate constants are involved. Rate constants that are not directly measured in the field may be determined by successive trials using literature values as guides. The first stop in this trial-and-error process is to reproduce the observed chlorophyll-*a* levels. This process is found to be efficient in the sense that most model components are close to calibration by the time chlorophyll-*a* levels are properly adjusted. Then there remains only some fine tuning of rate constants, which have a minor influence on chlorophyll-*a* levels.

The dissolved oxygen component is the last to be adjusted since the phytoplankton have an effect on DO levels. Changes in the decay rate of oxygen-demanding material tend to affect BOD levels more than DO levels since reaeration plays a dominant role in the DO cycle. The model predicts concentrations at high water slack, and it is against these observations that the predictions should be compared. Perfect fits of all constituents and total verification of all data sets are undoubtedly impossible. Fine tuning is probably best done after a gross calibration, sensitivity, and verification sequence has been carried out and the main features of the physical system are seen to be correctly reproduced.

6.3.2.2 NCDEM Model

The NCDEM DO model is selected as an alternative method in the mid-range model category. The NCDEM DO model is a steady-state program that is only capable of predicting DO concentrations. This model is applicable to one-, two-, and three-segment marinas. The NCDEM DO model incrementally mixes the ambient and marina waters as a function of the average lunar tides. The NCDEM Model version used for this study assumes that the marina to be evaluated can be approximated by two segments: an inlet channel and the marina basin.

Runoff is assumed to be equal to zero, and the volume of wastewater discharged to the basin other than from boats is also assumed to be equal to zero. The net flow out of the basin is therefore zero. The forcing function is the changing depth of the ambient water, primarily due to tidal forces, which brings water into the marina during the rising tide and takes water out of the marina during the falling tide.

The tidal variations are assumed to follow a sinusoidal distribution. For simplicity, a 12-hour tidal cycle is used. Calculations are performed at hourly time increments. Each segment is assumed to be completely mixed at the end of each time increment.

Changes in dissolved oxygen are possible from advection, reaeration, or bottom sediment oxygen demand. Boat discharges are not included since they have been shown to have a minor effect or no effect on DO concentrations. The NCDEM model assumes some initial values, iterates through 18 tidal cycles, and then prints out the results of the next two tidal cycles. This allows sufficient interactions for a steady state to be reached, which is verified by comparing the results of the last two tidal cycles.

NCDEM Model Application

The NCDEM DO model was applied to the Beacons Reach and Gull Harbor marinas. Since the Indian Hills marina is a flow-through type marina, the NCDEM model version used in this study, which is a two-segment marina model, could not be applied to this marina. Input parameters used for NCDEM model applications at the two marinas are listed in Table 6-13. Predicted dissolved oxygen levels at Beacons Reach and Gull Harbor marinas using the NCDEM model are listed in Table 6-14.

6.3.2.3 Summary of Mid-range Model Results

The NCDEM model underpredicted DO levels at both marinas (Table 6-14). Deviations from observed DO values ranged from 6 percent at the Gull Harbor marina to 14 percent at the Beacons Reach marina. Considering the limitations and variability of the parameters measured in those studies, the NCDEM Model appears to reasonably predict actual conditions.

6.3.3 Complex Model

The Water Quality Analysis Simulation Program (WASP4, Ambrose et al., 1987) is selected as the method of choice in the complex model category. This program is a dynamic compartment modeling system that can be used to analyze a variety of water quality problems in one, two, or three dimensions. WASP4 simulates the transport and transformation of conventional and toxic pollutants in the water column and benthos of ponds, streams, lakes, reservoirs, rivers, estuaries, and coastal waters. The WASP4 model system is supported by the U.S. EPA Center for Exposure Assessment Modeling (CEAM), Athens, Georgia, and has been applied to many aquatic environments. The primary strengths and advantages of the WASP4 model are discussed in Chapter 4.

TABLE 6-13. NCDEM Input Parameters Used to Estimate DO Levels

Parameter	Description (units)	Beacons Reach	Gull Harbor
HM	Average marina depth (ft)	6.0	4.5
HC	Average channel depth (ft)	7.0	5.0
AC	Channel surface area (ft^2)	8700	11700
AM	Marina surface area (ft^2)	93000	46000
TA	Tidal amplitude; half the tidal range (ft)	1	1
SOD	Sediment oxygen demand ($g/m^2/day$)	2.68	3.00
DO_A	Ambient DO (mg/L)	6.3	6.0
DO_S	Saturation DO mg/L)	6.9	7.0
K_d	Decay coefficient (per day)	1.0	1.0
K_r	Reaeration rate (per day)	0.3	0.3
NBC	Channel boat activity (boat-hr/day)	0	0
NBM	Marina boat activity (boat-hr/day)	0	0

TABLE 6-14. Predicted DO levels (NCDEM)

Marina Site	Predicted DO (mg/L)	Observed DO (mg/L)
Beacons Reach	4.82	5.60
Gull Harbor	3.74	4.00

Cautionary Note:

Typically, the DYNHYD4 hydrodynamic submodel of WASP4 is calibrated to measured tides and velocities in the water body. Since this is not possible for a proposed marina, a different approach is recommended. The DYNHYD4 submodel can be calibrated in two steps. First, a full two-dimensional hydrodynamic model is configured and calibrated to reproduce tidal heights and velocity at the proposed marina site. Second, DYNHYD4 is calibrated through successive adjustment of channel roughness and channel geometry (hydraulic radius and width) until the velocities in the DYNHYD4 submodel match those from the 2-D hydrodynamic model. In the first step, any two-dimensional hydrodynamic model can be used to calibrate the DYNHYD4 submodel. The Tidal Embayment Analysis (TEA) program and/or the CAFE1 model are recommended to establish the hydrodynamics at a proposed marina site (see Sections 2.2.3.6 and 2.2.3.7). An example application is provided in Appendix E to illustrate this approach.

6.3.3.1 WASP4 Model Application to Indian Hills Marina

The goal of applying WASP4 to the Indian Hills Marina is to determine how well the model provides site-specific predictions of water quality parameters such as dissolved oxygen. This is the most stringent type of modeling task. A good set of monitoring data is needed to provide credible predictions. Monitoring data in the canal provide the necessary rate coefficients, constants, and other parameters required by WASP4.

The WASP4 model applied to the Indian Hills Marina consisted of 12 model segments and 12 channels as shown in Figure 6-1. The segments were chosen so that monitoring stations were appropriately located near segment centers. Initially, the hydrodynamic submodel, DYNHYD4, was applied to compute the tidal elevations and current flows in the canal. Next, WASP4 was applied using only system variable #12 as the dye tracer variable. The dispersion coefficients were then adjusted through several iterations until a good match between observed and model dye concentration was obtained throughout the canal. Finally, dissolved oxygen was simulated using WASP4 by including the intermediate eutrophication kinetics option.

There are 13 state variables included in the version of WASP4 applied to the Indian Hills canal: two size-fractionated functional groups of phytoplankton (#1 nanoplankton chlorophytes and #2 netplankton diatoms); inorganic nitrogen (nitrate, nitrite and ammonia); organic nitrogen; dissolved silica; inorganic phosphorous; organic phosphorus; dissolved oxygen; CBOD; salinity; and total coliform bacteria. However, not all of these state variables were used to simulate the Indian Hills canal system. The state variables not used were phytoplankton #2, dissolved silica, and total coliform bacteria. All phytoplankton activity was combined into the phytoplankton #1 state variable as total chlorophyll.

Calibration

For model calibration, boundary conditions for DYNHYD5 included tidal heights recorded during the period July 12-15, 1984 (see data file listing in Appendix A). To ensure stability in the hydrodynamic solution, a time step of 8 seconds was required based on the following equation:

$$t \le \frac{L}{\sqrt{g\,y} + U} \tag{6-2}$$

where g is the gravitational acceleration constant (9.81 m^2/sec), the shortest channel length (L) is 44 m, the water depth (y) is about 2.3 m, and an assumed maximum velocity (U) is 0.5 m/sec. A time step of 6 seconds was actually used in the DYNHYD5 model run. Hydrodynamic results were stored in an output file at a time interval of 15 minutes for use by the WASP4 model.

One liter of dye tracer (20 percent Rhodamine WT) was introduced in a slug fashion in model segment 11 (dye station 13) at 1715 hours on July 12, 1984. In an iterative fashion, the dispersion coefficients were adjusted and a value of 1.0 m^2/sec was determined to provide a good match between observed and model dye concentrations. Results of model calibration to the dye tracer data are shown in Figure 6-7. In segments 6 through 12, the model matches the observed dye concentrations quite well. In Segments 1 through 5, however, the high initial peak in dye concentration is not reproduced in the model. Since no meteorological information was available with the data set, no wind data were input into the model. This could be one possible cause for the failure of the model to predict the early peaks in Segments 1 through 5. Another possible reason may be boat traffic in the canal, which is not accounted for in the model. Overall, the model advection and dispersion appear to be well calibrated based on the results of the dye comparisons.

Water quality data were collected in the canal on July 12 and 13, 1984. Next, the water quality monitoring data were used to provide initial conditions and boundary conditions for the WASP4 model. Since not all data required by WASP4 were available in the monitoring data set, certain assumptions were made to fill in missing data gaps. Orthophosphate was estimated as 60 percent of total phosphorus, and organic phosphorus was estimated to be 40 percent of total phosphorus. Chlorophyll-*a* was estimated from total organic carbon (TOC). It was assumed that particulate organic carbon (POC) was 20 percent of TOC and that the POC-to-chlorophyll ratio was 0.080 mg C/μg chlorophyll.

Temporal forcing functions constant in space but varying in time included incident solar radiation, photoperiod, wind velocity, zooplankton biomass, and temperature-dependent sediment flux terms for sediment oxygen demand, benthic ammonia, silica and phosphorous regeneration, and benthic nitrate flux. In the version of WASP4 used for this study, temporal forcing functions can be specified for up to five clusters of segments to represent subregions of a water system. However, since the Indian Hills canal is such a small system, only one of the temporal forcing function groups was used to represent the entire waterbody.

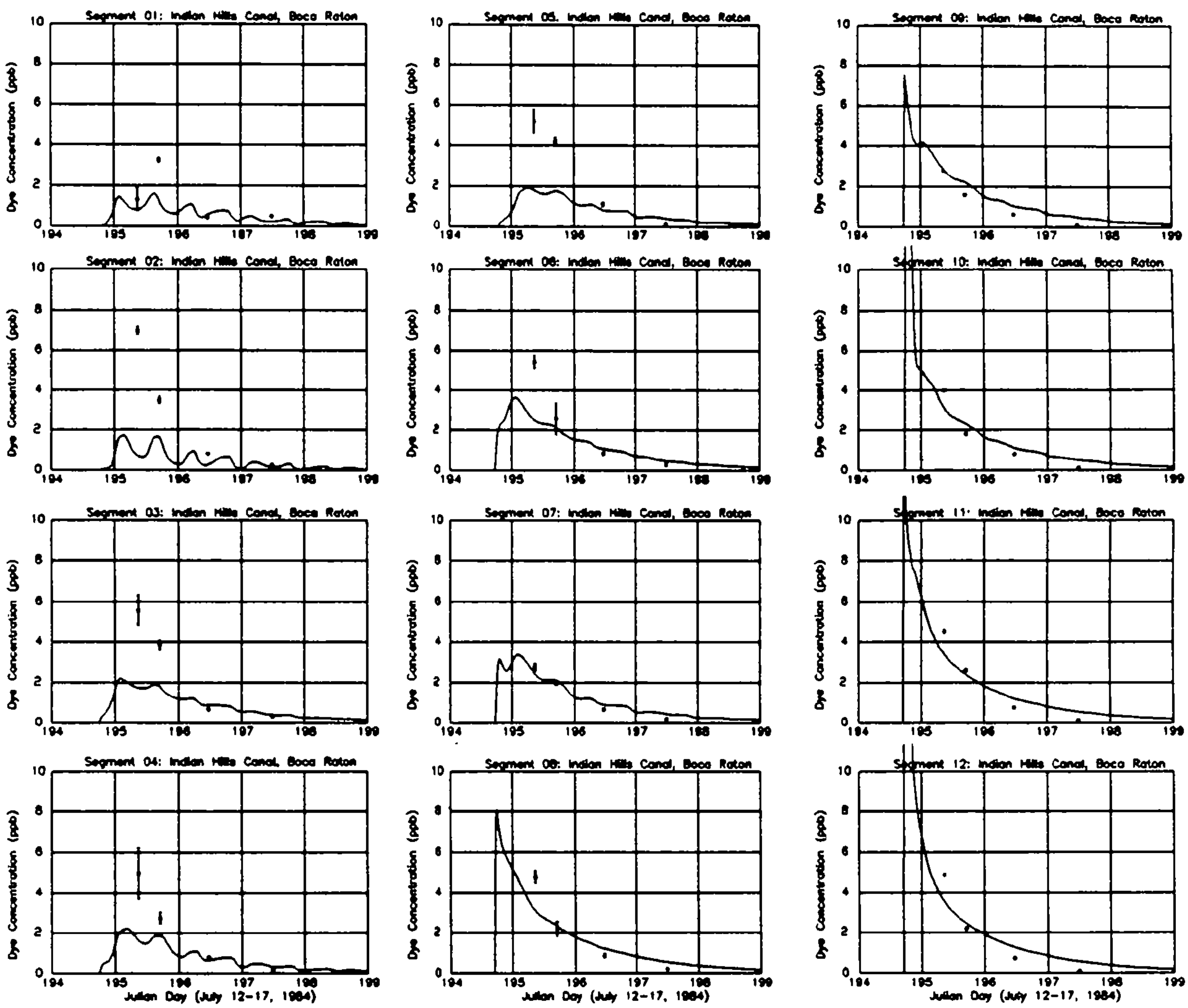

Figure 6-7. Predicted and Observed Dye Concentration at Indian Hills Marina.

Time invariant spatial forcing functions included sediment oxygen demand; benthic nutrient fluxes of ammonia, nitrate, phosphate and silica; groundwater concentrations of ammonia and nitrate; fraction of groundwater flow into a segment; and lateral dispersion. Non-point source loading included spatially and temporally constant estimates of atmospheric deposition. Groundwater inflow into the Indian Hills canal was assumed to be zero since no information was available to indicate otherwise.

Temporal variation of the nonphytoplankton (background) extinction coefficient was estimated using observed light transmission data at several stations in the Indian Hills canal. The total extinction coefficient (KE) was determined to be 1.5/m. Riley (1956) estimated the total extinction coefficient (in units of m^{-1}) as a function of chlorophyll-*a* as:

$$KE = KE_0 = 0.0088\ P + 0.054\ P^{2/3} \qquad (6\text{-}3)$$

where KE_0 is the background non-chlorophyll-related extinction coefficient and P is the phytoplankton biomass expressed as μg Chl-a/L. Given KE = 1.5/m and P = 16 μg/L, the background extinction coefficient of KE_0 = 1.02/m can be computed. This is the value used in the Indian Hills WASP4 model.

Sediment oxygen demand was measured at two locations (Station I-1 and Station I-3) in the canal during July 1984 and again in January 1985. The temperature dependence coefficient (Θ) was computed at the two stations as 1.015 and 1.072, respectively. The higher value was used in the WASP4 model because it yielded dissolved oxygen concentrations that better matched observed values. The equation for computing temperature-dependent SOD is:

$$SOD_T = SOD_{20}\ \Theta^{T-20} \qquad (6\text{-}4)$$

where:

SOD_T = Sediment oxygen demand at temperature T
SOD_{20} = Measured SOD at 20°C
Θ = Temperature dependence coefficient (1.072)

Benthic diagenesis of organic nitrogen is accounted for with empirical temperature-dependent forcing functions for ammonia regeneration and nitrification and denitrification for nitrate. Nutrient sediment flux data were not available for the Indian Hills canal. However, sediment flux rates of ammonia and phosphate were assumed to be stoichiometrically related to the sediment oxygen demand rate via the classical ratios for O:C:N:P (109:41:7.2:1) by weight (Redfield, 1963). The Redfield relationships for ammonia flux (j NH4) and phosphorus flux (j PO4) as a function of SOD ($gC/m^2/day$) are noted below:

$$j\ NH4 = SOD\ /\ (109/7.2) = SOD\ /\ 15.14 \tag{6-5}$$

$$j\ PO4 = j\ NH4\ /\ (7.2/1) = j\ NH4\ /\ 7.2 \tag{6-6}$$

Kinetic processes do not affect the distribution of salinity because salt is a conservative substance. Salinity is included in the model as a tracer to verify the transport submodel and to calculate density and the saturation value of dissolved oxygen.

The dissolved oxygen results of the WASP4 model are given in Figure 6-8. Observed values of DO were recorded at a number of stations in the canal at approximately 2-hour intervals over the course of a 27-hour time period (from about 1100 hours on July 12, 1984 to about 1300 hours on July 13, 1984). The WASP4 model does a reasonable job of predicting the mean DO concentration at most of the stations; however, it cannot reproduce the daily range in DO observed in the canal. This stems from the algorithm used in WASP4 to compute the dissolved oxygen and phytoplankton dynamics. The model computes daily average dissolved oxygen and the expected diurnal range that would be attributed to algal primary production. In its present form, the model cannot reproduce the hour-to-hour DO changes observed in the real world. The maximum and minimum DO curves computed by the model (see Figure 6-8) tend to underestimate the observed daily DO range evident in the monitoring data. A tabulation of the WASP model results and observed daily average and daily minimum dissolved oxygen data are also presented in Table 6-15.

6.3.3.2 WASP4 Model Application to Beacons Reach Marina

The WASP4 model was configured to represent the Beacons Reach marina by a grid network of nodes linked together by channels (Figure 6-2). The following are underlying assumptions of the WASP4 model:

- Beacon Reach marina is well mixed vertically.
- The law of conservation of mass is obeyed for water quality constituents.
- Chemical reaction rates may be estimated using first-order kinetics characterized by reaction-specific rate coefficients.

The area modeled by the WASP4 model includes the main channel and the entire basin. The WASP4 model node and channel geometry was selected to give approximately uniform representation for the Beacons Reach marina. The model consisted of four channels and five segments as shown in Figure 6-2. The first segment encompasses the marina channel, and segment 5 represents the dead end of the marina. The center of each segment was carefully selected to coincide with station locations where water quality observations were taken in the marina basin. Channel length ranged from 28 to 59 meters. To ensure numerical stability for all DYNHYD5 model runs, a time step of 6 seconds was used. All input parameters used in the DYNHYD5 and WASP4 models are listed in Appendix A.

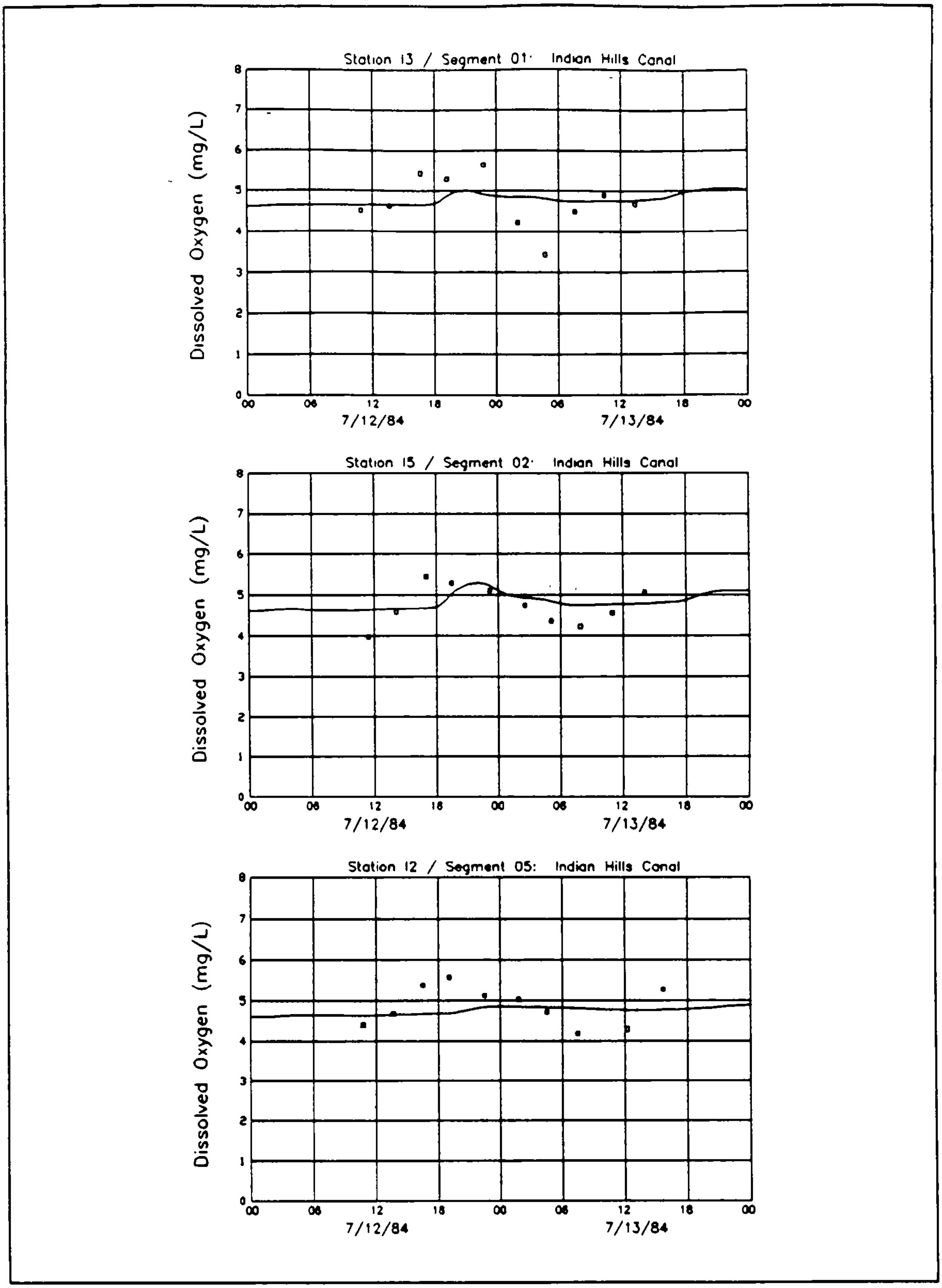

Figure 6-8. Predicted and Observed DO Concentration at Indian Hills Marina (WASP Model).

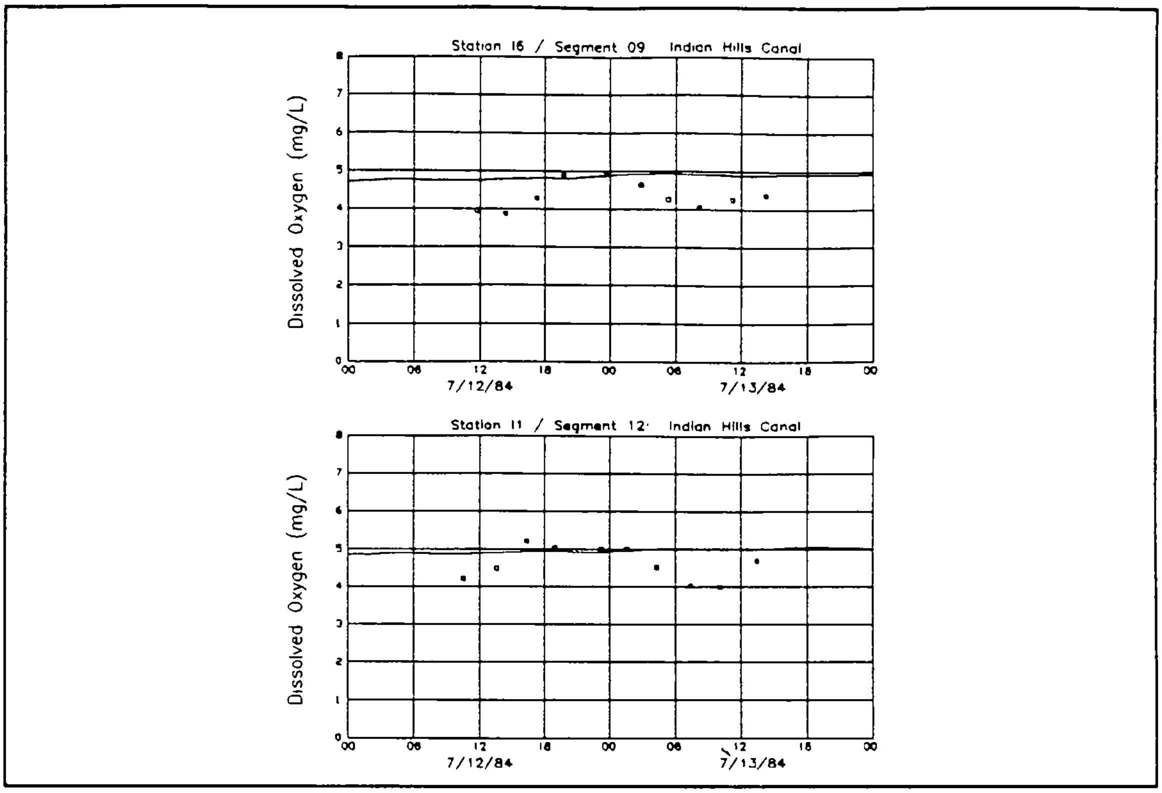

Figure 6-8. Predicted and Observed DO Concentration at Indian Hills Marina (WASP Model).

TABLE 6-15. Comparison of WASP Model Results to Observed Data (Indian Hills Marina).

	WASP Model Results			Observed Data	
Segment	Avgerage DO (mg/L)	Minimim DO (mg/L)	Monitoring Station	Average DO (mg/L)	Minimum DO (mg/L)
1	4.78	4.32	I-3	4.74	3.43
2	4.78	4.27	I-5	4.69	3.98
3	4.76	4.36			
4	4.82	4.33			
5	4.77	4.33	I-2	4.86	4.19
6	4.79	4.44			
7	4.78	4.32			
8	4.84	4.50			
9	4.85	4.46	I-6	4.34	3.87
10	4.87	4.50			
11	4.92	4.57			
12	4.96	4.62	I-1	4.54	3.99

Averages calculated are over the period 7/12/84 (11:00 am) to 7/13/84 (13:00 pm)

The dye study survey data were used for calibration of the WASP4 model. During this survey samples were collected over a 48-hour period at the Beacons Reach marina (stations A through O). Dye sampling stations did not coincide with stations sampled for physical and water quality parameters (stations BR-2 through BR-6). At each sampling time, contour plots of the measured dye data were made using data collected at stations A through O. Representative values of the observed dye at stations BR-2 through BR-6, where water quality parameters were sampled, were calculated, and the WASP4 model was calibrated against these values. The dye contour plots are shown in Appendix D. These observed values are used for model comparisons and are listed in Table 6-16.

Calibration

The purpose of model calibration is to supply reliable values for empirically based coefficients for bottom friction, boundary tidal exchange rates, and water quality reaction rates such as CBOD decay, reaeration rates, etc. The model is run using input conditions (tides, inflows, meteorological conditions, waste discharges, boundary conditions, etc.) that characterize one or more periods for which semisynoptic survey data are available. The model results are compared to in situ data, and system coefficients are adjusted until reasonable agreement between model and prototype is achieved.

Observed tidal information was measured at the channel entrance. Tidal observations of time and corresponding high and low water stages at the channel entrance were used as the basis for the seaward boundary tide for the calibration period October 10 to October 13, 1988. The boundary tide at model segment 1 was taken as the range of the observed tide at the entrance.

Calibration of the Beacons Reach WASP4 model was accomplished in two steps. First, DYNHYD5 was run with a set of bottom friction coefficients (Manning's n). Second, the hydrodynamics created by DYNHYD5, i.e., flows and volumes, were used to run the WASP4 model. Calibration of the WASP4 model was accomplished through successive adjustment of dispersion coefficients until the predicted dye concentrations matched those observed in the field. The results of WASP4 model calibration for the October 10 through October 13, 1988, period are shown in Figure 6-9. Reasonable agreement was achieved in all segments as indicated in Figure 6-9. Excellent agreement between model results and observed dye data is evident in both segments 4 and 5. The calibrated WASP4 model, based on the dye study, was used as the base for dissolved oxygen simulation.

Tide information was not provided for the summer period where observed water quality data are available. Tide predictions from a NOAA tide station at Bogue Inlet, North Carolina, were used as the boundary conditions for the DYNHYD5 submodel during the dissolved oxygen simulation period (May 20, to May 27, 1988). Hydrodynamics of this period were provided to the WASP4 model to simulate the dissolved oxygen concentration within the Beacons Reach marina.

TABLE 6-16. Observed Dye Concentration Used for Model Calibration at Beacons Reach Marina

Julian Day 1988	Dye Concentration (ppb)	Julian Day 1988	Dye Concentration (ppb)
BR-2		BR-5	
285.4847	20.0	285.4847	73.0
285.7431	19.0	285.7431	66.0
286.0166	19.0	286.0166	46.0
286.2674	5.0	286.2674	32.0
286.5014	4.0	286.5014	22.0
286.7500	4.0	286.7500	21.0
287.0069	4.0	287.0069	20.0
287.2708	2.0	287.2708	19.0
BR-3		BR-6	
285.4847	29.0	285.4847	74.0
285.7431	31.0	285.7431	60.0
286.0166	24.0	286.0166	40.0
286.2674	24.0	286.2674	26.0
286.5014	20.0	286.5014	20.0
286.7500	23.0	286.7500	18.0
287.0069	18.0	287.0069	18.0
287.2708	18.0	287.2708	16.0
BR-4			
		Date	Julian Day
285.4847	46.0	10/11/88	285
285.7431	48.0	10/12/88	286
286.0166	34.0	10/13/88	287
286.2674	27.0		
286.5014	20.0		
286.7500	21.0		
287.0069	18.0		
287.2708	19.0		

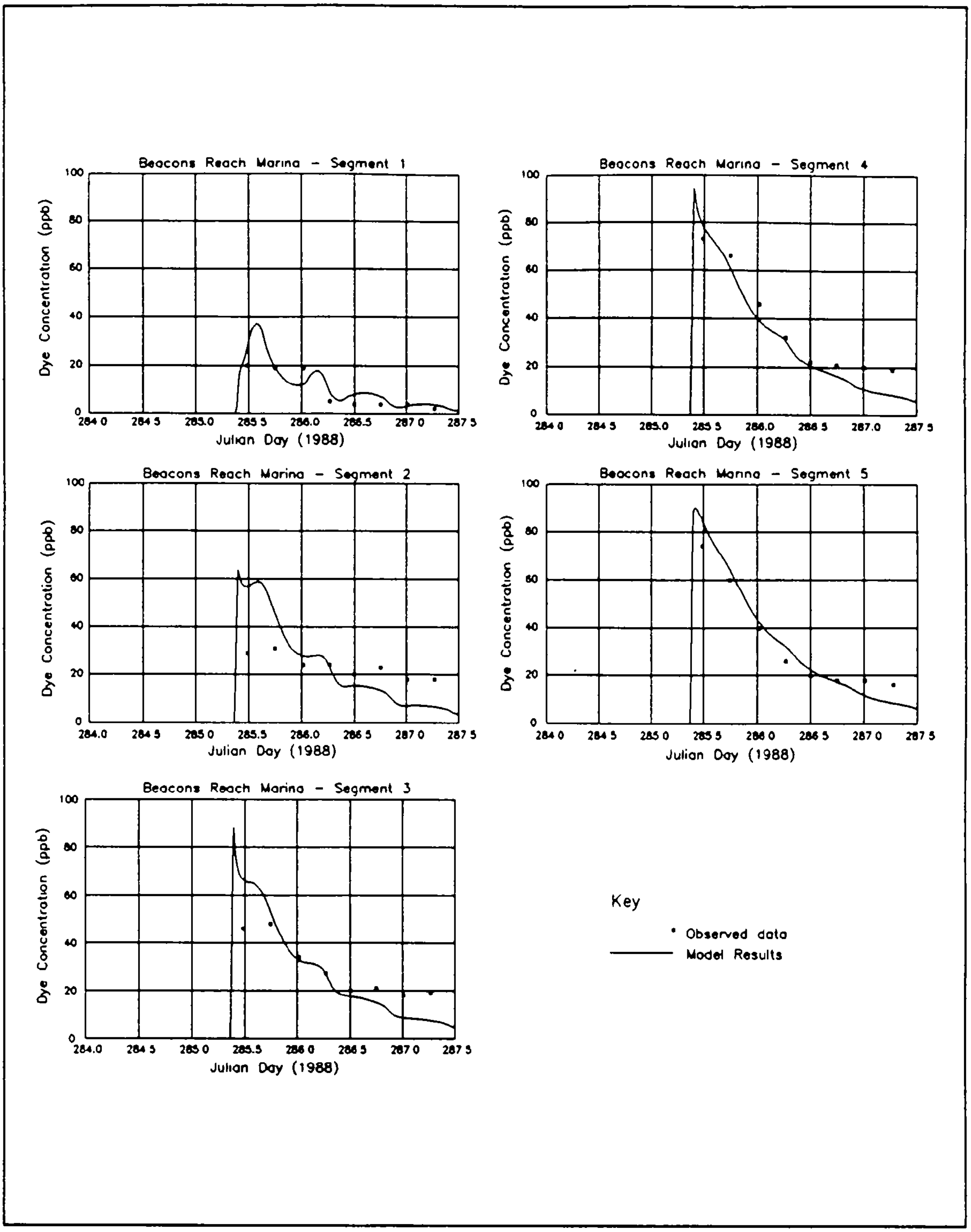

Figure 6-9. Model Calibration Using Dye Data at Beacons Reach Marina.

For dissolved oxygen simulation, the Beacons Reach WASP4 model was configured for an Intermediate Eutrophication Kinetics complexity level (Figure 6-10). Systems 1 through 8 are included in the dissolved oxygen balance. The Intermediate Eutrophication Kinetics add several nonlinear terms and functions to the simple eutrophication kinetics. For example, a variable carbon-to-chlorophyll ratio is used instead of a fixed ratio in dissolved oxygen calculations. Additional features are also included in this option (see WASP4 User's Manual for additional information).

Initial and boundary conditions for the Beacons Reach WASP4 model are based on average summer ambient and basin water quality conditions and are summarized in Table 6-2. Both sediment and biochmeical oxygen demand were assumed constant at all locations inside the Beacons Reach marina. The input data file for dissolved oxygen simulation is included in Appendix A.

Results

Model predictions are compared against dissolved oxygen data collected at stations BR-2, BR-4, and BR-6 on May 26, 1988. The comparison between predicted and observed dissolved oxygen in Beacons Reach marina is illustrated in Figure 6-11. This figure shows dissolved oxygen concentration as a function of distance from the marina entrance. WASP4 model predictions and observed dissolved oxygen are in excellent agreement. Agreement is also achieved at the dead end segment of Beacons Reach marina (model segment 5, 170 meters from the mouth). It is also clear that water inside the Beacons Reach marina is above the State of North Carolina Water Quality Standard of 5.0 mg/L dissolved oxygen during this time period.

6.3.3.3 WASP4 Model Application to Gull Harbor Marina

The WASP4 model was configured to represent the Gull Harbor marina by a grid network of nodes linked together by channels (Figure 6-3). The area modeled by the WASP4 model includes the main channel and the entire basin. The WASP4 model node and channel geometry was selected to give approximately uniform representation for the Gull Harbor marina. The model consisted of two channels and three segments as shown in Figure 6-3. The first segment encompasses the marina channel, and segment 3 represents the dead end of the marina. The center of each segment was carefully selected to coincide with station locations where water quality observations were taken in the marina basin. Channel length ranged from 32 to 39 meters. In all DYNHYD5 model runs, a time step of 6 seconds was used. All input parameters used in the DYNHYD5 and WASP4 models are listed in Appendix A.

The dye study survey data were used for calibration of the WASP4 model. During this survey samples were collected over a 44-hour period at the Gull Harbor marina (stations A through J). Dye sampling stations did not coincide with stations sampled for physical and water quality parameters (stations GH-3 and GH-5). At each sampling time, contour plots of the measured dye data were made using data collected at stations A through J. Representative values of the observed dye at stations GH-3 through GH-5, where water quality parameters were sampled, were calculated, and the WASP4 model was calibrated against these values. The dye

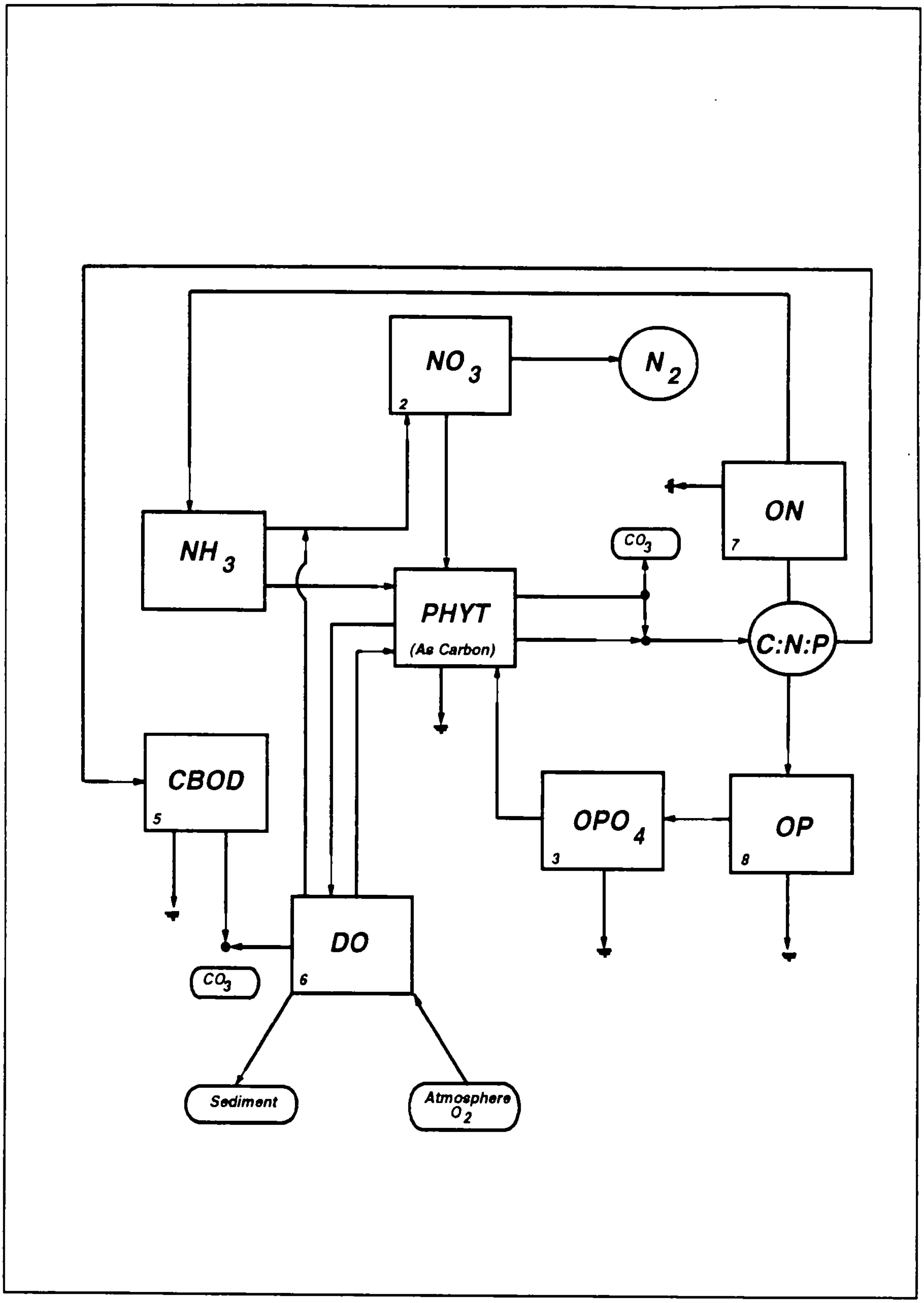

Figure 6-10. EUTRO4 State Variable Used in Modeling DO at Beacons Reach Marina (WASP4 Model).

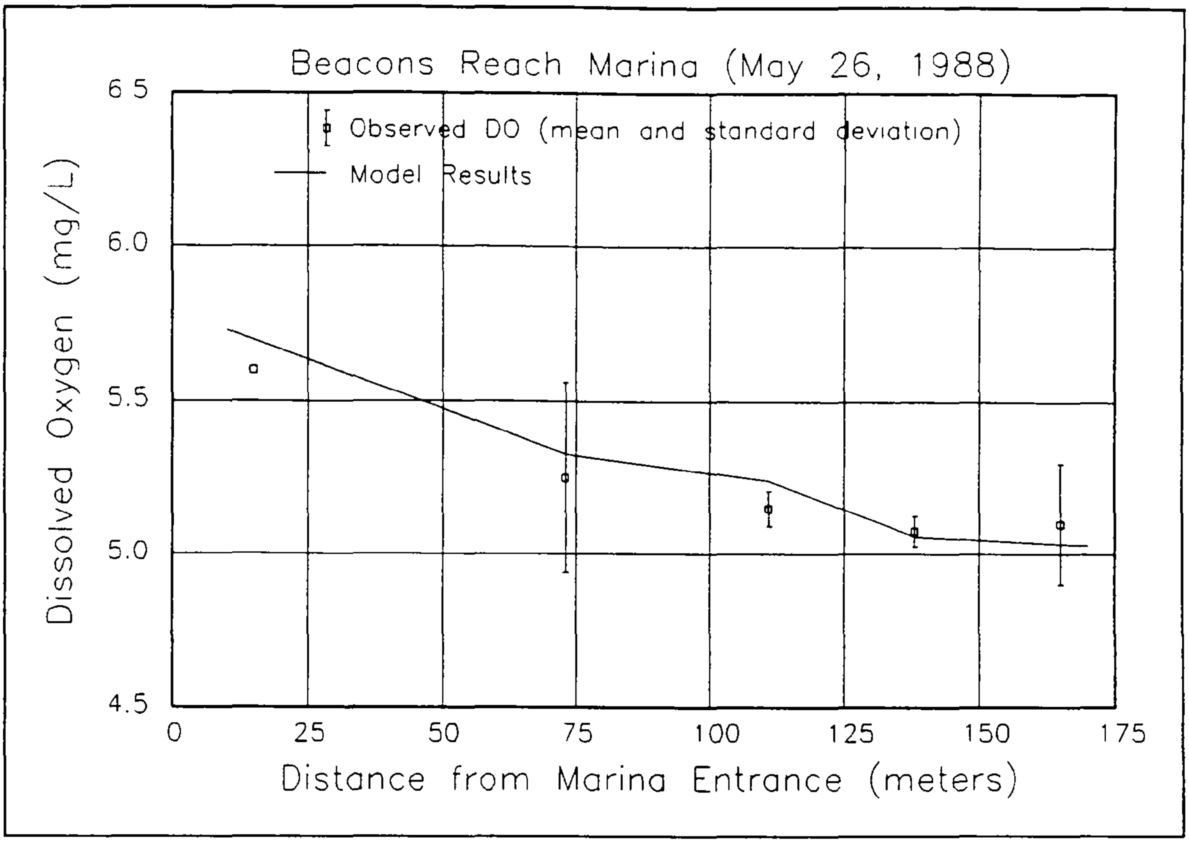

Figure 6-11. Observed and Predicted Dissolved Oxygen at Beacons Reach Marina

contour plots are shown in appendix D. These observed values are used for model comparisons and are listed in Table 6-17.

Calibration

Observed tidal information was measured at the channel entrance. Tidal observations of time and corresponding high and low water stages at the channel entrance were used as the basis for the seaward boundary tide for the calibration period October 24 to October 26, 1988. The boundary tide at model segment 1 was taken as the range of the observed tide at the entrance.

Calibration of the Gull Harbor WASP4 model was accomplished in two steps. First, DYNHYD5 was run with a set of bottom friction coefficients (Manning's n). Second, the hydrodynamics created by DYNHYD5, i.e., flows and volumes, were used to run the WASP4 model. Calibration of the WASP4 model was accomplished through successive adjustment of dispersion coefficients until the predicted dye concentrations matched those observed in the field. The results of WASP4 model calibration for the October 23 through October 26, 1988, period are shown in Figure 6-12. Reasonable agreement was achieved in all segments as indicated in Figure 6-12. The calibrated WASP4 model, based on the dye study, was used as the base for dissolved oxygen simulation.

TABLE 6-17. Observed Dye Content Used for Model Calibraton in Gull Harbor

Julian Day 1988	Dye Concentration (ppb)
GH-3	
298.9326	60.0
299.1458	10.0
299.4111	3.6
299.7194	5.5
300.2410	3.2
GH-5	
298.9326	70.0
299.1458	7.5
299.4111	3.4
299.7194	5.9
300.2410	3.0

Tide information was not provided for the summer period where observed water quality data are available. Tide predictions from NOAA's tide station at Bogue Inlet, North Carolina, were used as the boundary conditions for the DYNHYD5 submodel during the dissolved oxygen simulation period (May 20 to May 27, 1988). Hydrodynamics obtained by DYNHYD5 for this period were used to run the WASP4 model to simulate dissolved oxygen concentration within the Gull Harbor marina. WASP4 model was configured for an intermediate eutrophication kinetics complexity level for dissolved oxygen simulation at the Gull Harbor marina.

Initial and boundary conditions for the Gull Harbor WASP4 model are based on average summer ambient and basin water quality conditions and are summarized in Table 6-3. It was assumed that sediment oxygen demand and biochemical oxygen demand were equal at all locations inside the Gull Harbor marina. Input data files used with DYNHYD5 and WASP4 model for dissolved oxygen simulation are included in Appendix A.

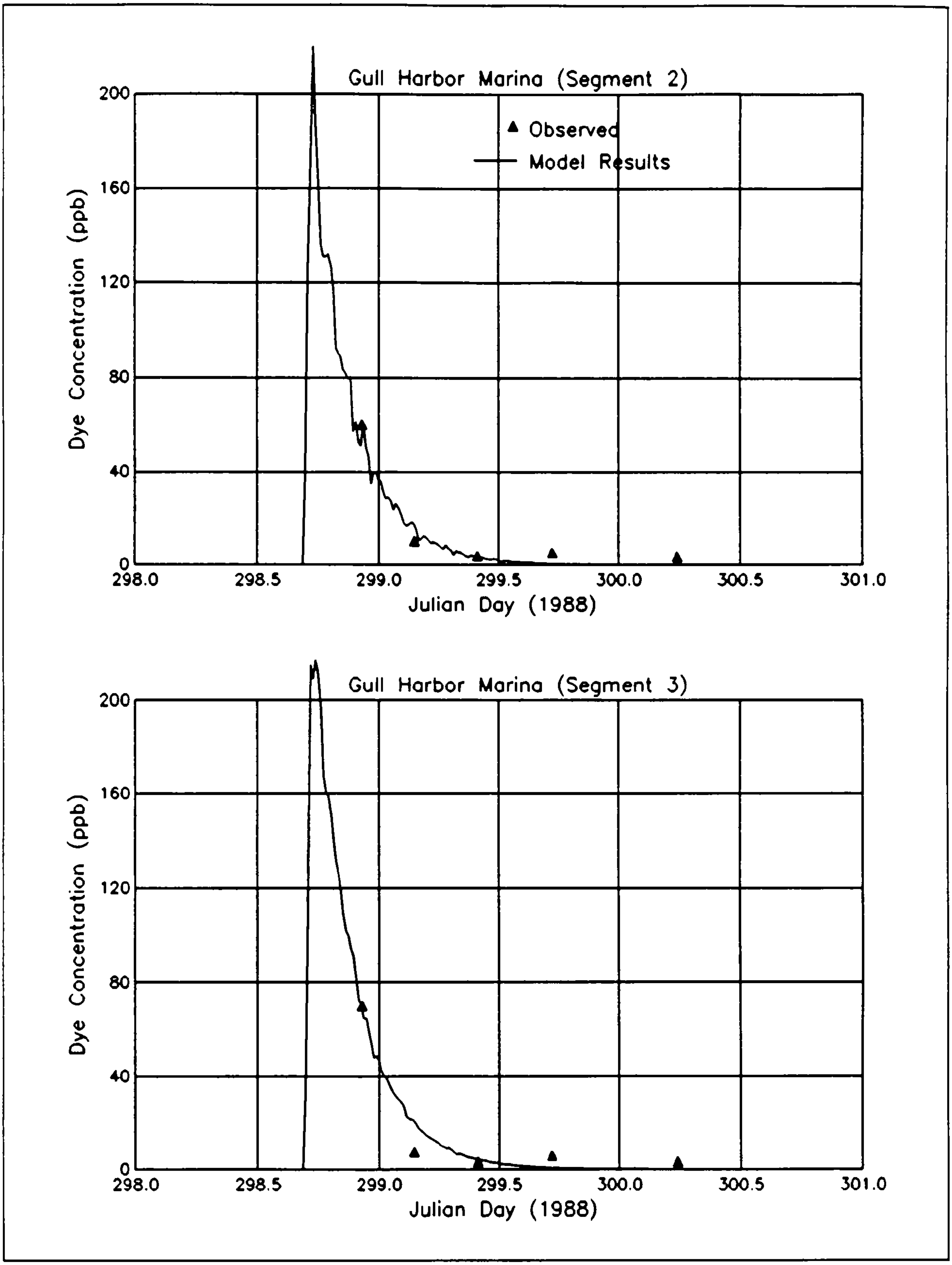

Figure 6-12. Observed and Predicted Dye Concentration at Gull Harbor Marina.

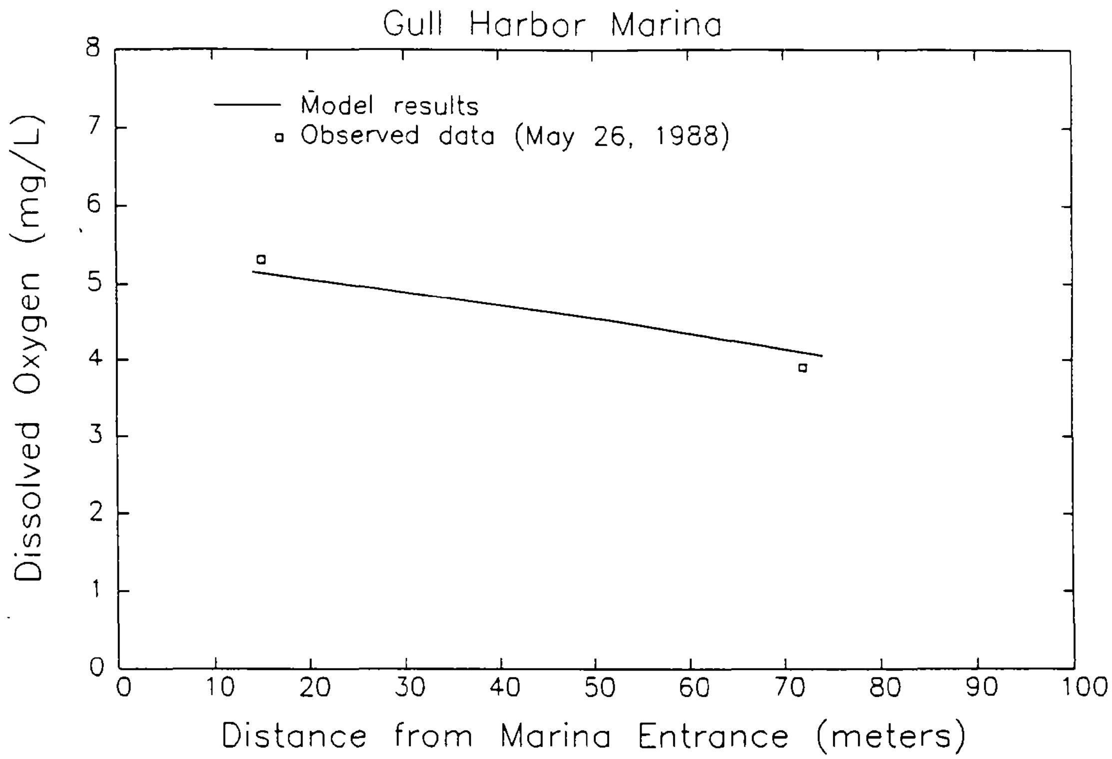

Figure 6-13. Observed and Predicted Dissolved Oxygen at Gull Harbor Marina.

Results

Gull Harbor WASP4 DO model results are shown in Figure 6-13. Observed DO at station GH-3 and GH-5 during May 26, 1988 are also shown in Figure 6-13. DO values are plotted as a function of distance from the marina entrance. Good agreement is obtained at both stations GH-3 and GH-5. DO levels within Gull Harbor marina basin decrease as distance increases from the marina entrance. DO at GH-3 is above the State water quality standard (WQS) of 5 mg/L, however, DO levels at GH-5 is approximately 3.5 mg/L (less than the WQS).

6.3.3.4 Summary of Advanced Model Results

Several conclusions can be drawn from the results of the modeling effort. The most important point is the major influence of SOD on DO. This highlights the importance of obtaining accurate values of SOD to estimate the DO of a proposed marina. While the return flow factor was assumed to be zero for the three marinas, the results were not conclusive and further study is needed on similar and less flushed marinas. The discharge of sewage from boats had a negligible impact on DO for the situations evaluated during this study. Therefore, except for situations with numerous slips in a poorly flushed marina, the number of boats should not be a critical factor with respect to DO. Sediment oxygen demand and flushing characteristics are far more important. Finally, marina shape was shown to have a significant impact on DO.

7. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The purpose of applying a model to a proposed marina is to make the best possible scientific estimate of the impacts that the marina may have on water quality (i.e., dissolved oxygen levels, fecal coliform counts, and/or toxic contaminant concentrations). It is important to remember that waters inside a marina are subject to the same water quality criteria and standards as the ambient waters outside the marina. Thus, it is not sufficient to simply demonstrate that a marina will have no impact on ambient waters; it must be shown that waters inside the marina will also meet appropriate water quality standards.

State and Federal regulators often receive marina permit applications accompanied by water quality assessments using a variety of models and approaches. To enable regulators to review marina applications from a common baseline, it would be helpful to provide guidance to permit applicants that directs them toward a consistent modeling and monitoring approach depending on the required complexity of analysis.

The focus of this study was to select the most appropriate simple, mid-range, and complex models available for predicting water quality phenomena in coastal marinas. After reviewing a number of models and methods, the following were selected as most appropriate for the coastal marina environment:

Simple Method:	Tidal Prism Analysis
Mid-Range Method:	Tidal Prism Model and NCDEM DO Model
Complex Method:	WASP4 Model

Because of certain limitations, the mid-range Tidal Prism Model was applied only to a hypothetical test case. Simple, mid-range (NCDEM DO), and complex models were applied to the Beacons Reach Marina (North Carolina), the Gull Harbor Marina (North Carolina), and the Indian Hills Canal/Marina (Florida). Given the limitations of the available data for the marinas, the complex WASP4 model was able to adequately match dye tracer data both spatially and temporally at the three marinas. WASP4 also adequately reproduced the observed daily average dissolved oxygen levels at the Beacons Reach, Gull Harbor, and Indian Hills marinas.

A comparison of the results of the simple method (Tidal Prism Analysis), the mid-range method (NCDEM DO), and the complex method (WASP4) is presented in Table 7-1 for Indian Hills Canal/Marina, Beacons Reach Marina, and Gull Harbor Marina. The Tidal Prism Analysis computes only a single value of dissolved oxygen for the entire marina. Using the Tidal Prism Analysis (TPA), the dissolved oxygen computed for Indian Hills was 5.06 mg/L; for Beacons Reach, 5.34 mg/L; and for Gull Harbor, 5.54 mg/L. The WASP4 model produced results that were generally closer to the observed dissolved oxygen levels than those produced by the Tidal Prism Analysis for the same set of coefficients. The Tidal Prism Analysis method underestimated the observed dissolved oxygen levels at the Beacons Reach marina and overestimated the observed dissolved oxygen levels at both the Gull Harbor and Indian Hills marinas. The NCDEM DO model consistently underestimated dissolved oxygen levels at both the Beacons Reach and Gull Harbor marinas. For the Beacons Reach Marina, the TPA method

TABLE 7-1.
Comparison of Dissolved Oxygen Results from Simple, Mid-range, and Complex Models

WASP4 Segment	Monitor Station	Observed* mg/L	TPA mg/L	NCDEM DO mg/L	WASP4 mg/L
Indian Hills Marina					
1	I-3	4.74	5.45	NA	4.78
2	I-5	4.69	5.45	NA	4.78
3			5.45	NA	4.76
4			5.45	NA	4.82
5	I-2	4.86	5.45	NA	4.77
6			5.45	NA	4.79
7			5.45	NA	4.78
8			5.45	NA	4.84
9	I-6	4.34	5.45	NA	4.85
10			5.45	NA	4.87
11			5.45	NA	4.82
12	I-1	4.59	5.45	NA	4.96
Ambient	I-4	4.94			
Beacons Reach Marina					
1	BR-2	5.60	5.06	4.82	5.12
2	BR-3	5.35	5.06	4.82	5.38
3	BR-4	5.15	5.06	4.82	5.30
4	BR-5	5.08	5.06	4.82	5.15
5	BR-6	5.10	5.06	4.82	5.12
Ambient	BR-1	6.70			
Gull Harbor Marina					
2	GH-3	5.30	5.54	3.74	5.13
3	GH-5	3.90	5.54	3.74	4.08
Ambient	BB-1	6.60			

For Indian Hills Marina observed DO is the average over 1100 hours 07/12/84 to 1300 hours 07/13/84.
For Beacons Reach Marina observed DO was measured on May 26, 1988.
For Gull Harbor Marina observed DO was measured on May 26, 1988.

and WASP4 provided similar results; however, results of the WASP4 model matched the observed data better than the results of the simple method.

Conclusions and Recommendations

For all practical purposes, the Tidal Prism Analysis is selected as the method of choice in the simple model category. The NCDEM DO (NCDEMDO) model is recommended for the mid-range category, and the Water Quality Analysis Simulation Program (WASP4) is the model of choice for the complex category. A variation of WASP4 using a full two-dimensional hydrodynamic model is also recommended for *proposed* marinas (i.e., where the marina basin or waterway does not yet exist). These predictive models (tools) are recommended for use by regulatory agencies as well as developers to determine and evaluate problem areas pertinent to marina development. It is anticipated that marina developers will utilize the models to determine whether a proposed marina will be in compliance with water quality regulatory requirements.

In the early stages of this study, the model chosen as the best available method to apply to a coastal marina was the mid-range Tidal Prism Model (Diana et al., 1987) because of its simplicity and its ability to simulate up to ten constituents, including dissolved oxygen and fecal coliform. When it came time to apply the model to the Beacons Reach, Gull Harbor, and Indian Hills Marinas, however, it became apparent that this model was not the most appropriate for application to marinas. Instead, it is intended more for a small coastal embayment that has tidal forcing at its mouth and freshwater input at its head and can be divided into segments based on the tidal excursion length. A typical marina will not have any significant freshwater input, and the tidal excursion length is likely to be greater than the largest dimension of the marina itself. The Tidal Prism Model can be applied to a marina that lies on a coastal embayment having a freshwater input by treating the marina as a tributary of the embayment. However, the Tidal Prism Model is not applicable to a marina constructed directly on the coast or on a sound (e.g., Beacon Reach Marina, and Gull Harbor Marina). In light of this, the Tidal Prism Model has limited applicability to coastal marinas.

In this study, WASP4 was applied to the Indian Hills, Beacons Reach, and Gull Harbor marinas using complexity level 5 (intermediate eutrophication kinetics), which is one of the more complicated means of applying the model. This report is a guidance document that steers the user through the application of WASP4 to a coastal marina. The guidance in this report directs the user through all the steps involved in a proper water quality assessment of a proposed marina, including data monitoring prior to, during, and after construction. Good planning and design practices will ensure that both appropriate and adequate environmental precautions will be incorporated into a prospective marina project. The guidance in this report has been written to help prospective developers and marina operators plan their projects with a vision toward protecting the aquatic ecosystem. A key part of this report was the compilation of the various modeling coefficients and parameters along with their typical values and site-specific data from field measurements in marinas.

An accurate application of the WASP4 model to a coastal marina requires more data than either the simple or mid-range methods. For the hydrodynamic submodel of WASP4, the following data are necessary for either *existing* or *proposed* marinas: bathymetry data, tidal stage data, wind speed and direction, and point or nonpoint source inflow data. Other useful data (spatially and temporally varying) for calibrating the hydrodynamic submodel for an *existing* marina include: current speed and direction, salinity, and dye concentrations. Assuming WASP4 is applied as a full eutrophication model, the following data are needed: meteorological data (solar radiation, air temperature, wind speed), physical data (salinity, water temperature), nutrients (ammonia, nitrite+nitrate, organic nitrogen, ortho-phosphate, organic nitrogen), water quality data (BOD, dissolved oxygen, chlorophyll-*a*), sediment sources and sinks (SOD, ammonia flux, phosphorus flux), as well as a number of kinetic constants. A more detailed description of the data requirements for WASP4 can be found in Section 5.3 of this document and in Ambrose et al. (1988a).

WASP4 is a complex model. Depending on the application, WASP4 set-up requires a substantial number of parameters and a significant amount of data. The novice modeler may have difficultly applying WASP4; however, the intermediate or advanced modeler should have little trouble. The USEPA Center for Exposure Assessment Modeling, has recently developed a pre-processing system for WASP4 that provides guidance, including typical values for model parameters as well as maximum and minimum limits. This pre-processor system helps to simplify the use of the WASP4 model.

Given the fact that WASP4 requires a large amount of data and is more difficult to apply than the simple Tidal Prism Analysis method or the mid-range NCDEM DO model, one might question why WASP4 should be used, especially when the complex and simple methods yielded similar values for computed dissolved oxygen for the three marinas in this study. The reasons for using a complex model such as WASP4 for marina water quality analysis include the following:

- The simple method provides information only on the *average* conditions in the marina. The simple method will not give an indication of spatial or time-varying conditions in different portions of the marina. For instance, in a marina of complex design (such as the Indian Hills Canal), the simple method will not be as sensitive to spatial dissolved oxygen differences as would a complex model such as WASP4. Thus, an analysis made with the simple method and/or the NCDEM DO model may not represent existing water quality conditions in the marina. Portions of the marina may exhibit poor flushing and poor water quality, which the simple and the mid-range methods may miss. The complex method, on the other hand, will identify those areas as locations where water quality standards may be contravened.

- Some states, (e.g., Florida and South Carolina) require post-construction water quality monitoring of new marinas to determine whether they will meet applicable water quality standards. If post-construction monitoring shows violations of standards, then the owner of the marina may be forced to either close the marina or modify the design to comply with standards. Thus, considering the long-term costs, it is often to the owner's advantage to invest a little more up-front for the application of a complex model to determine the design alternative that provides optimal flushing and water quality as insurance against potential costly modifications later.

For example, Tetra Tech (1988) applied the Dynamic Estuary Model, which is the predecessor to the selected complex model (WASP4), to determine the optimal flushing design and critical dissolved oxygen for a proposed marina/canal in Jacksonville, Florida. This case study, presented in Appendix E, clearly shows the advantages of applying complex models as cost-effective tools to determine water quality conditions at a proposed marina site. In addition, the Tetra Tech Interim report, *Environmental Assessment for Siting and Design of Marinas* (1992), presented the cost summary associated with applying numerical models. Based on literature surveys, the Tetra Tech report estimated that costs associated with applying the complex models ranged from 0.2 to 2.0 percent of the total project cost. The high end of this cost range (i.e., 2.0 percent) was only realized when a full environmental assessment was required (e.g., surveys of critical habitat areas, littoral transport studies, geotechnical studies, and physical modeling). Therefore, in most situations it appears reasonable from a cost standpoint for both the developers and the permitting agency to require the use of a complex model to perform water quality assessment for a proposed marina.

- The simple TPA method cannot be used to determine optimal design geometries for a marina since the only geometric properties included in this simple method are tide heights at high and low water and total marina surface area. The TPA method produced the same DO results for the Indian Hills Marina even when the total surface area was doubled to 68,000 m^2. If a long dead-end channel were added to the landward side of the Indian Hills Marina, one would expect the DO at the end of this channel to be very low due to extremely poor flushing. Unlike WASP4, however, the TPA method is simply not able to make this prediction.

- The NCDEM DO model is only capable of predicting steady-state dissolved oxygen conditions for a coastal marina. The NCDEM DO model predicts overall DO levels in the marina channel and marina basin, however, the model will not flag areas within the marina basin where water quality standards may be violated. The NCDEM DO model cannot be used to determine optimal design geometries, as discussed in the previous paragraph. The NCDEM DO model cannot simulate other pollutants such as coliform bacteria and toxic contaminants.

- The WASP4 model can be readily expanded to simulate other pollutants such as coliform bacteria and toxic contaminants.

- The combined effects of benthic fluxes, nitrification, and phytoplankton kinetics on dissolved oxygen are not included in the simple method.

Although WASP4 has been selected as the most appropriate model for coastal marina water quality analysis, it is not without limitations. The hydrodynamic submodel, DYNHYD5, is a pseudo two-dimensional model that relies on the modeler to select the pathways (i.e., channels) for water movement by advection. This type of "link-node" hydrodynamic model is more appropriate for channelized systems, but it may not simulate advection in systems where gyres are present. Linking a full two-dimensional finite-element or finite-difference hydrodynamic model to WASP4 would provide a much more rigorous advective solution. This is especially important for a *proposed* marina because the hydrodynamics cannot be calibrated to observed data. When applied using the proper physical dimensions, a full two-dimensional model requires little calibration, unlike the link-node type model.

In most States, a dissolved oxygen water quality standard exists for the 24-hour average concentration and an instantaneous minimum concentration. Since instantaneous DO at a proposed marina site must be addressed in an application for a marina permit, and since only the WASP4 model is capable of addressing time related DO concentrations, a supplementary method is suggested for the simple and mid-range methods. As a supplement to any of the models recommended in this report, the analytical solution calculates the diurnal minimum and maximum dissolved oxygen. This analytical solution takes into account benthic nutrient fluxes, light intensity, water depth, water velocity, water column nutrients, and phytoplankton kinetics. Complete documentation of the derivation of the diurnal oxygen analytical method is provided in Thomann and Mueller (1987).

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APPENDIX A: Annotated Input Files

1. Tidal Prism Model (TPM)
   - 1.1 STEADY.INP
   - 1.2 VARIABLE.INP

2. Water Quality Analysis Simulation Program (WASP)

   - 2.1 Indian Hills Marina
     - 2.1.1 DYNHYD5 Hydrodynamic File for Indian Hills Marina
     - 2.1.2 WASP4 DO Water Quality File for Indian Hills Marina

   - 2.2 Beacons Reach Marina
     - 2.2.1 Dye Hydrodynamic File for Beacons Reach Marina
     - 2.2.2 DO Hydrodynamic File for Beacons Reach Marina
     - 2.2.3 Dye Water Quality File for Beacons Reach Marina
     - 2.2.4 DO Water Quality File for Beacons Reach Marina

   - 2.3 Gull Harbor Marina
     - 2.3.1 Dye Hydrodynamic File for Gull Harbor Marina
     - 2.3.2 DO Hydrodynamic File for Gull Harbor Marina
     - 2.3.3 Dye Water Quality File for Gull Harbor Marina
     - 2.3.4 DO Water Quality File for Gull Harbor Marina

1. Tidal Prism Model (TPM)

1.1 STEADY.INP

```
    5    3    1    0    6
    1    3    5
 HUNTING CREEK GEOMETRICAL DATA      August 1
  11    0
   1   11    main channel
0.00      0.33      0.50      0.76      0.95      1.14      1.33
1.52      1.70      1.89      2.75
0.00      27.61     10.68     3.20      0.90      0.81      0.69
0.56      0.49      0.32      1.95
28.97     11.59     4.96      2.98      2.44      1.91      1.40
0.94      0.52      0.24      0.00
0.00      0.00      0.60      0.00      0.00      0.00      0.00
0.00      0.00      0.00      0.00
3.10      4.50      7.10      3.20      2.90      2.40      2.00
1.70      1.40      1.20      0.50
   99
    HUNTING CREEK PHYSICAL DATA GROUPS 1 THRU 8       August 1
 1  main channel
    1    1                                 WATER TEMPERATURE
28.8
    2   11                  INITIAL CONCENTRATIONS
0.0  0.0  0.0  14.  12.  8.5  7.0  4.0  2.0  0.0  0.0
```

1.2 VARIABLE.INP

```
    3    2                  August 1,2,3       POINTSOURCE WASTEWATER
    2     13.2

    6     36.5

    4    1                  August 1           NONPOINTSOURCE FRESHWATER
   11  1.7
    8    1                                     BOUNDARY CONCENTRATIONS
00.0


 99
999
1.0       1.0       1.0       1.0
1.0       1.0       1.0
1.0       1.0
1.0       1.0       1.0       1.0       1.0       1.0       1.0
1.0       1.0       1.0       1.0       1.0
1.0
1.0
1.0


   August 2nd FRESHWATER INPUT (THIRD CYCLE)
  1 MAIN CHANNEL
   4   1
 11  90.0
    99
   999
   August 3rd FRESHWATER INPUT (FIFTH CYCLE)
  1 MAIN CHANNEL
   4   1
 11  55.9
    99
   999
```

2. Water Quality Analysis Simulation Program (WASP)

2.1 Indian Hills Marina

2.1.1 DYNHYD5 Hydrodynamic File for Indian Hills Marina

```
----+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8

DYNHYD5 - Indian Hills Yacht Club Loop Canal (TC 5162-01)
HIH_03.INP - Hydrodynamics simulation for Jul 10, 1984 to Jul 15, 1984
***** Data Group A. PROGRAM CONTROL DATA ************************
   12   12 0000    6.00000     5    1984/07/08 00·00    1984/07/16 00.00
***** Data Group B: OUTPUT CONTROL DATA ************************
    1984/07/08 01 00        1.0  - 1   12    0
    1
    1    2    3    4    5    6    7    8    9   10   11   12
***** Data Group C: SUMMARY CONTROL DATA ***********************
    1    1984/07/08 00.00   12.5000  150
HIH_03.HYD
***** Data Group D: JUNCTION DATA ******************************
    1     0.001      3734      -2.3       421        350    1
    2     0.001      3569      -2.3       433        138    2
    3     0 001      4197      -2.3       278        348    1    3    5
    4     0 001      4313      -2.3       294        127    2    4    6
    5     0 001      5490      -2 3       290        243    3    4
    6     0.001      3577      -2.3       147        352    5    7
    7     0.001      3261      -2.3       171        117    6    8
    8     0.001      3519      -2.3        89        280    7    9
    9     0 001      3065      -2.3        92        126    8   10
   10     0.001       420      -2 3       114        182   10   11
   11     0.001      1146      -2.3       106        225    9   11   12
   12     0.001      1956      -2.3       151        212   12
***** Data Group E: CHANNEL DATA *******************************
    1       144        23        2.3     0.080      0.001    1    3
    2       139        26        2.3     0.020      0.001    2    4
    3       107        26        2.3     0.020      0.001    3    5
    4       114        28        2.3     0.020      0.001    4    5
    5       131        31        2.3     0.020      0.001    3    6
    6       123        34        2.3     0.020      0.001    4    7
    7       115        31        2.3     0.020      0 001    6    8
    8        82        34        2.3     0.020      0.001    7    9
    9        64        14        2.3     0.020      0.001    8   11
   10        65        33        2.3     0.015      0.001    9   10
   11        44        10        2.3     0.020      0.001   10   11
   12        46        28        2.3     0.020      0.001   11   12
***** Data Group F.1: CONSTANT INFLOWS (m/sec) ***************************
    0
***** Data Group F.2: VARIABLE INFLOWS (m/sec) - Daily Flows **************
    0
** Data Group G: SEAWARD BOUNDARY DATA (m) - Variable Tide
    2
    3    1   38   15        0.0    0.0000        0.0    0.3048     0.0000
    1984/07/07 15:15     -1.41    1984/07/07 21:27        1.74
    1984/07/08 03:40     -1.11    1984/07/08 09:25        1.13
    1984/07/08 15:15     -1.41    1984/07/08 21:27        1.74
    1984/07/09 03·40     -1.11    1984/07/09 09:25        1.13
    1984/07/09 15:15     -1.41    1984/07/09 21:27        1.74
    1984/07/10 03:40     -1.11    1984/07/10 09:25        1.13
    1984/07/10 15:15     -1.41    1984/07/10 21:27        1.74
    1984/07/11 03:40     -1.11    1984/07/11 09:25        1 13
    1984/07/11 15:15     -1.41    1984/07/11 21:27        1.74
    1984/07/12 03:40     -1.11    1984/07/12 09.25        1.13
    1984/07/12 15:55     -1.41    1984/07/12 22:27        1.74
    1984/07/13 04:20     -1.11    1984/07/13 10:23        1.13
    1984/07/13 16:35     -1.59    1984/07/13 23:27        1.48
    1984/07/14 05:00     -1.15    1984/07/14 11:32        0.99
    1984/07/14 17:25     -1.46    1984/07/15 00:26        1.56
    1984/07/15 05:59     -1.06    1984/07/15 12:51        1.08
    1984/07/15 18.14     -1 33    1984/07/16 00:56        1.48
    1984/07/16 06:10     -1.06    1984/07/16 13:10        1.08
    1984/07/16 18:30     -1.33    1984/07/17 01:10        1.48
    3    2   38   15        0.0    0.0000        0.0    0.3048     0.0000
    1984/07/07 15:15     -1.41    1984/07/07 21:27        1.74
    1984/07/08 03:40     -1.11    1984/07/08 09:25        1.13
    1984/07/08 15:15     -1.41    1984/07/08 21:27        1.74
    1984/07/09 03:40     -1.11    1984/07/09 09:25        1.13
    1984/07/09 15:15     -1.41    1984/07/09 21:27        1.74

----+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
```

```
    1984/07/10 03:40     -1.11    1984/07/10 09 25      1.13
    1984/07/10 15 15     -1.41    1984/07/10 21 27      1.74
    1984/07/11 03.40     -1.11    1984/07/11 09.25      1 13
    1984/07/11 15 15     -1 41    1984/07/11 21:27      1.74
    1984/07/12 03:40     -1.11    1984/07/12 09:25      1.13
    1984/07/12 15:55     -1.41    1984/07/12 22:27      1.74
    1984/07/13 04:20     -1.11    1984/07/13 10:23      1 13
    1984/07/13 16:35     -1.59    1984/07/13 23:27      1.48
    1984/07/14 05:00     -1.15    1984/07/14 11.32      0.99
    1984/07/14 17:25     -1.46    1984/07/15 00:26      1 56
    1984/07/15 05.59     -1.06    1984/07/15 12:51      1 08
    1984/07/15 18.14     -1.33    1984/07/16 00:56      1.48
    1984/07/16 06:10     -1.06    1984/07/16 13:10      1.08
    1984/07/16 18:30     -1.33    1984/07/17 01.10      1.48
** Data Group H: WIND DATA (m/sec) mean monthly winds at Beacons Reach **
    0
```

2.1.2 WASP4 DO Water Quality File for Indian Hills Marina

```
WIH_11 INP - Indian Hills Canal WASP4 Model Water 07/08/84 to 07/15/84
Dissolved Oxygen Calibration Run
 KSIM NSEG NSYS ICFL MFLG IDMP NSLN INTY ADFC  zyr/mm/dd hhmm   A MODEL OPTIONS
    0   13   13    1    1    1    0    0  0 0 1984/07/08 0000    1    2   11     0 00
   12
    1    2    3    4    5    6  - 7    8    9   10   11   12
    1
    900.    196.00
    3
   1800.       365.     86400        366.    86400.       640.
    0    0    0    0    0    0    0    0    1    1    0    0    0
    1    +    +    *    +    *    +    *    +    *    +    *    B EXCHANGES
    4     1.000      1.00                    (surface water)
    2
     52.9        79    0    1
     59.8        72    0    2
    2
  0 10E+00        0.  0.10E+00       366.
    9
     52.9       144    1    3
     59.8       139    2    4
     59.8       107    3    5
     64.4       114    4    5
     71.3       131    3    6
     78.2       123    4    7
     71.3       115    6    8
     78.2        82    7    9
     32.2        64    8   11
    2
  0.10E+01        0.  0.10E+01       366.
    2
     75.9        65    9   10
     23.0        44   10   11
    2
  0.10E+01        0.  0.10E+01       366.
    1
     64 4        46   11   12
    2
  0 10E+01        0.  0.10E+01       366.
    0    0    0    0    0    0    0    0    1    1    0    0    0
    2    0    366.0    +    *    +    *    +    *    +    *    C· VOLUMES
    1.0000    1.0000
         1        13         1       8588       0.0       1.0       1 0       1.0
         2        13         1       8209       0.0       1.0       1.0       1.0
         3        13         1       9653       0.0       1.0       1.0       1.0
         4        13         1       9920       0.0       1.0       1.0       1.0
         5        13         1      12627       0.0       1.0       1.0       1.0
         6        13         1       8227       0.0       1.0       1.0       1.0
         7        13         1       7500       0.0       1.0       1.0       1.0
         8        13         1       8094       0.0       1 0       1 0       1.0
         9        13         1       7050       0.0       1 0       1 0       1.0
        10        13         1        966       0.0       1 0       1.0       1.0
        11        13         1       2636       0.0       1.0       1.0       1.0
        12        13         1       4499       0.0       1.0       1.0       1.0
        13         0         3      87968       0.0       1.0       1.0       1.0
    2    5     SUMRY2.OUT (HIH_01.HYD)       *    +    *    +    *    D: FLOWS
    2    1    2                          (Data Block D.2 Field One Flows)
    1    2    3    4    5    6    7    8    9   10   11   12
    0       1.0       1.0       F#2 --NINQ(2)  SCALQ=1  CONVQ= 1
    1       1.0 1.157E-05       F#3 --NINQ(3)  SCALQ=1  CONVQ= m/day * 1/86400
   12                           F#3 --NOQS(3,ni) --> number of segment pairs
     3734    1   13      3369    2   13      4197    3   13      4313    4   13
     5490    5   13      3577    6   13      3261    7   13      3519    8   13
     3065    9   13       420   10   13      1146   11   13      1956   12   13
    2                           F#3 --NBRKQ(4,ni) --> number of time breaks
   0.50        0.0      0.50       366.0
    1       1.0 1 157E-05       F#4 --NINQ(3)  SCALQ=1  CONVQ= m/day * 1/86400
   12                           F#4 --NOQS(3,ni) --> number of segment pairs
     3734    1   13      3369    2   13      4197    3   13      4313    4   13
```

```
    5490     5    13      3577     6    13       3261     7    13       3519     8    13
    3065     9    13       420    10    13       1146    11    13       1956    12    13
  2                                F#4---NBRKQ(5,ni) --> number of time breaks
    0 02         0.0      0 02      366 0
  1        1.0 1.157E-05      F#5 --NINQ(3)  SCALQ=1  CONVQ= m/day * 1/86400
 12
    3734     1    13      3369     2    13       4197     3    13       4313     4    13
    5490     5    13      3577     6    13       3261     7    13       3519     8    13
    3065     9    13       420    10    13       1146    11    13       1956    12    13
  2                                F#5---NBRKQ(5,ni) --> number of time breaks
    0.20        0 0       0.20      366 0
  0    0     0    0     0    0     0    0     1    1     0    0     0
         2                     Sys#1 NH3          (Data Group E Boundary Conditions)
    1 0         1.0
  1   14     OCN :                   OCNBC001          Sys# 1  mg/L
   0 070     1.0000     0.070  194.4674     0.070  194 5833      0.070  194.6993
   0.070   194.8069     0.050  194.9583     0.050  195.0972      0.080  195.2000
   0.070   195 3229     0.070  195.5243     0.070  195 5799      0.070  200.0000
   0 070   250 0000     0.070  366.0000
  2   14     OCN :                   OCNBC002          Sys# 1  mg/L
   0.070     1.0000     0 070  194.4674     0.070  194 5833      0.070  194.6993
   0.070   194.8069     0.050  194.9583     0 050  195 0972      0.080  195.2000
   0.070   195.3229     0.070  195.5243     0.070  195.5799      0.070  200.0000
   0 070   250.0000     0.070  366.0000
         2                     Sys#2 NO3          (Data Group E Boundary Conditions)
    1 0         1.0
  1   14     OCN                     OCNBC001          Sys# 2
   0.050     1.0000     0.050  194.4674     0.050  194.5833      0.050  194 6993
   0.050   194.8069     0.050  194.9583     0.050  195.0972      0.050  195.2000
   0 050   195.3229     0 050  195.5243     0.050  195.5799      0 050  200.0000
   0.050   250.0000     0.050  366.0000
  2   14     OCN .                   OCNBC002          Sys# 2
   0.050     1.0000     0.050  194.4674     0.050  194.5833      0.050  194.6993
   0.050   194.8069     0.050  194.9583     0.050  195.0972      0 050  195 2000
   0 050   195.3229     0.050  195.5243     0.050  195.5799      0.050  200.0000
   0.050   250.0000     0.050  366.0000
         2                     Sys#3 OPO4         (Data Group E Boundary Conditions)
    1.0         1 0
  1   14     OCN :                   OCNBC001          Sys# 3
   0.102     1.0000     0.102  194.4674     0.102  194.5833      0.102  194.6993
   0 102   194.8069     0 054  194.9583     0 054  195 0972      0 066  195.2000
   0.066   195.3229     0.054  195.5243     0.054  195.5799      0 054  200.0000
   0.054   250.0000     0 054  366 0000
  2   14     OCN :                   OCNBC002          Sys# 3
   0.102     1.0000     0.102  194 4674     0.102  194.5833      0.102  194 6993
   0.102   194.8069     0.054  194.9583     0.054  195.0972      0.066  195.2000
   0.066   195.3229     0 054  195.5243     0.054  195.5799      0.054  200.0000
   0.054   250.0000     0.054  366.0000
         2                     Sys#4 Phyt#1       (Data Group E Boundary Conditions)
    1 0         1.0
  1   14     OCN :                   OCNBC001          Sys# 4  ug chl/L
   16.00     1.0000     16.00  194.4674     16.00  194.5833      16.00  194 6993
   16.00   194.8069     16.00  194.9583     16 00  195.0972      16 00  195.2000
   16.00   195.3229     16.00  195.5243     16.00  195.5799      16.00  200 0000
   16.00   250.0000     16.00  366.0000
  2   14     OCN :                   OCNBC002          Sys# 4  ug chl/L
   16.00     1.0000     16.00  194.4674     16.00  194.5833      16.00  194 6993
   16.00   194.8069     16.00  194.9583     16.00  195.0972      16.00  195.2000
   16.00   195 3229     16.00  195.5243     16.00  195.5799      16.00  200.0000
   16.00   250.0000    -16.00  366 0000
         2                     Sys#5 CBOD         (Data Group E Boundary Conditions)
    1.0         1.0
  1   14     OCN :                   OCNBC001          Sys# 5  mg/L (CBOD20)
    2.30     1.0000      2.30  194.4674      2.30  194.5833       2.30  194.6993
    2.30   194 8069      2.30  194.9583      2.30  195.0972       2.60  195.2000
    2.60   195.3229      2.60  195.5243      2.60  195.5799       2.60  200.0000
    2.60   250 0000      2.60  366.0000
  2   14     OCN :                   OCNBC002          Sys# 5
    2.30     1.0000      2.30  194.4674      2.30  194 5833       2 30  194.6993
```

```
    2.30  194 8069     2 30  194 9583     2.30  195 0972     2 60  195 2000
    2.60  195 3229     2.60  195 5243     2.60  195 5799     2 60  200 0000
    2.60  250 0000     2.60  366 0000
       2               Sys#6 DO          (Data Group E Boundary Conditions)
     1.0       1.0
   1  14    OCN                 OCNBC001         Sys# 6  mg/L
    4.61    1.0000     4 61  194.4674     4.34  194.5833     4.58  194 6993
    5.27  194.8069     5 73  194.9583     4.94  195.0972     4.58  195.2000
    4.74  195.3229     4 90  195.5243     5.21  195.5799     5.21  200.0000
    5.21  250.0000     5.21  366 0000
   2  14    OCN :               OCNBC002         Sys# 6
    4.61    1.0000     4.61  194.4674     4.34  194.5833     4 58  194.6993
    5.27  194.8069     5.73  194.9583     4.94  195.0972     4 58  195 2000
    4.74  195.3229     4.90  195.5243     5.21  195.5799     5 21  200.0000
    5.21  250 0000     5.21  366.0000
       2               Sys#7 OrgN        (Data Group E Boundary Conditions)
     1.0       1.0
   1  14    OCN :               OCNBC001         Sys# 7  mg/L
   0.030    1.0000    0.030  194.4674    0.030  194.5833    0.030  194.6993
   0 030  194.8069    0.050  194.9583    0 050  195.0972    0 020  195.2000
   0.020  195.3229    0 030  195.5243    0 030  195.5799    0.030  200.0000
   0.030  250.0000    0.030  366.0000
   2  14    OCN :               OCNBC002         Sys# 7
   0.030    1 0000    0 030  194.4674    0 030  194 5833    0.030  194.6993
   0.030  194 8069    0.050  194.9583    0.050  195 0972    0.020  195.2000
   0 020  195.3229    0.030  195.5243    0.030  195.5799    0.030  200.0000
   0.030  250 0000    0.030  366 0000
       2               Sys#8 OrgP        (Data Group E Boundary Conditions)
     1.0       1.0
   1  14    OCN                 OCNBC001         Sys# 8  mg/L
   0.068    1.0000    0.068  194.4674    0.068  194.5833    0.068  194.6993
   0.036  194.8069    0.036  194.9583    0.036  195.0972    0.044  195.2000
   0.044  195.3229    0.036  195.5243    0.036  195.5799    0.036  200.0000
   0 036  250.0000    0.036  366.0000
   2  14    OCN :               OCNBC002         Sys# 8  mg/L
   0.068    1.0000    0 068  194.4674    0 068  194 5833    0.068  194.6993
   0.036  194.8069    0.036  194.9583    0.036  195.0972    0.044  195.2000
   0.044  195.3229    0.036  195.5243    0.036  195.5799    0.036  200.0000
   0.036  250 0000    0.036  366.0000
       2               Sys#9 Phyt#2      (Data Group E Boundary Conditions)
     1.0       1.0
   1  14    OCN :               OCNBC001         Sys# 9  ug/L
   0 000    1.0000    0 000  194 4674    0.000  194.5833    0.000  194.6993
   0 000  194.8069    0.000  194.9583    0.000  195.0972    0.000  195.2000
   0.000  195.3229    0.000  195.5243    0 000  195.5799    0.000  200.0000
   0.000  250.0000    0 000  366.0000
   2  14    OCN :               OCNBC002         Sys# 9  ug/L
   0.000    1 0000    0 000  194.4674    0.000  194.5833    0.000  194.6993
   0.000  194 8069    0.000  194.9583    0.000  195.0972    0.000  195.2000
   0.000  195 3229    0.000  195.5243    0.000  195 5799    0.000  200.0000
   0.000  250.0000    0.000  366 0000
       2               Sys#10 Phyt#2     (Data Group E Boundary Conditions)
     1.0       1.0
   1  14    OCN :               OCNBC001         Sys# 10  ug/L
   0.000    1.0000    0.000  194.4674    0.000  194.5833    0 000  194.6993
   0.000  194.8069    0.000  194.9583    0.000  195.0972    0 000  195.2000
   0.000  195.3229    0.000  195.5243    0.000  195.5799    0.000  200.0000
   0.000  250.0000    0.000  366.0000
   2  14    OCN :               OCNBC002         Sys# 10  ug/L
   0.000    1.0000    0 000  194.4674    0.000  194.5833    0.000  194.6993
   0.000  194.8069    0 000  194.9583    0.000  195.0972    0 000  195.2000
   0 000  195.3229    0.000  195.5243    0.000  195.5799    0.000  200.0000
   0 000  250.0000    0.000  366.0000
       2               Sys#11 Si04       (Data Group E Boundary Conditions)
     1.0       1.0
   1  14    OCN :               OCNBC001         Sys# 11  mg/L
   0.000    1.0000    0.000  194.4674    0.000  194.5833    0.000  194.6993
   0.000  194.8069    0.000  194 9583    0 000  195.0972    0.000  195.2000
   0.000  195 3229    0.000  195.5243    0.000  195.5799    0.000  200.0000
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   0 000  250.0000     0.000  366 0000
  2   14   OCN                 OCNBC002        Sys# 11
   0 000    1.0000     0.000  194.4674    0 000  194 5833     0.000  194.6993
   0 000  194.8069     0.000  194 9583    0 000  195 0972     0 000  195 2000
   0.000  195 3229     0.000  195.5243    0.000  195 5799     0 000  200 0000
   0 000  250.0000     0 000  366.0000
        2                 Sys#12 Salinity   (Data Group E Boundary Conditions)
     1.0       1.0
  1   14   OCN :               OCNBC001        Sys# 12
   27 43    1.0000     27 43  194 4674    26 76  194 5833     26 69  194.6993
   27 33  194.8069     27.76  194 9583    27.40  195 0972     27.24  195 2000
   28.20  195.3229     28 75  195 5243    28.00  195 5799     28 00  200.0000
   28 00  250.0000     28.00  366.0000
  2   14   OCN ·               OCNBC002        Sys# 12
   27.43    1.0000     27.43  194.4674    26.76  194.5833     26.69  194.6993
   27.33  194.8069     27.76  194.9583    27.40  195.0972     27 24  195 2000
   28.20  195.3229     28.75  195.5243    28.00  195.5799     28.00  200.0000
   28.00  250.0000     28.00  366.0000
        2                 Sys#13 Coliforms  (Data Group E Boundary Conditions)
     1.0       1.0
  1   14   OCN :               OCNBC001        Sys# 13
   0.000    1.0000     0.000  194 4674    0.000  194 5833     0.000  194.6993
   0.000  194.8069     0.000  194.9583    0 000  195 0972     0.000  195.2000
   0 000  195.3229     0.000  195.5243    0.000  195.5799     0.000  200.0000
   0.000  250.0000     0.000  366.0000
  2   14   OCN :               OCNBC002        Sys# 13
   0.000    1.0000     0.000  194.4674    0 000  194.5833     0 000  194 6993
   0.000  194.8069     0.000  194.9583    0 000  195.0972     0.000  195.2000
   0.000  195.3229     0.000  195.5243    0 000  195.5799     0.000  200.0000
   0 000  250.0000     0.000  366.0000
        1  PS(t) Sys#1            (Data Block F 1 Waste Loads for Point Source)
0.100E+01 0.100E+01  PS(t)      ·System # 1 NH3      Kg/Day      Scale/conv fct
  11    6   Seg 011    Sys# 1
   0.000    194.000     0.000  194.7083     0.00  194.71875     0.000  194.7292
   0.000    250.000   000.000   366.000
        1  PS(t) Sys#2            (Data Block F.1 Waste Loads for Point Source)
0 100E+01 0.100E+01  PS(t)      :System # 2 NO3      Kg/Day      Scale/conv fct
  11    6   Seg 011    Sys# 2
   0 000    194.000     0.000  194 7083     0 00  194.71875     0.000  194.7292
   0.000    250.000   000.000   366.000
        1  PS(t) Sys#3            (Data Block F.1 Waste Loads for Point Source)
0 100E+01 0.100E+01  PS(t)      :System # 3 OPO4     Kg/Day      Scale/conv fct
  11    6   Seg 011    Sys# 3
   0 000    194 000     0.000  194 7083     0.00  194.71875     0.000  194 7292
   0 000    250.000   000.000   366.000
        1  PS(t) Sys#4            (Data Block F.1 Waste Loads for Point Source)
0 100E+01 0 100E+01  PS(t)      :System # 4 Phytl    Kg/Day      Scale/conv fct
  11    6   Seg 011    Sys# 4
   0 000    194.000     0.000  194.7083     0.00  194.71875     0.000  194.7292
   0.000    250.000   000.000   366.000
        1  PS(t) Sys#5            (Data Block F.1 Waste Loads for Point Source)
0.100E+01 0.100E+01  PS(t)      :System # 5 CBOD     Kg/Day      Scale/conv fct
  11    6   Seg 011    Sys# 5
   0 000    194.000     0.000  194.7083     0 00  194.71875     0.000  194.7292
   0.000    250.000   000.000   366.000
        1  PS(t) Sys#6            (Data Block F.1 Waste Loads for Point Source)
0.100E+01 0.100E+01  PS(t)      :System # 6 DO       Kg/Day      Scale/conv fct
  11    6   Seg 011    Sys# 6
   0.000    194.000     0.000  194.7083     0.00  194.71875     0.000  194.7292
   0.000    250.000   000.000   366 000
        1  PS(t) Sys#7            (Data Block F.1 Waste Loads for Point Source)
0 100E+01 0 100E+01  PS(t)      :System # 7 OrgN     Kg/Day      Scale/conv fct
  11    6   Seg 011    Sys# 7
   0.000    194.000     0.000  194 7083     0.00  194.71875     0 000  194 7292
   0.000    250.000   000.000   366.000
        1  PS(t) Sys#8            (Data Block F.1 Waste Loads for Point Source)
0.100E+01 0.100E+01  PS(t)      :System # 8 OrgP     Kg/Day      Scale/conv fct
  11    6   Seg 011    Sys# 8
   0.000    194.000     0.000  194.7083     0.00  194.71875     0.000  194.7292
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     0.000    250.000   000.000    366.000
         1    PS(t) Sys#9            (Data Block F.1 Waste Loads for Point Source)
 0 100E+01 0 100E+01  PS(t)       System # 9 Phyt2     Kg/Day      Scale/conv fct
   11    6    Seg 011    Sys# 9
     0.000    194 000     0 000  194.7083      0 00  194.71875      0 000  194.7292
     0.000    250.000   000.000   366.000
         1    PS(t) Sys#10           (Data Block F 1 Waste Loads for Point Source)
 0.100E+01 0.100E+01  PS(t)      :System # 10 Phyt3    Kg/Day      Scale/conv fct
   11    6    Seg 011    Sys# 10
     0.000    194 000     0 000  194.7083      0 00  194.71875      0.000  194.7292
     0.000    250 000   000.000    366.000
         1    PS(t) Sys#11           (Data Block F.1 Waste Loads for Point Source)
 0.100E+01 0.100E+01  PS(t)      :System # 11 Si04     Kg/Day      Scale/conv fct
   11    6    Seg 011    Sys# 11
     0.000    194.000     0.000  194.7083      0.00  194.71875      0.000  194.7292
     0.000    250.000   000.000    366.000
         3    PS(t) Sys#12           (Data Block F 1 Waste Loads for Point Source)
 0.100E+01 0.100E+01  PS(t)      :System # 12 Dye      Kg/Day      Scale/conv fct
    8    6    Seg 011    Sys# 12
     0.000    194.000     0.000  194 7083      0.00  194.71875      0 000  194.7292
     0 000    250.000   000.000    366 000
    9    6    Seg 011    Sys# 12
     0.000    194.000     0.000  194.7083      0.00  194.71875      0.000  194.7292
     0.000    250.000   000.000    366.000
   11    6    Seg 011    Sys# 12
     0.000    194.000     0.000  194.7083      0.00  194.71875      0.000  194.7292
     0 000    250.000   000.000    366.000
         1    PS(t) Sys#13           (Data Block F.1 Waste Loads for Point Source)
 0.100E+01 0.100E+01  PS(t)      :System # 13 Coli     Kg/Day      Scale/conv fct
   11    6    Seg 011    Sys# 13
     0.000    194.000     0.000  194 7083      0.00  194.71875      0 000  194.7292
     0.000    250.000   000.000    366.000
    0    0                                (Data Group F.2 ..NPS Loads)
        17         6             FF(xyz)- G wasp4g01.dat 05/12/90 21:20:28
Z001X    1         1.FSI04    2         1.TMPSG    3         1.TMPFN    4         1.
KESG     5         1.KEFN     6         1.FNH4     7         1.FP04     8         1.
SOD1D    9         1.MACRO   12         1.SHL1    13         1.SHL2    14         1.
SHL3    15         1.GWC1    21         1.GWC2    22         1.GWSW    23         1.
FN03    24         1.
         1  of    13
Z001X    1      1.000FSI04    2   143.750TMPSG    3      1.000TMPFN    4      1.000
KESG     5      1.000KEFN     6     1.000FNH4     7     15.140FP04     8      2.100
SOD1D    9      2.400MACRO   12     0.000SHL1    13      0.000SHL2    14      0.000
SHL3    15      0.000GWC1    21     0.201GWC2    22      1.262GWSW    23      0 000
FN03    24      4 570
         2  of    13
Z001X    1      1.000FSI04    2   143.750TMPSG    3      1.000TMPFN    4      1.000
KESG     5      1.000KEFN     6     1.000FNH4     7     15.140FP04     8      2.100
SOD1D    9      2.400MACRO   12     0.000SHL1    13      0 000SHL2    14      0.000
SHL3    15      0.000GWC1    21     0.000GWC2    22      0.000GWSW    23    . 0.000
FN03    24      4.570
         3  of    13
Z001X    1      1.000FSI04    2   143.750TMPSG    3      1.000TMPFN    4      1.000
KESG     5      1.000KEFN     6     1.000FNH4     7     15.140FP04     8      2.100
SOD1D    9      2.400MACRO   12     0.000SHL1    13      0.000SHL2    14      0.000
SHL3    15      0.000GWC1    21     0.803GWC2    22      5.047GWSW    23      0.000
FN03    24      4.570
         4  of    13
Z001X    1      1.000FSI04    2   143.750TMPSG    3      1.000TMPFN    4      1.000
KESG     5      1.000KEFN     6     1.000FNH4     7     15.140FP04     8      2.100
SOD1D    9      2.400MACRO   12     0.000SHL1    13      0.000SHL2    14      0.000
SHL3    15      0.000GWC1    21     0.201GWC2    22      1.262GWSW    23      0.000
FN03    24      4.570
         5  of    13
Z001X    1      1.000FSI04    2   143.750TMPSG    3      1.000TMPFN    4      1.000
KESG     5      1.000KEFN     6     1.000FNH4     7     15.140FP04     8      2.100
SOD1D    9      2.400MACRO   12     0.000SHL1    13      0.000SHL2    14      0.000
SHL3    15      0.000GWC1    21     0.134GWC2    22      0.841GWSW    23      0.000
FN03    24      4.570
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         6  of    13
Z001X    1      1.000FSI04    2   143 750TMPSG     3      1 000TMPFN     4       1 000
KESG     5      1 000KEFN     6     1.000FNH4      7     15 140FP04      8       2 100
SOD1D    9      2.200MACRO   12     0 000SHL1     13      0 000SHL2     14       0 000
SHL3    15      0 000GWC1    21     0 201GWC2     22      1.262GWSW     23       0.000
FNO3    24      4.570
         7  of    13
Z001X    1      1.000FSI04    2   143.750TMPSG     3      1 000TMPFN     4       1 000
KESG     5      1.000KEFN     6     1.000FNH4      7     15 140FP04      8       2.100
SOD1D    9      2 200MACRO   12     0.000SHL1     13      0.000SHL2     14       0.000
SHL3    15      0.000GWC1    21     0 000GWC2     22      0.000GWSW     23       0.000
FNO3    24      4.570
         8  of    13
Z001X    1      1.000FSI04    2   143.750TMPSG     3      1.000TMPFN     4       1.000
KESG     5      1.000KEFN     6     1.000FNH4      7     15.140FP04      8       2.100
SOD1D    9      2.000MACRO   12     0.000SHL1     13      0.000SHL2     14       0.000
SHL3    15      0.000GWC1    21     0 803GWC2     22      5.047GWSW     23       0.000
FNO3    24      4 570
         9  of    13
Z001X    1      1 000FSI04    2   143.750TMPSG     3      1.000TMPFN     4       1 000
KESG     5      1.000KEFN     6     1.000FNH4      7     15.140FP04      8       2.100
SOD1D    9      2.000MACRO   12     0 000SHL1     13      0.000SHL2     14       0.000
SHL3    15      0 000GWC1    21     0 201GWC2     22      1 262GWSW     23       0.000
FNO3    24      4.570
        10  of    13
Z001X    1      1.000FSI04    2   143.750TMPSG     3      1 000TMPFN     4       1.000
KESG     5      1 000KEFN     6     1.000FNH4      7     15.140FP04      8       2.100
SOD1D    9      1.800MACRO   12     0.000SHL1     13      0.000SHL2     14       0.000
SHL3    15      0.000GWC1    21     0.134GWC2     22      0.841GWSW     23       0 000
FNO3    24      4.570
        11  of    13
Z001X    1      1.000FSI04    2   143.750TMPSG     3      1.000TMPFN     4       1.000
KESG     5      1.000KEFN     6     1 000FNH4      7     15.140FP04      8       2 100
SOD1D    9      1.600MACRO   12     0.000SHL1     13      0.000SHL2     14       0.000
SHL3    15      0.000GWC1    21     0.201GWC2     22      1.262GWSW     23       0.000
FNO3    24      4.570
        12  of    13
Z001X    1      1.000FSI04    2   143.750TMPSG     3      1 000TMPFN     4       1.000
KESG     5      1 000KEFN     6     1.000FNH4      7     15.140FP04      8       2.100
SOD1D    9      0.700MACRO   12     0 000SHL1     13      0 000SHL2     14       0 000
SHL3    15      0.000GWC1    21     0.134GWC2     22      0.841GWSW     23       0.000
FNO3    24      4.570
        13  of    13           (Dummy Benthos Segment)
Z001X    1      1.000FSI04    2     0.000TMPSG     3      1.000TMPFN     4       1.000
KESG     5      0.000KEFN     6     1.000FNH4      7      0.000FP04      8       0.000
SOD1D    9      0.000MACRO   12     0.000SHL1     13      0.000SHL2     14       0 000
SHL3    15      0.000GWC1    21     0.000GWC2     22      0.000GWSW     23       0.000
FNO3    24      0.000
                   Nosys= 14      Const-H
GLOBAL             0
NH3-N              1
group #1-1        10
      K12C        11      0.250       K12T        12      1.080
      KNIT        13      2.000     ATMNH3        14      1.400
    GWFLOW        15   0.000000      GWNH3        16      0.488
     Z1CRB        17      2.500      Z1CDW        18      0.450
    NCRBZ1        19      0.167      NCRBM        39      0.082
NO3+NO2-N          1
group #1-2         5
      K20C        21     - 0.090      K20T        22      1.045
      KNO3        23      0.100     ATMNO3        24      1.865
     GWNO3        25      3.065
O-PO4              1
all param          4
    ATMDIP        31      0.083      GWDIP        32      0.005
    PCRBZ1        33      0.013      PCRBM        40      0.004
Phyt#1             2
group#1-4         15
       WS1        28      0 100        K1C        41      3.000
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       K1T         42     1.066     LGHTS         43     2.000
     PHIMX         44   720.000       XKC         45     0.017
     CCHL1         46    80.000       IS1         47   300.000
     KMNG1         48     0.007     KMPG1         49     0.001
      K1RC         50     0.150      K1RT         51     1.080
      TUL1        112    40.000     TOPT1        113    24.000
      TLL1        114     0.000
group#2-4          10
       K1D         52     0.500       K1G         53     0.800
        W1         54     1.000     KPZDC         55     0.000
     KPZDT         56     1.000     PCRB1         57     0.030
     NCRB1         58     0.155    KMPHYT         59     1.000
    SICRB1         89     0.300     KMSG1        111    0.0140
CBOD                1
group#1-5           7
       KDC         71     0.200       KDT         72     1.047
      KDSC         73     0.000      KDST         74     1.000
      KBOD         75     0.500     GWBOD         76     1.800
      OCRB         81     2.670
Diss 02             1
group #1-6          6
       K4C         26     0.000       K4T         27     1.000
        K2         82     0.000     GWOXY         83     4.000
     KM1RC        109     0.000     KM1RT        110     1.000
Org-N               1
group #1-7          7
      K71C         91     0.075      K71T         92     1.080
     KONDC         93     0.000     KONDT         94     1.000
       FON         95     0.700    ATM_ON         96     2.801
     GW_ON         97     0.091
Org-P               1
group #1-8          7
      K83C        100     0.220      K83T        101     1.080
     KOPDC        102     0.000     KOPDT        103     1.000
       FOP        104     0.600    ATM_OP        105     0.247
     GW_OP        106     0.005
Phyt#2              2
group #1-9         12
       WS2         29     0.200     CCHL2         34    65.000
       IS2         35    75.000       K2C         36     1.750
       K2D         37     0.020        W2         38     1.000
      K2RC         60     0.150      K2RT         61     1.045
       K2T         62     1.066      TUL2        115    37.000
     TOPT2        116    15.000      TLL2        117     0.000
group#2-9           6
     KMNG2         63     0.007     KMPG2         64    0.0015
     NCRB2         65     0.155     PCRB2         66     0.030
    SICRB2         90     0.462     KMSG2        107     0.028
Phyt#3              2
group #1-1         10
   CLLCRB3         20     0.000       WS3         30     0.000
     CCHL3         67     1.000       IS3         68     0.000
       K3C         69     0.000       K3D         70     0.000
        W3         77     0.000      K3RC         78     0.000
      K3RT         79     1.000       K3T         80     1.000
group#2-10          6
     KMNG3         84     0.000     KMPG3         85     0.000
     NCRB3         86     0.000     PCRB3         87     0.000
    SICRB3         98     0.000     KMSG3        108     0.000
SiO4                1
group #1-1          1
      GWSI         88    20.000
Salinity            1
group #1-1          1
    GWSALT         99     0.000
Coliforms           0
        21 FF(t) WASP Data Group I FF Time- I
 TEMP    1    14    FT#01-Temp #1   (deg C)
     30.83       1.00     30.83     15.00     30.83     45.00     30.83     75.00
```

```
    30.83     106 00     30 83     136 00     31 27     167 00     31.67     197 00
    31 67     228.00     30 51     259.00     30.51     289 00     30 51     320.00
    30.51     350.00     30.83     366 00
 TEMP    2    14    FT#02-Temp #2   (deg C)
    30.83       1 00     30 83      15.00     30.83      45 00     30 83      75.00
    30.83     106 00     30.83     136.00     31.27     167 00     31 67     197 00
    31.67     228.00     30.51     259.00     30.51     289.00     30 51     320.00
    30 51     350 00     30.83     366 00
 TEMP    3    14    FT#03-Temp #3   (deg C)
    30 83       1 00     30.83      15.00     30 83      45.00     30.83      75.00
    30 83     106 00     30.83     136.00     31 27     167 00     31 67     197.00
    31.67     228 00     30.51     259 00     30.51     289.00     30 51     320.00
    30.51     350.00     30.83     366.00
 TEMP    4    14    FT#04-Temp #4   (deg C)
    30 83       1.00     30.83      15.00     30.83      45.00     30.83      75.00
    30.83     106 00     30.83     136.00     31.27     167 00     31.67     197.00
    31.67     228.00     30.51     259.00     30.51     289.00     30 51     320.00
    30 51     350.00     30.83     366.00
  SUN    5    14    FT#05-solar radiation  (langleys/day) assumes 25% cloud cover
      365       1 00       380      15.00       454      45.00       535      75.00
      606     106.00       648     136.00       661     167 00       644     197 00
      608     228 00       562     259.00       485     289.00       403     320.00
      357     350 00       365     366 00
PHOTO    6    14    FT#06-photoperiod  (fraction of day which is sunny)
    0.440       1.00     0.444      15.00     0.456      45.00     0.497      75.00
    0.534     106 00     0.562     136.00     0 573     167.00     0.568     197.00
    0.546     228.00     0.512     259 00     0.478     289.00     0 452     320.00
    0.436     350.00     0.440     366.00
 WIND    7    14    FT#07-wind velocity (m/sec)
    0.000       1.00     0.000      15.00     0.000      45.00     0.000      75.00
    0.000     106.00     0.000     136.00     0 000     167.00     0.000     197.00
    0 000     228.00     0.000     259 00     0.000     289.00     0 000     320.00
    0.000     350.00     0.000     366 00
KE#01    8    14    FT#08-Ke #1    (1/meter)
    1.020       1.00     1.020      15.00     1.020      45.00     1.020      75.00
    1 020     106.00     1.020     136.00     1.020     167 00     1.020     197.00
    1.020     228.00     1.020     259.00     1.020     289.00     1 020     320.00
    1.020     350.00     1.020     366.00
KE#02    9    14    FT#09-Ke #2    (1/meter)
    1.020       1 00     1.020      15.00     1.020      45.00     1.020      75.00
    1 020     106.00     1.020     136.00     1.020     167.00     1.020     197.00
    1.020     228.00     1 020     259.00     1.020     289.00     1.020     320.00
    1.020     350.00     1.020     366.00
KE#03   10    14    FT#10-Ke #3    (1/meter)
    1.020       1.00     1.020      15.00     1.020      45.00     1 020      75.00
    1.020     106 00     1 020     136.00     1.020     167.00     1.020     197.00
    1.020     228 00     1.020     259.00     1.020     289.00     1.020     320.00
    1.020     350.00     1.020     366.00
KE#04   11    14    FT#11-Ke #4    (1/meter)
    1.020       1.00     1 020      15.00     1.020      45.00     1.020      75.00
    1.020     106 00     1.020     136.00     1.020     167 00     1.020     197.00
    1.020     228.00     1.020     259.00     1 020     289.00     1.020     320.00
    1.020     350.00     1.020     366.00
KE#05   12    14    FT#12-Ke #5    (1/meter)
    1.020       1.00     1.020      15.00     1.020      45.00     1.020      75.00
    1 020     106.00     1.020     136.00     1.020     167.00     1.020     197.00
    1.020     228.00     1.020     259.00     1.020     289.00     1.020     320.00
    1 020     350.00     1.020     366.00
TFNH4   13    14    FT#13-NH4 flux   (theta = 1.08)
    2.301       1.00     2.301      15.00     2.301      45.00     2.301      75.00
    2.301     106.00     2.301     136.00     2.381     167.00     2.455     197.00
    2.455     228.00     2.245     259.00     2.245     289.00     2.245     320.00
    2 245     350.00     2.301     366.00
TFPO4   14    14    FT#14-PO4 flux   (theta = 1.08)
    2.301       1.00     2.301      15.00     2.301      45.00     2.301      75.00
    2 301     106.00     2.301     136.00     2.381     167.00     2 455     197.00
    2.455     228 00     2.245     259.00     2.245     289.00     2.245     320.00
    2.245     350.00     2.301     366 00
MACRO   15    14    FT#15-Macrophy
```

```
     1.000      1 00     1 000     15 00     1 000     45.00     1.000     75 00
     1 000    106 00     1.000    136 00     1.000    167.00     1 000    197 00
     1.000    228.00     1 000    259 00     1 000    289.00     1 000    320 00
     1.000    350 00     1.000    366 00
SHL#1   16    14   FT#16-Shell #1
     1.000      1.00     1.000  - 15 00     1 000     45 00     1 000     75.00
     1.000    106.00     1.000    136.00     1 000    167.00     1.000    197.00
     1.000    228.00     1.000    259.00     1.000    289.00     1.000    320.00
     1.000    350.00  _  1.000    366.00
TFK1G   17    14   FT#17-time dependent grazing rate multiplier (theta=1.00)
     1.000      1.00     1.000     15 00     1 000     45.00     1.000     75.00
     1 000    106.00     1.000    136 00     1.000    167.00     1.000    197.00
     1 000    228.00     1.000    259.00     1.000    289.00     1.000    320.00
     1.000    350 00     1.000    366 00
TFSOD   18    14   FT#18-SOD flux  (theta = 1 072)
     2.123         1     2.123        15     2.123        45     2.123        75
     2.123       106     2 123       136     2.189       167     2.251       197
     2.251       228     2.077       259     2 077       289     2.077       320
     2 077       350     2.123       366
ZOOPL   19    14   FT#19-Zoopl... modified 73 micron net size
     20000      1.00     20000     15.00     20000     45.00     20000     75.00
     20000    106.00     20000    136.00     40000    167.00     80000    197.00
     40000    228.00     20000    259.00     20000    289.00     20000    320.00
     20000    350.00     20000    366.00
TFSIO   20    14   FT#20-Si04 flux  (theta = 1 08)
     2.301      1.00     2.301     15.00     2.301     45.00     2.301     75.00
     2.301    106.00     2.301    136.00     2.381    167.00     2.455    197.00
     2.455    228.00     2.245    259.00     2.245    289.00     2.245    320.00
     2.245    350.00     2.301    366.00
TFNO3   21    14   FT#21-NO3 flux  (theta = 1.08)
     2.301      1.00     2.301     15.00     2.301     45.00     2.301     75.00
     2 301    106.00     2.301    136.00     2.381    167.00     2.455    197.00
     2.455    228.00     2 245    259.00     2.245    289.00     2.245    320 00
     2.245    350.00     2.301    366.00
NH3_N (mg/L)                                5   1.      9999. J:INITIAL CONC.
 SG01    0.0600      1.000 SG02     0.0500     1.000 SG03    0.0600     1.000
 SG04    0.0500      1.000 SG05     0.0500     1.000 SG06    0.0500     1.000
 SG07    0 0550      1.000 SG08     0 0600     1.000 SG09    0.0600     1 000
 SG10    0.0550      1.000 SG11     0.0500     1 000 SG12    0.0500     1.000
 SG13    0.0000      1.000
NO2_N (mg/L)                                5   1.      9999. J:INITIAL CONC.
 SG01    0.0500      1.000 SG02     0.0500     1.000 SG03    0.0500     1.000
 SG04    0.0500      1.000 SG05     0.0500     1.000 SG06    0.0500     1.000
 SG07    0.0500      1.000 SG08     0 0500     1.000 SG09    0.0500     1.000
 SG10    0.0500      1.000 SG11     0.0500     1 000 SG12    0.0500     1.000
 SG13    0.0000      1.000
OPO4  (mg/L)                                5   1.      9999. J:INITIAL CONC.
 SG01    0.0660      0.600 SG02     0.0660     0.600 SG03    0.0700     0.600
 SG04    0.0700      0.600 SG05     0.0780     0.600 SG06    0.0750     0.600
 SG07    0.0740      0.600 SG08     0.0800     0.600 SG09    0.0780     0.600
 SG10    0.0800      0.600 SG11     0.0820     0.600 SG12    0.0840     0.600
 SG13    0.0000      0.600
Phytl (mg/L)                                4   1.      9999. J.INITIAL CONC.
 SG01   17.0000      0.000 SG02    18.7500     0.000 SG03   17.5000     0.000
 SG04   18.5000      0.000 SG05    18.0000     0.000 SG06   18.0000     0.000
 SG07   18.0000      0.000 SG08    19.0000     0.000 SG09   18.2500     0.000
 SG10   20.0000      0.000 SG11    20.0000     0.000 SG12   21.5000     0.000
 SG13    0.0000      0.000
CBOD  (mg/L)                                4   1.      9999. J:INITIAL CONC.
 SG01    3 1000      0.500 SG02     3.1000     0.500 SG03    3.2000     0.500
 SG04    3.2000      0.500 SG05     3.4000     0.500 SG06    3.1000     0.500
 SG07    3.3000      0.500 SG08     3.1000     0.500 SG09    3.4000     0.500
 SG10    3 3000      0.500 SG11     3.1000     0.500 SG12    3.1000     0.500
 SG13    0.0000      0.500
DO    (mg/L)                                5   1.      9999. J:INITIAL CONC.
 SG01    4.5100      1.000 SG02     3.9800     1.000 SG03    4.4600     1.000
 SG04    4.2000      1.000 SG05     4.4100     1.000 SG06    4.3000     1 000
 SG07    4.0000      1.000 SG08     4.3000     1.000 SG09    3.9500     1.000
 SG10    4.1000      1.000 SG11     4.1000     1.000 SG12    4.2100     1.000
```

```
 SG13     0.0000      1 000
OrgN  (mg/L)                                  5   1.     9999. J.INITIAL CONC
 SG01     0 3400      0.500 SG02    0 1000     0.500 SG03    0.4000     0 500
 SG04     0.2000      0.500 SG05    0 4500     0 500 SG06    0 3700     0.500
 SG07     0.1000      0.500 SG08    0.3600     0 500 SG09    0.0900     0 500
 SG10     0 2000      0.500 SG11    0.3500     0.500 SG12    0.3500     0.500
 SG13     0.0000      0.500
OrgP  (mg/L)                                  4   1.     9999. J INITIAL CONC.
 SG01     0.0440      0.700 SG02    0.0440     0.700 SG03    0 0480     0 700
 SG04     0.0480      0.700 SG05    0 0520     0 700 SG06    0 0520     0.700
 SG07     0.0500      0.700 SG08    0 0520     0 700 SG09    0 0520     0 700
 SG10     0 0540      0 700 SG11    0.0540     0.700 SG12    0.0560     0.700
 SG13     0.0000      0.700
Phyt2 (mg/L)                                  4   1.     9999  J INITIAL CONC.
 SG01     0.0000      0.000 SG02    0 0000     0 000 SG03    0 0000     0.000
 SG04     0.0000      0.000 SG05    0.0000     0.000 SG06    0 0000     0.000
 SG07     0.0000      0.000 SG08    0.0000     0.000 SG09    0.0000     0 000
 SG10     0.0000      0.000 SG11    0.0000     0.000 SG12    0.0000     0.000
 SG13     0.0000      0.000
Phyt3 (mg/L)                                  4   1.     9999. J:INITIAL CONC.
 SG01     0 0000      0.000 SG02    0.0000     0 000 SG03    0.0000     0.000
 SG04     0.0000      0 000 SG05    0.0000     0 000 SG06    0.0000     0.000
 SG07     0 0000      0.000 SG08    0 0000     0 000 SG09    0.0000     0.000
 SG10     0 0000      0.000 SG11    0.0000     0 000 SG12    0.0000     0.000
 SG13     0.0000      0.000
SiO4  (mg/L)                                  3   1.     9999. J·INITIAL CONC
 SG01     0 0000      0.300 SG02    0.0000     0.300 SG03    0.0000     0.300
 SG04     0.0000      0.300 SG05    0.0000     0 300 SG06    0.0000     0.300
 SG07     0.0000      0.300 SG08    0.0000     0.300 SG09    0.0000     0.300
 SG10     0.0000      0.300 SG11    0.0000     0.300 SG12    0.0000     0 300
 SG13     0.0000      0.300
Salinity (mg/L)                               5   1.  9.99E+06 J:INITIAL CONC.
 SG01       26860     1.000 SG02      25710    1.000 SG03      26600    1 000
 SG04       26200     1.000 SG05      26410    1.000 SG06      26400    1 000
 SG07       26300     1 000 SG08      26500    1.000 SG09      26300    1.000
 SG10       26300     1.000 SG11      26200    1.000 SG12      26260    1 000
 SG13     0.0000      1.000
Coliforms (MPN/100ml)                         5   1.  9.99E+14 J:INITIAL CONC.
 SG01     0.0000      1.000 SG02    0.0000     1.000 SG03    0.0000     1 000
 SG04     0.0000      1.000 SG05    0.0000     1.000 SG06    0.0000     1.000
 SG07     0.0000      1.000 SG08    0.0000     1.000 SG09    0.0000     1.000
 SG10     0.0000      1.000 SG11    0.0000     1 000 SG12    0.0000     1.000
 SG13     0 0000      1.000
```

2.1 Beacons Reach Marina

2.2.1 DYNHYD5 Dye Hydrodynamic File for Beacons Reach Marina

```
Filename. BEACONS INP    DYNHYD5 File for Beacons Reach Marina Dye Calibration
----+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8


DYNHYD5 - Beacons Reach Marina (TC 5162-01)
BEACONS.INP - Hydrodynamics for dye simulation Oct 11, 1988 to Oct 13, 1988
***** Data Group A. PROGRAM CONTROL DATA ***********************
    5    4 0000   6.00000    5    1988/10/10 00 00    1988/10/14 00.00
***** Data Group B· OUTPUT CONTROL DATA *************************
    1988/10/10 01:00        1.0   - 1    5    0
    1
    1    2    3    4    5
***** Data Group C: SUMMARY CONTROL DATA ***********************
    1    1988/10/10 00.00   25.0000  150
BEACONS.HYD
***** Data Group D: JUNCTION DATA ******************************
    1      0.001      1303      -2 1       109       56    1
    2      0 001      3165      -2.1       133      110    1    2
    3      0.001      2032      -2.1       101      117    2    3
    4      0.001      2172      -2.1        72      126    3    4
    5      0.001      2377      -2.1        44      134    4
***** Data Group E. CHANNEL DATA *******************************
    1         59        39        2.1     0.030     0.001    1    2
    2         31        81        2.1     0.030     0.001    2    3
    3         32        76        2.1     0.030     0.001    3    4
    4         28        73        2.1     0.030     0 001    4    5
***** Data Group F.1: CONSTANT INFLOWS (m/sec) ****************************
    0
***** Data Group F.2: VARIABLE INFLOWS (m/sec) - Daily Flows **************
    0
** Data Group G: SEAWARD BOUNDARY DATA (m) - Variable Tide
    1
    3    1    18    15       0.0    0.0000       0.0    1.0000    0.0000
    1988/10/09 23·00      0.300    1988/10/10 06:00     -0.300
    1988/10/10 11:30      0.300    1988/10/10 18:00     -0 300
    1988/10/10 23.00      0.300    1988/10/11 06:00     -0.300
    1988/10/11 11:30      0.300    1988/10/11 18:00     -0.300
    1988/10/11 23 00      0.300    1988/10/12 05:30     -0.300
    1988/10/12 12.00      0.300    1988/10/12 19:00     -0.300
    1988/10/12 23:45      0 300    1988/10/13 06·45     -0.300
    1988/10/13 13:15      0.300    1988/10/13 19:45     -0 300
    1988/10/14 01.30      0 300    1988/10/14 07·45     -0.300
** Data Group H: WIND DATA (m/sec) mean monthly winds at Beacons Reach **
    0
```

----+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8

2.2.2 DYNHYD5 DO Hydrodynamic File for Beacons Reach Marina

```
Filename: HBR_11 INP    DYNHYD5 File for Beacons Reach Marina DO Calibration
----+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8

DYNHYD5 - Beacons Reach Marina (TC 5162-01)
HBR_11 INP - Hydrodynamics for water quality May 20-27, 1988
***** Data Group A: PROGRAM CONTROL DATA ************************
    5    4 0000   6 00000    5    1988/05/20 00 00    1988/05/28 00.00
***** Data Group B: OUTPUT CONTROL DATA ************************
    1988/05/20 01:00        1 0  - 1    5    0
    1
    1    2    3    4    5
***** Data Group C: SUMMARY CONTROL DATA ***********************
    1    1988/05/20 00:00   25.0000  150
HBR_11 HYD
***** Data Group D: JUNCTION DATA ******************************
    1      0.001      1303      -2.1       109        56    1
    2      0.001      3165      -2.1       133       110    1    2
    3      0.001      2032      -2.1       101       117    2    3
    4      0 001      2172      -2.1        72       126    3    4
    5      0 001      2377      -2.1        44       134    4
***** Data Group E: CHANNEL DATA *******************************
    1        59        39        2.1     0.030     0.001    1    2
    2        31        81        2.1     0 030     0.001    2    3
    3        32        76        2.1     0 030     0.001    3    4
    4        28        73        2 1     0 030 .   0.001    4    5
***** Data Group F.1: CONSTANT INFLOWS (m/sec) ***************************
    0
***** Data Group F.2: VARIABLE INFLOWS (m/sec) - Daily Flows **************
    0
** Data Group G: SEAWARD BOUNDARY DATA (m) - Variable Tide
    1
    3    1   34   15       0.0    0 0000       0.0    1.0000    0 0000
    1988/05/19 22:24     0.715    1988/05/20 04:53     0 058
    1988/05/20 10:56     0.539    1988/05/20 16:43     0 109
    1988/05/20 23·09     0.662    1988/05/21 05:39     0 081
    1988/05/21 11:47     0.522    1988/05/21 17 33     0.139
    1988/05/21 23.57     0.613    1988/05/22 06:25     0 094
    1988/05/22 12:39     0.515    1988/05/22 18:29     0.154
    1988/05/23 00·47     0.569    1988/05/23 07·12     0.096
    1988/05/23 13:32     0.518    1988/05/23 19·29     0.152
    1988/05/24 01:39     0.534    1988/05/24 07 58     0.086
    1988/05/24 14:24     0.533    1988/05/24 20:28     0 132
    1988/05/25 02:32     0.507    1988/05/24 08:44     0.066
    1988/05/25 15:13     0.556    1988/05/24 21:25     0.098
    1988/05/26 03.24     0.489    1988/05/24 09:27     0 038
    1988/05/26 15:59     0.588    1988/05/24 22:17     0.057
    1988/05/27 04:12     0.479    1988/05/24 10:10     0.008
    1988/05/27 16:42     0.625    1988/05/24 23:05     0 016
    1988/05/28 04:59     0.478    1988/05/24 10:52    -0.022
** Data Group H: WIND DATA (m/sec) mean monthly winds at Beacons Reach **
    0
```

----+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8

2.2.3 WASP4 Dye Calibration File for Beacons Reach Marina

```
Filename:  BEACONWQ.INP    WASP4 File for Beacons Reach Marina DO Calibration
----+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8

BEACONWQ INP -  Beacons Reach WASP4 Model Water 10/10/88 10/13/88
Dye Results are used for model Calibration
 KSIM NSEG NSYS ICFL MFLG IDMP NSLN INTY ADFC  zyr/mm/dd hhmm   A MODEL OPTIONS
    0    6   13    1    1    1    0     0  0 0 1988/10/10 0000    1    1    3     0.00
    5
    1    2    3    4    5
    1
      900.    287.50
    3
       30.       365     86400.      366.    86400        640.
    1    1    1    1    1    1    1    1    1    1    1    0    1
    1    +    +    *    +    *    +    *    +    *    +    *     B:EXCHANGES
    5     1.000      1.00                    (surface water)
    1
      75.0        59    0    1
    2
   0.50E+00        0.  0.50E+00      640.
    1
      82.0        59    1    2
    2
   0.40E+00        0.  0.40E+00      640.
    1
     170.0        31    2    3
    2
   0.30E+00        0  0.30E+00      640.
    1
     160.0        32    3    4
    2
   0.10E+00        0.  0.10E+00      640.
    1
     153.0        28    4    5
    2
   0.30E+00        0.  0.30E+00      640.
    1    1    1    1    1    1    1    1    1    1    1    0    1
    2    0     720.0    +    *    +    *    +    *    +    *     C· VOLUMES
    1.0000    1 0000
         1         6         1       1303       0 0       1.0       1.0       1.0
         2         6         1       3165       0.0       1.0       1.0       1 0
         3         6         1       2032       0.0       1.0       1.0       1 0
         4         6         1       2172       0 0       1.0       1.0       1.0
         5         6         1       2377       0 0       1.0       1.0       1 0
         6         0         3      11049       0.0       1.0       1.0       1.0
    2    5      SUMRY2.OUT (BEACONS.HYD)  *    +    *    +    *     D: FLOWS
    1    1                               (Data Block D.2 Field One Flows)
    1    2    3    4    5
    0       1.0       1.0      F#2 --NINQ(2)  SCALQ=1  CONVQ= 1
    1       1.0 1.157E-05      F#3 --NINQ(3)  SCALQ=1  CONVQ= m/day * 1/86400
    5                          F#3 --NOQS(3,ni) --> number of segment pairs
      1303    1    6      3165    2    6      2032    3    6      2172    4    6
      2377    5    6
    2                          F#3 --NBRKQ(4,ni) --> number of time breaks
      0.0        0.0       0.0      640.0
    1       1.0 1.157E-05      F#4 --NINQ(3)  SCALQ=1  CONVQ= m/day * 1/86400
    5                          F#4 --NOQS(3,ni) --> number of segment pairs
      1303    1    6      3165    2    6      2032    3    6      2172    4    6
      2377    5    6
    2                          F#4---NBRKQ(5,ni) --> number of time breaks
      0.0        0.0    .  0.0      640.0
    1       1.0 1.157E-05      F#5 --NINQ(3)  SCALQ=1  CONVQ= m/day * 1/86400
    5                   -
      1303    1    6      3165    2    6      2032    3    6      2172    4    6
      2377    5    6
    2                          F#5---NBRKQ(5,ni) --> number of time breaks
      0.0        0 0       0.0      640.0
    1    1    1    1    1    1    1    1    1    1    1    0    1
         1                Sys#1 NH3         (Data Group E Boundary Conditions)
      1.0        1.0
    1    6    OCN ·              OCNBC001          Sys# 1
     0.000    284 000     0.000    285.354    000.00     285.355     0.000    285.396

----+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
```

```
    0 000    285 397    000.000   365 000
        1              Sys#2 NO3          (Data Group E Boundary Conditions)
      1.0        1.0
   1    6    OCN .                  OCNBC001          Sys# 2
    0 000    284.000     0.000   285.354   000.00    285.355     0.000   285 396
    0.000    285 397    000 000  -365.000
        1              Sys#3 OP04         (Data Group E Boundary Conditions)
      1 0        1 0
   1    6    OCN :                  OCNBC001          Sys# 3
    0 000    284.000     0 000   285.354   000.00    285.355     0.000   285 396
    0 000    285 397    000.000   365.000
        1              Sys#4 Phyt#1       (Data Group E Boundary Conditions)
      1.0        1.0
   1    6    OCN :                  OCNBC001          Sys# 4
    0.000    284 000     0.000   285 354   000.00    285.355     0.000   285.396
    0 000    285.397    000.000   365.000
        1              Sys#5 CBOD         (Data Group E Boundary Conditions)
      1.0        1.0
   1    6    OCN                    OCNBC001          Sys# 5
    0.000    284.000     0.000   285 354   000.00    285.355     0.000   285.396
    0.000    285.397    000.000   365.000
        1              Sys#6 DO           (Data Group E Boundary Conditions)
      1.0        1.0
   1    6    OCN :                  OCNBC001          Sys# 6
    0.000    284.000     0 000   285.354   000.00    285.355     0.000   285.396
    0 000    285.397    000.000   365.000
        1              Sys#7 OrgN         (Data Group E Boundary Conditions)
      1.0        1.0
   1    6    OCN :                  OCNBC001          Sys# 7
    0 000    284.000     0.000   285.354   000.00    285.355     0.000   285.396
    0.000    285.397    000.000   365.000
        1              Sys#8 OrgP         (Data Group E Boundary Conditions)
      1.0        1.0
   1    6    OCN :                  OCNBC001          Sys# 8
    0.000    284.000     0.000   285.354   000.00    285.355     0.000   285.396
    0.000    285.397    000.000   365.000
        1              Sys#9 Phyt#2       (Data Group E Boundary Conditions)
      1.0        1.0
   1    6    OCN :                  OCNBC001          Sys# 9
    0.000    284.000     0.000   285.354   000 00    285.355     0.000   285 396
    0.000    285 397    000.000   365 000
        1              Sys#10 Phyt#2      (Data Group E Boundary Conditions)
      1.0        1.0
   1    6    OCN :                  OCNBC001          Sys# 10
    0 000    284.000     0.000   285.354   000.00    285 355     0 000   285.396
    0.000    285.397    000.000   365.000
        1              Sys#11 SiO4        (Data Group E Boundary Conditions)
      1.0        1 0
   1    6    OCN .                  OCNBC001          Sys# 11
    0 000    284 000     0.000   285.354   000.00    285 355     0.000   285.396
    0 000    285 397    000.000   365.000
        1              Sys#12 Salinity    (Data Group E Boundary Conditions)
      1.0        1.0
   1    6    OCN :                  OCNBC001          Sys# 12
    0.000    284.000     0.000   285.354     0.000   285.355     0.000   285.396
    0.000    285.397     0.000   365.000
        1              Sys#13 Coliforms   (Data Group E Boundary Conditions)
      1 0        1.0
   1    6    OCN :                  OCNBC001          Sys# 13
    0.000    284.000    -0.000   285.354   000.00    285.355     0.000   285.396
    0.000    285.397    000.000   365.000
        4    PS(t) Sys#1           (Data Block F 1 Waste Loads for Point Source)
 0.100E+01 0.100E+01  PS(t)      :System # 1 Dye       Kg/Day      Scale/conv fct
   2    6   Seg 002   Dye Input          OCNBC001 INE   5 17 Sys# 1 OCN88RAT INE
    0.000    284.000     0.000   285 354    10.800   285.355    10.800   285.396
    0.000    285.397    000.000   365.000
   3    6   Seg 003   Dye Input            OCNBC001 INE  5 17 Sys# 1 OCN88RAT.INE
    0 000    284.000     0.000   285.354    10.800   285.355    10.800   285.396
    0.000    285.397    000.000   365 000
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    4     6   Seg 004    Dye Input               OCNBC001 INE   5 17 Sys# 1 OCN88RAT.INE
     0.000    284.000     0 000    285 354    10 800    285 355     10 800    285.396
     0.000    285.397   000 000    365 000
    5     6   Seg 005    Dye Input                    5 17 Sys# 1 OCN88RAT INE
     0 000    284 000     0 000    285.354    10.800    285 355     10.800    285 396
     0 000    285.397     0 000   -365.000
          4    PS(t) Sys#2             (Data Block F.1 Waste Loads for Point Source)
 0 100E+01 0.100E+01  PS(t)       :System # 2 NO3       Kg/Day      Scale/conv fct
    2     6   Seg 002    Dye Input           OCNBC001 INE   5 17 Sys# 1 OCN88RAT.INE
     0 000    284.000     0 000    285.354      0.00    285.355      0.000    285.396
     0.000    285 397   000.000    365 000
    3     6   Seg 003    Dye Input             OCNBC001.INE   5 17 Sys# 1 OCN88RAT INE
     0 000    284.000     0.000    285.354     0 00     285.355      0.000    285 396
     0 000    285.397   000 000    365.000
    4     6   Seg 004    Dye Input               OCNBC001.INE   5 17 Sys# 1 OCN88RAT.INE
     0.000    284.000     0.000    285.354     0.00     285.355      0.000    285.396
     0.000    285.397   000.000    365.000
    5     6   Seg 005    Dye Input                    5 17 Sys# 1 OCN88RAT.INE
     0.000    284.000     0.000    285.354      0.00    285.355      0.000    285.396
     0.000    285.397     0.000    365.000
          4    PS(t) Sys#3             (Data Block F.1 Waste Loads for Point Source)
 0.100E+01 0 100E+01  PS(t)        System # 3 OP04      Kg/Day      Scale/conv fct
    2     6   Seg 002    Dye Input           OCNBC001 INE   5 17 Sys# 1 OCN88RAT.INE
     0 000    284 000     0.000    285.354      0.00    285.355      1 000    285.396
     0 000    285.397   000.000    365.000
    3     6   Seg 003    Dye Input             OCNBC001.INE   5 17 Sys# 1 OCN88RAT INE
     0.000    284.000     0.000    285.354     0.00     285.355      1.000    285.396
     0.000    285.397   000.000    365 000
    4     6   Seg 004    Dye Input               OCNBC001 INE   5 17 Sys# 1 OCN88RAT.INE
     0.000    284.000     0.000    285.354     0.00     285.355      1.000    285.396
     0.000    285.397   000.000    365.000
    5     6   Seg 005    Dye Input                    5 17 Sys# 1 OCN88RAT.INE
     0.000    284.000     0.000    285.354      0.00    285.355      1.000    285.396
     0.000    285.397     0.000    365.000
          4    PS(t) Sys#4             (Data Block F.1 Waste Loads for Point Source)
 0.100E+01 0.100E+01  PS(t)        System # 4 Phytl     Kg/Day      Scale/conv fct
    2     6   Seg 002    Dye Input           OCNBC001.INE   5 17 Sys# 1 OCN88RAT.INE
     0.000    284.000     0.000    285.354      0 00    285.355      1.000    285.396
     0.000    285.397   000.000    365.000
    3     6   Seg 003    Dye Input             OCNBC001.INE   5 17 Sys# 1 OCN88RAT.INE
     0 000    284.000     0 000    285.354     0.00     285.355      1.000    285 396
     0 000    285.397   000 000    365.000
    4     6   Seg 004    Dye Input               OCNBC001.INE   5 17 Sys# 1 OCN88RAT.INE
     0.000    284.000     0.000    285.354     0 00     285.355      1 000    285 396
     0.000    285.397   000.000    365.000
    5     6   Seg 005    Dye Input                    5 17 Sys# 1 OCN88RAT.INE
     0 000    284.000     0.000    285.354      0.00    285.355      1.000    285.396
     0.000    285.397     0.000    365 000
          4    PS(t) Sys#5             (Data Block F.1 Waste Loads for Point Source)
 0.100E+01 0 100E+01  PS(t)       :System # 5 CBOD      Kg/Day      Scale/conv fct
    2     6   Seg 002    Dye Input           OCNBC001.INE   5 17 Sys# 1 OCN88RAT.INE
     0.000    284.000     0.000    285.354      0.00    285.355      1.000    285.396
     0.000    285.397   000.000    365.000
    3     6   Seg 003    Dye Input             OCNBC001.INE   5 17 Sys# 1 OCN88RAT.INE
     0.000    284.000     0.000    285.354     0.00     285.355      1.000    285.396
     0.000    285.397   000.000    365.000
    4     6   Seg 004    Dye Input               OCNBC001.INE   5 17 Sys# 1 OCN88RAT.INE
     0.000    284.000     0.000    285.354     0 00     285.355      1.000    285.396
     0.000    285.397   000.000    365.000
    5     6   Seg 005    Dye Input                    5 17 Sys# 1 OCN88RAT.INE
     0.000    284.000     0.000    285.354      0.00    285.355      1.000    285.396
     0.000    285.397     0.000    365.000
          4    PS(t) Sys#6             (Data Block F.1 Waste Loads for Point Source)
 0.100E+01 0.100E+01  PS(t)       ·System # 6 DO        Kg/Day      Scale/conv fct
    2     6   Seg 002    Dye Input           OCNBC001.INE   5 17 Sys# 1 OCN88RAT INE
     0 000    284.000     0.000    285.354      0 00    285.355      1.000    285 396
     0.000    285.397   000 000    365.000
    3     6   Seg 003    Dye Input             OCNBC001.INE   5 17 Sys# 1 OCN88RAT.INE
     0 000    284.000     0 000    285.354     0.00     285.355      1.000    285.396
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    0 000    285.397   000.000   365 000
   4    6   Seg 004    Dye Input             OCNBC001 INE  5 17 Sys# 1 OCN88RAT INE
    0.000    284 000     0 000   285.354      0 00     285 355      1 000    285 396
    0 000    285.397   000.000   365 000
   5    6   Seg 005    Dye Input                   5 17 Sys# 1 OCN88RAT.INE
    0 000    284.000     0.000   285.354      0.00     285.355      1 000    285.396
    0.000    285.397     0.000   365.000
        4   PS(t) Sys#7           (Data Block F.1 Waste Loads for Point Source)
 0 100E+01 0.100E+01  PS(t)       System # 7 OrgN     Kg/Day     Scale/conv fct
   2    6   Seg 002    Dye Input         OCNBC001 INE  5 17 Sys# 1 OCN88RAT INE
    0.000    284.000     0.000   285 354      0.00     285.355      1.000    285 396
    0.000    285.397   000 000   365 000
   3    6   Seg 003    Dye Input           OCNBC001.INE  5 17 Sys# 1 OCN88RAT.INE
    0 000    284.000     0.000   285 354      0 00     285.355      1.000    285.396
    0.000    285 397   000 000   365 000
   4    6   Seg 004    Dye Input             OCNBC001.INE  5 17 Sys# 1 OCN88RAT.INE
    0.000    284.000     0.000   285 354      0.00     285.355      1.000    285.396
    0 000    285.397   000.000   365.000
   5    6   Seg 005    Dye Input                   5 17 Sys# 1 OCN88RAT INE
    0.000    284.000     0.000   285.354      0.00     285.355      1.000    285.396
    0.000    285.397     0.000   365.000
        4   PS(t) Sys#8           (Data Block F 1 Waste Loads for Point Source)
 0.100E+01 0.100E+01  PS(t)      ·System # 8 OrgP     Kg/Day     Scale/conv fct
   2    6   Seg 002    Dye Input         OCNBC001.INE  5 17 Sys# 1 OCN88RAT.INE
    0.000    284.000     0.000   285.354      0.00     285 355      1.000    285 396
    0.000    285.397   000.000   365 000
   3    6   Seg 003    Dye Input           OCNBC001.INE  5 17 Sys# 1 OCN88RAT.INE
    0.000    284 000     0.000   285.354      0 00     285.355      1.000    285.396
    0.000    285.397   000.000   365.000
   4    6   Seg 004    Dye Input             OCNBC001.INE  5 17 Sys# 1 OCN88RAT.INE
    0.000    284.000     0.000   285.354      0.00     285.355      1.000    285.396
    0.000    285.397   000.000   365.000
   5    6   Seg 005    Dye Input                   5 17 Sys# 1 OCN88RAT.INE
    0.000    284.000     0.000   285.354      0.00     285.355      1 000    285 396
    0.000    285.397     0.000   365.000
        4   PS(t) Sys#9           (Data Block F.1 Waste Loads for Point Source)
 0 100E+01 0.100E+01  PS(t)      :System # 9 Phyt2    Kg/Day     Scale/conv fct
   2    6   Seg 002    Dye Input         OCNBC001.INE  5 17 Sys# 1 OCN88RAT INE
    0.000    284.000     0.000   285.354      0.00     285.355      1.000    285 396
    0.000    285.397   000.000   365.000
   3    6   Seg 003    Dye Input           OCNBC001.INE  5 17 Sys# 1 OCN88RAT.INE
    0.000    284.000     0.000   285.354      0.00     285.355      1.000    285.396
    0.000    285.397   000.000   365.000
   4    6   Seg 004    Dye Input             OCNBC001.INE  5 17 Sys# 1 OCN88RAT.INE
    0.000    284 000     0.000   285.354      0.00     285.355      1.000    285.396
    0.000    285.397   000.000   365.000
   5    6   Seg 005    Dye Input                   5 17 Sys# 1 OCN88RAT.INE
    0.000    284.000     0.000   285.354      0 00     285 355      1 000    285.396
    0 000    285.397     0.000   365.000
        4   PS(t) Sys#10          (Data Block F.1 Waste Loads for Point Source)
 0.100E+01 0.100E+01  PS(t)      :System # 10 Phyt3   Kg/Day     Scale/conv fct
   2    6   Seg 002    Dye Input         OCNBC001.INE  5 17 Sys# 1 OCN88RAT.INE
    0.000    284.000     0.000   285.354      0.00     285 355      1.000    285.396
    0 000    285.397   000.000   365.000
   3    6   Seg 003    Dye Input           OCNBC001.INE  5 17 Sys# 1 OCN88RAT.INE
    0.000    284.000     0.000   285.354      0.00     285.355      1.000    285.396
    0 000    285.397   000.000   365.000
   4    6   Seg 004    Dye Input             OCNBC001.INE  5 17 Sys# 1 OCN88RAT.INE
    0.000    284.000     0 000   285.354      0.00     285.355      1.000    285.396
    0.000    285 397   000.000   365.000
   5    6   Seg 005    Dye Input                   5 17 Sys# 1 OCN88RAT.INE
    0.000    284.000     0.000   285.354      0.00     285.355      1.000    285 396
    0.000    285.397     0.000   365 000
        4   PS(t) Sys#11          (Data Block F.1 Waste Loads for Point Source)
 0.100E+01 0.100E+01  PS(t)      :System # 11 Si04    Kg/Day     Scale/conv fct
   2    6   Seg 002    Dye Input         OCNBC001.INE  5 17 Sys# 1 OCN88RAT.INE
    0.000    284.000     0.000   285.354      0.00     285.355      1.000    285.396
    0.000    285.397   000.000   365.000
   3    6   Seg 003    Dye Input           OCNBC001.INE  5 17 Sys# 1 OCN88RAT.INE
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    0 000    284.000     0.000   285 354     0 00     285 355     1 000    285 396
    0 000    285 397   000.000   365 000
   4    6   Seg 004    Dye Input             OCNBC001.INE  5 17 Sys# 1 OCN88RAT INE
    0 000    284.000     0.000   285.354     0 00     285 355     1 000    285 396
    0.000    285.397   000.000   365 000
   5    6   Seg 005    Dye Input -                   5 17 Sys# 1 OCN88RAT.INE
    0.000    284 000     0.000   285.354     0.00    285.355      1.000    285.396
    0.000    285 397     0 000   365.000
        4    PS(t) Sys#12          (Data Block F.1 Waste Loads for Point Source)
 0.100E+01 0 100E+01  PS(t)      System # 12 Salin    Kg/Day      Scale/conv fct
   2    6   Seg 002    Dye Input          Sys# 12
    0.000    284.000     0 000   285.354   021 600    285.375     00.000   285.396
    0 000    300.000     0.000   365.000
   3    6   Seg 002    Dye Input          Sys# 12
    0 000    284.000     0.000   285 354   021.600    285.375     00 000   285.396
    0 000    300.000   000 000   365.000
   4    6   Seg 003    Dye Input          Sys# 12
    0.000    284.000     0 000   285.354   021.600    285.375     00 000   285.396
    0 000    300.000   000.000   365.000
   5    6   Seg 004    Dye Input          Sys# 12
    0.000    284 000     0.000   285.354   021.600    285 375     00.000   285 396
    0.000    300.000   000 000   365.000
        4    PS(t) Sys#13          (Data Block F.1 Waste Loads for Point Source)
 0 100E+01 0.100E+01  PS(t)      System # 13 Coli     Kg/Day      Scale/conv fct
   2    6   Seg 002    Dye Input          OCNBC001.INE  5 17 Sys# 1 OCN88RAT.INE
    0 000    284.000     0.000   285 354     0 00    285.355      1.000    285.396
    0.000    285.397   000 000   365.000
   3    6   Seg 003    Dye Input            OCNBC001.INE  5 17 Sys# 1 OCN88RAT.INE
    0.000    284.000     0.000   285 354     0 00    285.355      1.000    285.396
    0.000    285 397   000.000   365.000
   4    6   Seg 004    Dye Input               OCNBC001.INE  5 17 Sys# 1 OCN88RAT.INE
    0 000    284.000     0.000   285 354     0.00    285.355      1.000    285.396
    0.000    285.397   000.000   365.000
   5    6   Seg 005    Dye Input                     5 17 Sys# 1 OCN88RAT.INE
    0.000    284.000     0 000   285.354     0.00    285.355      1.000    285.396
    0 000    285.397     0.000   365.000
   0    0                             (Data Group F 2 ..NPS Loads)
       17          6                 FF(xyz)- G wasp4g01 dat 05/12/90 21·20.28
Z001X    1         1.FSI04     2        1 TMPSG     3          1.TMPFN     4          1.
KESG     5         1.KEFN      6        1.FNH4      7          1.FP04      8          1
SOD1D    9         1.MACRO    12        1 SHL1     13          1 SHL2     14          1.
SHL3    15         1.GWC1     21        1 GWC2     22          1 GWSW     23          1.
FN03    24         1.
         1  o=      6
Z001X    1      1.000FSI04     2   143.750TMPSG     3      1.000TMPFN     4       4.000
KESG     5      1.000KEFN      6     5.000FNH4      7      8.400FP04      8       1.560
SOD1D    9      0.600MACRO    12     0 000SHL1     13      0.000SHL2     14       0.000
SHL3    15      0.000GWC1     21     0 201GWC2     22      1.262GWSW     23       0.020
FN03    24      4.570
         2  o=      6
Z001X    1      1.000FSI04     2   143.750TMPSG     3      1.000TMPFN     4       4.000
KESG     5      1.000KEFN      6     5.000FNH4      7      8.400FP04      8       1.560
SOD1D    9      0.600MACRO    12     0.000SHL1     13      0.000SHL2     14       0.000
SHL3    15      0.000GWC1     21     0 000GWC2     22      0.000GWSW     23       0.000
FN03    24      4.570
         3  o=      6
Z001X    1      1.000FSI04     2   143.750TMPSG     3      1.000TMPFN     4       4.000
KESG     5      1.000KEFN      6     5.000FNH4      7      8.400FP04      8       1 560
SOD1D    9      0 600MACRO    12     0 000SHL1     13      0.000SHL2     14       0.000
SHL3    15      0 000GWC1     21     0.803GWC2     22      5.047GWSW     23       0.020
FN03    24      4.570
         4  o=      6
Z001X    1      1 000FSI04     2   143.750TMPSG     3      1.000TMPFN     4       4.000
KESG     5      1.000KEFN      6     5 000FNH4      7      8.400FP04      8       1.560
SOD1D    9      0.600MACRO    12     0.000SHL1     13      0.000SHL2     14       0.000
SHL3    15      0.000GWC1     21     0.201GWC2     22      1.262GWSW     23       0.020
FN03    24      4.570
         5  o=      6
Z001X    1      1.000FSI04     2   143.750TMPSG     3      1.000TMPFN     4       4.000
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KESG      5     1 000KEFN     6     5 000FNH4     7     8.400FP04     8     1.560
SOD1D     9     0 600MACRO   12     0 000SHL1    13     0 000SHL2    14     0 000
SHL3     15     0 000GWC1    21     0 134GWC2    22     0 841GWSW    23     0.000
FNO3     24    4.570
          6  of     6        (Dummy Benthos Segment)
Z001X     1     1.000FSI04    2  -  0 000TMPSG    3     1 000TMPFN    4     1 000
KESG      5     0 000KEFN     6     1 000FNH4     7     0.000FP04     8     0.000
SOD1D     9     0 000MACRO   12     0.000SHL1    13     0.000SHL2    14     0.000
SHL3     15     0 000GWC1    21     0 000GWC2    22     0.000GWSW    23     0.000
FNO3     24     0.000
                   Nosys= 14     Const-H
GLOBAL              0
NH3-N               1
group #1-1          10
      K12C          11     0 250      K12T       12     1.080
      KNIT          13     2.000    ATMNH3       14     0.000
    GWFLOW          15  0.000000     GWNH3       16     0 000
     Z1CRB          17     2.500     Z1CDW       18     0.450
    NCRBZ1          19     0.167     NCRBM       39     0.082
NO3+NO2-N           1
group #1-2          5
      K20C          21     0.045      K20T       22     1.045
      KNO3          23     0.100    ATMNO3       24     2.359
     GWNO3          25     3.065
O-PO4               1
all param           4
    ATMDIP          31     0.053     GWDIP       32     0.005
    PCRBZ1          33     0.013     PCRBM       40     0.004
Phyt#1              2
group#1-4           12
       WS1          28     0.100       K1C       41     2.500
       K1T          42     1.066     LGHTS       43     2.000
     PHIMX          44   720.000       XKC       45     0.017
     CCHL1          46    80.000       IS1       47   300.000
     KMNG1          48     0.014     KMPG1       49     0.001
      K1RC          50     0.100      K1RT       51     1.080
group#2-4           10
       K1D          52     0.040       K1G       53     0.800
        W1          54     1.000     KPZDC       55     0.000
     KPZDT          56     1.000     PCRB1       57     0 030
     NCRB1          58     0 150    KMPHYT       59     1.000
    SICRB1          89     0.177     KMSG1      111    0.0014
CBOD                1
group#1-5           7
       KDC          71     0.200       KDT       72     1.047
      KDSC          73     0.000      KDST       74     1.000
      KBOD          75     0.500     GWBOD       76     1 800
      OCRB          81     2.670
Diss O2             1
group #1-6          6
       K4C          26     0.000       K4T       27     1 000
        K2          82     0.000     GWOXY       83     4.000
     KM1RC         109     0.000     KM1RT      110     1 000
Org-N               1
group #1-7          7
      K71C          91     0.075      K71T       92     1.080
     KONDC          93     0.000     KONDT       94     1.000
       FON          95     0.750    ATM_ON       96     2.801
     GW_ON          97     0.091
Org-P               1
group #1-8          7
      K83C         100     0 220      K83T      101     1.080
     KOPDC         102     0.000     KOPDT      103     1.000
       FOP         104     0.600    ATM_OP      105     0.247
     GW_OP         106     0.005
Phyt#2              2
group #1-9          9
       WS2          29     0.200     CCHL2       34    50.000
       IS2          35   150.000       K2C       36     2.100
```

Filename BEACONWQ.INP   WASP4 File for Beacons Reach Marina DO Calibration

```
----+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8

      K2D         37     0.040        W2        38      1 000
     K2RC         60     0.100      K2RT        61      1.045
      K2T         62     1.066
group#2-9          6
    KMNG2         63     0.021     KMPG2        64     0 0015
    NCRB2         65     0 154  -  PCRB2        66      0 030
   SICRB2         90     0.462     KMSG2       107      0 042
Phyt#3             2
group #1-1        10 _
  CLLCRB3         20     0.000       WS3        30      0 000
    CCHL3         67     1 000       IS3        68      0.000
      K3C         69     0 000       K3D        70      0.000
       W3         77     0.000      K3RC        78      0.000
     K3RT         79     1.000       K3T        80      1.000
group#2-10         6
    KMNG3         84     0 000     KMPG3        85      0.000
    NCRB3         86     0.000     PCRB3        87      0.000
   SICRB3         98     0 000     KMSG3       108      0.000
SiO4               1
group #1-1         1
     GWSI         88    20 000
Salinity           1
group #1-1         1
   GWSALT         99     0.000
Coliforms          0
        21 FF(t) WASP Data Group I FF Time- I wasp4i01.dat 10/16/90
 TEMP    1    14    FT#01-Temp #1 PR/TRB      tempxxxx.ini  5  8 FF time # 1 Temp#1
 0.138E+02 0 267E+03 0.138E+02 0.289E+03 0.122E+02 0 320E+03 0.449E+01 0.350E+03
 0.393E+01 0 381E+03 0 338E+01 0.411E+03 0.601E+01 0 440E+03 0.117E+02 0.471E+03
 0.186E+02 0.501E+03 0.226E+02 0.532E+03 0.262E+02 0 562E+03 0.246E+02 0.593E+03
 0.209E+02 0.624E+03 0 209E+02 0 639E+03
 TEMP    2    14    FT#02-Temp #2 FB          tempxxxx ini  6  8 FF time # 2 Temp#2
 0.131E+02 0.267E+03 0.131E+02 0.289E+03 0.868E+01 0.320E+03 0.500E+01 0.350E+03
 0.128E+01 0.381E+03 0 265E+01 0 411E+03 0.480E+01 0.440E+03 0.105E+02 0.471E+03
 0.164E+02 0 501E+03 0.216E+02 0.532E+03 0.240E+02 0.562E+03 0.245E+02 0.593E+03
 0.211E+02 0.624E+03 0.211E+02 0 639E+03
 TEMP    3    14    FT#03-Temp #3 GLPB/SIS    tempxxxx.ini  7  8 FF time # 3 Temp#3
 0.139E+02 0 267E+03 0 139E+02 0.289E+03 0 964E+01 0.320E+03 0.275E+01 0 350E+03
 0.840E+00 0.381E+03 0.205E+01 0.411E+03 0 375E+01 0.440E+03 0.914E+01 0 471E+03
 0.149E+02 0.501E+03 0.213E+02 0.532E+03 0.237E+02 0.562E+03 0.244E+02 0.593E+03
 0.218E+02 0.624E+03 0 218E+02 0.639E+03
 TEMP    4    14    FT#04-Temp #4 GB          tempxxxx.ini  8  8 FF time # 4 Temp#4
 0.161E+02 0.267E+03 0 161E+02 0.289E+03 0.105E+02 0.320E+03 0.300E+01 0.350E+03
 0.185E+01 0 381E+03 0.490E+01 0.411E+03 0.819E+01 0.440E+03 0.143E+02 0.471E+03
 0 200E+02 0.501E+03 0.232E+02 0.532E+03 0 232E+02 0.562E+03 0.214E+02 0.593E+03
 0 218E+02 0 624E+03 0.218E+02 0.639E+03
  SUN    5    14    FT#05-solar rad           solarbnl.ini  5  6 FF time # 5 Solar
 0.233E+03 0.267E+03 0.233E+03 0.289E+03 0.156E+03 0.320E+03 0.121E+03 0.350E+03
 0.137E+03 0.381E+03 0.198E+03 0.411E+03 0.286E+03 0.440E+03 0.384E+03 0.471E+03
 0 462E+03 0.501E+03 0.499E+03 0.532E+03 0.485E+03 0 562E+03 0.422E+03 0 593E+03
 0.330E+03 0 624E+03 0.330E+03 0.639E+03
PHOTO    6    14    FT#06-photoperiod         solarbnl ini  6  6 FF time # 6 Photo
 0 460E+00 0.267E+03 0.460E+00 0.289E+03 0.406E+00 0.320E+03 0.381E+00 0.350E+03
 0.392E+00 0.381E+03 0.435E+00 0.411E+03 0 498E+00 0.440E+03 0.568E+00 0.471E+03
 0.623E+00 0.501E+03 0.649E+00 0.532E+03 0.639E+00 0.562E+03 0.595E+00 0.593E+03
 0.530E+00 0.624E+03 0 530E+00 0.639E+03
 WIND    7    14    FT#07-wind vel            wind-nyb ini  5  6 FF time # 7 Wind v
 0.412E+01 0.267E+03 0.412E+01 0.289E+03 0.412E+01 0.320E+03 0.412E+01 0.350E+03
 0.514E+01 0.381E+03 0.514E+01 0.411E+03 0.514E+01 0.440E+03 0.514E+01 0.471E+03
 0.412E+01 0 501E+03 0.412E+01 0.532E+03 0.412E+01 0.562E+03 0.412E+01 0.593E+03
 0.412E+01 0.624E+03 0 412E+01 0.639E+03
KE#01    8    14    FT#08-Ke #1   PR/TRB      extcoeff.ini  5  9 FF time # 8 Ke #1
 0.208E+01 0 267E+03 0.208E+01 0.289E+03 0.257E+01 0.320E+03 0.136E+01 0.350E+03
 0.996E+00 0.381E+03 0.123E+01 0.411E+03 0.116E+01 0.440E+03 0.109E+01 0.471E+03
 0.101E+01 0.501E+03 0.941E+00 0.532E+03 0.868E+00 0.562E+03 0.795E+00 0.593E+03
 0.723E+00 0.624E+03 0.723E+00 0.639E+03
KE#02    9    14    FT#09-Ke #2   FB          extcoeff.ini  6  9 FF time # 9 Ke #2
 0.132E+01 0 267E+03 0.132E+01 0 289E+03 0.163E+01 0 320E+03 0.862E+00 0 350E+03
 0.634E+00 0.381E+03 0.781E+00 0 411E+03 0.736E+00 0 440E+03 0.931E+00 0.471E+03


----+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
```

```
 0.907E+00 0.501E+03 0.632E+00 0 532E+03 0.709E+00 0.562E+03 0 604E+00 0 593E+03
 0 522E+00 0.624E+03 0 522E+00 0.639E+03
KE#03   10    14   FT#10-Ke #3   GPB          extcoeff.ini  7  9 FF time #10 Ke #3
 0 157E+01 0.267E+03 0.157E+01 0.289E+03 0 146E+01 0.320E+03 0 933E+00 0.350E+03
 0 568E+00 0.381E+03 0.801E+00 0.411E+03 0.610E+00 0.440E+03 0 958E+00 0.471E+03
 0.571E+00 0.501E+03 0 453E+00 0.532E+03 0 681E+00 0.562E+03 0 482E+00 0 593E+03
 0 634E+00 0.624E+03 0.634E+00 0 639E+03
KE#04   11    14   FT#11-Ke #4   LPB          extcoeff ini  8  9 FF time #11 Ke #4
 0 144E+01 0 267E+03 0.144E+01 0.289E+03 0.134E+01 0.320E+03 0 855E+00 0 350E+03
 0.520E+00 0 381E+03 0 606E+00 0.411E+03 0 619E+00 0 440E+03 0.720E+00 0 471E+03
 0.698E+00 0.501E+03 0 727E+00 0.532E+03 0.707E+00 0 562E+03 0.562E+00 0.593E+03
 0.590E+00 0 624E+03 0.590E+00 0.639E+03
KE#05   12    14   FT#12-Ke #5   SIS/GB       extcoeff.ini  9  9 FF time #12 Ke #5
 0.122E+01 0.267E+03 0.122E+01 0 289E+03 0.113E+01 0.320E+03 0.722E+00 0 350E+03
 0 332E+00 0.381E+03 0.512E+00 0.411E+03 0.645E+00 0.440E+03 0.513E+00 0.471E+03
 0.438E+00 0.501E+03 0.473E+00 0.532E+03 0.513E+00 0.562E+03 0.474E+00 0.593E+03
 0 453E+00 0.624E+03 0 453E+00 0.639E+03
TFNH4   13    14   FT#13-NH4 flux             sedfluxx.ini  5  9 FF time #13 NH4 fl
 0 268E+00 0 267E+03 0.268E+00 0.289E+03 0.109E+00 0 320E+03 0.287E-01 0.350E+03
 0.148E-01 0 381E+03 0.218E-01 0.411E+03 0.355E-01 0.440E+03 0.124E+00 0.471E+03
 0.468E+00 0.501E+03 0.152E+01 0 532E+03 0.250E+01 0.562E+03 0.241E+01 0.593E+03
 0.141E+01 0.624E+03 0.141E+01 0.639E+03
TFPO4   14    14   FT#14-PO4 flux             sedfluxx ini  6  9 FF time #14 PO4 fl
 0.396E+00 0 267E+03 0.396E+00 0.289E+03 0.210E+00 0 320E+03 0.821E-01 0.350E+03
 0.517E-01 0.381E+03 0.677E-01 0.411E+03 0.955E-01 0.440E+03 0.230E+00 0.471E+03
 0 586E+00 0.501E+03 0.134E+01 0.532E+03 0.190E+01 0.562E+03 0.186E+01 0.593E+03
 0 128E+01 0.624E+03 0.128E+01 0.639E+03
MACRO   15    14   FT#15-Macrophy             benthbio.ini  5  8 FF time #15 Macrop
 0.670E+00 0.267E+03 0 670E+00 0.289E+03 0.730E+00 0.320E+03 0.780E+00 0.350E+03
 0 400E+00 0 381E+03 0.450E+00 0.411E+03 0.360E+00 0 440E+03 0.520E+00 0.471E+03
 0 930E+00 0.501E+03 0.114E+01 0.532E+03 0.120E+01 0.562E+03 0.100E+01 0.593E+03
 0.450E+00 0.624E+03 0.450E+00 0.639E+03
SHL#1   16    14   FT#16-Shell #1             benthbio.ini  6  8 FF time #16 Shellf
 0.100E+01 0.267E+03 0.100E+01 0.289E+03 0.100E+01 0.320E+03 0.100E+01 0.350E+03
 0.100E+01 0.381E+03 0.100E+01 0.411E+03 0.100E+01 0.440E+03 0.100E+01 0.471E+03
 0.100E+01 0.501E+03 0 100E+01 0.532E+03 0.100E+01 0.562E+03 0.100E+01 0 593E+03
 0.100E+01 0.624E+03 0.100E+01 0.639E+03
TFK1G   17    14   FT#17-time dependent grazing rate multiplier (theta=1.08)
    0.635        267      0.635        289      0.465        320      0.294        350
    0.234        381      0.267        411      0.316        440      0.487        471
    0.770        501      1.150        532      1.370        562      1.350        593
    1.130        624      1.130        639
TFSOD   18    14   FT#18-SOD flux             sedfluxx.ini  7  9 FF time #18 SOD fl
 0.729E+00 0.267E+03 0.729E+00 0.289E+03 0.587E+00 0.320E+03 0.426E+00 0.350E+03
 0 364E+00 0.381E+03 0.399E+00 0.411E+03 0.449E+00 0.440E+03 0.606E+00 0.471E+03
 0 833E+00 0.501E+03 0.111E+01 0.532E+03 0.125E+01 0.562E+03 0 124E+01 0.593E+03
 0.109E+01 0.624E+03 0.109E+01 0.639E+03
ZOOPL   19    14   FT#19-Zoopl... modified 73 micron net size
     9000        267       9000        289      12000        320      22000        350
    40000        381      80000        411      50000        440      40000        471
    40000        501      40000        532      50000        562      35000        593
    15000        624      15000        639
TFSIO   20    14   FT#20-SiO4 flux            sedfluxx.ini  4  9 FF time #20 SiO4 f
 0 709E+00 0 267E+03 0.709E+00 0.289E+03 0.560E+00 0.320E+03 0.396E+00 0.350E+03
 0.333E+00 0.381E+03 0.368E+00 0.411E+03 0.418E+00 0.440E+03 0.580E+00 0.471E+03
 0.820E+00 0.501E+03 0.112E+01 0.532E+03 0.127E+01 0.562E+03 0.126E+01 0.593E+03
 0 109E+01 0.624E+03 0.109E+01 0.639E+03
TFNO3   21    14   FT#21-NO3 flux             sedfluxx.ini  8  9 FF time #21 NO3  f
 0.793E+00 0.267E+03 0.793E+00 0.289E+03 0.677E+00 0.320E+03 0.536E+00 0.350E+03
 0.477E+00 0 381E+03 0.510E+00 0.411E+03 0.556E+00 0.440E+03 0.693E+00 0.471E+03
 0.875E+00 0.501E+03 0.108E+01 0.532E+03 0.117E+01 0.562E+03 0.117E+01 0 593E+03
 0.106E+01 0.624E+03 0.106E+01 0.639E+03
NH3_N (mg/L)                                    5   1.   9.99E+03 J:INITIAL CONC.
 SG01     0 0000       1.000 SG02     0.0000     1.000 SG03     0.0000      1.000
 SG04     0 0000       1.000 SG05     0.0001     1.000 SG06     0.0000      0.000
NO2_N (mg/L)                                    5   1.      9999. J:INITIAL CONC.
 SG01     0.0000       1.000 SG02     0.0000     1.000 SG03     0.0000      1.000
 SG04     0.0000       1.000 SG05     0.0001     1.000 SG06     0.0000      0.000
OPO4  (mg/L)                                    5   1.      9999. J:INITIAL CONC.
```

```
 SG01    0 0000      1 000 SG02    0 0000      1.000 SG03    0 0000      1 000
 SG04    0 0000      1 000 SG05    0 0001      1 000 SG06    0 0000      0 000
Phytl (mg/L)                                 4   1.     9999  J.INITIAL CONC
 SG01    0.0000      1.000 SG02    0 0000      1.000 SG03    0 0000      1.000
 SG04    0 0000      1.000 SG05    0.0001      1 000 SG06    0.0000      0.000
CBOD  (mg/L)                     -           4   1.     9999. J.INITIAL CONC.
 SG01    0.0000      1.000 SG02    0 0000      1 000 SG03    0.0000      1 000
 SG04    0 0000      1.000 SG05    0.0001      1.000 SG06    0.0000      0.000
DO    (mg/L)          -                      5   1      9999  J.INITIAL CONC
 SG01    0.0000      1.000 SG02    0 0000      1.000 SG03    0.0000      1.000
 SG04    0.0000      1 000 SG05    0 0001      1.000 SG06    0.0000      0 000
OrgN  (mg/L)              .                  5   1.     9999. J·INITIAL CONC
 SG01    0 0000      1 000 SG02    0 0000      1.000 SG03    0 0000      1 000
 SG04    0.0000      1.000 SG05    0 0001      1.000 SG06    0 0000      0 000
OrgP  (mg/L)                                 4   1      9999. J INITIAL CONC
 SG01    0.0000      1.000 SG02    0 0000      1.000 SG03    0.0000      1 000
 SG04    0 0000      1.000 SG05    0 0001      1.000 SG06    0.0000      0 000
Phyt2 (mg/L)                                 4   1.     9999. J:INITIAL CONC.
 SG01    0.0000      1.000 SG02    0 0000      1.000 SG03    0.0000      1.000
 SG04    0 0000      1 000 SG05    0 0001      1.000 SG06    0 0000      0 000
Phyt3 (mg/L)                                 4   1.     9999. J·INITIAL CONC.
 SG01    0 0000      1.000 SG02    0.0000      1 000 SG03    0 0000      1.000
 SG04    0.0000      1.000 SG05    0.0001      1 000 SG06    0.0000      0.000
Si04  (mg/L)                                 3   1.     9999  J·INITIAL CONC.
 SG01    0 0000      1.000 SG02    0 0000      1.000 SG03    0.0000      1 000
 SG04    0.0000      1.000 SG05    0.0001      1 000 SG06    0 0000      0 000
Salinity (mg/L)                              5   1.  9.99E+03 J:INITIAL CONC.
 SG01    0.0000      1 000 SG02    0 0000      1 000 SG03    0 0000      1.000
 SG04    0.0000      1.000 SG05    0.0000      1.000 SG06    0.0000      0.000
Coliforms (MPN/100ml)                        5   1   9.99E+03 J:INITIAL CONC.
 SG01    0.0000      1.000 SG02    0.0000      1.000 SG03    0 0000      1.000
 SG04    0.0000      1.000 SG05    0.0001      1.000 SG06    0.0000      0.000
```

2.2.4 WASP4 DO Water Quality File for Beacons Reach Marina

```
Filename:  WBR_11 INP    WASP4 File for Beacons Reach Marina DO Calibration
----+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8

WBR_11 INP -  Beacons Reach WASP4 Model Water 05/20/88 05/28/88
Dissolved Oxygen Calibration Run
 KSIM NSEG NSYS ICFL MFLG IDMP NSLN INTY ADFC  zyr/mm/dd hhmm   A MODEL OPTIONS
    0    6   13    1    1    1    0    0  0.0 1988/05/20 0000    1    3    5    0 00
    5
    1    2    3    4    5
    1
     900.    148 00
    3
    1800       365.    86400.     366     86400.      640.
    0    0    0    0    0    0    0    0    1    1    0    0    0
    1    +    +    *    +    *    +    *    +    *    +    *    8 EXCHANGES
    5     1.000      1.00                    (surface water)
    1
     75 0        59    0    1
    2
  0 50E+00        0.  0.50E+00      640.
    1
     82.0        59    1    2
    2
  0.40E+00        0.  0.40E+00      640.
    1
    170.0        31    2    3
    2
  0 30E+00        0.  0.30E+00      640.
    1
    160.0        32    3    4
    2
  0 10E+00        0.  0.10E+00      640.
    1
    153.0        28    4    5
    2
  0.30E+00        0.  0.30E+00      640.
    0    0    0    0    0    0    0    0    1    1    0    0    0
    2    0     720 0    +    *    +    *    +    *    +    *    C: VOLUMES
    1.0000    1.0000
         1         6         1      1303       0.0       1.0       1.0       1.0
         2         6         1      3165       0.0       1.0       1.0       1.0
         3         6         1      2032       0.0       1.0       1.0       1.0
         4         6         1      2172       0.0       1.0       1.0       1.0
         5         6         1      2377       0.0       1.0       1.0       1.0
         6         0         3     11049       0.0       1.0       1.0       1.0
    2    5     SUMRY2.OUT (BEACONS.HYD)  *    +    *    +    *    D: FLOWS
    1    1                             (Data Block D.2 Field One Flows)
    1    2    3    4    5
    0       1.0       1.0      F#2 --NINQ(2)  SCALQ=1  CONVQ= 1
    1       1.0 1.157E-05      F#3 --NINQ(3)  SCALQ=1  CONVQ= m/day * 1/86400
    5                          F#3 --NOQS(3,ni) --> number of segment pairs
      1303    1    6      3165    2    6      2032    3    6      2172    4    6
      2377    5    6
    2                          F#3 --NBRKQ(4,ni) --> number of time breaks
     0.0        0.0       0.0      640 0
    1       1.0 1.157E-05      F#4 --NINQ(3)  SCALQ=1  CONVQ= m/day * 1/86400
    5                          F#4 --NOQS(3,ni) --> number of segment pairs
      1303    1    6      3165    2    6      2032    3    6      2172    4    6
      2377    5    6
    2                          F#4---NBRKQ(5,ni) --> number of time breaks
      0.0        0.0       0.0     640.0
    1       1 0 1.157E-05      F#5 --NINQ(3)  SCALQ=1  CONVQ= m/day * 1/86400
    5
      1303    1    6      3165    2    6      2032    3    6      2172    4    6
      2377    5    6
    2                          F#5---NBRKQ(5,ni) --> number of time breaks
      0.0        0 0       0.0     640.0
    0    0    0    0    0    0    0    0    1    1    0    0    0
         1                Sys#1 NH3          (Data Group E Boundary Conditions)
      1 0        1.0
    1    3    OCN :                OCNBC001         Sys# 1
     0.040   140.000     0.040   150.000     0.040   365.000     0 000    366 000

----+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
```

```
        1                Sys#2 NO3         (Data Group E Boundary Conditions)
     1.0        1 0
   1    3    OCN                   OCNBC001          Sys# 2
    0 010   140 000     0 010   150.000    0 010   365 000     0.000   366 000
        1                Sys#3 OPO4        (Data Group E Boundary Conditions)
     1 0        1.0
   1    3    OCN                   OCNBC001          Sys# 3
    0.030   140.000     0.030   150.000    0.030   365.000     0.000   366.000
        1                Sys#4 Phyt#1      (Data Group E Boundary Conditions)
     1.0        1.0
   1    3    OCN ·                 OCNBC001          Sys# 4
    12 00   140.000     12 00   150.000    12 00   365.000     0.000   366.000
        1                Sys#5 CBOD        (Data Group E Boundary Conditions)
     1 0        1.0
   1    3    OCN ·                 OCNBC001          Sys# 5
    2.470   140.000     2.470   150 000    2.470   365 000     0 000   366.000
        1                Sys#6 DO          (Data Group E Boundary Conditions)
     1.0        1 0
   1    3    OCN :                 OCNBC001          Sys# 6
    6.150   140.000     6.150   150 000    6.150   365 000     6 150   366.000
        1                Sys#7 OrgN        (Data Group E Boundary Conditions)
     1.0        1.0
   1    3    OCN :                 OCNBC001          Sys# 7
    0.360   140 000     0.360   150.000    0.360   365.000     0.000   366.000
        1                Sys#8 OrgP        (Data Group E Boundary Conditions)
     1.0        1 0
   1    3    OCN .                 OCNBC001          Sys# 8
    0.020   140.000     0.020   150 000    0 020   365.000     0.000   366.000
        1                Sys#9 Phyt#2      (Data Group E Boundary Conditions)
     1.0        1.0
   1    3    OCN :                 OCNBC001          Sys# 9
    0.000   140.000     0.000   150 000    0.000   365 000     0.000   366.000
        1                Sys#10 Phyt#2     (Data Group E Boundary Conditions)
     1.0        1.0
   1    3    OCN                   OCNBC001          Sys# 10
    0.000   140 000     0.000   150 000    0.000   365 000     0.000   366.000
        1                Sys#11 SiO4       (Data Group E Boundary Conditions)
     1.0        1.0
   1    3    OCN ·                 OCNBC001          Sys# 11
    0 000   140.000     0.000   150 000    0.000   365 000     0 000   366.000
        1                Sys#12 Salinity   (Data Group E Boundary Conditions)
     1 0        1.0
   1    3    OCN :                 OCNBC001          Sys# 12
    0.000   140.000     30 80   150.000    30.80   365.000     0.000   366.000
        1                Sys#13 Coliforms  (Data Group E Boundary Conditions)
     1.0        1.0
   1    3    OCN :                 OCNBC001          Sys# 13
    0.000   140.000     0.000   150.000    0.000   365.000     0.000   366.000
        0    PS(t) Sys#1           (Data Block F.1 Waste Loads for Point Source)
        0    PS(t) Sys#2
        0    PS(t) Sys#3
        0    PS(t) Sys#4
        0    PS(t) Sys#5
        0    PS(t) Sys#6
        0    PS(t) Sys#7
        0    PS(t) Sys#8
        0    PS(t) Sys#9
        0    PS(t) Sys#10
        0    PS(t) Sys#11
        0    PS(t) Sys#12
        0    PS(t) Sys#13
   0    0                               (Data Group F.2 ..NPS Loads)
       17          6               FF(xyz)- G wasp4g01.dat 05/12/90 21.20:28
ZOO1X   1         1.FSIO4    2         1.TMPSG    3          1.TMPFN    4         1.
KESG    5         1.KEFN     6         1.FNH4     7       3.35FPO4      8      3.35
SOD1D   9       3.35MACRO   12         1.SHL1    13          1.SHL2    14         1.
SHL3   15         1.GWC1    21         1.GWC2    22          1.GWSW    23         1.
FNO3   24         1.
        1   of     6
```

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----+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8


Z001X    1      1 000FSI04    2   143 750TMPSG    3     1 000TMPFN    4      1 000
KESG     5      1.000KEFN     6     1.000FNH4     7    15 140FP04     8      2 100
SOD1D    9      1 000MACRO   12     0 000SHL1    13     0 000SHL2    14      0 000
SHL3    15      0 000GWC1    21     0.201GWC2    22     1 262GWSW    23      0 000
FNO3    24      4.570
         2  of     6
Z001X    1      1 000FSI04    2   143 750TMPSG    3     1 000TMPFN    4      1.000
KESG     5      1 000KEFN     6     1.000FNH4     7    15 140FP04     8      2.100
SOD1D    9      1 000MACRO   12     0 000SHL1    13     0.000SHL2    14      0 000
SHL3    15      0 000GWC1    21     0 000GWC2    22     0.000GWSW    23      0.000
FNO3    24      4.570
         3  of     6
Z001X    1      1 000FSI04    2   143 750TMPSG    3     1 000TMPFN    4      1 000
KESG     5      1 000KEFN     6     1 000FNH4     7    15 140FP04     8      2 100
SOD1D    9      1 000MACRO   12     0 000SHL1    13     0.000SHL2    14      0.000
SHL3    15      0 000GWC1    21     0 803GWC2    22     5.047GWSW    23      0.000
FNO3    24      4.570
         4  of     6
Z001X    1      1.000FSI04    2   143.750TMPSG    3     1 000TMPFN    4      1.000
KESG     5      1.000KEFN     6     1.000FNH4     7    15 140FP04     8      2.100
SOD1D    9      1 000MACRO   12     0 000SHL1    13     0.000SHL2    14      0.000
SHL3    15      0 000GWC1    21     0.201GWC2    22     1.262GWSW    23      0 000
FNO3    24      4 570
         5  of     6
Z001X    1      1 000FSI04    2   143.750TMPSG    3     1.000TMPFN    4      1 000
KESG     5      1.000KEFN     6     1.000FNH4     7    15 140FP04     8      2.100
SOD1D    9      1.000MACRO   12     0.000SHL1    13     0.000SHL2    14      0.000
SHL3    15      0.000GWC1    21     0.134GWC2    22     0.841GWSW    23      0.000
FNO3    24      4.570
         6  of     6
Z001X    1      1.000FSI04    2     0 000TMPSG    3     1.000TMPFN    4      1.000
KESG     5      1.000KEFN     6     1 000FNH4     7     0.000FP04     8      0.000
SOD1D    9      0.000MACRO   12     0.000SHL1    13     0.000SHL2    14      0.000
SHL3    15      0.000GWC1    21     0.000GWC2    22     0 000GWSW    23      0.000
FNO3    24      0.000
                   Nosys= 14      Const-H
GLOBAL               0
NH3-N                1
group #1-1          10
      K12C          11      0 250      K12T         12      1.080
      KNIT          13      2.000    ATMNH3         14      1.400
    GWFLOW          15   0.000000     GWNH3         16      0 488
     Z1CRB          17      2 500     Z1CDW         18      0.450
    NCRBZ1          19      0.167     NCRBM         39      0.082
NO3+NO2-N            1
group #1-2           5
      K20C          21      0 090      K20T         22      1.045
      KNO3          23      0.100    ATMNO3         24      1 865
     GWNO3          25      3 065
O-PO4                1
all param            4
    ATMDIP          31      0.083     GWDIP         32      0.005
    PCRBZ1          33      0.013     PCRBM         40      0.004
Phyt#1               2
group#1-4           15
       WS1          28      0.100       K1C         41      1 000
       K1T          42      1.066     LGHTS         43      2.000
     PHIMX          44    720.000       XKC         45      0.017
     CCHL1          46     80.000       IS1         47    300.000
     KMNG1          48      0.007     KMPG1         49      0.001
      K1RC          50      0.300      K1RT         51      1.080
      TUL1         112     40.000     TOPT1        113     24.000
      TLL1         114      0.000
group#2-4           10
       K1D          52      1.000       K1G         53      0.800
        W1          54      1 000     KPZDC         55      0.000
     KPZDT          56      1 000     PCRB1         57      0.030
     NCRB1          58      0.155    KMPHYT         59      1.000
    SICRB1          89      0.300     KMSG1        111      0.0140


----+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
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Filename:  WBR_11.INP    WASP4 File for Beacons Reach Marina DO Calibration
----+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8

CBOD               1
group#1-5          7
       KDC        71      0 300       KDT        72      1.047
      KDSC        73      0 000      KDST        74      1.000
      KBOD        75      0.500     GWBOD        76      1.800
      OCRB        81      2 670
Diss O2            1
group #1-6         6
       K4C        26      0.000       K4T        27      1.000
        K2        82      0 000     GWOXY        83      4.000
     KM1RC       109      0 000     KM1RT       110      1.000
Org-N              1
group #1-7         7
      K71C        91      0.075      K71T        92      1 080
     KONDC        93      0 000     KONDT        94      1.000
       FON        95      0.700    ATM_ON        96      2.801
     GW_ON        97      0.091
Org-P              1
group #1-8         7
      K83C       100      0.220      K83T       101      1.080
     KOPDC       102      0.000     KOPDT       103      1.000
       FOP       104      0.600    ATM_OP       105      0.247
     GW_OP       106      0.005
Phyt#2             2
group #1-9        12
       WS2        29      0.200     CCHL2        34     65.000 .
       IS2        35     75.000       K2C        36      1.750
       K2D        37      0.020        W2        38      1.000
      K2RC        60      0.150      K2RT        61      1.045
       K2T        62      1.066      TUL2       115     37.000
     TOPT2       116      3.000      TLL2       117      0.000
group#2-9          6
     KMNG2        63      0.007     KMPG2        64     0.0015
     NCRB2        65      0.155     PCRB2        66      0.030
    SICRB2        90      0.462     KMSG2       107      0.028
Phyt#3             2
group #1-1        10
   CLLCRB3        20      0.000       WS3        30      0.000
     CCHL3        67      1.000       IS3        68      0.000
       K3C        69      0.000       K3D        70      0.000
        W3        77      0 000      K3RC        78      0.000
      K3RT        79      1 000       K3T        80      1.000
group#2-10         6
     KMNG3        84      0.000     KMPG3        85      0 000
     NCRB3        86      0.000     PCRB3        87      0.000
    SICRB3        98      0.000     KMSG3       108      0.000
SiO4               1
group #1-1         1
      GWSI        88     20.000
Salinity           1
group #1-1         1
    GWSALT        99      0.000
Coliforms          0
        21 FF(t) WASP Data Group I FF Time- I wasp4i01.dat 10/16/90
  TEMP     1    14    FT#01-Temp #1 PR/TRB     tempxxxx.ini  5  8 FF time # 1 Temp#1
      20 70      1.00     20.70     15.00     20.70     45.00     20.70     75.00
      20.70    106.00     20.70    136.00     20.70    167.00     20.70    197.00
      20.70    228.00     20.70    259.00     20.70    289.00     20.70    320.00
      20.70    350 00     20.70    366.00
  TEMP     2    14    FT#02-Temp #2  (deg C)
      20.70      1.00     20.70     15 00     20.70     45.00     20.70     75.00
      20.70    106.00     20.70    136.00     20.70    167.00     20.70    197.00
      20.70    228.00     20.70    259.00     20.70    289.00     20.70    320.00
      20.70    350.00     20.70    366.00
  TEMP     3    14    FT#03-Temp #2  (deg C)
      20.70      1.00     20.70     15 00     20.70     45.00     20.70     75.00
      20.70    106.00     20.70    136.00     20.70    167.00     20.70    197.00
      20.70    228.00     20.70    259.00     20.70    289.00     20.70    320.00
      20 70    350.00     20.70    366.00

----+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
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 TEMP    4    14    FT#04-Temp #2  (deg C)
     20.70      1.00      20 70      15 00      20 70      45.00      20.70      75.00
     20 70    106 00      20.70     136 00      20.70     167 00      20 70     197.00
     20.70    228.00      20 70     259 00      20.70     289 00      20.70     320.00
     20.70    350.00      20.70     366.00
  SUN    5    14    FT#05-solar radiation  (langleys/day) assumes 25% cloud cover
       365      1.00        380      15.00        454      45.00        535      75 00
       606    106 00        479     136 00        479     167.00        644     197 00
       608    228 00        562     259.00        485     289.00        403     320 00
       357    350 00        365     366 00
PHOTO    6    14    FT#06-photoperiod  (fraction of day which is sunny)
     0.440      1.00      0.444      15 00      0.456      45 00      0 497      75.00
     0.534    106 00      0.438     136.00      0.438     167.00      0.568     197.00
     0 546    228.00      0 512     259.00      0.478     289.00      0.452     320.00
     0 436    350 00      0.440     366.00
 WIND    7    14    FT#07-wind velocity (m/sec)
     0.000      1.00      0.000      15.00      0.000      45.00      0 000      75.00
     0 000    106.00      0.000     136.00      0.000     167.00      0.000     197.00
     0.000    228 00      0 000     259.00      0.000     289.00      0.000     320 00
     0.000    350 00      0.000     366.00
KE#01    8    14    FT#08-Ke #1    (1/meter)
     2 430      1.00      2 430      15 00      2.430      45.00      2 430      75.00
     2.430    106.00      2 430     136 00      2 430     167.00      2 430     197.00
     2.430    228 00      2.430     259.00      2.430     289.00      2 430     320 00
     2.430    350.00      2.430     366.00
KE#02    9    14    FT#09-Ke #2    (1/meter)
     2.430      1.00      2.430      15.00      2 430      45.00      2.430      75.00
     2.430    106.00      2.430     136.00      2 430     167 00      2 430     197.00
     2 430    228 00      2.430     259.00      2 430     289.00      2 430     320.00
     2 430    350 00      2.430     366.00
KE#03   10    14    FT#10-Ke #3    (1/meter)
     2.430      1.00      2 430      15.00      2.430      45.00      2.430      75.00
     2.430    106.00      2.430     136.00      2 430     167.00      2.430     197.00
     2.430    228.00      2.430     259.00      2.430     289.00      2 430     320.00
     2 430    350 00      2.430     366.00
KE#04   11    14    FT#11-Ke #4    (1/meter)
     2 430      1.00      2.430      15.00      2 430      45.00      2 430      75.00
     2 430    106.00      2.430     136.00      2.430     167.00      2.430     197.00
     2.430    228.00      2.430     259.00      2.430     289.00      2.430     320.00
     2.430    350.00      2.430     366.00
KE#05   12    14    FT#12-Ke #5    (1/meter)
     2.430      1.00      2.430      15 00      2 430      45.00      2.430      75.00
     2.430    106.00      2.430     136.00      2.430     167 00      2.430     197.00
     2.430    228 00      2.430     259.00      2 430     289 00      2.430     320.00
     2.430    350 00      2.430     366 00
TFNH4   13    14    FT#13-NH4 flux  (theta = 1.08)
     2.301      1.00      2 301      15.00      2.301      45.00      2.301      75.00
     2 301    106.00      2.301     136.00      2.381     167.00      2.455     197.00
     2.455    228.00      2.245     259.00      2.245     289.00      2.245     320.00
     2 245    350.00      2.301     366.00
TFPO4   14    14    FT#14-PO4 flux  (theta = 1.08)
     2 301      1.00      2.301      15.00      2.301      45.00      2.301      75 00
     2 301    106.00      2.301     136.00      2.381     167 00      2.455     197.00
     2 455    228.00      2.245     259.00      2.245     289 00      2.245     320.00
     2.245    350.00      2.301     366.00
MACRO   15    14    FT#15-Macrophy
     1.000      1.00      1.000      15.00      1.000      45.00      1 000      75.00
     1.000    106.00      1.000     136.00      1.000     167.00      1.000     197 00
     1.000    228.00      1.000     259.00      1 000     289.00      1.000     320.00
     1 000    350.00     ~1 000     366.00
SHL#1   16    14    FT#16-Shell #1
     1.000      1.00      1.000      15.00      1.000      45.00      1.000      75.00
     1.000    106.00      1.000     136.00      1.000     167.00      1.000     197.00
     1.000    228.00      1.000     259.00      1.000     289 00      1.000     320.00
     1.000    350.00      1.000     366.00
TFK1G   17    14    FT#17-time dependent grazing rate multiplier (theta=1.00)
     1.000      1 00      1.000      15 00      1.000      45.00      1.000      75.00
     1.000    106 00      1.000     136.00      1 000     167.00      1.000     197.00
     1.000    228 00      1.000     259.00      1 000     289.00      1 000     320.00
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     1.000    350 00     1.000    366 00
TFSOD   18     14   FT#18-SOD flux  (theta = 1.047)
     1 644      1 00     1 644     15.00     1.644     45.00     1.644     75 00
     1 644    106.00     1 644    136.00     1.678    167 00     1 709    197 00
     1 709    228.00     1.620    259.00     1.620    289.00     1.620    320.00
     1 620    350 00     1.620   - 366.00
ZOOPL   19     14   FT#19-Zoopl.   modified 73 micron net size
     20000      1.00     20000     15.00     20000     45.00     20000     75.00
     20000    106.00     20000    136.00     40000    167.00     80000    197 00
     20000    228 00     20000    259 00     20000    289.00     20000    320.00
     20000    350.00     20000    366.00
TFSIO   20     14   FT#20-Si04 flux  (theta = 1 08)
     2.301      1.00     2.301     15.00     2.301     45.00     2.301     75.00
     2.301    106.00     2 301    136.00     2.381    167.00     2 455    197.00
     2.455    228.00     2.245    259.00     2.245    289.00     2.245    320.00
     2 245    350.00     2 301    366.00
TFNO3   21     14   FT#21-NO3 flux  (theta = 1.08)
     2.301      1 00     2.301     15.00     2.301     45.00     2 301     75.00
     2 301    106.00     2 301    136.00     2.381    167 00     2.455    197 00
     2.455    228 00     2.245    259 00     2.245    289.00     2 245    320.00
     2 245    350 00     2.301    366 00
NH3_N (mg/L)                                5   1.  9.99E+03 J:INITIAL CONC.
 SG01    0.0700      1.000 SG02    0.0700     1.000 SG03    0.0700     1.000
 SG04    0.0700      1.000 SG05    0 0700     1.000 SG06    0.0000     0.000
NO2_N (mg/L)                                5   1.     9999. J INITIAL CONC.
 SG01    0.0200      1 000 SG02    0.0200     1.000 SG03    0.0200     1.000
 SG04    0.0200      1 000 SG05    0.0200     1.000 SG06    0.0000     0.000
OPO4  (mg/L)                                5   1.     9999. J:INITIAL CONC.
 SG01    0.0420      0.600 SG02    0 0420     0.600 SG03    0.0420     0.600
 SG04    0.0420      0.600 SG05    0.0420     0.600 SG06    0.0000     0 000
Phytl (mg/L)                                4   1.     9999. J:INITIAL CONC.
 SG01    14 000      0.000 SG02    14.000     0.000 SG03    14 000     0.000
 SG04    14.000      0.000 SG05    14.000     0.000 SG06    0 0000     0.000
CBOD  (mg/L)                                4   1.     9999. J:INITIAL CONC.
 SG01    2.4700      0.500 SG02    2.4700     0.500 SG03    2 4700     0.500
 SG04    2.4700      0.500 SG05    2.4700     0.500 SG06    0.0000     0.000
DO    (mg/L)                                5   1.     9999  J:INITIAL CONC.
 SG01    5 0000      1.000 SG02    5.0000     1 000 SG03    5.0000     1.000
 SG04    5.0000      1.000 SG05    5.0000     1 000 SG06    0 0000     0.000
OrgN  (mg/L)                                5   1.     9999. J:INITIAL CONC.
 SG01    0.0420      0.500 SG02    0 0420     0 500 SG03    0.0420     0.500
 SG04    0 0420      0.500 SG05    0.0420     0.500 SG06    0.0000     0.000
OrgP  (mg/L)                                4   1.     9999. J.INITIAL CONC.
 SG01    0.0280      0.700 SG02    0.0280     0 700 SG03    0.0280     0 700
 SG04    0.0280      0.700 SG05    0.0280     0.700 SG06    0.0000     0.000
Phyt2 (mg/L)                                4   1.     9999. J:INITIAL CONC
 SG01    0.0000      0.000 SG02    0.0000     0.000 SG03    0.0000     0.000
 SG04    0.0000      0.000 SG05    0.0001     0 000 SG06    0.0000     0.000
Phyt3 (mg/L)                                4   1.     9999. J.INITIAL CONC.
 SG01    0 0000      0.000 SG02    0.0000     0.000 SG03    0.0000     0.000
 SG04    0.0000      0.000 SG05    0.0001     0.000 SG06    0 0000     0.000
Si04  (mg/L)                                3   1.  9.99E+06 J:INITIAL CONC.
 SG01    0.0000      0.300 SG02    0 0000     0.300 SG03    0.0000     0.300
 SG04    0.0000      0.300 SG05    0.0001     0.300 SG06    0.0000     0.000
Salinity (mg/L)                             5   1.  9 99E+03 J:INITIAL CONC.
 SG01   30.8000      1.000 SG02   30.8000     1.000 SG03   30.8000     1.000
 SG04   30.8000      1.000 SG05   30.8000     1.000 SG06    0.0000     0 000
Coliforms (MPN/100ml)                       5   1.  9.99E+10 J:INITIAL CONC.
 SG01    0.0000      1.000 SG02    0.0000     1.000 SG03    0.0000     1.000
 SG04    0.0000      1.000 SG05    0.0001     1.000 SG06    0.0000     0.000
```

2.3 Gull Harbor Marina

2.3.1 DYNHYD5 Dye Hydrodynamic File for Gull Harbor Marina

```
DYNHYD5 - Gull Harbor Marina
GULL INP - Hydrodynamics for dye simulation Oct 24, 1988 to Oct 26, 1988
***** Data Group A. PROGRAM CONTROL DATA ************************
    3    2 0000   6.00000    5    1988/10/23 00.00    1988/10/27 00 00
***** Data Group B· OUTPUT CONTROL DATA *************************
    1988/10/23 01 00        1.0   - 1    3    0
    1
    1    2    3
***** Data Group C. SUMMARY CONTROL DATA ************************
    1    1988/10/23 00.00   25.0000  150
Gull HYD
***** Data Group D: JUNCTION DATA *******************************
    1     0 001       698       -1 5        44        33    1
    2     0 001      1023       -1 5        35        71    1    2
    3     0.001      1245       -1 5        36       103    2
***** Data Group E: CHANNEL DATA ********************************
   .1        39        18        1.5     0 030     0.001    1    2
    2        32        33        1.5     0.030     0.001    2    3
***** Data Group F 1: CONSTANT INFLOWS (m/sec) ****************************
    0
***** Data Group F 2: VARIABLE INFLOWS (m/sec) - Daily Flows **************
    0
** Data Group G: SEAWARD BOUNDARY DATA (m) - Variable Tide
    1
    3    1   22   15       0.0    0.0000       0.0    1.0000    0 0000
    1988/10/22 16 30     0 300    1988/10/22 21.30    -0.300
    1988/10/23 04.45     0.300    1988/10/23 10.45    -0 300
    1988/10/23 18:30     0.300    1988/10/24 01:30    -0.300
    1988/10/24 06:30     0.300    1988/10/24 11:30    -0 300
    1988/10/24 16:30     0.300    1988/10/24 21·30    -0.300
    1988/10/25 04 45     0.300    1988/10/25 10:45    -0.300
    1988/10/25 17·30     0.300    1988/10/25 22:45    -0.300
    1988/10/26 05·30     0.300    1988/10/26 11:30    -0.300
    1988/10/26 16:30     0.300    1988/10/26 21:30    -0.300
    1988/10/27 04:45     0.300    1988/10/27 10:45    -0.300
    1988/10/27 17:30     0.300    1988/10/14 22:45    -0.300
** Data Group H: WIND DATA (m/sec) mean monthly winds at Gull Harbor **
    0
```

2.3.2 DYNHYD5 DO Hydrodynamic File for Gull Harbor Marina

```
Filename   HGH_11 INP    DYNHYD5 File for Gull Harbor Marina DO Calibration
----+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8

DYNHYD5 - Gull Harbor Marina
HGH_11.INP - Hydrodynamics for water quality simulation May 20,to May 27, 1988
***** Data Group A  PROGRAM CONTROL DATA ************************
    3    2 0000   6.00000    5    1988/05/20 00 00    1988/05/28 00 00
***** Data Group B· OUTPUT CONTROL DATA ************************
    1988/05/20 01:00        1.0  - 1    3    0
    1
    1    2    3
***** Data Group C. SUMMARY CONTROL DATA ************************
    1    1988/05/20 00:00   25.0000  150
HGH_11.HYD
***** Data Group D: JUNCTION DATA *******************************
    1     0.001       698      -1.5        44        33    1
    2     0.001      1023      -1.5        35        71    1    2
    3     0.001      1245      -1.5        36       103    2
***** Data Group E: CHANNEL DATA *******************************
    1        39        18       1 5    0.030     0.001    1    2
    2        32        33       1.5    0.030     0.001    2    3
***** Data Group F.1: CONSTANT INFLOWS (m/sec) ***************************
    0
***** Data Group F.2: VARIABLE INFLOWS (m/sec) - Daily Flows **************
    0
** Data Group G: SEAWARD BOUNDARY DATA (m) - Variable Tide
    1
    3    1   34   15        0.0    0 0000       0.0    1.0000    0 0000
    1988/05/19 22:24      0.715    1988/05/20 04:53      0.580
    1988/05/20 10.56      0.539    1988/05/20 16:43      0 109
    1988/05/20 23.09      0.662    1988/05/21 05:39      0.081
    1988/05/21 11:47      0.522    1988/05/21 17:33      0.139
    1988/05/21 23:57      0.613    1988/05/22 06:25      0.094
    1988/05/22 12·39      0.515    1988/05/22 18.29      0.154
    1988/05/23 00:47      0.569    1988/05/23 07.12      0.096
    1988/05/23 13·32      0.518    1988/05/23 19:29      0.152
    1988/05/24 01:39      0.534    1988/05/24 07:58      0.086
    1988/05/24 14:24      0.533    1988/05/24 20:28      0.132
    1988/05/25 02:32      0.507    1988/05/25 08:44      0.066
    1988/05/25 15:13      0.556    1988/05/25 21:25      0.098
    1988/05/25 03 24      0.489    1988/05/26 09:27      0.038
    1988/05/26 15:59      0.588    1988/05/26 22:17      0.057
    1988/05/26 04:12      0.479    1988/05/27 10:10      0.008
    1988/05/27 16:42      0.625    1988/05/27 23:05      0.016
    1988/05/27 04:59      0.478    1988/05/28 10:52     -0.022
** Data Group H: WIND DATA (m/sec) mean monthly winds at Gull Harbor **
    0

----+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
```

2.3.3 WASP4 Dye Water Quality File for Gull Harbor Marina

```
GULLDYE.INP -  Gull Harbor WASP4 Model Dye Release Simulation 10/23/88 10/27/88
Dye Results are used for model Calibration
 KSIM NSEG NSYS ICFL MFLG IDMP NSLN INTY ADFC  zyr/mm/dd hhmm   A MODEL OPTIONS
    0    4   13    1    1    1    0    0  0 0 1988/10/24 1200    1    1    3   0.00
    3
    1    2    3
    1
      180.     301 00
    3
       30.      365.    86400       366     86400       640
    1    1    1    1    1    1    1    1    1    1    1    0    1
    1    +    +    *    +    *    +    *    +    *    +    *    B EXCHANGES
    3     1 000      1.00                   (surface water)
    1
      27.0        40    0    1
    2
  0.90E+00        0.  0.00E+00      640.
    1
      50.0        39    1    2
    2
  0.90E+00        0.  0 00E+00      640.
    1
      50.0        32    2    3
    2
  0.30E+00        0.  0 30E+00      640.
    1    1    1    1    1    1    1    1    1    1    1    0    1
    2    0     720 0    +    *    +    *    +    *    +    *    C: VOLUMES
    1.0000    1.0000
         1         4         1      1047       0.0        1.0        1.0        1.0
         2         4         1      1535       0.0        1.0        1.0        1.0
         3         4         1      1868       0.0        1.0        1.0        1.0
         4         0         3      6622       0.0        1.0        1.0        1.0
    2    5     SUMRY2.OUT (GULL.HYD)  *    +    *    +    *   D: FLOWS
    1    1                           (Data Block D.2 Field One Flows)
    1    2 .  3
    0        1.0       1.0      F#2 --NINQ(2)  SCALQ=1  CONVQ= 1
    1        1.0 1.157E-05      F#3 --NINQ(3)  SCALQ=1  CONVQ= m/day * 1/86400
    3                           F#3 --NOQS(3,ni) --> number of segment pairs
     1047    1    4      1535    2    4      1868    3    4
    2                           F#3 --NBRKQ(4,ni) --> number of time breaks
     0.0        0 0      0.0      640.0
    1        1.0 1.157E-05      F#4 --NINQ(3)  SCALQ=1  CONVQ= m/day * 1/86400
    3                           F#4 --NOQS(3,ni) --> number of segment pairs
     1047    1    4      1535    2    4      1868    3    4
    2                           F#4---NBRKQ(5,ni) --> number of time breaks
      0 0       0.0        0.0      640.0
    1        1.0 1.157E-05      F#5 --NINQ(3)  SCALQ=1  CONVQ= m/day * 1/86400
    3                           F#5 --NOQS(5,ni) --> number of segment pairs
     1047    1    4      1535    2    4      1868    3    4
    2                           F#5---NBRKQ(5,ni) --> number of time breaks
      0.0       0.0        0.0      640.0
    1    1    1    1    1    1    1    1    1    1    1    0    1
         1                Sys#1 NH3         (Data Group E Boundary Conditions)
      1.0       1.0
    1    6    OCN :               OCNBC001          Sys# 1
   0 000    284.000     0.000   285.354   000.00    285.355      0.000   285.396
   0.000    285.397   000.000   365.000
         1                Sys#2 NO3         (Data Group E Boundary Conditions)
      1.0       1.0
    1    6    OCN :       -       OCNBC001          Sys# 2
   0.000    284.000     0.000   285.354   000.00    285.355      0.000   285 396
   0.000    285.397   000.000   365.000
         1                Sys#3 OPO4        (Data Group E Boundary Conditions)
      1.0       1.0
    1    6    OCN ·               OCNBC001          Sys# 3
   0.000    284.000     0.000   285.354   000.00    285 355      0.000   285 396
   0.000    285.397   000.000   365 000
         1                Sys#4 Phyt#1      (Data Group E Boundary Conditions)
      1.0       1 0
```

```
   1    6   OCN                    OCNBC001          Sys# 4
    0 000   284 000     0 000   285 354   000 00    285 355     0.000    285 396
    0.000   285 397   000.000   365 000
       1                 Sys#5 CBOD         (Data Group E Boundary Conditions)
      1.0        1 0
   1    6   OCN .                - OCNBC001          Sys# 5
    0.000   284.000     0.000   285 354   000.00    285.355     0 000    285.396
    0.000   285 397   000.000   365 000
       1                 Sys#6 DO           (Data Group E Boundary Conditions)
      1.0        1 0
   1    6   OCN :                  OCNBC001          Sys# 6
    0.000   284.000     0 000   285.354   000 00    285.355     0 000    285.396
    0.000   285.397   000 000   365 000
       1                 Sys#7 OrgN         (Data Group E Boundary Conditions)
      1.0        1 0
   1    6   OCN :                  OCNBC001          Sys# 7
    0.000   284.000     0.000   285 354   000 00    285.355     0.000    285.396
    0.000   285.397   000 000   365.000
       1                 Sys#8 OrgP         (Data Group E Boundary Conditions)
      1.0        1.0
   1    6   OCN :                  OCNBC001          Sys# 8
    0.000   284 000     0 000   285 354   000.00    285.355     0.000    285 396
    0.000   285.397   000 000   365.000
       1                 Sys#9 Phyt#2       (Data Group E Boundary Conditions)
      1.0        1 0
   1    6   OCN .                  OCNBC001          Sys# 9
    0.000   284.000     0.000   285.354   000.00    285 355     0.000    285 396
    0 000   285.397   000.000   365.000
       1                 Sys#10 Phyt#2      (Data Group E Boundary Conditions)
      1 0        1 0
   1    6   OCN :                  OCNBC001          Sys# 10
    0.000   284 000     0.000   285.354   000.00    285 355     0.000    285.396
    0.000   285.397   000 000   365.000
       1                 Sys#11 SiO4        (Data Group E Boundary Conditions)
      1.0        1 0
   1    6   OCN :                . OCNBC001          Sys# 11
    0.000   284 000     0.000   285.354   000.00    285.355     0.000    285.396
    0.000   285.397   000.000   365 000
     . 1                 Sys#12 Salinity    (Data Group E Boundary Conditions)
      1.0        1.0
   1    6   OCN :                  OCNBC001          Sys# 12
    0.000   284.000     0 000   285.354     0 000   285.355     0 000    285.396
    0.000   285 397     0.000   365.000
       1                 Sys#13 Coliforms   (Data Group E Boundary Conditions)
      1.0        1.0
   1    6   OCN :                  OCNBC001          Sys# 13
    0.000   284.000     0.000   298.697    00 000   298.698    00.000    298.719
    0.000   295 720   000.000   365.000
       2    PS(t) Sys#1            (Data Block F.1 Waste Loads for Point Source)
 0 100E+01 0.100E+01  PS(t)     :System # 1 Dye      Kg/Day      Scale/conv fct
   2    6  Seg 002    Dye Input         OCNBC001.INE  5 17 Sys# 1 OCN88RAT.INE
    0.000   284.000     0.000   298.677    19.200   298.698    00.000    298.719
    0 000   295.720   000 000   365.000
   3    6  Seg 003    Dye Input            OCNBC001.INE  5 17 Sys# 1 OCN88RAT.INE
    0.000   284.000     0.000   298.677    19.200   298.698    00.000    298.719
    0.000   295.720   000.000   365.000
       2    PS(t) Sys#2            (Data Block F.1 Waste Loads for Point Source)
 0.100E+01 0.100E+01  PS(t)     :System # 2 NO3      Kg/Day      Scale/conv fct
   2    6  Seg 002    Dye Input         OCNBC001 INE  5 17 Sys# 1 OCN88RAT.INE
    0.000   284.000    -0.000   285.354      0.00   285 355     0.000    285.396
    0.000   285.397   000 000   365.000
   3    6  Seg 003    Dye Input            OCNBC001.INE  5 17 Sys# 1 OCN88RAT.INE
    0.000   284.000     0 000   285.354      0.00   285.355     0.000    285.396
    0.000   285.397   000.000   365.000
       2    PS(t) Sys#3            (Data Block F.1 Waste Loads for Point Source)
 0.100E+01 0 100E+01  PS(t)     ·System # 3 OP04     Kg/Day      Scale/conv fct
   2    6  Seg 002    Dye Input         OCNBC001.INE  5 17 Sys# 1 OCN88RAT.INE
    0.000   284.000     0.000   285 354      0.00   285.355     1.000    285.396
    0 000   285.397   000.000   365.000
```

```
Filename: GULLDYE.INP    WASP4 File for Gull Harbor Marina Dye Calibration
----+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8

    3    6  Seg 003    Dye Input           OCNBC001.INE  5 17 Sys# 1 OCN88RAT.INE
    0.000    284.000      0.000   285.354      0.00    285.355     1.000   285.396
    0.000    285.397    000.000   365.000
         2  PS(t) Sys#4           (Data Block F.1 Waste Loads for Point Source)
 0.100E+01 0.100E+01  PS(t)      :System # 4 Phyt1     Kg/Day     Scale/conv fct
    2    6  Seg 002    Dye Input        OCNBC001.INE  5 17 Sys# 1 OCN88RAT.INE
    0.000    284.000      0.000   285.354      0.00    285.355     1.000   285.396
    0.000    285.397    000.000   365.000
    3    6  Seg 003    Dye Input           OCNBC001.INE  5 17 Sys# 1 OCN88RAT.INE
    0.000    284.000      0.000   285.354      0.00    285.355     1.000   285.396
    0.000    285.397    000.000   365.000
         2  PS(t) Sys#5           (Data Block F.1 Waste Loads for Point Source)
 0.100E+01 0.100E+01  PS(t)      :System # 5 CBOD      Kg/Day     Scale/conv fct
    2    6  Seg 002    Dye Input        OCNBC001.INE  5 17 Sys# 1 OCN88RAT.INE
    0.000    284.000      0.000   285.354      0.00    285.355     1.000   285.396
    0.000    285.397    000.000   365.000
    3    6  Seg 003    Dye Input           OCNBC001.INE  5 17 Sys# 1 OCN88RAT.INE
    0.000    284.000      0.000   285.354      0.00    285.355     1.000   285.396
    0.000    285.397    000.000   365.000
         2  PS(t) Sys#6           (Data Block F.1 Waste Loads for Point Source)
 0.100E+01 0.100E+01  PS(t)      :System # 6 DO        Kg/Day     Scale/conv fct
    2    6  Seg 002    Dye Input        OCNBC001.INE  5 17 Sys# 1 OCN88RAT.INE
    0.000    284.000      0.000   285.354      0.00    285.355     1.000   285.396
    0.000    285.397    000.000   365.000
    3    6  Seg 003    Dye Input           OCNBC001.INE  5 17 Sys# 1 OCN88RAT.INE
    0.000    284.000      0.000   285.354      0.00    285.355     1.000   285.396
    0.000    285.397    000.000   365.000
         2  PS(t) Sys#7           (Data Block F.1 Waste Loads for Point Source)
 0.100E+01 0.100E+01  PS(t)      :System # 7 OrgN      Kg/Day     Scale/conv fct
    2    6  Seg 002    Dye Input        OCNBC001.INE  5 17 Sys# 1 OCN88RAT.INE
    0.000    284.000      0.000   285.354      0.00    285.355     1.000   285.396
    0.000    285.397    000.000   365.000
    3    6  Seg 003    Dye Input           OCNBC001.INE  5 17 Sys# 1 OCN88RAT.INE
    0.000    284.000      0.000   285.354      0.00    285.355     1.000   285.396
    0.000    285.397    000.000   365.000
         2  PS(t) Sys#8           (Data Block F.1 Waste Loads for Point Source)
 0.100E+01 0.100E+01  PS(t)      :System # 8 OrgP      Kg/Day     Scale/conv fct
    2    6  Seg 002    Dye Input        OCNBC001.INE  5 17 Sys# 1 OCN88RAT.INE
    0.000    284.000      0.000   285.354      0.00    285.355     1.000   285.396
    0.000    285.397    000.000   365.000
    3    6  Seg 003    Dye Input           OCNBC001.INE  5 17 Sys# 1 OCN88RAT.INE
    0.000    284.000      0.000   285.354      0.00    285.355     1.000   285.396
    0.000    285.397    000.000   365.000
         2  PS(t) Sys#9           (Data Block F.1 Waste Loads for Point Source)
 0.100E+01 0.100E+01  PS(t)      :System # 9 Phyt2     Kg/Day     Scale/conv fct
    2    6  Seg 002    Dye Input        OCNBC001.INE  5 17 Sys# 1 OCN88RAT.INE
    0.000    284.000      0.000   285.354      0.00    285.355     1.000   285.396
    0.000    285.397    000.000   365.000
    3    6  Seg 003    Dye Input           OCNBC001.INE  5 17 Sys# 1 OCN88RAT.INE
    0.000    284.000      0.000   285.354      0.00    285.355     1.000   285.396
    0.000    285.397    000.000   365.000
         2  PS(t) Sys#10          (Data Block F.1 Waste Loads for Point Source)
 0.100E+01 0.100E+01  PS(t)      :System # 10 Phyt3    Kg/Day     Scale/conv fct
    2    6  Seg 002    Dye Input        OCNBC001.INE  5 17 Sys# 1 OCN88RAT.INE
    0.000    284.000      0.000   285.354      0.00    285.355     1.000   285.396
    0.000    285.397    000.000   365.000
    3    6  Seg 003    Dye Input           OCNBC001.INE  5 17 Sys# 1 OCN88RAT.INE
    0.000    284.000      0.000   285.354      0.00    285.355     1.000   285.396
    0.000    285.397    000.000   365.000
         2  PS(t) Sys#11          (Data Block F.1 Waste Loads for Point Source)
 0.100E+01 0.100E+01  PS(t)      :System # 11 SiO4     Kg/Day     Scale/conv fct
    2    6  Seg 002    Dye Input        OCNBC001.INE  5 17 Sys# 1 OCN88RAT.INE
    0.000    284.000      0.000   285.354      0.00    285.355     1.000   285.396
    0.000    285.397    000.000   365.000
    3    6  Seg 003    Dye Input           OCNBC001.INE  5 17 Sys# 1 OCN88RAT.INE
    0.000    284.000      0.000   285.354      0.00    285.355     1.000   285.396
    0.000    285.397    000.000   365.000
         2  PS(t) Sys#12          (Data Block F.1 Waste Loads for Point Source)
 0.100E+01 0.100E+01  PS(t)      :System # 12 Salin    Kg/Day     Scale/conv fct

----+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
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```
    2    6  Seg 002   Dye Input          Sys# 12
     0 000   284.000      0.000   298 680   019 200   298 704     00 000    298.728
     0 000   300.000      0.000   365 000
    3    6  Seg 002   Dye Input          Sys# 12
     0 000   284 000      0.000   298 680   019 200   298.704     00 000    295 728
     0.000   300.000    000.000  -365.000
         2   PS(t) Sys#13          (Data Block F.1 Waste Loads for Point Source)
 0.100E+01 0 100E+01  PS(t)      :System # 13 Coli    Kg/Day      Scale/conv fct
    2    6  Seg 002   Dye Input          OCNBC001.INE  5 17 Sys# 1 OCN88RAT.INE
     0.000   284.000      0 000   285 354      0.00   285.355     1.000   285.396
     0.000   285.397    000.000   365 000
    3    6  Seg 003   Dye Input            OCNBC001 INE  5 17 Sys# 1 OCN88RAT.INE
     0.000   284.000      0.000   285 354      0 00   285.355     1.000   285.396
     0.000   285.397    000.000   365 000
    0    0                             (Data Group F.2 ..NPS Loads)
        17          4                FF(xyz)- G wasp4g01.dat 05/12/90 21:20:28
Z001X    1          1 FSI04     2         1 TMPSG     3          1.TMPFN     4          1.
KESG     5          1 KEFN      6         1 FNH4      7          1.FP04      8          1.
SOD1D    9          1 MACRO    12         1 SHL1     13          1.SHL2     14          1.
SHL3    15          1 GWC1     21         1 GWC2     22          1 GWSW     23          1.
FN03    24          1.
         1  of      4
Z001X    1       1.000FSI04     2   143 750TMPSG      3        1.000TMPFN     4       4 000
KESG     5       1.000KEFN      6     5 000FNH4       7        8.400FP04      8       1 560
SOD1D    9       0.600MACRO    12     0 000SHL1      13        0.000SHL2     14       0 000
SHL3    15       0 000GWC1     21     0.201GWC2      22        1.262GWSW     23       0.020
FN03    24       4.570
         2  of      4
Z001X    1       1.000FSI04     2   143.750TMPSG      3        1 000TMPFN     4       4.000
KESG     5       1.000KEFN      6     5.000FNH4       7        8 400FP04      8       1.560
SOD1D    9       0.600MACRO    12     0.000SHL1      13        0.000SHL2     14       0.000
SHL3    15       0.000GWC1     21     0.000GWC2      22        0 000GWSW     23       0.000
FN03    24       4.570
         3  of      4
Z001X    1       1.000FSI04     2   143 750TMPSG      3        1.000TMPFN     4       4.000
KESG     5       1.000KEFN      6     5 000FNH4       7        8 400FP04      8       1.560
SOD1D    9       0.600MACRO    12     0.000SHL1      13        0.000SHL2     14       0.000
SHL3    15       0.000GWC1     21     0.803GWC2      22        5.047GWSW     23       0.020
FN03    24       4.570
         4  of      4
Z001X    1       1.000FSI04     2   143.750TMPSG      3        1 000TMPFN     4       4 000
KESG     5       1.000KEFN      6     5.000FNH4       7        8.400FP04      8       1.560
SOD1D    9       0.600MACRO    12     0 000SHL1      13        0.000SHL2     14       0.000
SHL3    15       0.000GWC1     21     0.201GWC2      22        1.262GWSW     23       0 020
FN03    24       4.570
                   Nosys= 14      Const-H
GLOBAL             0
NH3-N              1
group #1-1        10
      K12C        11      0.250      K12T         12      1.080
      KNIT        13      2.000    ATMNH3         14      0.000
    GWFLOW        15   0.000000     GWNH3         16      0.000
     Z1CRB        17      2.500     Z1CDW         18      0.450
    NCRBZ1        19      0.167     NCRBM         39      0.082
N03+N02-N          1
group #1-2         5
      K20C        21      0.045      K20T         22      1.045
      KN03        23      0.100    ATMN03         24      2.359
     GWN03        25      3.065
O-P04              1
all param          4
    ATMDIP        31      0.053     GWDIP         32      0.005
    PCRBZ1        33      0.013     PCRBM         40      0.004
Phyt#1             2
group#1-4         12
       WS1        28      0.100       K1C         41      2.500
       K1T        42      1.066     LGHTS         43      2.000
     PHIMX        44    720.000       XKC         45      0.017
     CCHL1        46     80.000       IS1         47    300.000
```

```
     KMNG1        48     0 014     KMPG1        49     0 001
      K1RC        50     0.100      K1RT        51     1.080
group#2-4         10
       K1D        52     0.040       K1G        53     0 800
        W1        54     1.000     KPZDC        55     0 000
     KPZDT        56     1.000     PCRB1        57     0.030
     NCRB1        58     0 150    KMPHYT        59     1 000
    SICRB1        89     0.177     KMSG1       111    0.0014
CBOD               1
group#1-5          7
       KDC        71     0 200       KDT        72     1.047
      KDSC        73     0.000      KDST        74     1.000
      KBOD        75     0 500     GWBOD        76     1.800
      OCRB        81     2.670
Diss 02            1
group #1-6         6
       K4C        26     0 000       K4T        27     1 000
        K2        82     0.000     GWOXY        83     4 000
     KM1RC       109     0 000     KM1RT       110     1.000
Org-N              1
group #1-7         7
      K71C        91     0.075      K71T        92     1 080
     KONDC        93     0.000     KONDT        94     1 000
       FON        95     0.750    ATM_ON        96     2.801
     GW_ON        97     0.091
Org-P              1
group #1-8         7
      K83C       100     0 220      K83T       101     1.080
     KOPDC       102     0.000     KOPDT       103     1.000
       FOP       104     0 600    ATM_OP       105     0 247
     GW_OP       106     0.005
Phyt#2             2
group #1-9         9
       WS2        29     0.200     CCHL2        34    50 000
       IS2        35   150.000       K2C        36     2.100
       K2D        37     0.040        W2        38     1 000
      K2RC        60     0.100      K2RT        61     1.045
       K2T        62     1.066
group#2-9          6
     KMNG2        63     0.021     KMPG2        64    0.0015
     NCRB2        65     0.154     PCRB2        66     0.030
    SICRB2        90     0 462     KMSG2       107     0 042
Phyt#3             2
group #1-1        10
   CLLCRB3        20     0.000       WS3        30     0.000
     CCHL3        67     1.000       IS3        68     0.000
       K3C        69     0.000       K3D        70     0.000
        W3        77     0.000      K3RC        78     0.000
      K3RT        79     1.000       K3T        80     1.000
group#2-10         6
     KMNG3        84     0.000     KMPG3        85     0.000
     NCRB3        86     0.000     PCRB3        87     0.000
    SICRB3        98     0.000     KMSG3       108     0.000
Si04               1
group #1-1         1
      GWSI        88    20.000
Salinity           1
group #1-1         1
    GWSALT        99     0.000
Coliforms          0
        21 FF(t) WASP Data Group I FF Time- I wasp4i01.dat 10/16/90
 TEMP    1    14    FT#01-Temp #1 PR/TRB     tempxxxx.ini  5  8 FF time # 1 Temp#1
 0 138E+02 0.267E+03 0.138E+02 0 289E+03 0.122E+02 0 320E+03 0 449E+01 0.350E+03
 0.393E+01 0.381E+03 0.338E+01 0.411E+03 0.601E+01 0.440E+03 0.117E+02 0.471E+03
 0.186E+02 0.501E+03 0.226E+02 0 532E+03 0.262E+02 0 562E+03 0.246E+02 0.593E+03
 0.209E+02 0.624E+03 0.209E+02 0.639E+03
 TEMP    2    14    FT#02-Temp #2 FB         tempxxxx.ini  6  8 FF time # 2 Temp#2
 0.131E+02 0.267E+03 0.131E+02 0.289E+03 0 868E+01 0.320E+03 0.500E+01 0.350E+03
 0.128E+01 0.381E+03 0.265E+01 0.411E+03 0.480E+01 0.440E+03 0 105E+02 0.471E+03
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 0.164E+02 0.501E+03 0.216E+02 0.532E+03 0.240E+02 0.562E+03 0.245E+02 0.593E+03
 0.211E+02 0.624E+03 0.211E+02 0.639E+03
 TEMP    3    14   FT#03-Temp #3 GLPB/SIS    tempxxxx.ini  7  8 FF time # 3 Temp#3
 0.139E+02 0.267E+03 0.139E+02 0.289E+03 0.964E+01 0.320E+03 0.275E+01 0.350E+03
 0.840E+00 0.381E+03 0.205E+01 0.411E+03 0.375E+01 0.440E+03 0.914E+01 0.471E+03
 0.149E+02 0.501E+03 0.213E+02 0.532E+03 0.237E+02 0.562E+03 0.244E+02 0.593E+03
 0.218E+02 0.624E+03 0.218E+02 0.639E+03
 TEMP    4    14   FT#04-Temp #4 GB          tempxxxx.ini  8  8 FF time # 4 Temp#4
 0.161E+02 0.267E+03 0.161E+02 0.289E+03 0.105E+02 0.320E+03 0.300E+01 0.350E+03
 0.185E+01 0.381E+03 0.490E+01 0.411E+03 0.819E+01 0.440E+03 0.143E+02 0.471E+03
 0.200E+02 0.501E+03 0.232E+02 0.532E+03 0.232E+02 0.562E+03 0.214E+02 0.593E+03
 0.218E+02 0.624E+03 0.218E+02 0.639E+03
  SUN    5    14   FT#05-solar rad           solarbnl.ini  5  6 FF time # 5 Solar
 0.233E+03 0.267E+03 0.233E+03 0.289E+03 0.156E+03 0.320E+03 0.121E+03 0.350E+03
 0.137E+03 0.381E+03 0.198E+03 0.411E+03 0.286E+03 0.440E+03 0.384E+03 0.471E+03
 0.462E+03 0.501E+03 0.499E+03 0.532E+03 0.485E+03 0.562E+03 0.422E+03 0.593E+03
 0.330E+03 0.624E+03 0.330E+03 0.639E+03
PHOTO    6    14   FT#06-photoperiod         solarbnl.ini  6  6 FF time # 6 Photo
 0.460E+00 0.267E+03 0.460E+00 0.289E+03 0.406E+00 0.320E+03 0.381E+00 0.350E+03
 0.392E+00 0.381E+03 0.435E+00 0.411E+03 0.498E+00 0.440E+03 0.568E+00 0.471E+03
 0.623E+00 0.501E+03 0.649E+00 0.532E+03 0.639E+00 0.562E+03 0.595E+00 0.593E+03
 0.530E+00 0.624E+03 0.530E+00 0.639E+03
 WIND    7    14   FT#07-wind vel            wind-nyb.ini  5  6 FF time # 7 Wind v
 0.412E+01 0.267E+03 0.412E+01 0.289E+03 0.412E+01 0.320E+03 0.412E+01 0.350E+03
 0.514E+01 0.381E+03 0.514E+01 0.411E+03 0.514E+01 0.440E+03 0.514E+01 0.471E+03
 0.412E+01 0.501E+03 0.412E+01 0.532E+03 0.412E+01 0.562E+03 0.412E+01 0.593E+03
 0.412E+01 0.624E+03 0.412E+01 0.639E+03
KE#01    8    14   FT#08-Ke #1   PR/TRB      extcoeff.ini  5  9 FF time # 8 Ke #1
 0.208E+01 0.267E+03 0.208E+01 0.289E+03 0.257E+01 0.320E+03 0.136E+01 0.350E+03
 0.996E+00 0.381E+03 0.123E+01 0.411E+03 0.116E+01 0.440E+03 0.109E+01 0.471E+03
 0.101E+01 0.501E+03 0.941E+00 0.532E+03 0.868E+00 0.562E+03 0.795E+00 0.593E+03
 0.723E+00 0.624E+03 0.723E+00 0.639E+03
KE#02    9    14   FT#09-Ke #2   FB          extcoeff.ini  6  9 FF time # 9 Ke #2
 0.132E+01 0.267E+03 0.132E+01 0.289E+03 0.163E+01 0.320E+03 0.862E+00 0.350E+03
 0.634E+00 0.381E+03 0.781E+00 0.411E+03 0.736E+00 0.440E+03 0.931E+00 0.471E+03
 0.907E+00 0.501E+03 0.632E+00 0.532E+03 0.709E+00 0.562E+03 0.604E+00 0.593E+03
 0.522E+00 0.624E+03 0.522E+00 0.639E+03
KE#03   10    14   FT#10-Ke #3   GPB         extcoeff.ini  7  9 FF time #10 Ke #3
 0.157E+01 0.267E+03 0.157E+01 0.289E+03 0.146E+01 0.320E+03 0.933E+00 0.350E+03
 0.568E+00 0.381E+03 0.801E+00 0.411E+03 0.610E+00 0.440E+03 0.958E+00 0.471E+03
 0.571E+00 0.501E+03 0.453E+00 0.532E+03 0.681E+00 0.562E+03 0.482E+00 0.593E+03
 0.634E+00 0.624E+03 0.634E+00 0.639E+03
KE#04   11    14   FT#11-Ke #4   LPB         extcoeff.ini  8  9 FF time #11 Ke #4
 0.144E+01 0.267E+03 0.144E+01 0.289E+03 0.134E+01 0.320E+03 0.855E+00 0.350E+03
 0.520E+00 0.381E+03 0.606E+00 0.411E+03 0.619E+00 0.440E+03 0.720E+00 0.471E+03
 0.698E+00 0.501E+03 0.727E+00 0.532E+03 0.707E+00 0.562E+03 0.562E+00 0.593E+03
 0.590E+00 0.624E+03 0.590E+00 0.639E+03
KE#05   12    14   FT#12-Ke #5   SIS/GB      extcoeff.ini  9  9 FF time #12 Ke #5
 0.122E+01 0.267E+03 0.122E+01 0.289E+03 0.113E+01 0.320E+03 0.722E+00 0.350E+03
 0.332E+00 0.381E+03 0.512E+00 0.411E+03 0.645E+00 0.440E+03 0.513E+00 0.471E+03
 0.438E+00 0.501E+03 0.473E+00 0.532E+03 0.513E+00 0.562E+03 0.474E+00 0.593E+03
 0.453E+00 0.624E+03 0.453E+00 0.639E+03
TFNH4   13    14   FT#13-NH4 flux            sedfluxx.ini  5  9 FF time #13 NH4 fl
 0.268E+00 0.267E+03 0.268E+00 0.289E+03 0.109E+00 0.320E+03 0.287E-01 0.350E+03
 0.148E-01 0.381E+03 0.218E-01 0.411E+03 0.355E-01 0.440E+03 0.124E+00 0.471E+03
 0.468E+00 0.501E+03 0.152E+01 0.532E+03 0.250E+01 0.562E+03 0.241E+01 0.593E+03
 0.141E+01 0.624E+03 0.141E+01 0.639E+03
TFPO4   14    14   FT#14-PO4 flux            sedfluxx.ini  6  9 FF time #14 PO4 fl
 0.396E+00 0.267E+03 0.396E+00 0.289E+03 0.210E+00 0.320E+03 0.821E-01 0.350E+03
 0.517E-01 0.381E+03 0.677E-01 0.411E+03 0.955E-01 0.440E+03 0.230E+00 0.471E+03
 0.586E+00 0.501E+03 0.134E+01 0.532E+03 0.190E+01 0.562E+03 0.186E+01 0.593E+03
 0.128E+01 0.624E+03 0.128E+01 0.639E+03
MACRO   15    14   FT#15-Macrophy            benthbio.ini  5  8 FF time #15 Macrop
 0.670E+00 0.267E+03 0.670E+00 0.289E+03 0.730E+00 0.320E+03 0.780E+00 0.350E+03
 0.400E+00 0.381E+03 0.450E+00 0.411E+03 0.360E+00 0.440E+03 0.520E+00 0.471E+03
 0.930E+00 0.501E+03 0.114E+01 0.532E+03 0.120E+01 0.562E+03 0.100E+01 0.593E+03
 0.450E+00 0.624E+03 0.450E+00 0.639E+03
SHL#1   16    14   FT#16-Shell #1            benthbio.ini  6  8 FF time #16 Shellf
 0.100E+01 0.267E+03 0.100E+01 0.289E+03 0.100E+01 0.320E+03 0.100E+01 0.350E+03
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 0 100E+01 0 381E+03 0.100E+01 0 411E+03 0.100E+01 0 440E+03 0.100E+01 0.471E+03
 0 100E+01 0 501E+03 0 100E+01 0 532E+03 0 100E+01 0 562E+03 0.100E+01 0.593E+03
 0.100E+01 0.624E+03 0.100E+01 0 639E+03
TFK1G   17    14    FT#17-time dependent grazing rate multiplier (theta=1 08)
     0 635        267      0 635        289      0 465        320      0 294        350
     0 234        381      0.267        411      0 316        440      0.487        471
     0 770        501      1.150        532      1 370        562      1 350        593
     1.130        624      1.130        639
TFSOD   18    14    FT#18-SOD flux            sedfluxx.ini  7  9 FF time #18 SOD fl
 0.729E+00 0 267E+03 0.729E+00 0.289E+03 0 587E+00 0.320E+03 0.426E+00 0.350E+03
 0.364E+00 0 381E+03 0.399E+00 0.411E+03 0 449E+00 0 440E+03 0.606E+00 0.471E+03
 0 833E+00 0 501E+03 0.111E+01 0.532E+03 0.125E+01 0 562E+03 0.124E+01 0.593E+03
 0 109E+01 0.624E+03 0.109E+01 0.639E+03
ZOOPL   19    14    FT#19-Zoopl.   modified 73 micron net size
      9000        267       9000        289      12000        320      22000        350
     40000        381      80000        411      50000        440      40000        471
     40000        501      40000        532      50000        562      35000        593
     15000        624      15000        639
TFSIO   20    14    FT#20-SiO4 flux           sedfluxx.ini  4  9 FF time #20 SiO4
 0.709E+00 0.267E+03 0.709E+00 0.289E+03 0.560E+00 0.320E+03 0.396E+00 0 350E+03
 0 333E+00 0.381E+03 0.368E+00 0.411E+03 0.418E+00 0.440E+03 0.580E+00 0 471E+03
 0.820E+00 0.501E+03 0.112E+01 0.532E+03 0 127E+01 0.562E+03 0.126E+01 0 593E+03
 0.109E+01 0.624E+03 0.109E+01 0.639E+03
TFNO3   21    14    FT#21-NO3 flux            sedfluxx.ini  8  9 FF time #21 NO3
 0 793E+00 0.267E+03 0.793E+00 0.289E+03 0.677E+00 0.320E+03 0.536E+00 0.350E+03
 0 477E+00 0 381E+03 0.510E+00 0.411E+03 0.556E+00 0.440E+03 0.693E+00 0.471E+03
 0 875E+00 0 501E+03 0.108E+01 0.532E+03 0.117E+01 0.562E+03 0.117E+01 0.593E+03
 0.106E+01 0 624E+03 0.106E+01 0.639E+03
NH3_N (mg/L)                                5   1    9.99E+03 J:INITIAL CONC.
 SG01     0 0000      1.000 SG02     0.0000      1.000 SG03     0.0000     1 000
 SG04     0 0000      1.000 SG05     0.0001      1.000 SG06     0.0000     0.000
NO2_N (mg/L)                                5   1.       9999. J:INITIAL CONC.
 SG01     0.0000      1.000 SG02     0 0000      1.000 SG03     0.0000     1.000
 SG04     0.0000      1.000 SG05     0.0001      1.000 SG06     0.0000     0.000
OPO4  (mg/L)                                5   1.       9999. J:INITIAL CONC.
 SG01     0 0000      1.000 SG02     0.0000      1.000 SG03     0.0000     1.000
 SG04     0.0000      1.000 SG05     0 0001      1.000 SG06     0.0000     0.000
Phyt1 (mg/L)                                4   1.       9999. J:INITIAL CONC.
 SG01     0 0000      1.000 SG02     0.0000      1.000 SG03     0.0000     1.000
 SG04     0 0000      1.000 SG05     0 0001      1.000 SG06     0.0000     0 000
CBOD  (mg/L)                                4   1.       9999  J:INITIAL CONC.
 SG01     0 0000      1.000 SG02     0 0000      1.000 SG03     0 0000     1.000
 SG04     0 0000      1.000 SG05     0 0001      1 000 SG06     0.0000     0 000
DO    (mg/L)                                5   1.       9999. J:INITIAL CONC.
 SG01     0 0000      1.000 SG02     0.0000      1.000 SG03     0.0000     1.000
 SG04     0.0000      1.000 SG05     0.0001      1.000 SG06     0.0000     0.000
OrgN  (mg/L)                                5   1.       9999. J:INITIAL CONC
 SG01     0.0000      1.000 SG02     0.0000      1.000 SG03     0.0000     1 000
 SG04     0.0000      1.000 SG05     0.0001      1 000 SG06     0.0000     0 000
OrgP  (mg/L)                                4   1.       9999. J:INITIAL CONC.
 SG01     0.0000      1.000 SG02     0.0000      1.000 SG03     0.0000     1.000
 SG04     0.0000      1.000 SG05     0.0001      1.000 SG06     0.0000     0.000
Phyt2 (mg/L)                                4   1.       9999. J:INITIAL CONC.
 SG01     0.0000      1.000 SG02     0.0000      1.000 SG03     0.0000     1.000
 SG04     0.0000      1.000 SG05     0.0001      1.000 SG06     0.0000     0 000
Phyt3 (mg/L)                                4   1.       9999. J:INITIAL CONC
 SG01     0.0000      1.000 SG02     0.0000      1.000 SG03     0.0000     1.000
 SG04     0 0000      1.000 SG05     0.0001      1.000 SG06     0.0000     0 000
SiO4  (mg/L)                                3   1.       9999. J:INITIAL CONC.
 SG01     0 0000      1.000 SG02     0.0000      1.000 SG03     0.0000     1.000
 SG04     0.0000      1.000 SG05     0.0001      1.000 SG06     0.0000     0.000
Salinity (mg/L)                             5   1.  9.99E+03 J:INITIAL CONC.
 SG01     0.0000      1.000 SG02     0 0000      1.000 SG03     0.0000     1.000
 SG04     0 0000      1.000 SG05     0 0000      1 000 SG06     0.0000     0.000
Coliforms (MPN/100ml)                       5   1.  9 99E+03 J:INITIAL CONC.
 SG01     0.0000      1 000 SG02     0.0000      1.000 SG03     0.0000     1 000
 SG04     0.0000      1.000 SG05     0.0001      1.000 SG06     0.0000     0.000
```

2.3.4 WASP4 DO Water Quality File for Gull Harbor Marina

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----+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8

WGH_11 INP -  Gull Harbor WASP4 Model Water 05/20/88 05/28/88
Dissolved Oxygen Calibration Run
 KSIM NSEG NSYS ICFL MFLG IDMP NSLN INTY ADFC  zyr/mm/dd hhmm   A.MODEL OPTIONS
    0    4   13    1    1    1    0    0  0 0 1988/05/20 0000    1    1    3    0.00
    3
    1    2    3
    1
     900.    148.00
    3
    1800.      365.    86400.     366     86400.      640
    0    0    0    0    0    0    0    0    1    1    0    0    0
    1    +    +    *    +    *    +    *    +    *    +    *    B EXCHANGES
    3     1.000      1.00                 (surface water)
    1
     27.0        40    0    1
    2
  0 20E+00        0.  0.20E+00      640.
    1
     50 0        39    1    2
    2
  0.15E+00        0.  0.15E+00      640.
    1
     50 0        32    2    3
    2
  0.10E+00        0.  0.10E+00      640.
    0    0    0    0    0    0    0    0    1    1    0    0    0
    2    0     720.0    +    *    +    *    +    *    +    *    C: VOLUMES
    1 0000    1.0000
         1         4         1      1047       0.0       1.0       1.0       1.0
         2         4         1      1535       0.0       1.0       1.0       1.0
         3         4         1      1868       0.0       1.0       1.0       1.0
         4         0         3      6622       0.0       1.0       1.0       1.0
    2    5     SUMRY2.OUT (GULLHYD HYD)  *    +    *    +    *    D: FLOWS
    1    1                          (Data Block D.2 Field One Flows)
    1    2    3
    0       1.0       1 0     F#2 --NINQ(2)  SCALQ=1  CONVQ= 1
    1       1.0 1.157E-05     F#3 --NINQ(3)  SCALQ=1  CONVQ= m/day * 1/86400
    3                         F#3 --NOQS(3,ni) --> number of segment pairs
      1303    1    4      3165    2    4      2032    3    4
    2                         F#3 --NBRKQ(4,ni) --> number of time breaks
     0 5       0.5      0.0      640.0
    1       1.0 1.157E-05     F#4 --NINQ(3)  SCALQ=1  CONVQ= m/day * 1/86400
    3                         F#4 --NOQS(3,ni) --> number of segment pairs
      1303    1    4      3165    2    4      2032    3    4
    2                         F#4---NBRKQ(5,ni) --> number of time breaks
      0 3       0.3       0.0      640.0
    1       1.0 1.157E-05     F#5 --NINQ(3)  SCALQ=1  CONVQ= m/day * 1/86400
    3
      1303    1    4      3165    2    4      2032    3    4
    2                         F#5---NBRKQ(5,ni) --> number of time breaks
      0.2       0 2       0.0      640.0
    0    0    0    0    0    0    0    0    1    1    0    0    0
         1               Sys#1 NH3        (Data Group E Boundary Conditions)
      1.0       1.0
    1    3   OCN :               OCNBC001        Sys# 1
    0.040   140.000     0.040   150.000    0.040   365.000     0.000   366.000
         1               Sys#2 NO3        (Data Group E Boundary Conditions)
      1.0       1.0
    1    3   OCN :               OCNBC001        Sys# 2
    0.010   140.000    -0 010   150.000    0.010   365.000     0 000   366.000
         1               Sys#3 OPO4       (Data Group E Boundary Conditions)
      1.0       1.0
    1    3   OCN :               OCNBC001        Sys# 3
    0.030   140.000     0.030   150.000    0.030   365.000     0.000   366.000
         1               Sys#4 Phyt#1     (Data Group E Boundary Conditions)
      1.0       1.0
    1    3   OCN :               OCNBC001        Sys# 4
    12.00   140.000     12.00   150.000    12.00   365.000     0.000   366.000
         1               Sys#5 CBOD       (Data Group E Boundary Conditions)

----+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
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    1 0       1 0
 1    3   OCN                   OCNBC001        Sys# 5
  2 470   140.000     2 470   150 000      2.470   365 000      0.000   366 000
      1                Sys#6 DO           (Data Group E Boundary Conditions)
    1 0       1.0
 1    3   OCN :                 OCNBC001        Sys# 6
  6 150   140 000     6.150   150.000      6 150   365.000      6.150   366.000
      1                Sys#7 OrgN         (Data Group E Boundary Conditions)
    1.0       1 0
 1    3   OCN :                 OCNBC001        Sys# 7
  0.360   140.000     0 360   150.000      0 360   365.000      0.000   366.000
      1                Sys#8 OrgP         (Data Group E Boundary Conditions)
    1.0       1.0
 1    3   OCN :                 OCNBC001        Sys# 8
  0 020   140.000     0.020   150.000      0.020   365.000      0 000   366.000
      1                Sys#9 Phyt#2       (Data Group E Boundary Conditions)
    1.0       1.0
 1    3   OCN .                 OCNBC001        Sys# 9
  0.000   140.000     0.000   150.000      0.000   365.000      0.000   366.000
      1                Sys#10 Phyt#2      (Data Group E Boundary Conditions)
    1.0       1 0
 1    3   OCN :                 OCNBC001        Sys# 10
  0.000   140.000     0.000   150.000      0 000   365.000      0 000   366.000
      1                Sys#11 SiO4        (Data Group E Boundary Conditions)
    1.0       1.0
 1    3   OCN :                 OCNBC001        Sys# 11
  0.000   140.000     0.000   150 000      0 000   365.000      0 000   366.000
      1                Sys#12 Salinity    (Data Group E Boundary Conditions)
    1.0       1.0
 1    3   OCN :                 OCNBC001        Sys# 12
  0.000   140.000     30.80   150 000      30.80   365.000      0.000   366.000
      1                Sys#13 Coliforms   (Data Group E Boundary Conditions)
    1.0       1.0
 1    3   OCN :                 OCNBC001        Sys# 13
  0.000   140.000     0 000   150.000      0.000   365 000      0.000   366 000
      0   PS(t) Sys#1              (Data Block F.1 Waste Loads for Point Source)
      0   PS(t) Sys#2
      0   PS(t) Sys#3
      0   PS(t) Sys#4
      0   PS(t) Sys#5
      0   PS(t) Sys#6
      0   PS(t) Sys#7
      0   PS(t) Sys#8
      0   PS(t) Sys#9
      0   PS(t) Sys#10
      0   PS(t) Sys#11
      0   PS(t) Sys#12
      0   PS(t) Sys#13
 0    0                                 (Data Group F.2 ..NPS Loads)
     17          4             FF(xyz)- G wasp4g01.dat 05/12/90 21.20 28
Z001X    1        1.FSI04    2        1.TMPSG    3        1.TMPFN    4        1.
KESG     5        1 KEFN     6        1.FNH4     7        1.FP04     8        1.
SOD1D    9        1 MACRO   12        1.SHL1    13        1.SHL2    14        1.
SHL3    15        1.GWC1    21        1.GWC2    22        1.GWSW    23        1.
FN03    24        1.
      1   of     4
Z001X    1     1.000FSI04    2   143.750TMPSG    3     1.000TMPFN    4     4.000
KESG     5     1.000KEFN     6     5.000FNH4     7    30.000FP04     8     6.000
SOD1D    9     2.680MACRO   12     0.000SHL1    13     0.000SHL2    14     0.000
SHL3    15     0.000GWC1-   21     0.201GWC2    22     1.262GWSW    23     0.020
FN03    24     4.570
      2   of     4
Z001X    1     1 000FSI04    2   143.750TMPSG    3     1.000TMPFN    4     4 000
KESG     5     1.000KEFN     6     5 000FNH4     7    30.000FP04     8     6.000
SOD1D    9     4.400MACRO   12     0 000SHL1    13     0.000SHL2    14     0.000
SHL3    15     0.000GWC1    21     0.000GWC2    22     0.000GWSW    23     0.000
FN03    24     4.570
      3   of     4
Z001X    1     1.000FSI04    2   143 750TMPSG    3     1.000TMPFN    4     4.000
```

```
KESG      5     1 000KEFN     6      5.000FNH4     7     30.000FP04     8      6 000
SOD1D     9     5 500MACRO   12      0 000SHL1    13      0 000SHL2    14      0 000
SHL3     15     0 000GWC1    21      0.803GWC2    22      5 047GWSW    23      0 020
FNO3     24     4 570
          4  of     4
Z001X     1     1.000FSI04    2      0.000TMPSG    3      1.000TMPFN    4      1.000
KESG      5     1 000KEFN     6      1 000FNH4     7      0.000FP04     8      0.000
SOD1D     9     0.000MACRO   12      0 000SHL1    13      0 000SHL2    14      0 000
SHL3     15     0 000GWC1    21      0.000GWC2    22      0.000GWSW    23      0.000
FNO3     24     0 000
                   Nosys= 14      Const-H
GLOBAL              0
NH3-N               1
group #1-1         10
      K12C         11      0 250      K12T       12      1.080
      KNIT         13      2.000    ATMNH3       14      1.400
    GWFLOW         15   0.000000     GWNH3       16      0.488
     Z1CRB         17      2.500     Z1CDW       18      0.450
    NCRBZ1         19      0.167     NCRBM       39      0.082
NO3+NO2-N           1
group #1-2          5
      K20C         21      0.090      K20T       22      1 045
      KNO3         23      0.100    ATMNO3       24      1.865
     GWNO3         25      3.065
O-PO4               1
all param           4
    ATMDIP         31      0.083     GWDIP       32      0.005
    PCRBZ1         33      0.013     PCRBM       40      0.004
Phyt#1              2
group#1-4          15
       WS1         28      0.100       K1C       41      1.000
       K1T         42      1.066     LGHTS       43      2.000
     PHIMX         44    720 000       XKC       45      0.017
     CCHL1         46     80.000       IS1       47    300.000
     KMNG1         48      0.007     KMPG1       49      0.001
      K1RC         50      0 300      K1RT       51      1.080
      TUL1        112     40 000     TOPT1      113     24.000
      TLL1        114      0.000
group#2-4          10
       K1D         52      1.000       K1G       53      0.800
        W1         54      1.000     KPZDC       55      0 000
     KPZDT         56      1 000     PCRB1       57      0 030
     NCRB1         58      0.155    KMPHYT       59      1 000
    SICRB1         89      0.300     KMSG1      111     0.0140
CBOD                1
group#1-5           7
       KDC         71      0.300       KDT       72      1.047
      KDSC         73      0.000      KDST       74      1.000
      KBOD         75      0 500     GWBOD       76      1.800
      OCRB         81      2.670
Diss O2             1
group #1-6          6
       K4C         26      0 000       K4T       27      1.000
        K2         82      0.200     GWOXY       83      4 000
     KM1RC        109      0.000     KM1RT      110      1.000
Org-N               1
group #1-7          7
      K71C         91      0.075      K71T       92      1.080
     KONDC         93      0.000     KONDT       94      1.000
       FON         95      0.700    ATM_ON       96      2.801
     GW_ON         97      0.091
Org-P               1
group #1-8          7
      K83C        100      0.220      K83T      101      1 080
     KOPDC        102      0 000     KOPDT      103      1.000
       FOP        104      0.600    ATM_OP      105      0 247
     GW_OP        106      0 005
Phyt#2              2
group #1-9         12
```

```
      WS2        29     0 200     CCHL2        34     65 000
      IS2        35    75 000       K2C        36      1.750
      K2D        37     0 020        W2        38      1 000
     K2RC        60     0 150      K2RT        61      1 045
      K2T        62     1.066      TUL2       115     37.000
    TOPT2       116     3.000      TLL2       117      0 000
group#2-9         6
    KMNG2        63     0.007     KMPG2        64     0.0015
    NCRB2        65     0 155     PCRB2        66      0.030
   SICRB2        90     0 462     KMSG2       107      0.028
Phyt#3            2
group #1-1       10
  CLLCRB3        20     0 000       WS3        30      0.000
    CCHL3        67     1.000       IS3        68      0.000
      K3C        69     0.000       K3D        70      0 000
       W3        77     0.000      K3RC        78      0.000
     K3RT        79     1.000       K3T        80      1 000
group#2-10        6
    KMNG3        84     0.000     KMPG3        85      0.000
    NCRB3        86     0 000     PCRB3        87      0 000
   SICRB3        98     0.000     KMSG3       108      0.000
Si04              1
group #1-1        1
     GWSI        88    20.000
Salinity          1
group #1-1        1
   GWSALT        99     0.000
Coliforms         0
        21 FF(t) WASP Data Group I FF Time- I wasp4i01.dat 10/16/90
 TEMP     1    2   FT#01-Temp #1 PR/TRB     tempxxxx.ini  5  8 FF time # 1 Temp#1
    20.70      1.00     20.70    366.00
 TEMP     2    2   FT#02-Temp #2  (deg C)
    20.70      1 00     20.70    366.00
 TEMP     3    2   FT#03-Temp #2  (deg C)
    20.70      1.00     20.70    366.00
 TEMP     4    2   FT#04-Temp #2  (deg C)
    20.70      1 00     20.70    366.00
  SUN     5    2   FT#05-solar radiation  (langleys/day) assumes 25% cloud cover
      630      1.00       630    336.00
PHOTO     6    2   FT#06-photoperiod  (fraction of day which is sunny)
    0.530      1.00     0.530    366 00
 WIND     7    2   FT#07-wind velocity (m/sec)
    0.000      1.00     0.000    366.00
KE#01     8    2   FT#08-Ke #1   (1/meter)
    2.430      1.00     2.430    366.00
KE#02     9    2   FT#09-Ke #2   (1/meter)
    2.430      1.00     2.430    366.00
KE#03    10    2   FT#10-Ke #3   (1/meter)
    2.430      1 00     2 430    366.00
KE#04    11    2   FT#11-Ke #4   (1/meter)
    2.430      1.00     2.430    366.00
KE#05    12    2   FT#12-Ke #5   (1/meter)
    2.430      1.00     2.430    366.00
TFNH4    13    2   FT#13-NH4 flux  (theta = 1.08)
    1.055      1 00     1.055    366.00
TFP04    14    2   FT#14-P04 flux  (theta = 1.08)
    1.055      1.00     1.055    366.00
MACRO    15    2   FT#15-Macrophy
    1.000      1.00     1.000    366.00
SHL#1    16    2   FT#16-Shell #1
    1.000      1.00     1.000    366.00
TFK1G    17    2   FT#17-time dependent grazing rate multiplier (theta=1.00)
    1.000      1.00     1 000    366.00
TFSOD    18    2   FT#18-SOD flux  (theta = 1.047)
    1.032      1.00     1.032    366.00
ZOOPL    19    2   FT#19-Zoopl... modified 73 micron net size
    40000      1 00     40000    366.00
TFSIO    20    2   FT#20-Si04 flux  (theta = 1.08)
    1.055      1.00     1.055    366.00
```

```
TFNO3   21     2   FT#21-NO3 flux  (theta = 1 08)
     1 055      1 00      1 055    366.00
NH3_N (mg/L)                                       5   1.  9 99E+03 J·INITIAL CONC.
 SG01     0.0700     1.000 SG02    0.0700     1 000 SG03     0.0700      1.000
 SG04     0 0700     1.000
NO2_N (mg/L)                                       5   1.     9999. J·INITIAL CONC.
 SG01     0 0200     1 000 SG02    0.0200     1.000 SG03     0 0200      1 000
 SG04     0 0200     1.000
OPO4  (mg/L)           -                           5   1.     9999. J.INITIAL CONC
 SG01     0 0420     0.600 SG02    0 0420     0 600 SG03     0 0420      0.600
 SG04     0 0420     0.600
Phyt1 (mg/L)                                       4   1.     9999. J:INITIAL CONC.
 SG01     14.000     0 000 SG02    14.000     0 000 SG03     14.000      0 000
 SG04     14 000     0.000
CBOD  (mg/L)                                       4   1.     9999. J·INITIAL CONC.
 SG01     2.4700     0.500 SG02    2 4700     0.500 SG03     2.4700      0.500
 SG04     2.4700     0.500
DO    (mg/L)                                       5   1.     9999  J·INITIAL CONC.
 SG01     5.0000     1 000 SG02    5.0000     1.000 SG03     5 0000      1.000
 SG04     5 0000     1 000
OrgN  (mg/L)                                       5   1.     9999. J:INITIAL CONC.
 SG01     0.0420     0 500 SG02    0 0420     0.500 SG03     0 0420      0.500
 SG04     0.0420     0.500
OrgP  (mg/L)                                       4   1.     9999. J:INITIAL CONC.
 SG01     0 0280     0.700 SG02    0.0280     0.700 SG03     0.0280      0 700
 SG04     0.0280     0.700
Phyt2 (mg/L)                                       4   1.     9999. J:INITIAL CONC.
 SG01     0.0000     0 000 SG02    0.0000     0.000 SG03     0 0000      0.000
 SG04     0.0000     0.000
Phyt3 (mg/L)                                       4   1.     9999. J:INITIAL CONC.
 SG01     0.0000     0.000 SG02    0.0000     0.000 SG03     0.0000      0.000
 SG04     0.0000     0.000
Si04  (mg/L)                                       3   1   9.99E+06 J:INITIAL CONC.
 SG01     0 0000     0 300 SG02    0.0000     0.300 SG03     0.0000      0.300
 SG04     0.0000     0 300
Salinity (mg/L)                                    5   1.  9.99E+03 J·INITIAL CONC.
 SG01    30.8000     1.000 SG02   30.8000     1.000 SG03    30.8000      1.000
 SG04    30.8000     1.000
Coliforms (MPN/100ml)                              5   1.  9 99E+10 J:INITIAL CONC.
 SG01     0.0000     1.000 SG02    0.0000     1 000 SG03     0.0000      1 000
 SG04     0.0000     1.000
```

APPENDIX B: User's Guides

for

Tidal Prism Model (TPM)

and

WASP Model

1.0 Tidal Prism Model (TPM)

This is a line-by-line, entry-by-entry Guide to creating your own input files for the model. You may create a valid input file which will work with the model simply by starting at the beginning of the Guide and following through to the end, entering all the inputs as described.

If no variable data is available, only the steady data file is necessary. Time-constant data are generally things like geometry, returning ratio, initial concentration, and boundary conditions. When you have both types of data, you will simply open two files, and put time-constant data into one, and time-varying data into the other. Time-variable data are most often non-point sources, involving daily measurements of runoff over several weeks or months. The variable file contains data which vary in time from the SECOND day of simulation onward. Its format and units are the same as for the steady file except that generally only data groups 3 or 4 will be specified, along with a title and date for each entry.

Two types of data are required, geometric and physical data. Geometric data defines the system being simulated and specifies the printing option and the length of simulation. In addition, geometry, returning ratio, initial concentration, and boundary conditions are also specified under the geometric data type.

Physical data includes: Water temperature, reaction rates, point and nonpoint sources, and initial as well as boundary conditions for water quality parameters modeled. This section summarizes the input parameters that must be specified in order to run the model.

A. GEOMETRIC DATA

Miscellaneous introductory data:

Record 1 (5I5):

NTMAX = Total number of tidal cycles the model is to be run.

NTN = The total number of tidal cycles at which you want output concentrations if you request it to print out after 1, 3, and 5 cycles, enter '   3' here.

TIMDEP = Flag for indicating presence of variable data file.
= 1 tells it to look for a variable file.
= 0 tells it not to look for a variable file.

MPREF = Flag to indicate algal nitrogen preference.
REF = 0 indicates ammonia-nitrogen preference.
REF = 1 indicates nitrate-nitrogen preference.

ID = This input has actually become extinct- leave it at 6'. When we still used punched card inputs, '5' would specify the punched cards, and '6' was for disk file.

Record 2 (14I5):

NTOUT(I) = List the number of each tidal cycle at which to print output concentration, If you want it to print out after 1, 3, and 5 cycles, list ' 1 3 5' here.

I = 1 ,NTN

Segment and tributary/marina numbering:

Record 1 (1x,35A2):

TITLE = Alphanumeric characters to describe the data. FORMAT(1x,35A2)

Record 2 : Number of Segments and Tributaries/Marinas (2I5)

NS = is the number of segments in main channel
NUT = is the number of tributaries. Note: The water outside the mouth of the main channel is numbered as main channel segment(1).

In the example, there are no tributaries (NUT=0). If there are tributaries/marinas, include the following data about them here.

NSTR(I) = (One card for each tributary/marina.) NSTR(I) is the number of segments in the Ith tributary/marina.

NMT(I) = is the number of the main channel segment into which the Ith tributary/marina empties (this main channel segment is the tributary's segment 1.)

I = 1 , NUT

Geometry and returning ratio :

Record 1 (2I5,30A2):

NCH = channel number, Main Channel NCH=1, First Tributary/Marina NCH=2, Second Tributary/Marina NCH=3, Last Tributary/marina NCH=NUT+1.

NS = number of segments in channel

TITLE = description of channel.

Record 2 (7F10.0):

DIST(I) = distance of transect from mouth, in statute miles.

Record 3 (7F10.0):

VH(I) = volume of the Ith segment at high tide, in millions of cubic ft.

Record 4 (7F10.0):

P(I) = tidal prism upstream of the Ith transect, in millions of cubic ft.

Record 5 (7F10.0):

AL(I) = returning ratio at the Ith transect.

Record 2 (7F10.0):

HA(I) = average depth of the Ith segment, in feet.

I = 1 , NS

If there are tributaries/marinas, now enter this data for the first tributary exactly as for the main channel, beginning with the first card above, with NCH=2. Do the same for all the tributaries/marinas.

************* END OF DATA CARD *****************
At the end of the data for the LAST TRIBUTARY,
insert one card with '99' in first five columns.
****

B. PHYSICAL DATA

This section describes the additional information required to run the Tidal Prism Model. To arrange the input into a logical format, the data are divided into 8 groups, 1 through 8.

Data Group 1: Provide the correct water temperature.

Data Group 2: Add the initial concentrations of each component and salinity, unless freshwater

Data Group 3: Include volume/mass flow rate of point sources/ constituents.

Data Group 4: Include volume/mass flow rate of runoff/constituents.

Data Group 5: Sediment oxygen demand field data are entered hare, and an exponential temperature base generally taken from the literature. (See 'BEN').

Data Group 6: Turbidity field data are entered here.

Data Group 7: Decay coefficient of CBOD may need to be calibrated for, the temperature coefficient is generally taken from the literature

(See 'CKC').

Data Group 8: Include initial concentrations at the mouth for all components.

Data Group 1 :

Record 1 (1X,35A2):

TITLE = Alphanumeric characters to identify the data group.

Record 2 (I3,2X,30A2):

NCH = channel number (=1 main channel).

TITLE = channel identification (main/tributary/marina).

Record 3 (2I5,30A2):

NDG = number of points in group A.

TITLE = parameter name 'WATER TEMPERATURE.'

Record 3 (7F10.0):

TEMP = Water temperature in degrees centigrade.

You will now enter 8 different sets of physical data, identified by a data group name (A through H), listed below, beginning with those for the main channel.

Data Group Description	Data Group Number-NDG	Number of points in group-a
Water Temperature	1	1
Initial Concentrations	2	of segments
Point Sources	3	of segments with point sources
Non-point Sources	4	of segments with non-pt sources
Benthic demand	5	of segments
Turbidity	6	of segments
[CLOD decay	7	0 of segments
Boundary Conditions	8	1

The first group simply contains the water temperature. The rest of the groups follow the first and are illustrated on the following pages. When you have finished entering all the data groups for the main channel, begin again and repeat the same process for the 1st tributary/marina, beginning with the second card above, with NCH=2. Repeat for all tributaries/marina.

************* END OF DATA CARDS **************
At the end of the data for EACH CHANNEL,insert
one card with '99' in first 5 columns. After
'99' card for the last tributary,insert one
card with '999'in first 3 columns.
****

Data Group 2 Initial concentrations:

Record 1 (2I5,30A2):

NP = number of data group (2).

NBG = number of segments.

HEADER = alphanumeric characters to identify data group 'INITIAL CONCENTRATIONS'

Record 2 (14F5.0):

S(I) = initial salinity, in part per thousand.

Record 3 (14F5.0):

N1(I) = initial organic nitrogen concentration, in milligrams per liter.

Record 4 (14F5.0):

N2(I) = The initial ammonia nitrogen concentration, in milligrams per liter.

Record 5 (14F5.0):

N3(I) = initial nitrate nitrogen concentration, in parts per thousand.

Record 6 (14F5.0):

P1(I) = initial organic phosphorus concentration, in milligrams per liter.

Record 7 (14F5.0):

P2(I) = initial inorganic phosphorus concentrations, in milligrams per liter.

Record 8 (14F5.0):

CH(I) = initial chlorophyll concentration, in micrograms per liter.

Record 9 (14F5.0):

CBOD(I) = initial CBOD concentration, in milligrams per liter.

Record 10 (14F5.0):

DO(I) = initial dissolved oxygen concentration, in milligrams per liter.

Record 11 (14F5.0):

BAC(I) = initial coliform bacteria concentration, in MPN per 100 ml. Note: This data group need not be specified by the user. Default values are as follows.

S(I)	= 0.10	P2(I)	= 0.02
N1(I)	= 0.10	CH(I)	= 10.0
N2(I)	= 0.10	CBOD(I)	= 1.50
N3(I)	= 0.10	DO(I)	= 7.00
PI (I)	= 0.02	BAC(I)	= 5.00

I = 1 , NP

Data Group 3 Point Sources:

Record 1 (2I5,30A2):

NDG = number of data group (3).

NP = number of segments into which sources of wastewater are introduced.

HEADER = alphanumeric characters to identify data group 'POINTSOURCE WASTEWATER.'

Record 3 (I5,5X,5F10.0):

K = Reach Number.

QWAST(K) = Flow rate of wastewater in cubic feet per second.

WS(K) = Concentration of salinity in wastewater in parts per thousand.

WN1(K) = Flow rate of HI in wastewater, in pounds every two tidal cycles.

WN2(K) = Flow rate of H2 in wastewater, in pounds every two tidal cycles.

WN3(K) = Flow rate of N3 in wastewater, in pounds every two tidal cycles.

Record 4 (10X, 5F10.0):

WP1(K) = Flow rate of PI in wastewater, in pounds every two tidal cycles.

WP2(K) = Flow rate of P2 in wastewater, in pounds every two tidal cycles.

WBOD(K) = Flow rate of CBOD is wastewaer, in pounds every two tidal cycles.

DOWAST(K) = Concentration of DO in wastewater, in milligrams per liter.

WBAC(K) = Concentration of coliform bacteria in wastewater, in MPH per 100 milliliter.

Note: This data group need not be specified by the user. Default values are zero for each variable. However, if you have data to enter on the first card, but not for the second, do not omit a blank second card.

Data Group 4 Non-point Sources:

Record 1 (2I5,30A2):

NDG = number of data group (4).

NP = number of segments into which non-point sources are introduced.

HEADER = alphanumeric characters to identify data group 'NON-POINT SOURCE WASTEWATER.'

Record 2 (I3, 1X, F6.0, 7F10.0):

K = Reach number.

RINC(K) = Flow rate of freshwater input including all types of runoff in cfs.

WN1NP(K) = Flow rate of N1, in pounds every two tidal cycles.

WH2NP(K) = Flow rate of N2, in pounds every two tidal cycles.

WH3NP(K) = Flow rate of H3, in pounds every two tidal cycles.

WP1NP(K) = Flow rate of P1; in pounds every two tidal cycles.

WP2NP(K) = Flow rate of P2, in pounds every two tidal cycles.

WBODHP(K) = Flow rate of CBOD, in pounds every two tidal cycles.

WBACNP(K) = Flow rate of coliform bacteria, in billions every two tidal cycles.

Note: This data group need not be specified by the user. Default values are zero for each variable. To reset the non-point loadings to zero after storm event, set NP to > 100 for the main channel and each of the branches.

Data Group 5: Benthic Demand

Record 1 (2I5,30A2):

NDG = number of data group (5).

NP = number of segments in main channel.

HEADER = alphanumeric characters to identify data group 'Benthic Demand.'

Record 2 (F10.0):

TCBEN = Exponential base for the temperature dependence of benthic demand.

Record 3 (14F5.0):

BEM(I) = Benthic oxygen demand at 20 deg. C, in gm per square meter per day.

Note: This data group need not be specified by the user. Default values are zero.

Data Group 6: Turbidity

Record 1 (2I5,30A2):

NDG = number of data group (6).

NP = number of segments in main channel.

HEADER = alphanumeric characters to identify data group 'Turbidity.'

Record 2 (14F5.0):

TURB(I) = Turbidity of water in 1/meter.

NOTE: This data group need not be specified by the user. Default values are 1.0.

Data Group 7: CBOD Reaction Rate

Record 1 (2I5,30A2):

NDG = number of data group (6).

NP = number of segments in main channel. (or setting NP=1 establishes uniform values throughout)

HEADER = alphanumeric characters to identify data group 'CBOD decay'

Record 2 (F10.0):

CKC = Temperature coefficient for CBOD decay rate.

Record 3 (14F5.0):
CK1(I) = Decay coefficient of CBOD at 20 deg. C, in 1/day.

Data Group 8 Boundary Conditions:

Record 1 (2I5,30A2):

NDG = number of data group (8).

NP = 1, segment 1. Specifies the down stream boundary at the mouth of estuary.

HEADER = alphanumeric characters to identify data group 'INITIAL CONCENTRATION AT MOUTH'

Record 2 (F10.0):

S(1) = Salinity in parts per thousand.

Record 3 (3F10.0):

N1(1) = Organic nitrogen, in mg/L.
N2(1) = ammonia nitrogen, in mg/L.
N3(1) = nitrate- nitrite nitrogen, in mg/L.

Record 4 (2F10.0):

P1(1) = Organic phosphorus, in mg/L.
P2(1) = inorganic phosphorus, in mg/L.

Record 5 (F10.0):

CH(1) = Chlorophyll 'a', in ug/L.

Record 6 (2F10.0):

CBOD(1) = dissolved oxygen, in mg/L.

DO(1) = Carbonaceous biochemical oxygen demand, in mg/L.

Record 7 (F10.0):

BAC(1) = Coliform bacteria in MPN/100 mL.

Biological parameters:

Record 1 (4F10.0):

KN11 = Settling rate of organic nitrogen, in 1('one')/day.
KN12 = Rate of conversion of organic nitrogen to ammonia in 1/day/degree centigrade.
KN23 = Rate of oxidation of ammonia to nitrate, in 1/day/ degree centigrade.
KN33 = Denitrification rate, in 1/day.

Record 2 (3F10.0):

KP11 = Settling rate of organic phosphorus, in 1/day.
KP12 = Rate of conversion of organic phosphorus to inorganic phosphorus, in 1/day/degree centigrade.
KP22 = Settling rate of inorganic phosphorus, in 1/day.

Record 3 (2F10.0):

KBODS = Settling rate of carbonaceous oxygen demand, in 1/day.
REAR = Reaeration coefficient

Record 4 (7F10.0):

AC = Carbon to chlorophyll ratio in mg/ug.
AN = Nitrogen to chlorophyll ratio in mg/ug.
AP = Phosphorus to chlorophyll ratio in mg/ug.
KMN = Half-saturation concentration of nitrogen for phytoplankton growth rate, in mg/liter.
KMP = Half-saturation concentration of phosphorus for phytoplankton growth rate, in mg/liter.
KCC = Saturation growth rate, in 1/day/degree centigrade.
RIS = Saturation light level, in units of power/unit area.

Record 6 (5F10.0):

RIA = Average light level over photo period in units of

		power/unit area.
RESP	=	Phytoplankton endogenous respiration rate, in 1/day/degree centigrade.
RCS	=	Phytoplankton settling rate, in 1/day.
PQ	=	Photosynthesis quotient, or the ratio of oxygen produced to carbon fixed, in moles per mole.
RQ	=	Respiration quotient, or the ratio of carbon dioxide liberated to oxygen consumed, in moles per mole.

Record 7 (F10.0):

FRAL = Fraction of day with sunlight.

Record 8 (F10.0):

KGRAZ = Zooplankton grazing rate, in 1/day.

Record 9 (F10.0):

KBAC = Net die-off rate of coliform, in 1/day.

2.0 Water Quality Analysis Simulation Program (WASP)

USER'S GUIDE FOR WASP5

Tetra Tech Version
February 20, 1991

This is a modified version of WASP4 which was developed for the Peconic Bay Brown Tide Comprehensive Assessment and Management Plan for the Department of Health Services, Suffolk County, New York. The model includes five additional state variables not found in the EPA version: three phytoplankton groups (netplankton, nanoplankton, and picoplankton), silica, salinity, and coliform bacteria.

THE BASIC WATER QUALITY MODEL

Introduction

This section describes the input required to run the WASP water quality program. To arrange the input into a logical format, the data are divided into 10 groups, A through J.

A - Model Identification and Simulation Control

B - Exchange Coefficients

C - Volumes

D - Flows

E - Boundary Concentrations

F - Waste Loads

G - Environmental Parameters

H - Chemical Constants

I - Time Functions

J - Initial Conditions

The following is a brief explanation of each data group:

Data Group A is generally for model identification and contains simulation control options. The user must specify the number of segments and the number of systems. The user must also specify time steps and print intervals here.

DATA GROUP B contains dispersive exchange information. Dispersion occurs between segments and along a characteristic length.

DATA GROUP C supplies initial segment volume information.

DATA GROUP D supplies flow and sediment transport information between segments. Flows may be constant or variable.

DATA GROUP E supplies concentrations for each system at the boundaries. All system concentrations must be supplied for each boundary.

DATA GROUP F defines the waste loads and segments that receive the waste loads for both point and diffuse sources.

DATA GROUP G contains appropriate environmental characteristics of the water body. These parameters are spatially variable.

DATA GROUP H contains appropriate chemical characteristics or constants.

DATA GROUP I contains appropriate environmental or kinetic time functions.

DATA GROUP J contains initial concentrations for each segment and each system.

WASP4 Data Group Descriptions

DATA GROUP A: Model Identification and Simulation Control

VARIABLES

Record 1--Title of Simulation (A80)

TITLE1 = descriptive title of simulation (A80).

Record 2--Description of Simulation (A80)

TITLE2 = description of simulation (A80).

Record 3--Record 4 Names (A80)

HEADER = names of Record 4 variables, positioned properly; for user convenience only (A80).

Record 4--Simulation Control Parameters (8I5,2F5.0,F3.0,F2.0,3I5,F10.0)

KSIM = simulation type: 0 - dynamic, 1 - steady state. (I5)

NOSEG = number of segments in model network. (I5)

NOSYS = number of model systems (state variables). (I5)

ICFL = flag controlling use of restart file; 0 = neither read from nor write to restart file (initial conditions located in input file); 1 = write final simulation results to restart file (initial conditions located in input file); 2 = read initial conditions from restart file created by earlier simulation, and write final simulation results to new restart file. (I5)

MFLAG	=	flag controlling messages printed on screen during simulation; 0 = all messages printed; 1 = simulation time only printed; 2 = all messages are suppressed. (I5)
IDMP	=	system number for which mass balance analysis will be performed. (I5)
NEGSLN	=	negative solution option; 0 = prevents negative solutions; 1 = allows negative solutions. (I5)
INTYP	=	time step option; 0 = user inputs time step history; 1 = model calculates time step. (I5)
ADFAC	=	advection factor; 0 = backward difference; 0.5 = central difference; 0-0.4 recommended. (F5.0)
ZYR	=	year at beginning of simulation (I5)
ZMON	=	month at beginning of simulation (1X,I2)
ZDAY	=	day at beginning of simulation (1X,I2)
ZHR	=	hour at the beginning of simulation. (F3.0)
MIN	=	minute at the beginning of simulation. (F2.0)
IDSY	=	system for which concentrations will be displayed on screen throughout the simulation. (I5)
IDSG1	=	segments for which system "IDSY" concentrations will be IDSG2 displayed on screen throughout the simulation. (2I5)
TADJ	=	factor by which input kinetic rates will be adjusted; 0 or 1.0 will cause no adjustment; 24.0 will adjust input rates in hours^{-1} to days^{-1}; 86400. will adjust input rates in seconds^{-1} to days^{-1}. (F10.0)

<u>Record 5--Number of Time Steps (I5)</u>

NOBRK	=	number of different model time steps (I5)

<u>Record 6--Time Steps (4(F10.0, F10.0)</u>

DTS(I)	=	time step to be used until time T(I), seconds. (F10.0)
T(I)	=	time up to when time step DTS(I) will be used,

Julian Day. (F10.0)

Record 7--Number of Print Intervals (I5)

NPRINT = number of print intervals. NOTE: The maximum number of printouts must be equal to or less than the FORTRAN parameter MP that was used when compiling the program. (I5)

Record 8--Print Intervals (4(F10.0, F10.0))

PRINT(I) = print interval to be used until time TPRINT(I), seconds. (F10.0)

TPRINT(I) = time up to when print interval PRINT(I) will be used, Julian Day. (F10.0)

Record 9--System Bypass Options (16I5)

SYSBY(ISYS) = bypass option for system ISYS; 0 = system will be simulated; 1 = system will be bypassed. (I5)

DATA GROUP B: Exchange Coefficients

Exchange coefficients are computed from input dispersion coefficients, cross-sectional areas, and characteristic lengths. Dispersion coefficients may vary in time according to piecewise-linear time functions, with groups of segment pairs having the same dispersion time function. Exchange data are read for each exchange field. Field one contains dispersion coefficients for water column exchanges. Field two contains exchange data for pore water exchange. Fields three, four and five contain sediment exchange data, with a separate field available for each solid type.

VARIABLES

Record 1--Number of Exchange Fields (I5, 75X)

NRFLD = number of exchange fields. NRFLD will generally equal 2 for water column and pore water exchanges. (I5)

TITLE = name of data group. (75X)

If no exchange rates are to be read, set NRFLD to zero and continue with Data Group C.

Record 2--Exchange Time Functions for Each Field (I5, 2F10.0)

NTEX(NF) = number of exchange time functions for field NF. (I5)

SCALR = scale factor for exchange coefficients. All exchange coefficients for field NF will be multiplied by this factor. (F10.0)

CONVR = conversion factor for exchanges in field NF. (F10.0)

NF = 1, NRFLD

To skip exchange field NF, set NTEX(NF) to zero and continue with the next exchange field.

Record 3--Exchange Data (I5)

NORS(NF,NT) = number of exchanges for field NF, time function NT. (I5)

NT = 1, NTEX(NF)

Record 4--Areas, Characteristic Lengths (2F10.0, 2I5)

A(K) = area in square meters for exchange pair K. (F10.0)

EL(K) = characteristic length in meters for exchange pair K. (F10.0)

IR(K),JR(K) = segments between which exchange occurs. The order of the segments is unimportant. (2I5)

K = 1, NORS(NF,NT)

Record 5--Number of Breaks

NBRKR(NF,NT)= number of values and times used to describe dispersion coefficient piecewise-linear time function. (I5)

Record 6--Piece Linear Dispersion Time Function (4(F10.0, F10.0))

RT(K) = value of dispersion coefficient in m^2/sec at time TR(K). (F10.0)

TR(K) = time in days. (F10.0)

K = 1, NBRKR(NF,NT)

Record 7--Exchange Bypass Options (16I5)

RBY(K) = 0, exchange occurs in system K. (I5)
1, bypass exchange for system K.

K = 1, NOSYS

ORGANIZATION OF RECORDS

Record 1 is entered once for Data Group B. Records 2 through 6 are repeated for each exchange field, and Records 3, 4, 5, and 6 are repeated for each time function in a given exchange field. Record 4 uses as many lines as necessary to input NORS sets of A(K), EL(K), IR(K), and JR(K), with 1 set on each line. Record 6 uses as many lines as needed to input NBRKR pairs of RT(K) and TR(K), with 4 pairs occupying each line. After data for all exchange fields are entered, Record 7 is input on the following line with NOSYS entries.

DATA GROUP C: Volumes

Record 1--Preliminary Data (2I5, F10.0, 60X)

IVOPT = 1, constant water column volumes.(I5)

= 2, 3, volumes adjusted to maintain flow continuity. (I5)

IBEDV = 0, constant bed volumes. (I5)

= 1, bed volumes change in response to sediment transport. (I5)

TDINTS = time step in days for porosity computations, IBEDV = 0. (F10.0)

= time step in days for sediment bed compaction, IBEDV = 1. (F10.0)

TITLE = name of data group. (60X)

Record 2--Scale Factors (2f10.0)

SCALV = scale factor for volumes. All volumes will be multiplied by this factor. (F10.0)

CONVV = conversion factor for volumes. (F10.0)

Record 3--Segment Types and Volumes (3I10, 5F10.0)

ISEG = segment number.

IBOTSG = segment immediately below ISEG. Enter zero if no segment is below ISEG. (I10)

ITYPE(ISEG) = segment types;

1 = surface water segment,

2 = subsurface water segment,

3 = upper bed segment,

4 = lower bed segment. (I10)

BVOL(ISEG) = volume of segment ISEG in cubic meters. (F10.0)

VMULT(ISEG) = hydraulic coefficient "a" for velocity in ISEG as a function of flow:

$$v = a\ Q^b$$

If b = 0, VMULT is a constant velocity in m/sec. (F10.0)

VEXP(ISEG) = hydraulic exponent "b" for velocity in ISEG as a function of flow (0-1). A value of 0.4 represents rectangular channels. (F10.0)

DMULT(ISEG) = hydraulic coefficient "c" for depth of ISEG as a function of flow:

$$d = c\ Q^d$$

If d = 0, DMULT is a constant depth in m. (F10.0)

DXP(ISEG) = hydraulic exponent "d" for depth of ISEG as a function of flow (0-1). A value of 0.6 represents rectangular channels. (F10.0)

ISEG = 1, NOSEG

ORGANIZATION OF RECORDS

Records 1 and 2 are entered once for Data Group C. Record 3 is repeated NOSEG times. If ICFL = 2 in Data Group A, volumes are read from the restart file (*.RST, where * is the input data set name), and Records 2 and 3 should not be included in the input data set.

DATA GROUP D: Flows

Data Group D consists of the flows that are used in the model. Flows may be input for several fields. Field one consists of advective flows in the water column, and may be input by one of three options. Field two consists of pore water flows, while Fields three, four, and five consist of sediment transport velocities and cross-sectional areas. A separate sediment transport field is specified for each solid type. Field six is for evaporation and precipitation velocities and cross-sectional areas. All flows may vary in time according to piecewise linear time functions.

Record 1 is read first. If IQOPT = 1, Data Block D1 is read next; if IQOPT = 2 or 3, Data Block D2 is read. Data Blocks D3, D4, D4, D4, and D5 follow in order for NFIELD = 2, 3, 4, 5, and 6, respectively. Following all specified Data Blocks, Record 7 is read.

VARIABLES

<u>Record 1--Data Input Options: Number of Flow Fields (2I5)</u>

IQOPT = 1, Field one (advective) flows are specified directly by user.

= 2, Field one flows are read from an unformatted file (SUMRY2.OUT) created by DYNHYD4.

= 3, flows are read from a formatted file created by DYNHYD4. (I5)

NFIELD = number of flow fields. The first two fields are advective and pore water flows. An additional field (3, 4, or 5) is used for each type of solid modeled. Field 6 is used for evaporation and precipitation. If no flows are used, set NFIELD to zero and continue with Data Group E. (I5)

FNAME = DYNHYD5 hydrodymanic file name (e.g., SUMRY2.OUT)

DATA BLOCK D.1: Direct Input of Field One Flows (IQOPT = 1)

VARIABLES

Record 2--Number of Flow Time Functions (I5, 2F10.0)

NINQ(1) = number of time functions for Field One. If no flows are used in field one, set NINQ to zero and skip to next field. (I5)

SCALQ = scaling factor. All flows in Field one are multiplied by SCALQ. (F10.0)

CONVQ = units conversion factor. (F10.0)

Record 3--Number of Flows (I5)

NOQS(1,NI)= number of unit flow responses in field one, time function NI; each unit flow is defined for a single segment pair. (I5)

Record 4--Flow Routing for Field One (4(F10.0, 2I15))

BQ(1,NI,K)= portion of flow for field one, time function NI that flows between segment pair K. (F10.0)

JQ(1,NI,K)= upstream segment. (I5)

IQ(1,NI,K)= downstream segment. (I5)

K = 1, NOQS(1,NI)

Record 5--Number of Breaks in Advective Time Functions (I5)

NBRKQ(1,NI)= the number of flows and times used to describe piecewise linear time function NI. (I5)

Record 6--Piecewise Linear Advective Time Function (4(2F10.0))

QT(1,NI,K)= advective flow in m^3/s. (F10.0)

TQ(1,NI,K)= time in days. (F10.0)

K = 1, NBRKQ(1,NI)

ORGANIZATION OF RECORDS

Records 1 and 2 are input once for Data Block D.1. Records 3, 4, 5, and 6 are input once for each flow time function. Record 4 uses as many lines as needed to input NOQS sets of BQ, JQ, and IQ, with four sets per line. Record 6 uses as many lines as necessary to input NBRKQ sets of QT and TQ, with four sets on each line.

DATA BLOCK D.2: DYNHYD4 Field One Flows (IQOPT = 2 or 3)

VARIABLES

Record 3--Seaward Boundaries (I5)

NSEA = number of downstream (seaward) boundary segments (same as in hydrodynamic simulation). (I5)

JSEA(I) = segment numbers for downstream boundary junction. (I5)

I = 1, NSEA

Record 4--Junction-Segment Map (16I5)

JUNSEG(I) = segment number corresponding to hydrodynamic junction I. (I5)

I = 1, NJ

ORGANIZATION OF RECORDS

Records 2 and 3 are read in once for Data Block D.2. Record 4 will be repeated until NJ entries have been input.

DATA BLOCK D.3: Field Two (Pore Water) Flows

VARIABLES

Record 2--Number of Pore Water Time Functions (I5, 2F10.0)

NINQ(2) = number of pore water time functions. If no flows are used in Field Two, set NINQ to zero and skip to sediment transport fields. (I5)

SCALQ = scaling factor for pore water flows. (F10.0)

CONVQ = units conversion factor. (F10.0)

Record 3--Number of Flows (I5)

NOQS(2,NI) = number of segment pair flows in Field 2, time function NI. (I5)

NI = 1, NINQ(2)

Record 4--Flow Routing for Field Two (4(F10.0, 2I5))

BQ(2,NI,K) = portion of pore water flow for time function NI that flows between segment pair K. (F10.0)

JQ(2,NI,K) = upstream segment. (I5)

IQ(2,NI,K) = downstream segment. (I5)

Record 5--Number of Breaks in Pore Water Time Function (I5)

NBRKQ(2,NI) = number of pore water flows and times used to describe piecewise linear time function NI. (I5)

Record 6--Piecewise Linear Velocity Time Function (4(2F10.0))

QT(2,NI,K) = pore water flow in m^3/s. (F10.0)

TQ(2,NI,K) = time in days. (F10.0)

K = 1, NBRKQ(2,NI)

ORGANIZATION OF RECORDS

Record 2 is input once for Data Group D.3. Records 3, 4, 5 and 6 are input once for each pore water time function. Record 4 uses as many lines as necessary to input NOQS sets of BQ, JQ, and IQ, with four sets on each line. Record 6 uses as many lines as necessary to input NBRKQ sets of QT and TQ, with four sets on each line.

DATA BLOCK D.4: Sediment Transport Fields

Sediment transport flow data are input as velocities and areas. Velocities may vary in time, and represent settling, sedimentation, deposition, and scour. Only solids and sorbed chemical are transported by these fields. A separate field is specified for each sediment size fraction. If no solids are modeled, skip directly to Record 7 (Flow Bypass Options).

VARIABLES

Record 2--Number of Velocity Time Functions (I5, 2F10.0)

NINQ(NF) = number of velocity time functions for Field NF. (I5)

SCALQ = scaling factor for velocities. (F10.0)

CONVQ = units conversion factor. (F10.0)

NF = 3, 5

Record 3--Number of Segment Pairs (I5)

NOQS(NF,NI) = number of segment pairs involved in sediment transport. (I5)

NI = 1,NINQ(NF)

Record 4--Areas for Evaporation, Precipitation (4(F10.0, 2I5))

BQ(NF,NI,K) = area in square meters between segment pair K. (F10.0)

JQ(NF,NI,K) = segment sediment is transported from. (I5)

IQ(NF,NI,K) = segment sediment is transported to. (I5)

K = 1, NOQS(NF,NI)

Record 5--Number of Breaks in Velocity Time Function (I5)

NBRKQ(NF,NI)= number of velocities and times used to describe piecewise linear time function NI. (I5)

QT(NF,NI,K) = sediment transport velocity in m/s. (F10.0)

TQ(NF,NI,K) = time in days. (F10.0)

K = 1, NBRKQ(NF,NI)

ORGANIZATION OF RECORDS

Records 2 through 6 are read for each solid transport field. Records 3, 4, 5 and 6 are input for each time function in each field. Record 4 uses as many lines as needed to input NOQS sets of BQ, JQ, and IQ, with four sets on one line. Record 6 uses as many lines as needed to input NBRKQ sets of QT and TQ, with four sets per line.

DATA BLOCK D.5: Evaporation and Precipitation Field

Evaporation and precipitation flow data are input as velocities and areas. Velocities may vary in time to represent rainfall events or seasonal evaporation. No chemical is transported with evaporation, but volumes are adjusted to maintain continuity. If this field is not modeled, skip directly to Record 7 (Flow Bypass Qptions). After all transport field data is entered, Record 7 is input with NOSYS entries. If no evaporation or precipitation fields are specified, Record 7 follows Data Group D.4 (solids transport).

VARIABLES

Record 2--Number of Velocity Time Functions (I5, 2F10.0))

NINQ(NF) = number of velocity time functions for Field 6. (I5)

SCALQ = scaling factor for velocities. (F10.0)

CONVQ = units conversion factor. (F10.0)

NF = 6

Record 3--Number of Segments (I5)

NOQS(NF,NI) = number of segments involved in evaporation and precipitation transport. (I5)

Record 4--Areas for Water Transport (4(F10.0, 2I5))

BQ(NF,NI,K) = area in square meters of segment K. (F10.0)

JQ(NF,NI,K) = segment water is transported from; if = 0, this is precipitation. (I5)

IQ(NF,NI,K) = segment water is transported to; if = 0, this is evaporation. (I5)

K = 1, NOQS(NF,NI)

Record 5--Number of Breaks in Velocity Time Function (I5)

NBRKQ(NF,NI)= number of velocities and times used to describe piecewise linear time function NI. (I5)

Record 6--Piecewise Linear Velocity Time Function (4(2F10.0))

QT(NF,NI,K) = water transport velocity in m/s; if more traditional units of cm/day or cm/year are desired, then specify CONVQ = $1.1574E^{-7}$ or $3.169E^{-10}$, respectively. (F10.0)

TQ(NF,NI,K) = time in days. (F10.0)

K = 1, NBRKQ(NF,NI)

-END OF DATA BLOCKS FOR D-

Card 7--Flow Bypass Options (16I5)

QBY(ISYS) = 0, flow transport occurs in system ISYS.
= 1, bypass flow transport for system K. (I5)

K = 1, NOSYS

The flow bypass option allows flow transport to be set to zero in one or more systems. The bypass option applies to all transport fields.

DATA GROUP E: Boundary Concentrations

Data Group E is repeated, in its entirety, NOSYS times.

VARIABLES

Record 1--Data Input Option--Number of Boundary Conditions (I10, 70X)

NOBC(K) = number of boundary conditions used for system K. (I10)

TITLE = name of data group. (70X)

K = 1, NOSYS

If no boundary conditions are to be input, set NOBC(K) equal to zero and either continue with the next system or go to the next card group.

Record 2--Scale Factor for Boundary Conditions (2F10.0)

SCALB = scale factor for boundary conditions. All boundary conditions will be multiplied by this factor. (F10.0)

CONVB = unit conversion factor for boundary conditions. Boundary conditions are expected to be in milligrams per liter (mg/L). If boundary conditions are given in SI units (grams per cubic meter), CONVB will be 1.0. (F10.0)

Record 3--Boundary Conditions (2I5)

IBC(K) = boundary segment number. (I5)

NOBRK(K) = number of values and times used to describe the broken line approximation. The number of breaks must be equal for all boundary conditions within a system. (I5)

K = 1, NOBC

Record 4--Boundary Concentrations (4(2F10.0))

BCT(K) = value of the boundary concentration at time T(K) in mg/L. (F10.0)

T(K) = time in days. If the length of the simulation exceeds T(NOBRK), the broken line approximation is repeated, starting at T(1), i.e., the approximation is assumed to be periodic, with period equation to T(NOBRK). All break times must agree for all segments, i.e., T(1) must be the same for all boundaries, T(2) must be the same for all boundaries, etc. (F10.0)

K = 1, NOBRK

ORGANIZATION OF RECORDS

Records 1 and 2 are entered once. Records 3 and 4 are a set and are repeated NOBC times. Within each NOBC set, Record 3 is entered once and Record 4 is repeated until NOBRK entries are input. Four entries (four BCT(K)-T(K) pairs) will fit on each 80-space line. The whole group is repeated NOSYS times, once for each model system.

DATA GROUP F.1: Waste Loads

Data Group F.1 contains the point source waste loads used in the model. Data Group F.1 is repeated NOSYS times for point source loads. Following complete specification of point source loads, nonpoint source loads will be read from Data Group F.2.

VARIABLES

Record 1--Data Input Option: No. of Forcing Functions (I10, 70X)

NOWK(ISYS) = number of forcing functions used for system ISYS. Forcing functions may also be considered as sources (loads) or sinks of a water quality constituent. If no forcing functions are to be input, set NOWK(ISYS) to zero, and continue with next system or go to next data group.(I10)

TITLE = name of data group. (70X)

SCALW = scale factor for forcing functions. All forcing functions will be multiplied by this factor. (F10.0)

CONVW = unit conversion factor for forcing functions.

Forcing functions are expected to be in kilograms per day. If forcing functions are given in English units (pounds per day), this factor will be 0.4535. (F10.0)

Record 3--Number of Point Sources (2I5)

IWK(K) = segment number that has forcing function BWK(K). (I5)

NOBRK(K) = number of breaks used to describe the forcing function approximation. The number of breaks must be equal for all forcing functions within a system. (I5)

K = 1, NOWK

Record 4--Point Source Time Function (4(2F10.0))

WKT(K) = value of the forcing function at time T(K), in kg/day. (F10.0)

T(K) = time in days. If the length of the simulation exceeds T(NOBRK), the approximation is repeated, starting at T(1), i.e., the approximation is assumed to be periodic with period equal to T(NOBRK). All break times must agree for all segments; i.e., T(1) must be the same for all loads, T(2) must be the same for all loads, etc. (F10.0)

K = 1, NOBRK

ORGANIZATION OF RECORDS

Records 1 and 2 are input once. Records 3 and 4 are a set and are repeated (as a set) NOWK times. Within each set, Record 3 is entered once and Record 4 is repeated until all NOBRK entries are entered. Four entries (WKT(K)-T(K) pairs) will fit on each 80-space line. The entire group is repeated NOSYS times, once for each system.

DATA GROUP F.2, Nonpoint Source Waste Loads

VARIABLES

Record 1--Number of Runoff Loads, Initial Day (2I5)

This record must be included in the data file. If there are no segments receiving runoff loads, enter zero for NOWKS.

NOWKS = number of segments receiving runoff loads. (I5)

NPSDAY = the time in the runoff file corresponding to the initial simulation time, in days. (I5)

If NOWKS = 0, skip to Data Group G. If NOWKS >0, read records 2, 3, and 4.

Record 2--Scale Factor for Runoff Loads (2F10.0)

SCALN = scale factor for runoff loads. All runoff loads will be multiplied by this factor. (F10.0)

CONVN = unit conversion factor for runoff loads. Runoff loads are expected in kilograms per day. If runoff loads are given in English units (pounds per day), this factor will be 0.4535. (F10.0)

Record 3--Runoff Segments (16I5)

INPS(J) = segment number to which runoff load J is applied. (I5)

J = 1,NOWKS

Record 4--Print Specifications (16I5)

KT1 = initial day for which nonzero runoff loads from file NPS.DAT will be printed. (I5)

KT2 = final day for which nonzero runoff loads from file NPS.DAT will be printed. (I5)

KPRT(I) = indicator specifying whether nonzero runoff loads will be printed for each system. If KPRT(I) is greater than zero, then runoff loads will be printed for system I. (I5)

I = 1,NOSYS

ORGANIZATION OF RECORDS

Records 1 and 2 are entered once in Data Group F2. Record 3 has NOWKS entries and uses as many 80-space lines as needed to enter all NOWKS segment numbers. Sixteen entries will fit on one line. Record 4 is entered once.

DATA GROUP G: Parameters

The definition of the parameters will vary, depending upon the structure and kinetics of the systems comprising each model. The input format, however, is constant.

VARIABLES

Record 1--Number of Parameters (I10, 70X)

NOPAM = number of parameters required by the model. If no parameters are to be input, set NOPAM to zero and go to Data Group H. (I10)

TITLE = name of data group. (70X)

Record 2--Scale Factors for Parameters (4(A5, I5, F10.0)

ANAME(ISC) = descriptive name for parameter ISC. (A5)

ISC = parameter number identifying parameter. (I5)

PSCAL(ISC) = scale factor for parameter ISC. (F10.0)

K = 1, NOPAM

Record 3--Segment Number (I10)

ISG = segment number for the following parameter values. (I10)

Record 4--Segment Parameters (4(A5, I5, F10.0))

PNAME(ISC) = an optional one to five alphanumeric character descriptive name for parameter PARAM(ISG,ISC). (A5)

ISC = parameter number identifying parameter. (I5)

PARAM(ISEG,K)= the value of parameter ISC in segment ISG. (F10.0)

K = 1, NOPAM

ISEG = 1, NOSEG

ORGANIZATION OF RECORDS

Record 1 is input once in Data Group G, occupying one line. Record 2 has NOPAM entries. Four entries will fit on one line; thus, Record 2 uses as many 80-space lines as needed to enter all NOPAM entries. Records 3 and 4 are entered NOSEG times, once for each segment. For each segment, Record 4 uses as many lines as needed to enter all NOPAM entries.

DATA GROUP H: Constants--

The definition of the constants will vary, depending upon the structure and kinetics of the systems comprising each model. This data group is subdivided into global constants and constants for each system (thus NOSYS+1 groups are read). Each of these groups can be subdivided into any number of fields containing similar kinds of data.

VARIABLE

Record 1--Header (80X)

TITLE = name of data group. (80X)

Record 2--Data Fields in Group H (A10, I10)

CHNAME(K)= a ten-character descriptive name for System (K). (A10)

NFLD = number of fields of constants for this group; 0 = no constants for this group; the user may subdivide the constants into any number of arbitrary fields. (I10)

If no constants are to be input for this group, set NFLD equal to zero and continue with next group.

Record 3--Number of Constants in Field (A10, I10)

FLDNAME = ten-character name identifying field of constants. (A10)

NCONS = number of constants to be entered in this field; 0 = no constants for this field (skip to next field). (I10)

Record 4--Constants (2(A10, I10, F10.0))

TNAME(ISC)= name identifying constant ISC. (A10)

ISC = number identifying constant; these numbers are set by model developer. (I10)

CONST(ISC)= value of constant ISC. (F10.0)

ORGANIZATION OF RECORDS

Record 1 is entered once in Data Group H. Records 2 through 4 are entered as NOSYS +1 groups. For each group, Records 3 and 4 are entered NFLD times. For each field, Record 4 uses as many lines as needed for NCONS entries (2 per line).

DATA GROUP I: Kinetic Time Functions--

The definition of the kinetic time function will vary depending upon the structure and the kinetics of the systems comprising each model. The input format, however, is constant.

VARIABLES

Record 1--Number of Time Functions (I10, 70X)

NFUNC = number of time functions required by the model. If no time functions are to be input, set NFUNC equal to zero and go to Card Group J. (I10)

TITLE = name of data group. (70X)

Record 2--Time Function Descriptions (A5, 2I5)

ANAME(ISC)= an optional one to five alphanumeric character descriptive name for the time function K. (A5)

ISC = number of breaks used to describe the time function K. (I5)

NOBRK(ISC)= number identifying the time function; these numbers are set by the model developer. (I5)

I = 1, NFUNC

Record 3--Time Functions (4(2F10.0))

VALT(K) = value of time function ISC at time T(K). (F10.0)

T(K) = time in days. If the length of the simulation exceeds T(NOBRK), the time function will repeat itself, starting at T(1), i.e., the approximation is assumed to be periodic, with period equal to T(NOBRK). (F10.0)

K = 1, NOBRK

ORGANIZATION OF RECORDS

Record 1 in entered once in Data Group I. Records 2 and 3, as a set, are repeated NFUNC times. Within each NFUNC set, Record 2 is input once and Record 3 uses as many 80-space lines as needed to input NOBRK entries. Four entries (four VALK(K)-T(K) pairs) will fit on each 80-space line.

DATA GROUP J: Initial Concentrations--

The initial conditions are the segment concentrations and densities for the state variables at time zero (or the start of the simulation).

VARIABLES

Record 1--System Information (A40, I5, F5.0, F10.0, 20X)

CHEML = chemical or system name (A40).

IFIELD = solids field (3, 4, or 5) that transports this system in its pure or sorbed form (I5).

DSED = density of system; 0.0 for chemical, 0.5-2.5 for solids, kg/L. (F5.0).

CMAX = maximum concentration, mg/L. (F10.0)

TITLE = name of data group. (20X)

Record 2--Initial Conditions (3(A5, 2F10.0)

ANAME(K) = an optional one to five alphanumeric character descriptive name or number identifying segment K. (A5)

C(ISYS,K)= initial concentration in segment K of system ISYS in the appropriate units, mg/L. (F10.0)

DISSF = dissolved fraction of chemical in segment K. (F10.0)

K = 1, NOSEG

ISYS = 1, NOSYS

ORGANIZATION OF RECORDS

Records 1 and 2 are a set and will be repeated NOSYS times. Within each NOSYS set Record 2 will use as many 80-space lines as needed to input NOSEG entries. Three entries (ANAME-C-DISSF) will fit on one line. After NOSEG entries have been entered in a NOSYS set, begin the next NOSYS set on the following line. If ICFL = 2 in Data Group A, initial conditions are read from the restart file (*.RST, where * is the input data set name), and Data Group J should not be included in the input data set.

TABLE 2.2.3 CROSS REFERENCES FOR WASP4 INPUT VARIABLES

Name	Data Record	Name	Data Record	Name	Data Record
A	B 4	ADFAC	A 4	ANAME	G 2, I 2, J 2
BCT	E 4	BQ	D 4	BVOL	C 3
C	J 2	CHEML	J 1	CHKNAME	H 2
CMAX	I 1	CONST	H 4	CONVB	E 2
CONVN	F2 2	CONVR	B 2	CONVQ	C 2
CONVV	C 2	CONVW	F1 1	DISSF	J 2
DMULT	C 3	SDED	I 1	DTS	A 6
DXP	C 3	IL	B 4	FLDNAME	H 3
IBEDV	C 1	IBC	E 3	IBOTSG	C 3
ICFL	A 4	IDMP	A 4	IFIELD	J 1
INPS	F2 3	INTYP	A 4	IQ	D 4
EQOPT	D 1	IR	B 4	ISC	G 2, G 4, H 4, I 2
ISEG	G 3	ISG	G 3	IVOPT	C 1
IWK	F1 1	JQ	D 4	JR	B 4
JSEA	D2 3	JMASS	A4	IDSY	A4
IDSG1	A4	IDSG2	A4	JUNSEG	D2 4
KPRT	F2 4	KSIM	A 4	KT1	F2 4
KT2	F2 4	MFLAG	A 4	NBRKQ	D 5
NBRKR	B 5	NCONS	H 3	NEGSLN	A 4
NFIELD	D 1	NFLD	H 2	NFUNC	I 1
NINQ	D 2	NOBC	E 1	NOBRK	A 5, E 3, F1 3, I 2
NOPAM	G 1	NOQS	D 3	NORS	B 3
NOSEG	A 4	NOSYS	A 4	NOWK	F1 1
NOWKS	F2 1	NPRINT	A 7	NPSDAY	F2 1
NRFLD	B 1	NSEA	D2 3	NTEX	B 2
PARAM	G 4	PNAME	G 4	PRINT	A 8
PSCAL	G 2	QBY	D 7	QT	D 6
RBY	B 7	RT	B 6	SCALB	E 2
SCALN	F2 2	SCALQ	D 2	SCALR	B 2
SCALV	C 2	SCALW	F1 1	T	A 6, I 3, E 4, F1 4

TABLE 2.2.3 CROSS REFERENCES FOR WASP4 INPUT VARIABLES

Name	Data Record	Name	Data Record	Name	Data Record
SYSBY	A 9	TADJ	A 4	TDINTS	C 1
TNAME	H 4	TPRINT	A 8	TQ	D 6
TR	B 6	VALT	I 3	VEXP	C 3
VMULT	C 3	WKT	F1 4	ZDAY	A 4
ZHR	A 4	ZMIN	A 4		

WASP4 Output

WASP4 simulations produce several files that may be examined by the user. These files use the file name of the input data set with a unique extension. The most important of these is the DMP file, which contains all kinetic display variables for each segment at each print interval throughout the simulation. These display variables include concentrations, certain calculated variables, and some rates. Available display variables for EUTRO4 and TOXI4 are summarized in the eutrophication and toxics user manual sections.

The W4DSPLY program is provided to help the user interactively examine the display variables contained in the DMP file. To use this program, simply type in the VAX (VMS) command "RUN W4DSPLY" or the PC (DOS) command "W4DSPLY." The program will prompt the user for information, as explained in Section 2.1.

Other files created by a WASP simulation include *.OUT, *.TRN, *.MSB, and *.RST (where * is the name of the input data set). The OUT file contains a record of the input data plus any simulation error messages that may have been generated. The TRN file contains a set of transport associated variables for each segment at each print interval throughout the simulation. These variables include the time step (day), calculated maximum time steps (day), segment volumes (m^3), segment flows (m^3/sec), flow changes (m^3/sec), time constants for segment flow (day^{-1}), segment exchange flows (m^3/sec), the time constant for segment exchanges (day^{-1}), the segment dispersion coefficient (m^3/sec), and the numerical dispersion coefficient (m^2/sec). The MSB file contains a mass balance record for one designated system in the model network as a whole (in kg). For each print interval, this file records the accumulated mass in from advection, dispersion, and loading; the accumulated mass out through advection, dispersion, burial (or volatilization, and kinetic transformation; the total resident mass; and the residual (unaccounted for) mass.

The RST file contains a snapshot of volumes and concentrations of each system in each segment at the conclusion of the simulation. This file can be read by WASP4 to continue a series of simulations.

2.4 THE EUTROPHICATION MODEL

Introduction

EUTRO4 requires the same input format as the basic WASP4 model. This format is explained in detail in Section 2.3. This section describes variables needed specifically for EUTRO4. Elaborations on WASP4 occur only in Data Groups G, H, and I. Records or variables within a record that are not mentioned here remain the same as described in Section 2.3.

As described in Section 1.4, the 13 systems for eutrophication modeling are: ammonia nitrogen, nitrate nitrogen, ortho-phosphate phosphorus, three phytoplankton carbon groups, carbonaceous BOD, dissolved oxygen, organic nitrogen, organic phosphorus, silica, salinity, and coliform bacteria. Table 2.4.1 summarizes these systems and their use in six levels of complexity.

EUTRO4 Data Descriptions

DATA GROUP A: Model Identification and System Bypass Option--

Record 4--Model Identification

NOSYS = 13

SYSBY(K) = 0 for those variables checked in the relevant complexity level in Table 2.4.1.

= 1 for those variables not checked in the relevant complexity level in Table 2.4.1.

TABLE 2.4.1 EURTO4 SYSTEMS AND COMPLEXITY LEVELS

System Number	Symbol	Name	Use in Complexity Level 1	2	3	4	5	6
1	NH3	Ammonia nitrogen		X	X	X	X	X
2	NO3	Nitrate nitrogen			X	X	X	X
3	PO4	Inorganic phosphorus				X	X	X
4	PHY1	Phytoplanktonl carbon				X	X	X
5	CBOD	Carbonaceous BOD	X	X	X	X	X	X
6	DO	Dissolved oxygen	X	X	X	X	X	X
7	ON	Organic nitrogen			X	X	X	X
8	OP	Organic phosphorus				X	X	X
9	PHY2	Phytoplankton2 Carbon				X	X	X
10	PHY3	Phytoplankton3 Carbon				X	X	X
11	SIO4	Silica				X	X	X
12	SAL	Salinity	X	X	X	X	X	X
13	BAC	Coliform Bacteria	X	X	X	X	X	X

TABLE 2.4.1 EURT04 SYSTEMS AND COMPLEXITY LEVELS

Complexity Level	Explanation
1	"Streeter-Phelps" BOD-DO with SOD
2	"Modified Streeter-Phelps" with NBOD
3	Linear DO balance with nitrification
4	Simple eutrophication
5	Intermediate eutrophication
6	Intermediate eutrophication with benthos

DATA GROUP B: Exchange Coefficients--

No changes.

DATA GROUP C: Volumes--

No changes.

DATA GROUP D: Flows--

No changes.

DATA GROUP E: Boundary Concentrations--

No changes. Input is repeated 13 times, once for each system. No boundary concentrations need be specified for those systems being bypassed.

DATA GROUP F: Waste Loads--

No changes. Input is repeated 13 times, once for each system. No loads need be specified for those systems being bypassed.

DATA GROUP G: Environmental Parameters--

Listed below are the 9 parameters required for eutrophication. For Level 1 and 2 analyses, only TMPSG, TMPFN, and SOD1D (3, 4, and 9) need be specified. For Level 3 analysis, VELFN and FNH4 (1 and 7) may be added (DEPTH and VELFN are used to compute reaeration; if rate constant K2 is specified (Constant 82), then VELFN can be omitted). For analyses at Level 4 and above, all parameters should be specified.

ISC	PARAM (ISEG,ISC)	Definitions and Units
1	VELFN(ISEG)	Pointer to the time-variable velocity function to be used for ISEG. The four velocity functions are defined by the user in data group I.

2	SAL(ISEG)	Average salinity of ISEG, in g/L; used in calculation of DO saturation.
3	TMPSG (ISEG)	Segment temperature multiplier (CC). TMPSG varies overspace and can be either actual temperature or a normalized function, depending on the definition of TEMP. TMPSG(ISEG) * TEMP(TMPFN(ISEG)) = STP, the temperature of segment ISEG.
4	TMPFN (ISEG)	Flag designating the time-variable temperature function to be used for ISEG. The four temperature functions are defined by the user in data group I.
5	KESG (ISEG)	Segment extinction coefficient multiplier (m^{-1}). KESG varies over space and can be either an actual extinction coefficient or a normalized function, depending on the definition of KE. KESG(ISEG) * KE(KEFN(ISEG)) = Ke, the extinction coefficient for segment ISEG.
6	KEFN (ISEG)	Pointer designating the time variable extinction coefficient (KE) to be used for segment ISEG. The five extinction coefficients available are defined in data group I.
7	FNH4 (ISEG)	Average ammonium flux multiplier for segment (mg/m^2-day).
8	FPO4 (ISEG)	Average phosphate flux multiplier for segment (mg/m^2-day).
9	SOD1D (ISEG)	Sediment oxygen demand for segment (g/m^2-day).

DATA GROUP H: Constants--

Listed below are the 42 constants available for a full eutrophication simulation. Figures 2.4.1 through 2.4.6 list the constants required for each level of complexity.

ISC	CONST(ISC)	ANAME(ISC)	Definition and Units
11	K1320C	K12C	Nitrification rate at 20°C, per day.
12	K1320T	K12T	Temperature coefficient for K1320C.
13	KNIT	KNIT	Half-saturation constant for nitrification-oxygen limitation, mg O_2/L.
21	K140C	K20C	Denitrification rate at 20°C, per day.
22	K140T	K20T	Temperature coefficient for K140C.

23	KNO3	KNO3	Half-saturation constant for denitrification oxygen limitation, mgO_2/L.
41	K1C	K1C	Saturated growth rate of phytoplankton (day^{-1}).
42	K1T	K1T	Temperature coefficient.
43	LGHTSW	LGHTS	Light formulation switch: = 1, use Dick Smith's (USGS) formulation = 2, use Di Toro et al. (1971) formulation
44	PHIMX	PHIMX	Maximum quantum yield constant. Used only when LIGHTSW = 1, mg C/mole photons
45	XKC	XKC	Chlorophyll extinction coefficient. Used only when LGHTSW = 1, $(mg\ chla/m^3)^{-1}/m$.
46	CCHL	CCHL	Carbon-to-chlorophyll ratio. Used only when LGHTSW = 2 (mg carbon/mg chla). Default = 30.
47	IS1	IS1	Saturation light intensity for phytoplankton. Used only when LGHTSW = 2 (Ly/day).
48	KMNG1	KMNG1	Nitrogen half-saturation constant for nitrogen for phytoplankton growth, which also affects ammonia preference, mg-N/L. NOTE: This affects ammonia preference: = 0, PNH3G1 = 1.0 = Large, PNH3G1 = $NH_3/(NH_3 + NO_3)$ NOTE: For standard model application, use a large KMNG1.
49	KMPG1	KMPG1	Phosphorous half-saturation constant for phytoplankton growth, mg PO_4-P/L.
50	K1RC	K1RC	Endogenous respiration rate of phytoplankton at 20°C, day^{-1}
51	K1RT	K1RT	Temperature coefficient for phytoplankton respiration.
52	K1D	K1D	Non-predatory phytoplankton death rate, day^{-1}.

53	K1G	K1G	Grazing rate on phytoplankton per unit zooplankton population, L/cell-day.
54	NUTLIM	NUTLIM	Nutrient limitation option (default = 0). 0 = minimum 1 = multiplicative
55	KPZDC	KPZDC	Decomposition rate constant for phytoplankton in the sediment at 20°C, per day.
56	KPZDT	KPZDT	Temperature coefficient for decomposition of phytoplankton in sediment.
57	PCRB	PCRB	Phosphorus-to-carbon ratio in phytoplankton, mg PO_4-P/mg C.
58	NCRB	NCRB	Nitrogen-to-carbon ratio in phytoplankton, mg N/mg C.
59	KMPHYT	KMPHY	Half-saturation constant for phytoplankton, mg carbon/L. NOTE: As phytoplankton increases, mineralization of organic nitrogen and organic phosphorus increases. KMPHYT = small; little phytoplankton effect on mineralization = large; large concentration of phytoplankton needed to drive mineralization For standard model application, use KMPHYT = 0.
71	KDC	KDC	BOD deoxygenation rate at 20°C, per day.
72	KDSC	KDSC	Decomposition rate of carbonaceous BOD in the sediment at 20°C, per day.
73	KDST	KDST	Temperature coefficient for carbonaceous deoxygenation in the sediment.
74	KBOD	KBOD	Half saturation constant for carbonaceous deoxygenation oxygen limitation.
75	KDT	KDT	Temperature coefficient for

			carbonaceous deoxygenation in water column.
81	OCRB	OCRB	Oxygen to carbon ratio in phytoplankton, mg O_2/mg C.
82	K2	K2	Reaeration rate constant at 20°C for entire water body, day^{-1}. NOTE: If K2 is not entered, the reaeration rate will be calculated from water velocity, depth, and wind velocity.
91	K1013C	K71C	Mineralization rate of dissolved organic nitrogen, per day.
92	K1013T	K71T	Temperature coefficient for K1013C.
93	KONDC	KONDC	Decomposition rate constant for organic nitrogen in the sediment at 20°C, per day.
94	KONDT	KONDT	Temperature coefficient for decomposition of organic nitrogen in the sediment.
95	FON	FON	Fraction of dead and respired phytoplankton nitrogen recycled to organic nitrogen. Default = 1.0.
100	K58C	K83C	Mineralization rate of dissolved organic phosphorus, per day.
101	K58T	K83T	Temperature coefficient for K58C.
102	KOPDC	KOPDC	Decomposition rate of organic phosphorus in the sediment at 20°C, per day.
103	KOPDT	KOPDT	Temperature coefficient for decomposition of organic phosphorus in the sediment.
104	FOP	FOP	Fraction of dead and respired phytoplankton phosphorus recycled to organic phosphorus. Default = 1.0.

DATA GROUP I: Miscellaneous Time Functions--

Listed below are the 18 time functions available for eutrophication. Only TEMP(1) is required for Level 1 and 2 analyses. For Level 3 analyses, TFNH4, VELN(1), and WIND may be added (WIND is needed only for calculating reaeration in non-flowing water bodies such as lakes). For analyses at Level 4 and above, ITOT, F, KE, and TFPO4 should be used. For resolution of spatial variability in temperature, light extinction, and water velocity the four TEMP functions, the five KE functions, and the four VELN functions may be used.

NOTE: Functions 1-4 are the four temperature-function options available for TMPFN in Data Group G. Functions 8-12 are the five extinction coefficient options for KEFN in Data Group G. Functions 15-18 are the four water velocity options for VELFN in Data Group G.

ISC	ANAME(ISC)		VALT(ISC)
1	TEMP(1)	=	Time-variable temperature function 1. TEMP(K) can be either a normalized function or an actual temperature in °C, depending upon the definition of the parameter multiplier TMPSG(ISEG).
2	TEMP(2)	=	Time-variable temperature function 2, unitless or °C.
3	TEMP(3)	=	Time-variable temperature function 3, unitless or °C.
4	TEMP(4)	=	Time-variable temperature function 4, unitless or °C.
5	ITOT	=	Total daily solar radiation, langleys.
6	F	=	Fraction of daylight, days.
7	WIND	=	Wind velocity, m/sec.
8	KE(1)	=	Time-variable extinction coefficient function 1. This can be either a normalized function or an actual extinction coefficient in m^{-1}, depending upon the definition of the parameter multiplier KESG(ISEG).
9	KE(2)	=	Time-variable extinction coefficient function 2, unitless or m^{-1}.
10	KE(3)	=	Time-variable extinction coefficient function 3, unitless or m^{-1}.
11	KE(4)	=	Time-variable extinction coefficient function 4, unitless or m^{-1}.
12	KE(5)	=	Time-variable extinction coefficient function 5, unitless or m^{-1}.
13	TFNH4	=	Normalized ammonium flux from bed, unitless.
14	TFPO4	=	Normalized phosphate flux from bed, unitless.
15	VELN(1)	=	Time variable velocity function 1, m/sec. This velocity is added to the net velocity VELOCG(ISEG) computed from the segment flow and the hydraulic parameters read in Data Group C.
16	VELN(2)	=	Time variable velocity function 2, m/sec.
17	VELN(3)	=	Time variable velocity function 3, m/sec.

18 VELN(4) = Time variable velocity function 4, m/sec.

19 ZOO = Herbivorous zooplankton population, mgC/L.

DATA GROUP J: Initial Concentrations--

No changes. Input is repeated 8 times, once for each system. Solids transport fields must be specified for the particulate fraction of each system (Solids Field 3 here is particulate organic matter; Solids Field 4 is phytoplankton; Solids Field 5 is inorganic sediment). The dissolved fraction of each system in each segment must also be specified.

Record 1--Solids Transport Fields

IFIELD(1) = 3

IFIELD(2) = 5

IFIELD(3) = 5

IFIELD(4) = 4 (make sure DISSF = 0.0)

IFIELD(5) = 3

IFIELD(6) = 5 (make sure DISSF = 1.0)

IFIELD(7) = 3

IFIELD(8) = 3

TABLE 2.4.2 CROSS REFERENCES FOR EUTRO4 INPUT VARIABLES

Name	Data Record	Name	Data Record	Name	Data Record
CCHL	H 46	DEPTH	G 1	F	I 6
FNH4	G 7	FPO4	G 8	IS1	H 47
ITOT	I 5	K12C	H 11	FON	H 95
K1C	H 41	K1D	H 52	K1G	H 53
K12T	H 12	FOP	H 104	K1T	H 42
K2	H 82	K1RC	H 50	K1RT	H 51
K71C	H 91	K71T	H 92	K20C	H 21
K20T	H 22	KBOD	H 75	KDC	H 71
K83C	H 100	K83T	H 101	KDT	H 72
KDSC	H 73	KDST	H 74	KE(1)	I 8
KE(2)	I 9	KE(3)	I 10	KE(4)	I 11
KE(5)	I 12	KEFN	G 6	KMNG1	H 48
KMPHYT	H 9	KESG	G 5	KNO3	H 23

TABLE 2.4.2 CROSS REFERENCES FOR EUTRO4 INPUT VARIABLES

Name	Data Record	Name	Data Record	Name	Data Record
KONDC	H 93	KMPG1	H 49	KNIT	H 13
KOPDT	H 103	KPZDC	H 55	KONDT	H 94
KOPDC	H 102	KCRB	H 58	NUTLIM	H 54
KPZDT	H 56	LGHTSW	H 43	PHIMX	H 44
SOD1D	G 9	OCRB	H 81	PCRB	H 57
TEMP(1)	I 1	TEMP(2)	I 2	TEMP(3)	I 3
TEMP(4)	I 4	TMPFN	G 4	TMPSG	G 3
TFNH4	I 13	TFPO4	I 14	VELFN	G 1
VELN(1)	I 15	VELN(2)	I 16	VELN(3)	I 17
VELN(4)	I 18	WIND	I 7	XKC	H 45
ZOO	I 19				

EUTRO4 Output

The standard WASP4 output files were summarized in Section 2.3. EUTRO4 stores in the DMP file 36 kinetic display variables. These variables are defined in Table 2.5.2. To examine these variables in tabular form, the user may run W4DSPLY as explained in Section 2.3.

TABLE 2.4.3 EUTRO4 KINETIC DISPLAY VARIABLES

Number	Variable	Definition
1	SEG. DEPTH	Depth in segment (m).
2	WATER VEL.	Water velocity within segment (m/sec).
3	ITOT	Incoming solar radiation (Langleys/day).
4	SEG. TEMP	Temperature within segment (°C).
5	SEG. TYPE	Segment type (1, 2, 3 or 4)
6	PHYT	Phytoplankton biomass as carbon (mg/L).
7	RESP	Phytoplankton respiration rate constant (day^{-1}).
8	DEATH	Phytoplankton death rate constant (day^{-1}).
9	LIMIT	Nutrient limitation indicator ("+" = nitrogen, "-" = phosphorus).
10	TCHLAX	Phytoplankton chlorophyll a concentration (μg/L).
11	XEMP1	Nitrogen limitation factor for phytoplankton.
12	XEMP2	Phosphorus limitation factor for phytoplankton.

TABLE 2.4.3 EUTRO4 KINETIC DISPLAY VARIABLES

Number	Variable	Definition
13	GP1	Light and nutrient limited phytoplankton growth rate constant (day^{-1}).
14	RLIGHT	Light limitation factor for phytoplankton growth.
15	RNUTR	Nutrient limitation factor for phytoplankton.
16	PHN3GI	Preference factor for ammonia over nitrate.
17	NH3	Segment ammonia concentration (mg/L).
18	NO3	Segment nitrate plus nitrite concentration (mg/L).
19	ON	Segment organic nitrogen concentration (mg/L).
20	TIN	Total inorganic nitrogen concentration (mg/L).
21	TOT. N	Total nitrogen concentration (mg/L).
22	TON	Total organic nitrogen concentration (mg/L).
23	CN	Total inorganic nitrogen (mg/L).
24	OP	Segment organic phosphorus concentration (mg/L).
25	OPO4	Segment orthophosphate concentration (mg/L).
26	TIP	Total inorganic phosphorus concentration (mg/L).
27	TOP	Total organic phosphorus concentration (mg/L).
28	RATIO	Inorganic nitrogen to phosphorus ratio (mg/mg).
29	DO	Dissolved oxygen concentration (mg/L).
30	CBOD	Carbonaceous biochemical oxygen demand (mg/L).
31	BOD5	5-Day biochemical oxygen demand (mg/L).
32	UBOD	Ultimate 30-day BOD (mg/L).
33	DOMIN	Minimum diurnal dissolved oxygen (mg/L).
34	DOMAX	Maximum diurnal dissolved oxygen (mg/L).
35	CS	Dissolved oxygen saturation concentration (mg/L).
36	KDC	Dissolved carbonaceous BOD deoxygenation rate at 20°C (day^{-1}).
37	DELO2	Diurnal dissolved oxygen variation (mg/L).

APPENDIX C: Contact List

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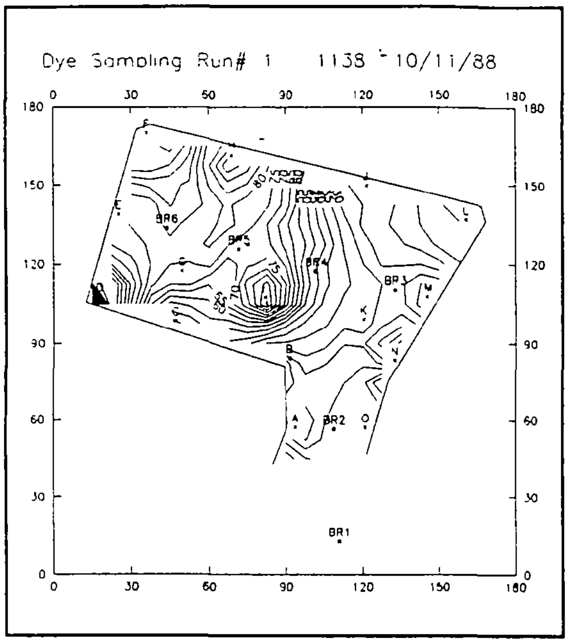
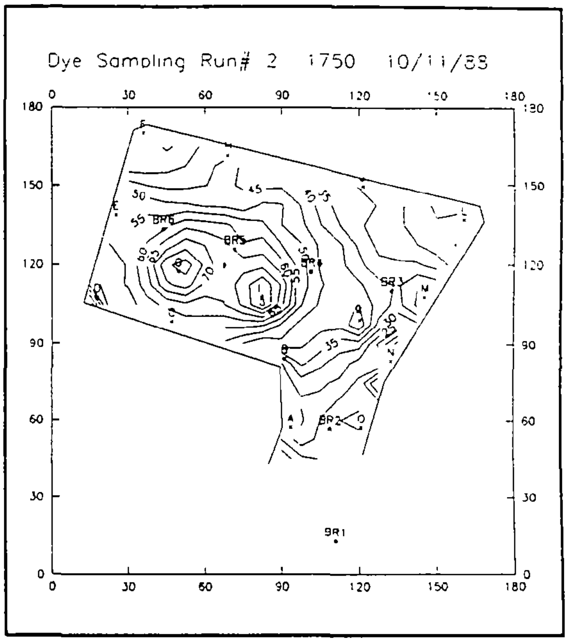
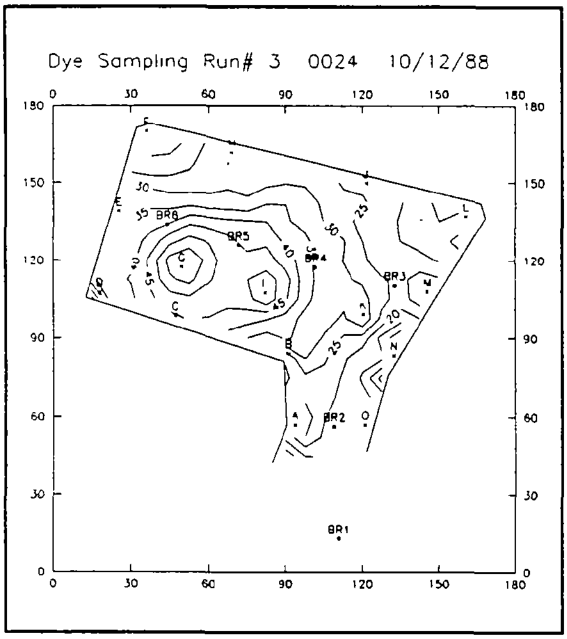
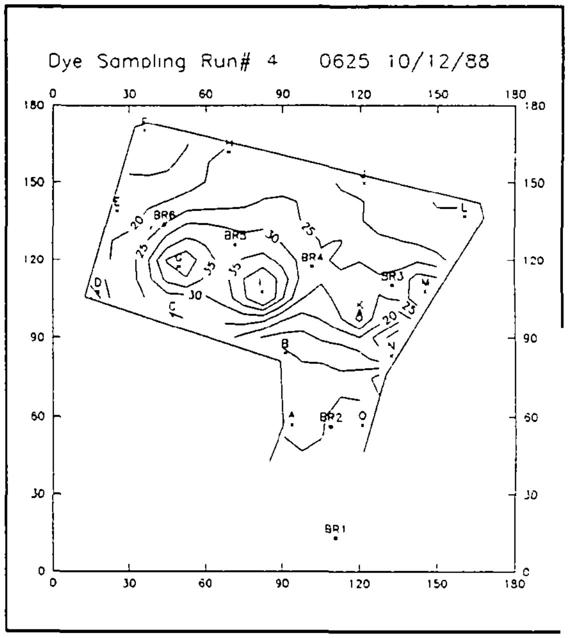
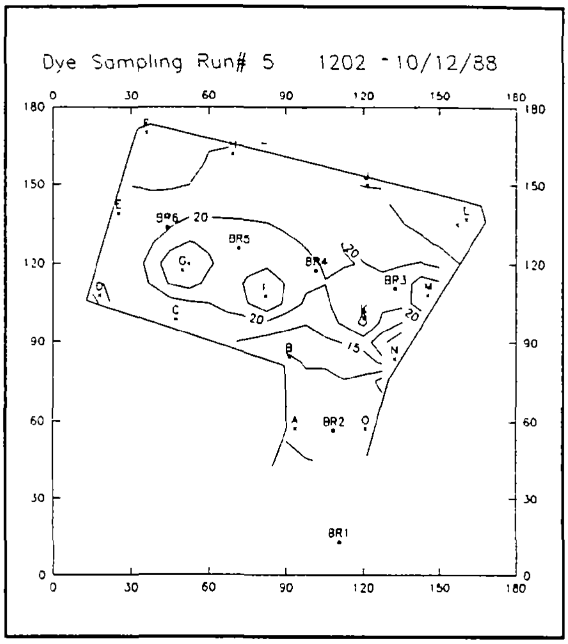
APPENDIX D: Dye Concentration Contours


Dye Sampling Run# 1 1138 10/11/88


Dye Sampling Run# 2 1750 10/11/88


Dye Sampling Run# 3 0024 10/12/88


Dye Sampling Run# 4 0625 10/12/88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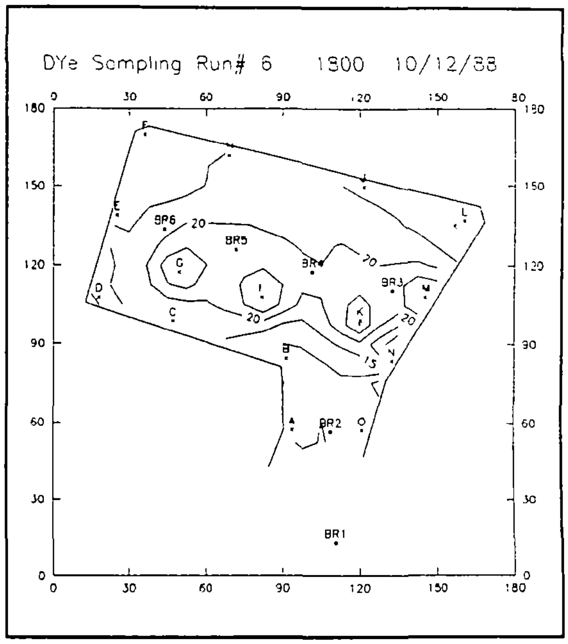
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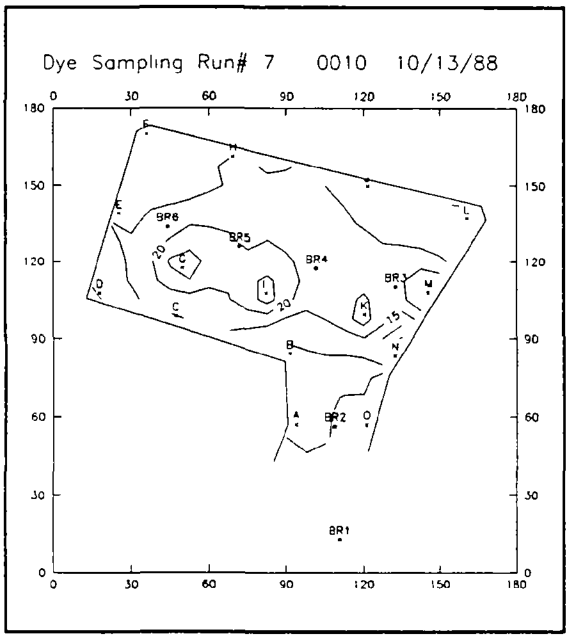
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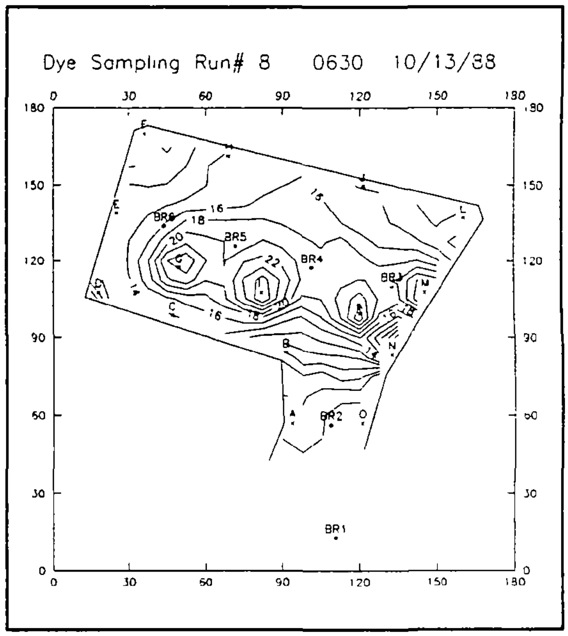
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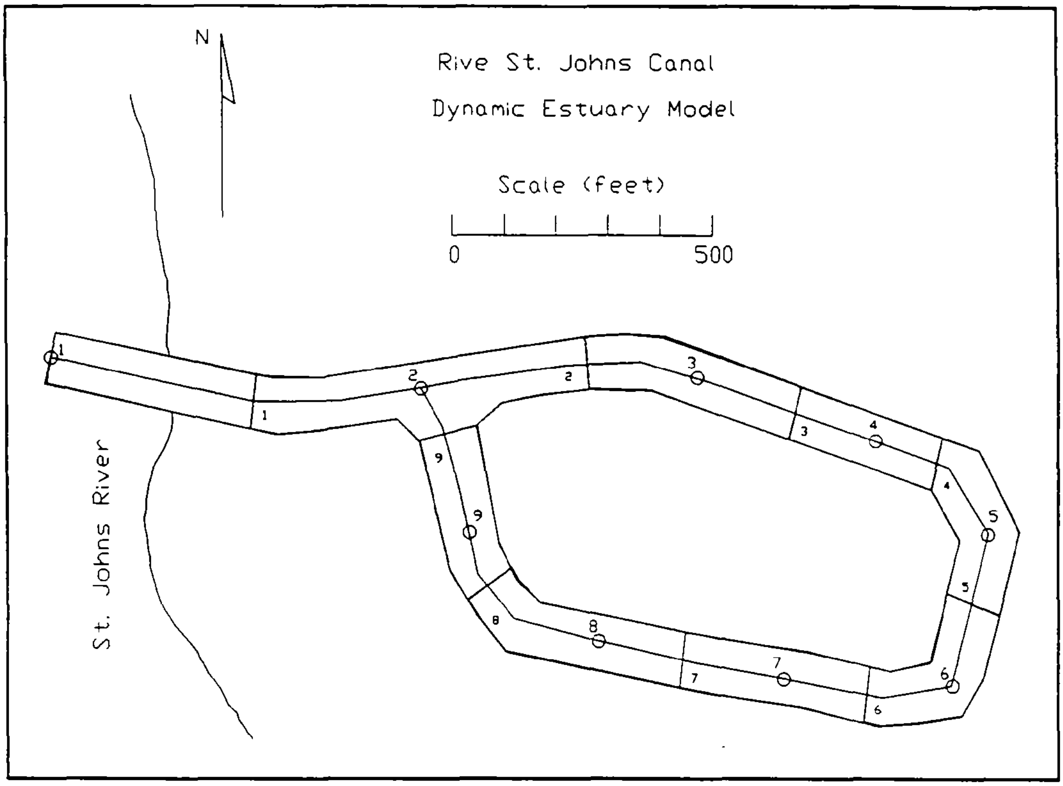
APPENDIX E: Case Study for a Proposed Marina

TC-3668-04

RIVE ST. JOHNS PHASE II CANAL SYSTEM WATER QUALITY MODEL STUDY



September 1988

prepared for

Dostie Builders, Inc.
2960 Hartley Road
Jacksonville, Florida 32217

TC-3668-04

RIVE ST. JOHNS PHASE II CANAL SYSTEM WATER QUALITY MODEL STUDY

prepared for

Dostie Builders, Inc.
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TABLE OF CONTENTS

1.0 INTRODUCTION

1.1 Purpose

This report documents a water quality analysis of a proposed recreational boat canal for the Rive St. Johns Phase II development on the St. Johns River, Jacksonville, Florida. This study was initiated as a result of the Environmental Protection Agency Region IV review of the Rive St. Johns permit application submitted to the Corps of Engineers by Dostie Builders (Public Notice No. 87IPF-21164). Upon review of a previous study of flushing characteristics of the proposed canal (Tetra Tech, 1988), EPA expressed concern that water quality in the canal could possibly depress dissolved oxygen levels below the 4.0 mg/L standard set by the State of Florida for marine waters.

In a letter from Robert F. McGhee, Chief of Water Quality Management Branch at EPA Region IV, to Mr. Charles Ashton of the Regulatory Division of the Corps of Engineers (see Appendix A) it was suggested that the applicant use the Dynamic Estuary Model (DEM) to perform the water quality calculations necessary to predict dissolved oxygen levels in the canal. This report documents the application of DEM to the proposed canal system.

1.2 Project Location

The Rive St. Johns Phase II development site is located in Jacksonville, Duval County, Florida, on the east bank of the St. Johns River about one-half mile south of Reddie Point (see Figure 1.1). The study area is located directly across the river from the U.S. Coast Guard Station at the mouth of the Trout River. The flow in the St. Johns River in the study area is affected by tides which are semidiurnal in nature, that is, there are two high and two low waters in a tidal day with comparatively little diurnal inequality. Boundary conditions for the DEM model were taken from the State of Florida long-term monitoring station #4 "Off Talleyrand Avenue" on the St. Johns River within one mile of the study area (see Figure 1.1). The Main Street Bridge is the approximate geographical divisor of predominantly fresh and predominantly marine waters in Duval County. The study area is about 7 miles downriver from the Main Street Bridge and the waters are classified as marine.

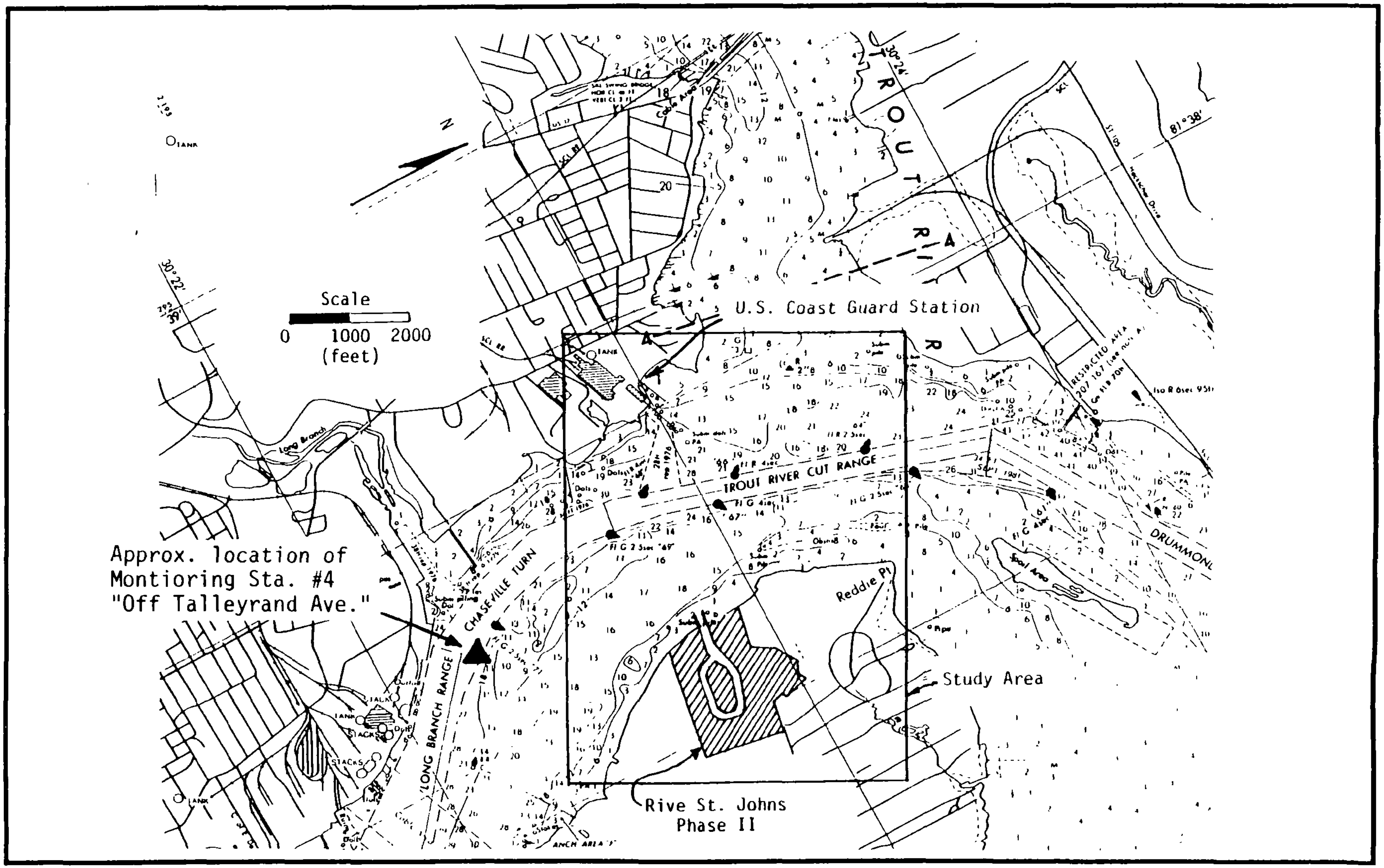

Figure 1.1 Location of Study Area for Rive St. Johns Phase II Development.

2.0 DEM MODEL DESCRIPTION

2.1 Model Selection

The Dynamic Estuary Model (DEM) was originally developed for the U.S. Environmental Protection Agency and has been suggested by EPA Region IV as the model of choice for this study. In addition, DEM has been selected for the following reasons:

- DEM is "network" type model which is ideally suited for simulation of channelized streams, estuaries, and waterways, such as the Rive St. Johns proposed canal system.
- DEM is widely used by government and private industry, and is an approved EPA model (developed under EPA funding and supported by the EPA research lab at Athens, Georgia).
- DEM has been tested and successfully verified based on extensive field-studies in numerous different water systems.

2.2 DEM Model Description

The DEM model represents the estuarine system as a network of "nodes" and "channels". Nodes are discrete volume units of a waterbody, characterized by surface area, depth, side slope and volume (see Figure 2-1). The nodes are interconnected by channels, each having associated length, width, cross-sectional area, hydraulic radius, side slope and friction factor. Water is constrained to flow from one node to another through these channels, advecting and diffusing water quality constituents between nodes.

The overall two-dimensional DEM model is composed of three separate components, a hydrodynamic model (HYD1), a dynamic quality model (DQUAL), and a steady-state quality model (AQUAL). The first uses the equations of motion and continuity to calculate channel flows and nodal volume changes in response to wind and tidal boundary fluctuations. Dynamic and/or steady-state results (averaged over a complete tidal cycle) are stored on disk files to be used

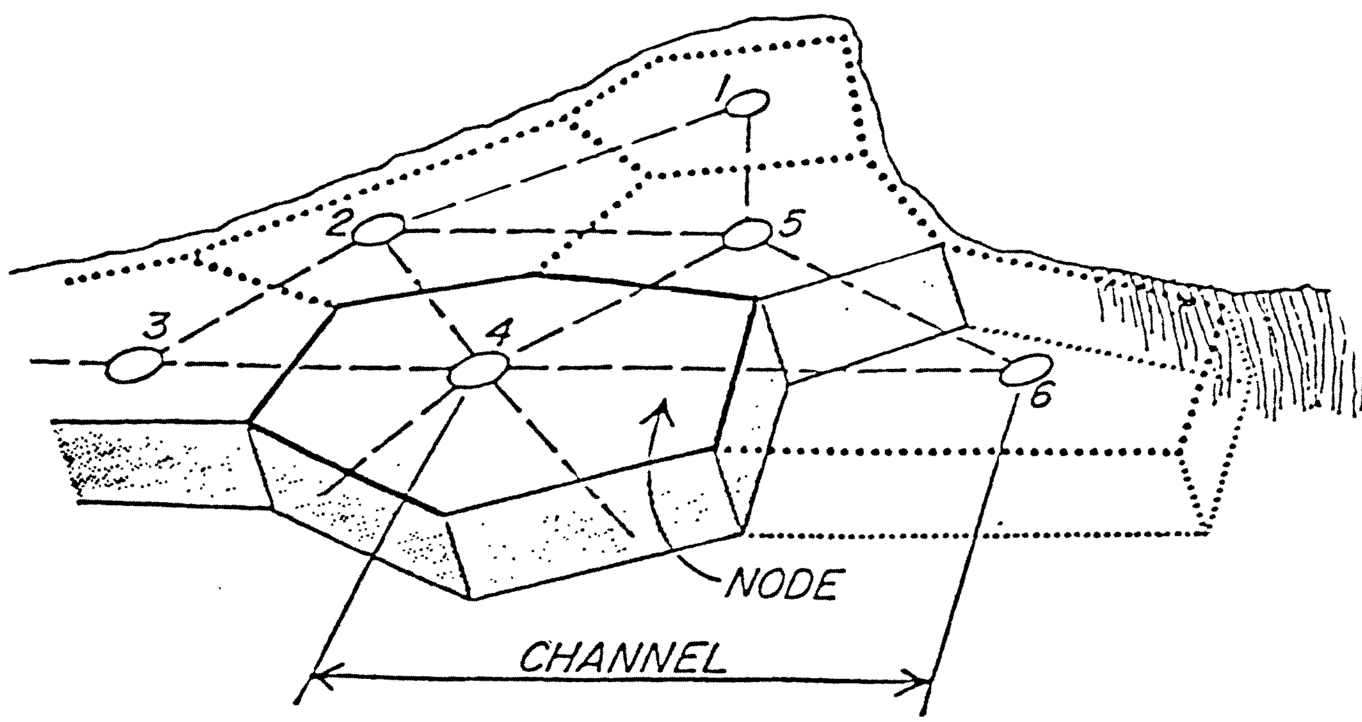

Figure 2-1. Figure section of an estuary link-node network.

repeatedly in the calibration of the quality models. Once the physical transport mechanisms of water flow and velocities are determined, the biological and chemical reactions can be superimposed to calculate water quality at any location and time.

The dynamic and steady-state water quality models used in this evaluation assume that the estuarine-system is well mixed vertically, that the law of conservation of mass is obeyed for water quality constituents, and that biochemical reaction rates may be estimated using first order kinetics characterized by reaction-specific rate coefficients. DQUAL and AQUAL can be used to simulate any combination of the following 9 constituents and have the capability to include up to four additional user specified conservative constituents.

1. Salinity (chloride)
2. Total Nitrogen (TKN + NO_2 + NO_3)
3. Total Phosphorus (PO_4 - P)
4. Total Coliform Bacteria
5. Fecal Coliform Bacteria
6. Carbonaceous BOD (5-day) (model converts to ultimate BOD)
7. TKN (model converts to nitrogenous BOD)
8. Dissolved Oxygen
9. Temperature

Inputs to the dynamic estuary model are as follows:

- Physical and geometric characteristics of the estuary, including slopes, channel widths, friction factors, node depths and areas;
- Time-varying meteorological and climatological data, including cloud cover, dry and wet bulb air temperature, atmospheric pressure, wind speed and direction, and precipitation;
- Initial <u>in-situ</u> water quality parameter concentrations;
- Time-varying tidal stages and currents at the seaward boundaries;
- Time-varying water quality at boundaries;
- Tributary inflows and waste discharges;
- Groundwater inflow;
- Inflow quality (including groundwater);
- Time-varying stormwater inflow;
- Stormwater quality characteristics, and
- Rate coefficients for the kinetic reactions.

Outputs from the dynamic estuary model (DQUAL) include detailed time profiles of tidal stages and water quality constituent concentrations at the nodal locations within the estuary system.

Inputs and outputs for the steady-state estuary model (AQUAL) are essentially the same as for the dynamic model, except inputs and outputs represent long term, averaged conditions.

The dissolved oxygen concentration of a natural water body is a function of a variety of physical, chemical, and biological processes. The diagram shown in Figure 2-2 is a schematic representation of the processes which are considered to be the major components affecting dissolved oxygen. These processes have been incorporated in the model which links the oxygen sinks (such as CBOD, NBOD, phytoplankton respiration and benthic demand) with oxygen sources (such as photosynthesis and reaeration) to calculate the dynamic dissolved oxygen concentration.

The remaining water quality constituents are not interrelated in the model Each is considered to act independently of the others. Since salinity (or chloride) is considered a conservative constituent, it can be used to test the ability of the model to simulate the hydrodynamics and transport of the system. The phenomenon of dispersive transport in the model results from a combination of "numerical" dispersion and dispersion coefficients which can be adjusted to simulate the turbulent mixing properties of the water body.

All other constituents are assumed to be advected and diffused in a manner analogous to salinity (chloride), though they may be non-conservative through one or more of the following natural processes:

- Decay
- Macrophytic Growth
- Grazing
- Excretion
- Mortality
- Settling
- Upwelling

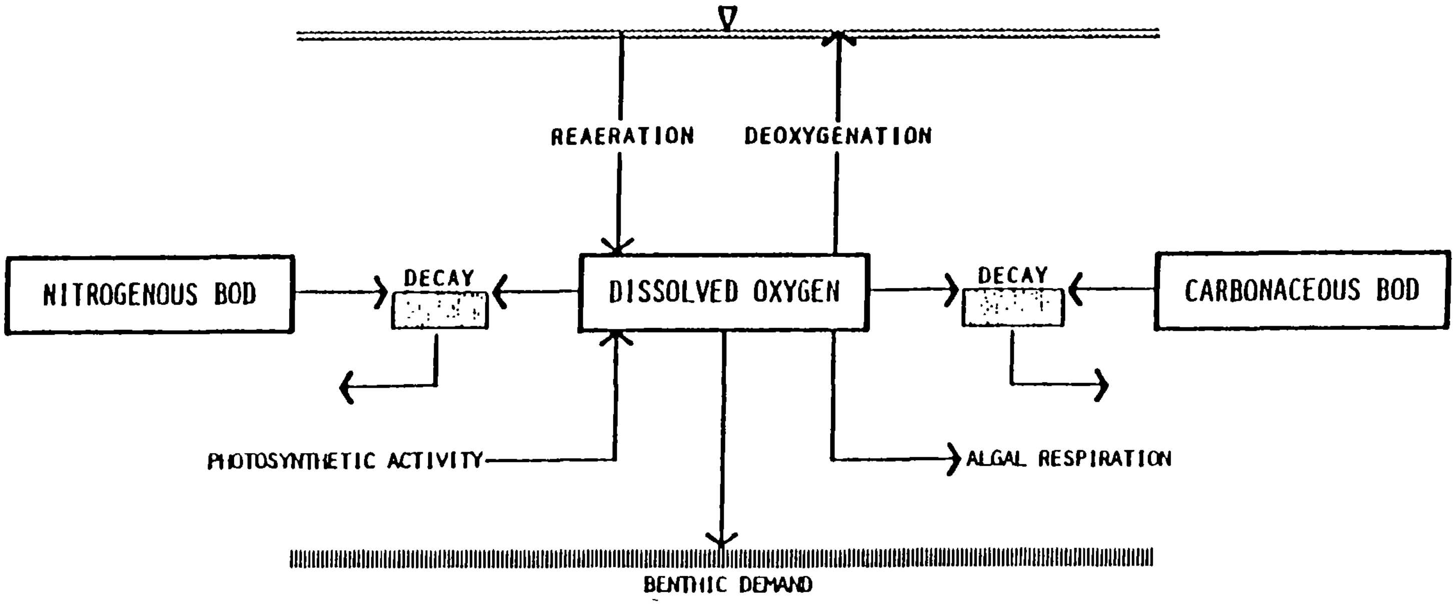

Figure 2-2. Flow diagram of modeled processes related to dissolved oxygen.

These processes are represented by the first order decay terms and rate coefficients which add to the complexity of the mass balance equation which describes the prototype system.

Constituents which decay in the marine environment such as BOD and TKN are described mathematically by first order decay terms, K_d, K_n, in addition to the terms for advection, inflow and withdrawal. The amount of constituent which decays in a given time step is a function of the concentration of the constituent at the beginning of the time step. The first order decay coefficients are temperature dependent according to the following formula.

$$K_{(T)} = K_{(20)}\ \theta^{(T-20)} \qquad (2\text{-}1)$$

where

K = first order rate coefficient
T = water temperature in °C
θ = 1.047 for oxygen demand and 1.02 for coliform decay coefficients and user specified nonconservative constituents.

Due to this temperature dependency, it is important that the water quality model give reasonably accurate simulation of water temperature variations over both space and time.

Since nutrients such as nitrogen and phosphorus can be affected by a complex combination of biological processes, source/sink terms are also included in the equations which describe these constituents in mathematical terms. These source/sink terms are used to represent the net effect of all the above processes acting in concert. Since it is not possible to measure the individual contribution of each process, it is necessary to determine the collective source/sink rate by "calibrating" the model so that it recreates what is measured in the field. Once this is done, the resulting model is tested or verified using one or more additional sets of data to ensure that the source/sink term which was selected proves correct for more than one set of conditions.

However, for this study the proposed canal does not yet exist so the DEM model cannot be calibrated and verified based on field data. Instead, a base condition consisting of average typical values of the various rate coefficients for the kinetic reaction terms and source/sink terms was defined. A model sensitivity analysis was then performed by varying the rate coefficients about their typical ranges and the effect on dissolved oxygen was documented. Water quality impacts of the proposed canal can then be implied from the sensitivity analysis.

3.0 HYDRODYNAMIC CALIBRATION

3.1 DEM Model Layout

The Dynamic Estuary Model was configured to represent the proposed canal system by a grid network of nodes linked together by channels. The following are underlying assumptions of the Dynamic Estuary Model:

- The estuarine system is well mixed vertically
- The law of conservation of mass is obeyed for water quality constituents
- Chemical reaction rates may be estimated using first order kinetics characterized by reaction-specific rate coefficients.

The area modeled by DEM includes the main entrance channel and the entire loop canal system. The DEM model node and channel geometry was selected to give approximately uniform representation along the entire canal system. A node spacing of 289 ft to 721 ft was necessary to ensure stability for the given 2.5 ft tide range. The model consisted of 9 nodes and 9 channels as shown in Figure 3-1. The node and channel geometry is given in Table 3-1. The width, hydraulic radius, and Manning n values shown for each channel were the adjusted numbers necessary to calibrate the HYDRO velocities with the previous CAFE1 velocities.

3.2 DEM Tide/Velocity Calibration

Typically the hydrodynamic sub-model (HYDRO) of DEM is calibrated to measured tides and velocities in the water body. Of course, this was not possible for the proposed canal. Instead, a different approach was undertaken in which the hydrodynamic results from a previous study (Tetra Tech, 1988) based on a detailed finite-element model (CAFE1) of the canal system were used to calibrate HYDRO. Calibration of HYDRO was accomplished through successive adjustment of channel roughness and channel geometry (hydraulic radius and width) until the velocities in the DEM model channels matched those from the CAFE1 model. Reasonable agreement between HYDRO and CAFE1 velocities was achieved as shown in Figures 3-2(a) through 3-2(i).

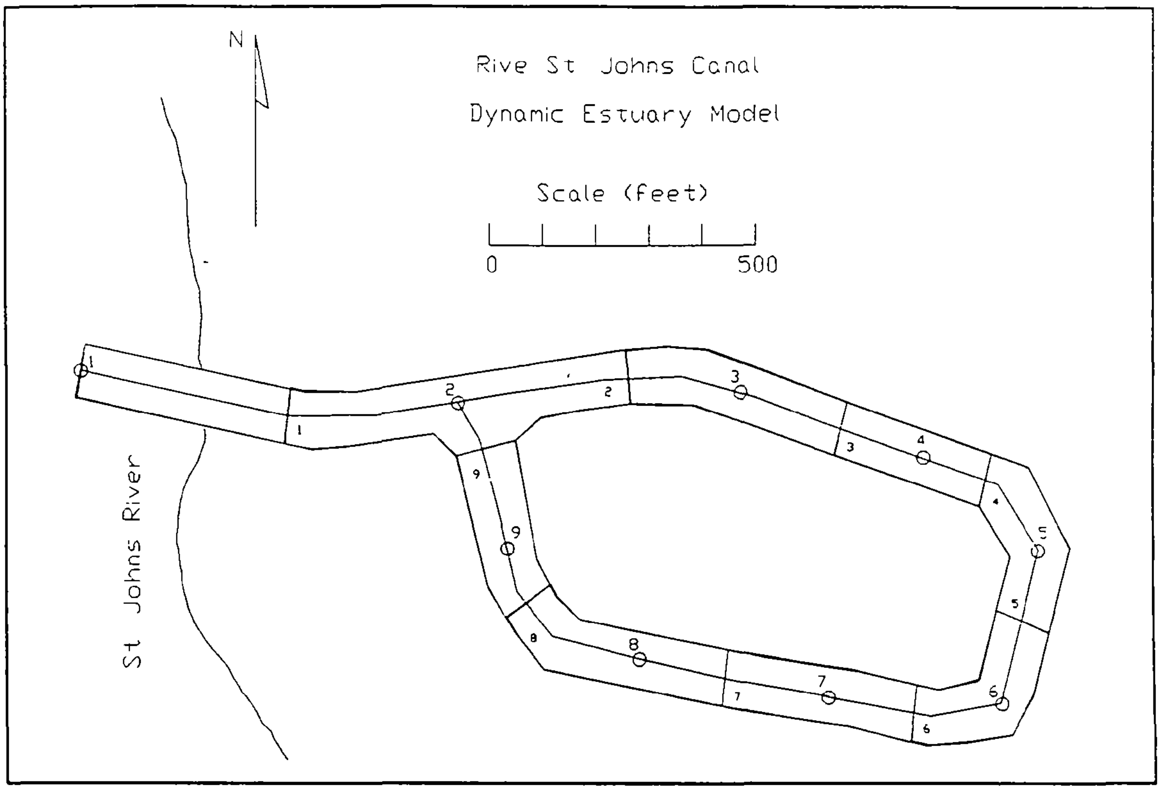

Figure 3-1. Dynamic Estuary Model applied to Rive St. Johns Canal.

Table 3-1
Node Geometry for DEM Model of Rive St. Johns Canal

Junction	Surface Area (sq. feet)	Depth (ft)	Channel	Length (ft)	Width (ft)	Hyd. Rad. (ft)	Manning n
1	39,696	5.2					
			1	721	100	4.7	0.017
2	71,220	5.2					
			2	541	60	4.7	0.017
3	43,011	5.2					
			3	365	40	4.7	0.018
4	28,763	5.2					
			4	290	35	4.5	0.019
5	33,252	5.2					
			5	296	60	4.5	0.020
6	34,130	5.2					
			6	335	150	4.7	0.025
7	37,871	5.2					
			7	362	260	4.7	0.035
8	43,468	5.2					
			8	361	220	4.7	0.045
9	31,820	5.2					
			9	289	130	4.7	0.065

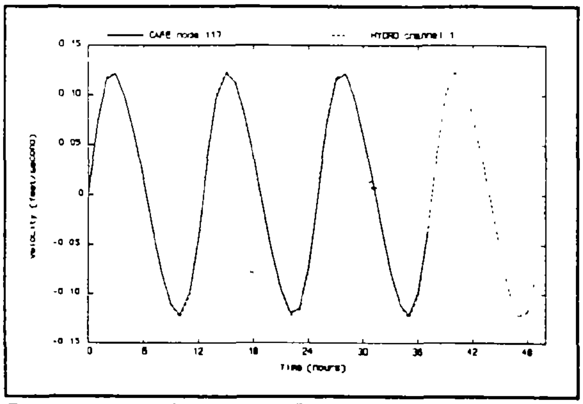

Figure 3-2(a). HYDRO channel 1

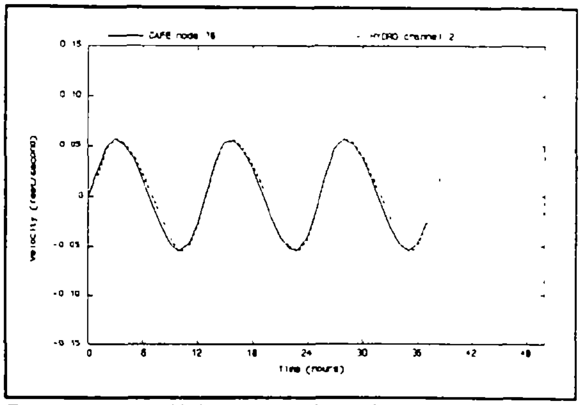

Figure 3-2(b). HYDRO channel 2

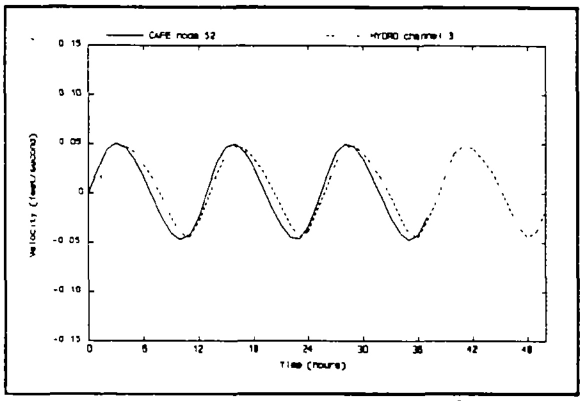

Figure 3-2(c). HYDRO channel 3

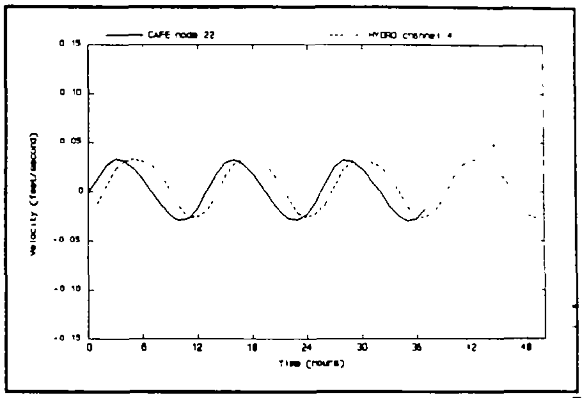

Figure 3-2(d). HYDRO channel 4

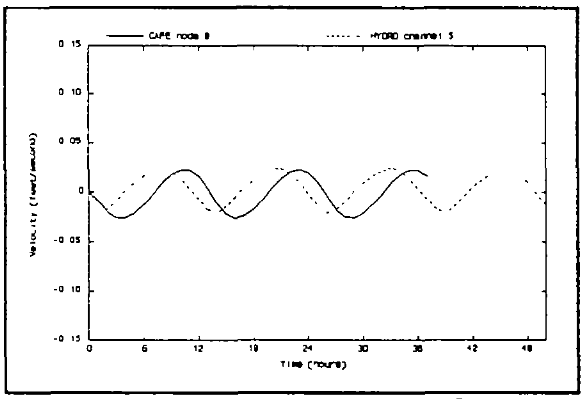

Figure 3-2(e). HYDRO channel 5

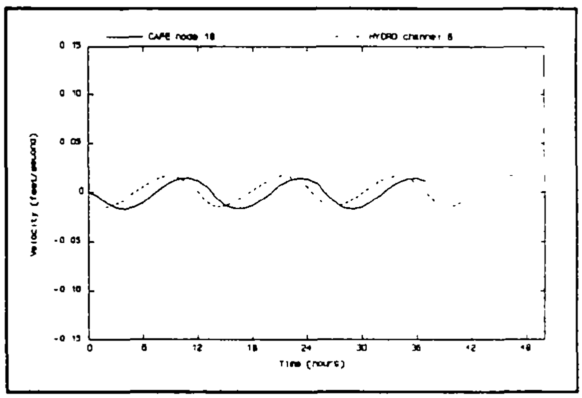

Figure 3-2(f). HYDRO channel 6

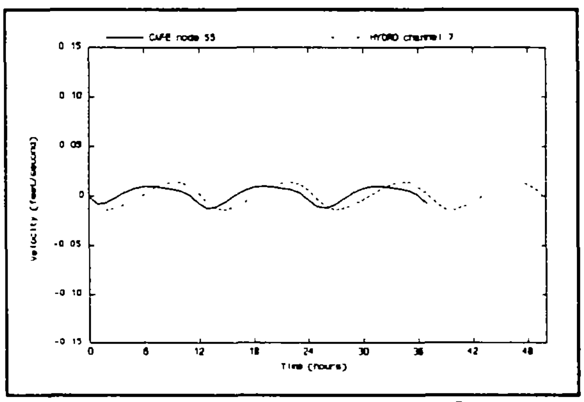

Figure 3-2(g). HYDRO channel 7

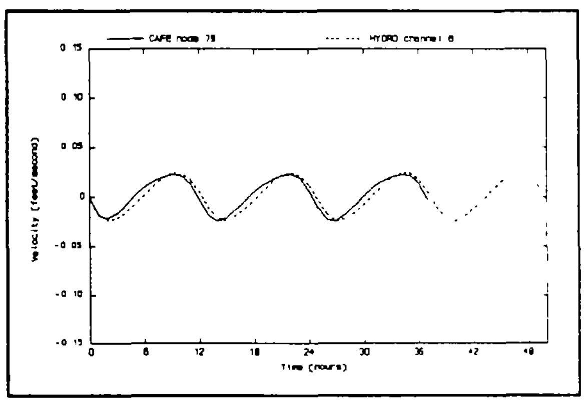

Figure 3-2(h). HYDRO channel 8

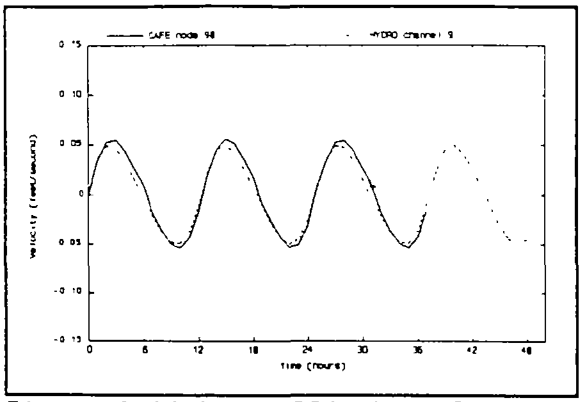

Figure 3-2(i). HYDRO channel 9

4.0 WATER QUALITY MODEL (DQUAL)

4.1 Boundary Conditions

The boundary conditions for the water quality model DQUAL were based on measured values at the closest long-term monitoring station, Sta. #4 Talleyrand Avenue, which is within one mile of the canal entrance (Figure 1.1). Constituent concentrations were taken from monitoring data sheets for summer months over the period 1983-1986 and averaged to form a data set of typical summer conditions. The parameters and associated concentrations used to derive the boundary conditions are given in Table 4-1. Typical ranges for the system rate coefficients used in the DQUAL model are summarized below:

System Rate Coefficient	Typical Range
K_d, Carbonaceous BOD decay rate (1/day)	0.1 - 0.3
K_n, Nitrification rate (1/day)	0.05 - 0.15
P, Algal photosynthetic oxygen production (g/m^2-day)	0.0 - 15.0
R, Algal oxygen consumption due to respiration (g/m^2-day)	0.0 - 7.5
SOD, Sediment oxygen demand rate (g/m^2-day)	0.0 - 5.0
K_a, Reaeration rate (1/day)	0.25 - 3.0

Table 4-1
Summer Conditions in St. Johns River at Sta. #4 (Talleyrand Avenue)

Parameter	(units)	7/8/86	9/8/86	6/11/85	6/26/84	8/14/84	Average
Chlorides	(mg/L)	7200	7600	11200	7500	2700	7240
Conductivity	(mmho/cm)	21.2	23.1	29.4	23.0	9.0	22.4
Total N	(mg/L)	0.841	0.307	0.101	0.098	0.193	0.31
Total P	(mg/L)	0.202	0.069	0.104	0.124	0.069	0.11
D.O.	(mg/L)	6.3	6.2	6.9	6.5	4.7	6.3
Temp.	(°C)	29.5	28.0	29.4	28.5	29.7	29.0
TKN	(mg/L)	-	-	-	0.59*	0.60**	0.60

* 3/14/84 ** 12/14/83

The meteorological conditions used in the DQUAL model were obtained from NOAA and are average conditions for the month of August based on 10 years of continuous data from 1965-1974 at the Jacksonville Airport (NOAA, 1978).

4.2 Water Quality Analyses

The DQUAL model was initially set-up to simulate a "typical" summertime condition referred to as the base condition or base case (Run 00). Next, 13 additional model runs were made in which each of the six system rate coefficients was varied within the typical range of values to determine the effect on dissolved oxygen levels in the canal system. Finally, a worst case scenario based on the results of model runs 00 through 13 was simulated to determine the effect on dissolved oxygen. The system rate coefficients used for the various DQUAL model simulations are given in Table 4-2.

Figures 4-1(a) and 4-1(b) show the effect of changes in sediment oxygen demand (SOD) on daily average dissolved oxygen and daily minimum dissolved oxygen, respectively. The base condition (Run 00) which represents a typical summertime condition shows that dissolved oxygen (D.O.) levels throughout the canal system will remain nearly the same as those in the St. Johns River. As SOD is increased, the D.O. concentrations are depressed in the vicinity of nodes 5, 6, and 7. However, at all times the D.O. levels remain above the Florida state water quality standard of 4.0 mg/L for marine waters.

The effect of different reaeration rates (K_a) on dissolved oxygen is shown in Figures 4-2(a) and 4-2(b). It is evident that dissolved oxygen is sensitive to the value of K_a in the model. The reaeration rate of 0.50/day used in the base case (Run 00) is thought to be conservatively low, and 0.30/day (Run 03) was considered unrealistically low but was included for comparison purposes. The DQUAL model calculated a reaeration rate of 0.89/day based on the hydrodynamic velocities and meteorological conditions of the system.

Algal oxygen consumption due to respiration (R) impacts on dissolved oxygen are shown in Figures 4-3(a) and 4-3(b). Also, the effects of changes in algal oxygen production (P) on dissolved oxygen are shown in Figure 4-4(a) and 4-4(b). Generally, algal consumption values are one-half algal oxygen production rates.

Table 4-2

Summary of System Rate Coefficients used in DQUAL Model Simulations

Run Number	SOD (g/m^2-day)	K_a (1/day)	R (g/m^2-day)	P (g/m^2-day)	K_n (1/day)	K_d (1/day)	Figure Number
Run 00	1.5	0.50	2.5	4.0	0.10	0.25	
Run 01	2.0	0.50	2.5	4.0	0.10	0.25	4-1
Run 02	2.5	0.50	2.5	4.0	0.10	0.25	
Run 03	1.5	0.30	2.5	4.0	0.10	0.25	
Run 04	1.5	0.70	2.5	4.0	0.10	0.25	4-2
Run 05	1.5	0.90	2.5	4.0	0.10	0.25	
Run 06	1.5	0.50	2.0	4.0	0.10	0.25	4-3
Run 07	1.5	0.50	3.0	4.0	0.10	0.25	
Run 08	1.5	0.50	2.5	3.0	0.10	0.25	4-4
Run 09	1.5	0.50	2.5	5.0	0.10	0.25	
Run 10	1.5	0.50	2.5	4.0	0.05	0.25	4-5
Run 11	1.5	0.50	2.5	4.0	0.15	0.25	
Run 12	1.5	0.50	2.5	4.0	0.10	0.15	4-6
Run 13	1.5	0.50	2.5	4.0	0.10	0.30	
Run 14	2.5	0.50	2.0	4.0	0.15	0.30	4-7

Notes:

SOD = Sediment Oxygen Demand
K_a = Reaeration rate
R = Algal oxygen comsumption due to Respiration
P = Algal photosynthetic oxygen production
K_n = Nitrification rate
K_d = CBOD decay rate

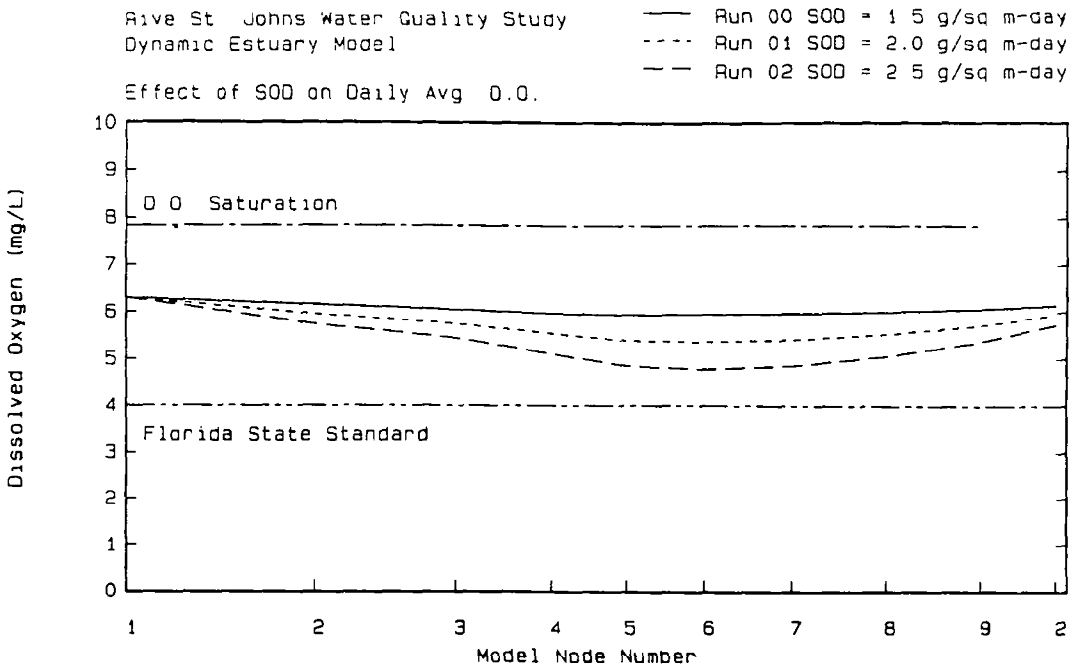

Figure 4-1(a). Effects of sediment oxygen demand (SOD) on daily average dissolved oxygen.

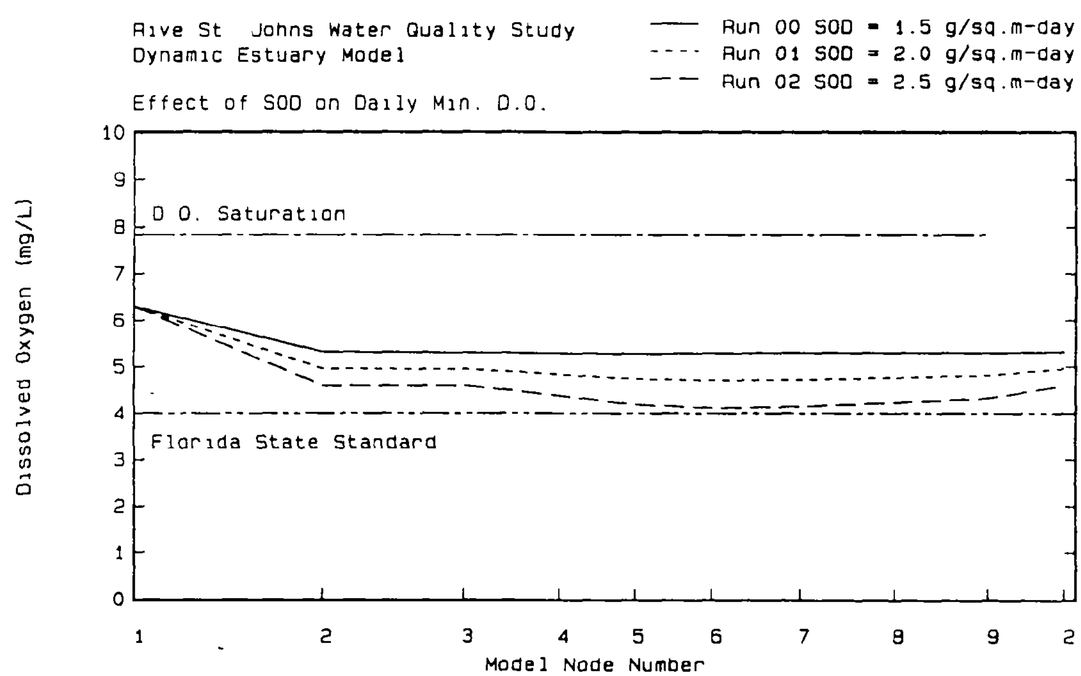

Figure 4-1(b). Effects of sediment oxygen demand (SOD) on daily minimum dissolved oxygen.

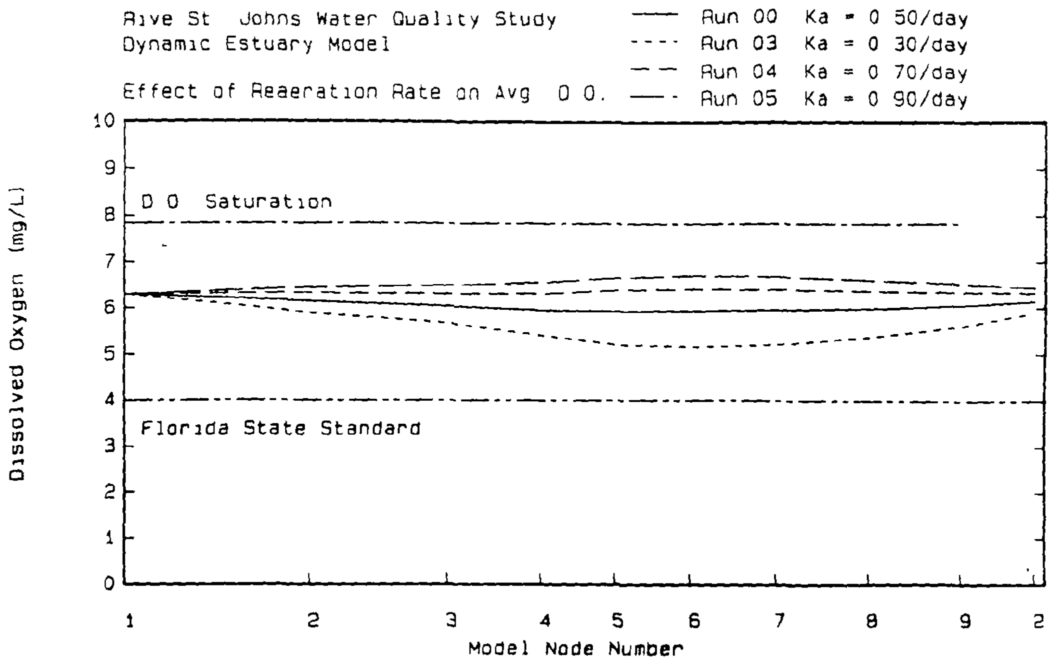

Figure 4-2(a). Effects of reaeration rate (K_a) on daily average dissolved oxygen.

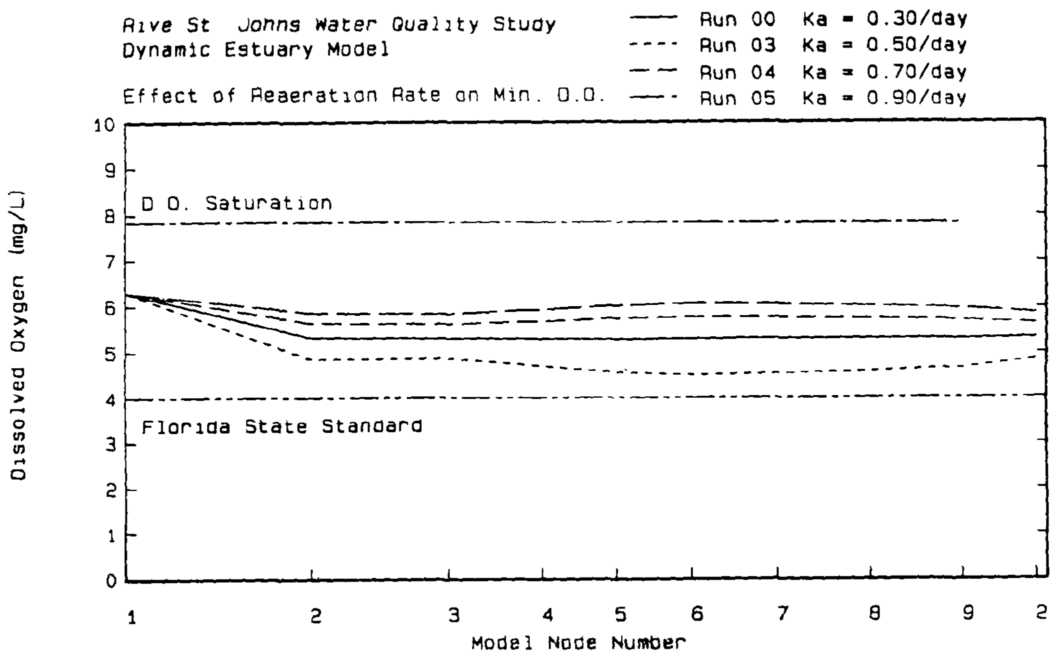

Figure 4-2(b). Effects of reaeration rate (K_a) on daily minimum dissolved oxygen.

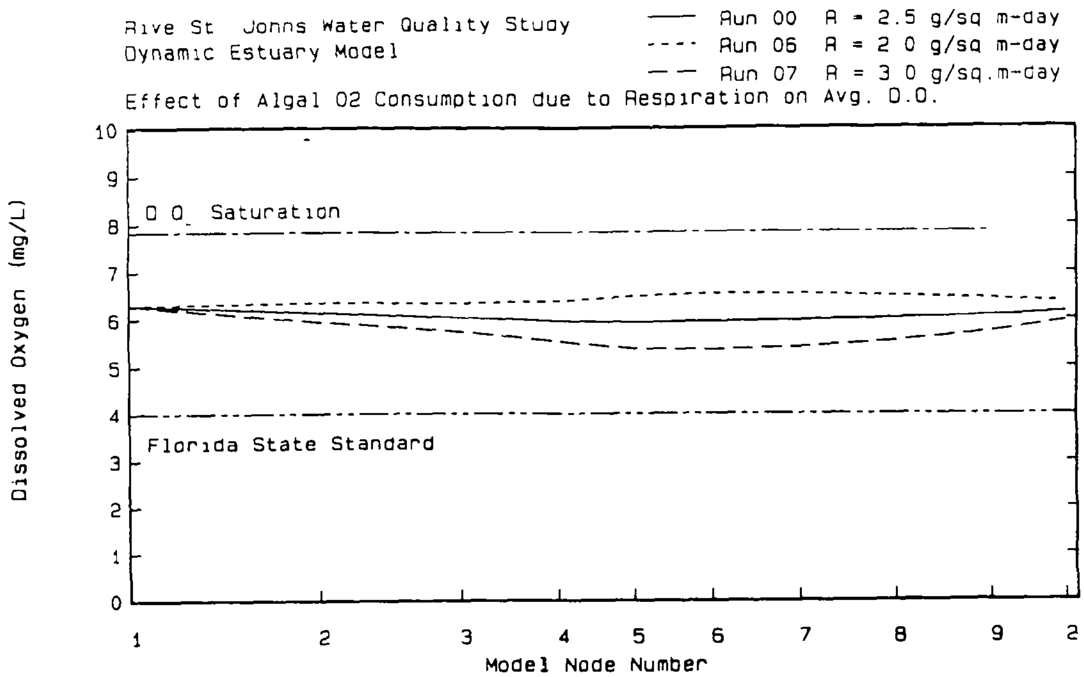

Figure 4-3(b). Effects of algal oxygen consumption due to respiration (R) on daily average dissolved oxygen.

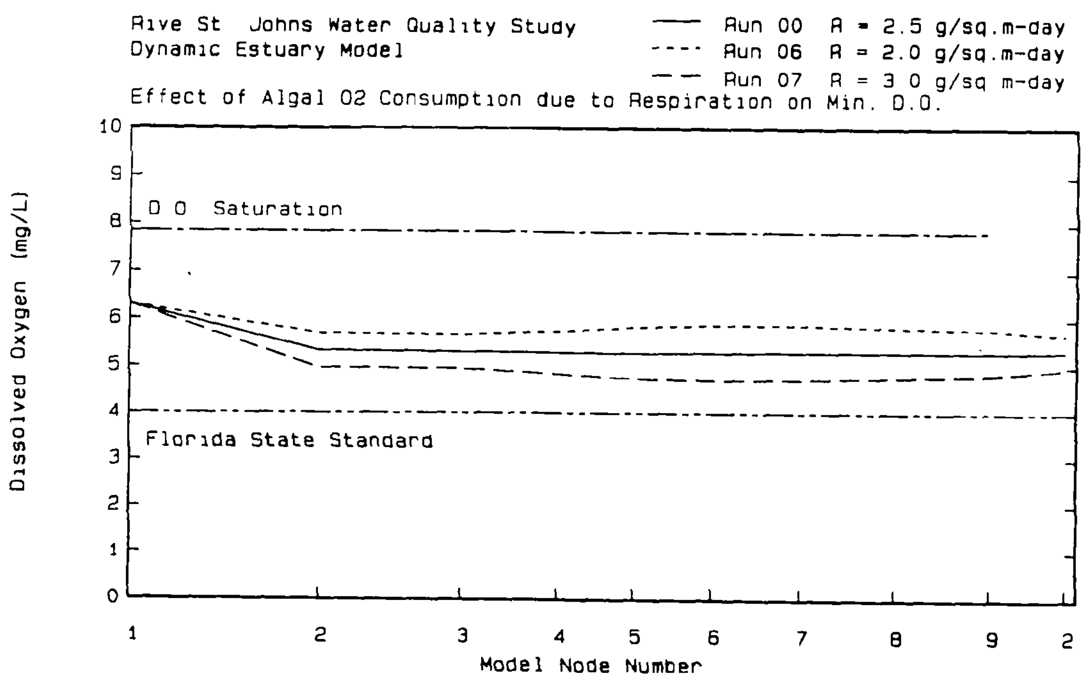

Figure 4-3(b). Effects of algal oxygen consumption due to respiration (R) on daily minimum dissolved oxygen.

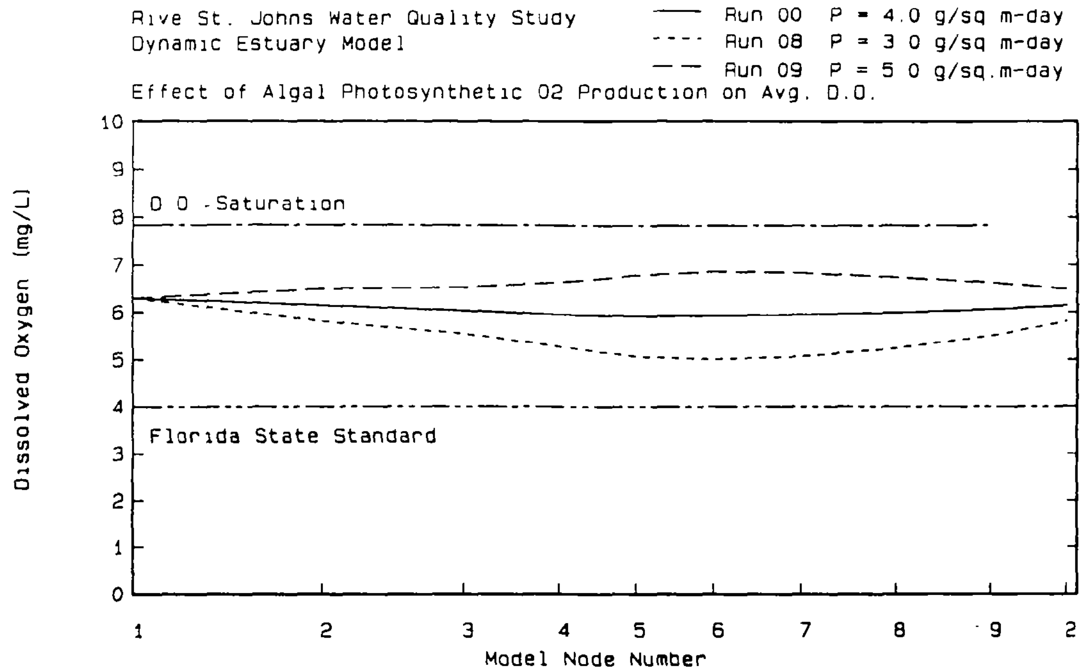

Figure 4-4(a). Effects of algal photosynthetic oxygen production (P) on daily average dissolved oxygen.

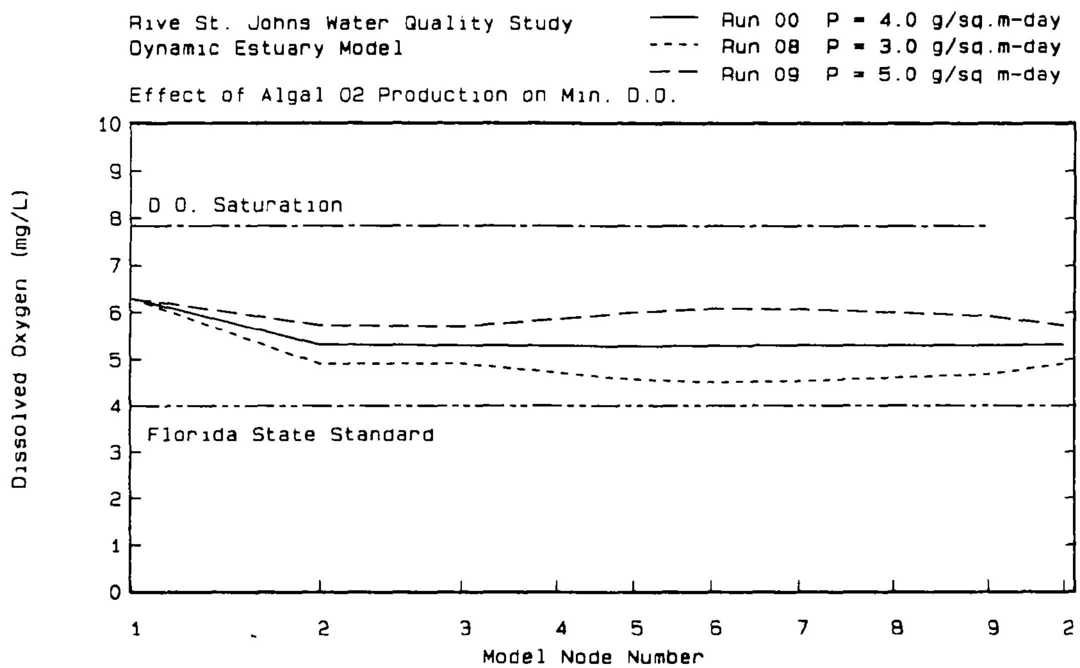

Figure 4-4(b). Effects of algal photosynthetic oxygen production on daily minimum dissolved oxygen.

The effects of changing nitrification rates (K_n) on dissolved oxygen in the canal system is given in Figures 4-5(a) and 4-5(b). Varying K_n through its typical range of values had little effect on dissolved oxygen values. Similarly, changing the value of K_d, the CBOD decay rate, had a very small effect on dissolved oxygen as shown in Figures 4-6(a) and 4-6(b).

Results for the worst case scenario (Run 14) are given in Figures 4-7(a) and 4-7(b), the daily average dissolved oxygen and daily minimum dissolved oxygen, respectively. The system rate coefficients for the worst case scenario are given in Table 4-2. The algal oxygen production rate (P) was set to twice the algal oxygen consumption rate (R) which is a typical ratio for these two coefficients. Even under these extreme conditions, the Florida state water quality standard for dissolved oxygen was not contravened at any time nor at any point in the canal system. The typical range of SOD used in this analysis (1.5 - 2.5 g/m^2-day) was obtained via personal conservation with Mr. Tom Cavinder, EPA Region IV, by M.R. Morton, Tetra Tech, Inc.

The DEM model was run for 10 days for each of the simulation runs to allow the dissolved oxygen concentrations at each node to reach a steady-state condition. A time history of dissolved oxygen concentration for nodes 4, 5, and 6 for Run 00 is shown in Figure 4-8. It is evident that the model reaches steady conditions at about 10 to 12 days.

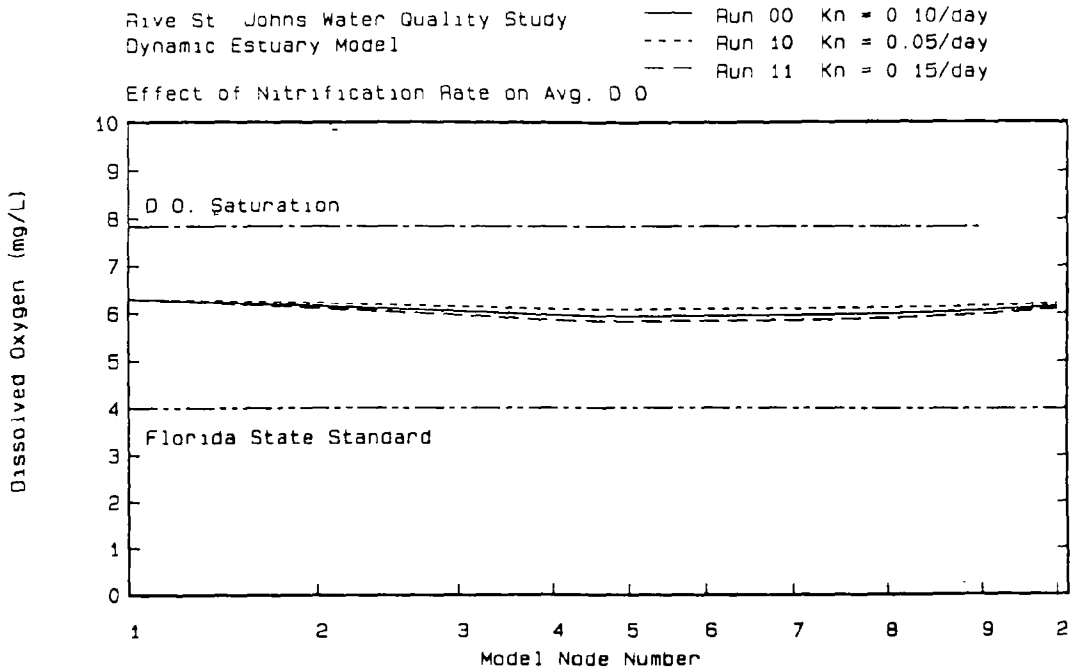

Figure 4-5(a). Effects of nitrification rate (K_n) on daily average dissolved oxygen.

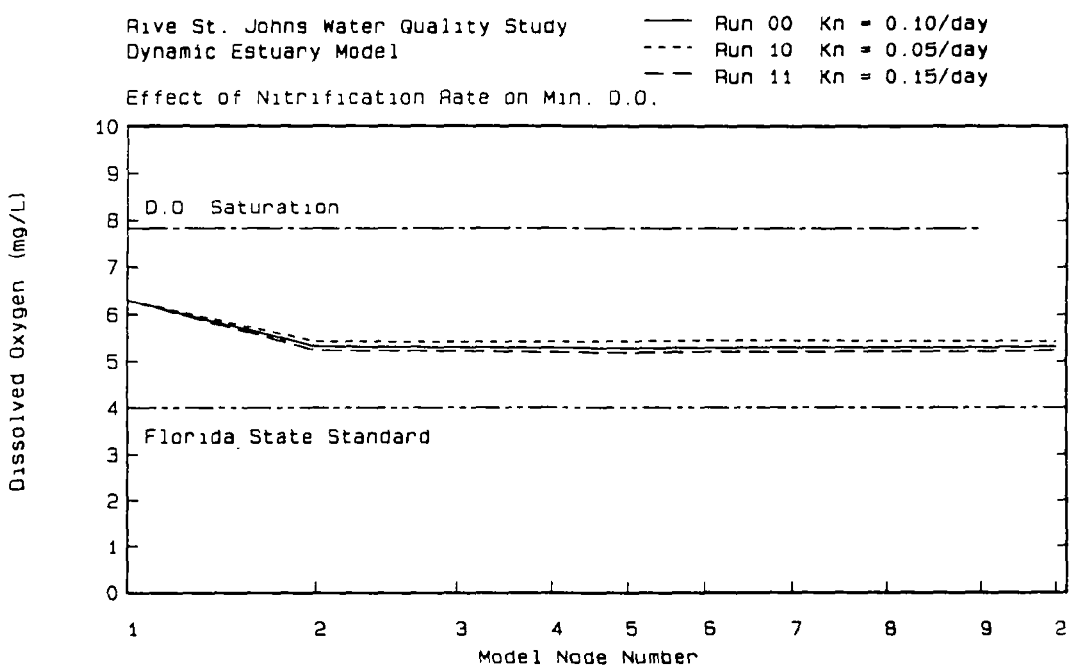

Figure 4-5(b). Effects of nitrification rate (K_n) on daily minimum dissolved oxygen.

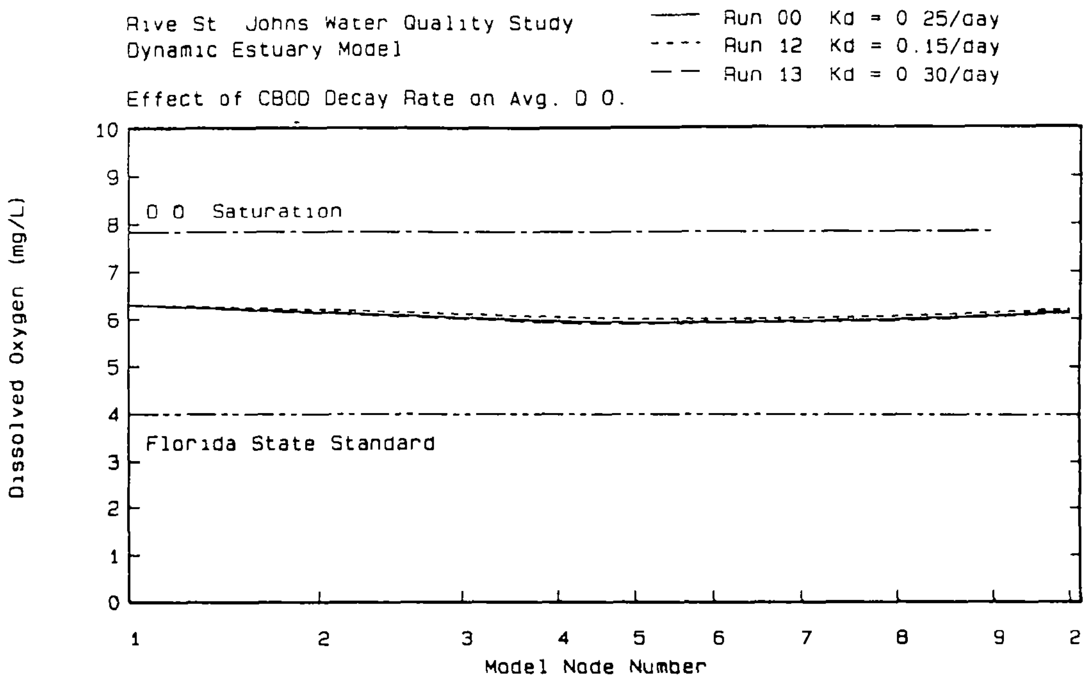

Figure 4-6(a). Effects of carbonaceous BOD decay rate (K_d) on daily average dissolved oxygen.

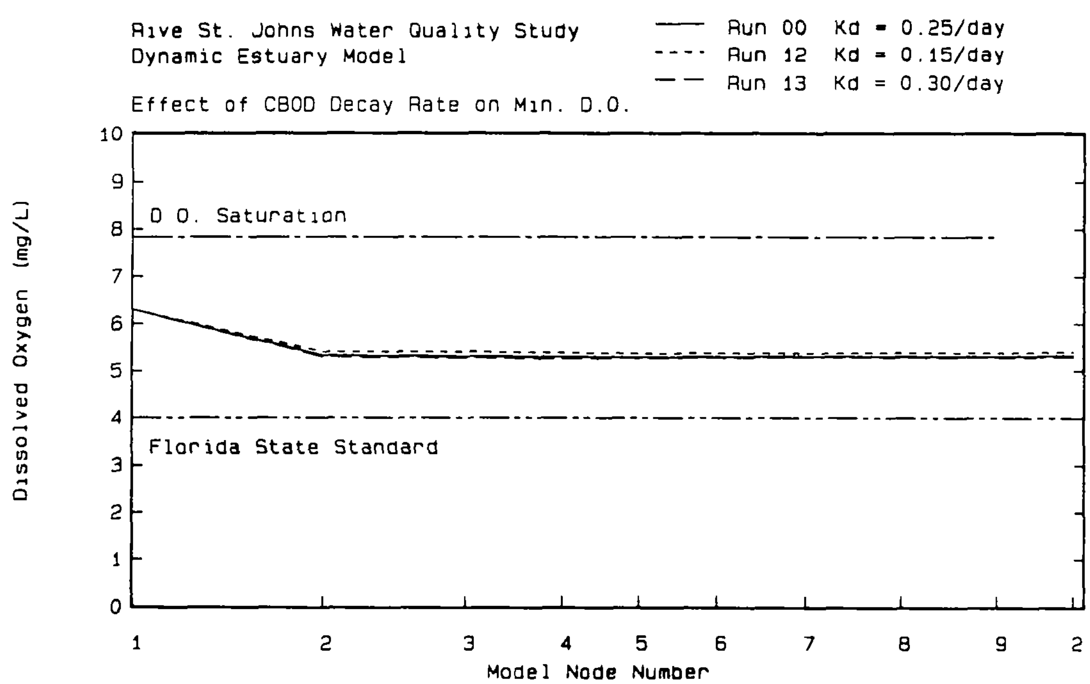

Figure 4-6(b). Effects of carbonaceous BOD decay rate (K_d) on daily minimum dissolved oxygen.

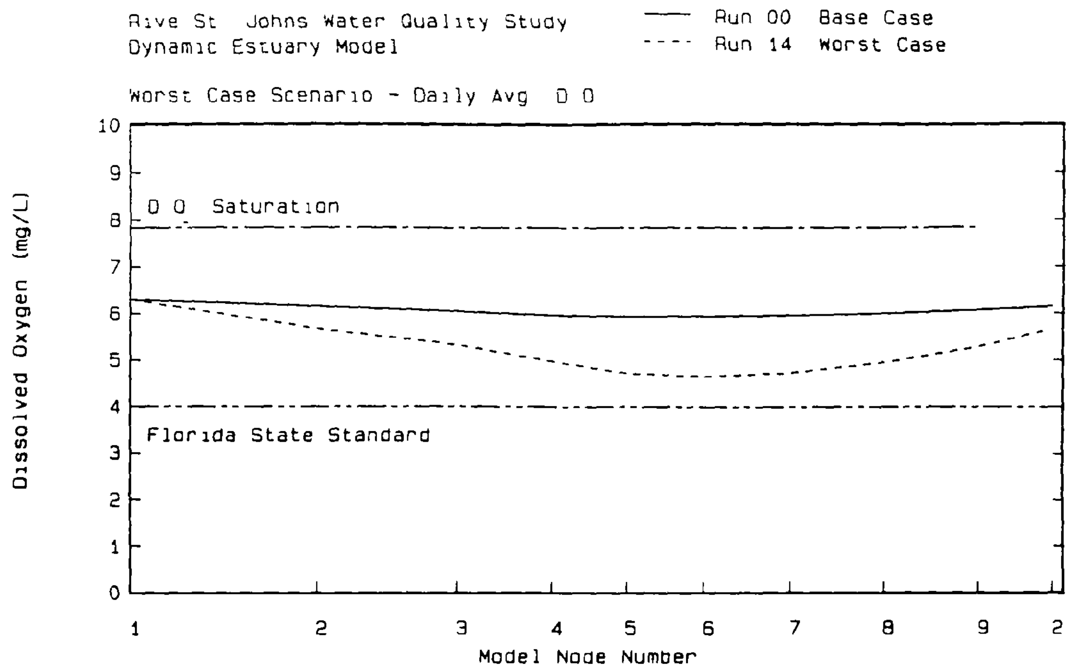

Figure 4-7(a). Predicted daily average dissolved oxygen concentrations under the worst case scenario.

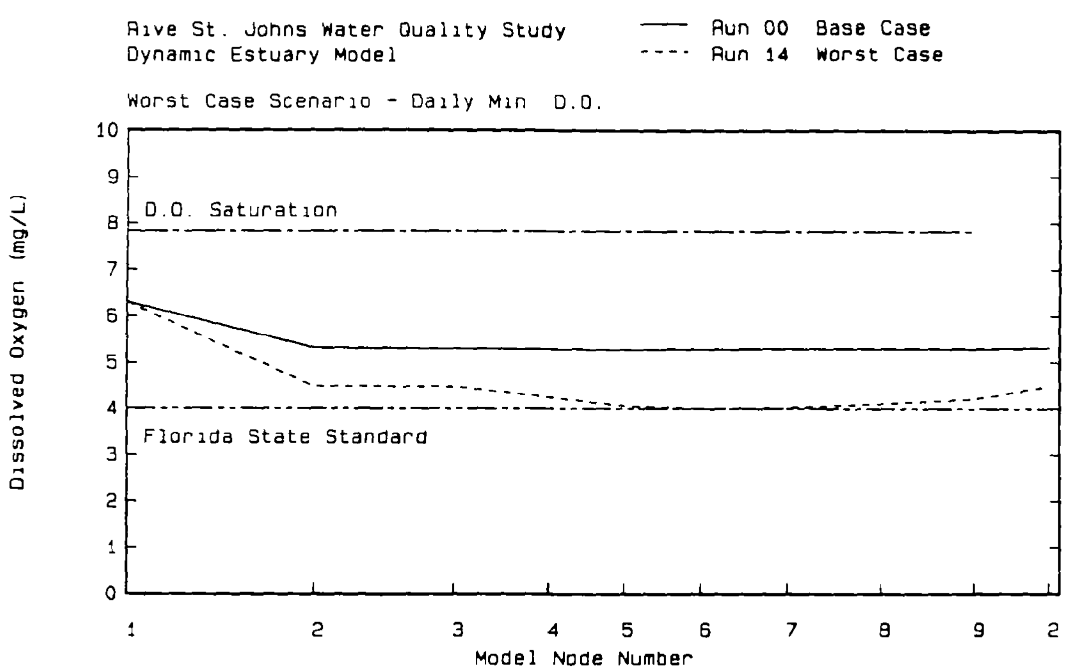

Figure 4-7(b). Predicted daily minimum dissolved oxygen concentrations under the worst case scenario.

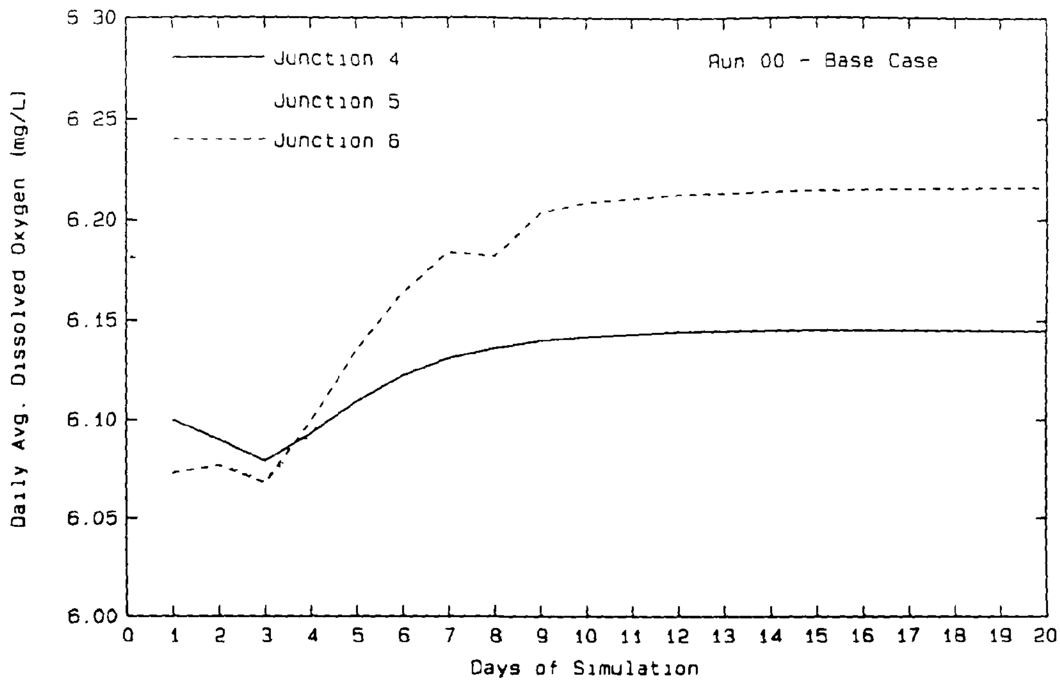

Figure 4-8. Time required for DQUAL to reach steady-state conditions.

5.0 SUMMARY AND CONCLUSIONS

The Dynamic Estuary Model (DEM) was applied to the proposed waterway canal at the Rive St. Johns Phase II development site on the St. Johns River, Jacksonville, Florida. The purpose of applying DEM was to address the concerns of Region IV Environmental Protection Agency regarding possible water quality contraventions in the canal. The DEM model application takes into account reaeration, sediment oxygen demand, and the water quality of receiving waters.

The results of the DEM model (see Figures 4-1 through 4-7) indicate that the proposed canal will not cause degredation of water quality below the 4.0 mg/L dissolved oxygen standard set by the State of Florida for marine waters. Even under an assumed worst case condition in which the reaeration rate was set to a conservatively low value (0.50/day) and the sediment oxygen demand was set at a conservatively high value (2.5 g/m^2-day) the daily minimum dissolved oxygen concentrations remained at or above 4.0 mg/L (Figure 4-7).

The original canal design was significantly improved to provide for better flushing as documented in a previously study (Tetra Tech 1988). Based on the results of the present water quality study, the improved canal design also provides for a suitable aquatic habitat in terms of dissolved oxygen levels.

6.0 REFERENCES

Tetra Tech. 1988. Rive St. Johns Phase II Canal: Littoral Transport and Flushing Analysis. Tetra Tech Report TC-3668. Prepared for Dostie Builders, Inc. Jacksonville, Florida.

NOAA. 1978. Airport Climatological Summary, Jacksonville, Florida, International Airport. Climatography of the United States No. 90 (1965-1974). National Oceanic and Atmospheric Administration. Environmental Data Service. National Climatic Center. Asheville, NC.

Appendix A

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

REGION IV

345 COURTLAND STREET
ATLANTA, GEORGIA 30365

JUL 22 1988

REF: 4WM/WQMB/BK

Mr. Charles Ashton
Regulatory Division
U.S. Army Corps of Engineers
P.O. Box 4970
Jacksonville, Florida 32232

SUBJECT: Dostie Builders
(Public Notice No. 87IPF-21164)

Dear Mr. Ashton:

We have completed our review of the hydrographic report prepared by TetraTech and the wetland mitigation proposal prepared by Allen W. Potter, Inc. for the above referenced project. In addition, Dr. Bill Kruczynski of my staff inspected the site of the proposed activity on June 8, 1988.

The wetland areas proposed to be filled are isolated from the St. Johns River and are vegetated predominantly by transitional wetland species. It is our opinion that the proposed wetland creation mitigation is adequate and we withdraw our objections to the filling of these wetland areas.

However, it remains our opinion, as we expressed in our letter dated March 18, 1988, that there are practicable, less environmentally damaging alternatives to excavation of the proposed canal system. A properly designed marina constructed along the shoreline of the St. Johns River at this site is environmentally preferable to a canal system since it is probable that water quality within the canals will not meet State water quality standards. Also, an excavated central marina basin with a short entrance channel would flush better than the canal designs analyzed in the TetraTech study. Thus, although the applicant has made significant improvements to the originally proposed canal system, we continue to recommend that a permit for their construction be denied.

The hydrographic report concludes that of the canal designs analyzed, the currently proposed design is the optimum configuration since it will flush within two or three tidal cycles. The study does not address water quality in the proposed canal system. In order to determine whether water quality within the canal will meet State of Florida standards the system must be modeled.

If the applicant wishes to continue the permitting process for an interior canal system, we require that a water quality model of the proposed system be performed. We suggest that the applicant use the Dynamic Estuary Model which takes into account reaeration, sediment oxygen demand, and quality of the receiving waters. We can provide estimates of the sediment oxygen demand from our data file for similar systems. We suggest that the applicant utilize water quality data from the closest long term monitoring station for parameters required in the model. Mean dissolved oxygen concentration for the three warmest months of the year will provide an estimate of worst case conditions.

Thank you for the opportunity to review the mitigation plan and the hydrographic report. If you have any questions concerning our comments, please contact Dr. Bill Kruczynski directly at telephone (904) 438-6891.

Sincerely yours,

R F McGhee

Robert F. McGhee, Chief
Water Quality Management Branch
Water Management Division

APPENDIX F: MODEL SENSITIVITY ANALYSES

F.1 INTRODUCTION

Data available for a water quality model study are likely to be both incomplete and imprecise. Some of the model inputs will have to be estimated, while others may be taken from measurements with unavoidable errors. Therefore, much caution is needed to insure that estimated quantities do not dominate the output to the extent that minor alterations of an input parameter will completely change the nature of the result. However, there are instances when past modelling experience indicates that the model should be sensitive to a particular parameter. There are also fundamental limiting cases to which the model should adhere, such as the cessation of phytoplankton growth resulting from the depletion of inorganic phosphorus. Thus, many modelers will want to examine the sensitivity of the model to various input parameters.

The sensitivity analysis, presented in this appendix, is designed to assist the ultimate users of this report in making decisions related to the selection, application, and accuracy of the various modeling techniques (simple, mid-range, and complex). The sensitivity analysis is designed to help inexperienced users identify the modeling parameters which have the most impact on dissolved oxygen results. The sensitivity analysis is designed to also help identify those parameters for which typical data are scarce or missing, thereby helping to determine the types of data which should be collected in future studies. For example, the sensitivity study may show that SOD is the most sensitive model parameter--thus, if adequate observed SOD information on coastal marinas is not available in the literature, then future monitoring studies at existing marinas can be designed to fill that data gap. In addition, the sensitivity analysis is useful for determining whether field data needs to be collected for a certain model parameter or whether a typical literature value is sufficient. For example, if the sensitivity analysis shows that computed dissolved oxygen is not responsive to changes in the phytoplankton death rate coefficient, then the use of literature values may be appropriate.

Sensitivity analyses are performed on the simple method (Tidal Prism Analysis), the alternative mid-range model (NCDEM DO Model), and the complex model (WASP4) to determine the dissolved oxygen response to typical ranges of various model parameters and other input data. Because Beacons Reach marina represent a typical two-segement marina type with only one entrance channel, it was selected as a test site to conduct model sensitivity analysis. For both the simple and mid-range models, the following parameters are included:

Biochemical Oxygen Demand (BOD)
Sediment Oxygen Demand (SOD)
Oxidation Coefficient (k_1)
Reaeration Coefficient (k_a)
Tidal Range (R)
Marina Surface Area (A)

For the WASP4 Model, the following parameters are included in the sensitivity analysis:

SOD, Ammonia, and Phosphorus Sediment Flux Rates
Impact of wind speed on DO concentration
Reaeration coefficient (K2)
Deoxygenation Rate (KDC)
Phytoplankton Death Rate (K1D)
Phytoplankton Growth Rate Constant (K1C)
Phytoplankton Respiration Rate Constant (K1RC)
Carbon to Chlorophyll Ratio (CCHL)

F.2 Sensitivity Analysis - Simple Model (TPA)

The procedure for sensitivity tests is simply to rerun the calibrated model with a single input altered. Generally, it is efficient and most satisfactory to run sensitivity tests in pairs, with the given parameter shifted both up and down in separate tests.

Testing model sensitivity provides information about which processes are most influential and/or interactive in a given system. It can also lead to improved calibration parameters and is an excellent way to check for any gross calibration errors. Tables F-1 and F-2 list the results of the simple TPA model sensitivity analysis for Beacons Reach marina, which the user may reproduce using the input parameters listed in these tables.

Shown are the sensitivity of dissolved oxygen levels versus the oxidation coefficient (Base Run and Run 1), reaeration coefficient (Run 2 and 3), sediment oxygen demand (Run 4 and 5), biochemical oxygen demand (Run 6 and 7), tidal range (Run 8 and 9), and marina surface area (Run 10 and 11). The oxidation rate, tidal range, and sediment oxygen demand shows the obvious result that when these parameters are halved or doubled, the dissolved oxygen levels should decrease or increase. Such fundamental relationships between the input parameters and outputs are easily verified in this way.

Note the small sensitivity of dissolved oxygen (Tables F-1) to changes in the marina surface area (Run 10 and 11) and reaeration coefficient (Run 2 and 3), compared to its large sensitivity to oxidation rate (Base Run and Run 1), sediment oxygen demand (Run 4 and 5), biochemical oxygen demand (Run 6 and 7), and tidal range (Run 8 and 9). Apparently, tidal range is an important source and sediment oxyegn demand is an important sink of dissolved oxygen in the marina system.

From Table F-1, one can conclude that the most important parameters affecting dissolved oxygen levels in the TPA model are: oxidation rate, tidal range, and sediment oxygen demand. Therefore, these parameters should be measured at a proposed marina site if site specific data are not available. Sensitivity analysis also indicated that the least important parameters affecting dissolved oxyegn levels are: marina surface area and reaeration coefficient. Therefore, these parameters can be estimated from existing data bases and/or literature.

TABLE F-1. TPA Sensitivity Analysis Results

Input Parameter	Calibrated Run Beacons Reach	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Run 11
DO_p (mg/L)	3 30	1.42	3 20	3 57	5.45	1 44	4 32	2.28	1.29	4.79	3 30	3.30
k_1 (day^{-1})	*0.1*	*0.3*	0.1	0.1	0 1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
k_a (day^{-1})	0 7	0.7	*0.25*	*3.00*	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
B (g/L)	2.680	2.68	2.68	2.68	*0.0*	*5.0*	2.68	2.68	2.68	2.68	2.68	2.68
C_b (mg/L)	7.23	7.23	7.23	7.23	7.23	7 23	*0.0*	*14.5*	7.23	7.23	7.23	7.23
R (ft)	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	*0.3*	*1.2*	0.6	0.6
A (ft^2)											*4724*	*18896*

DO_p = Predicted DO at high tide
k_1 = deoxygenation rate
k_a = reaeration rate
B = Sediment Oxygen Demand (SOD)
C_b = Biochemical Oxygen Demand (BOD)
R = Tidal range
A = Marina surface area

F.3 Sensitivity Analysis - Mid-range Model (NCDEM)

The NCDEM model was initially set-up to simulate a "typical" summertime condition at the Beacons Reach marina, referred to as the base condition. Next, eight additional model runs were made in which each of the four parameters was varied within the typical range of values to determine the effect on dissolved oxygen levels in the marina system. The system rate coefficients used for the various NCDEM DO model simulations are given in Table F-2.

The effect of different reaeration rates (K_a) on dissolved oxygen is listed in Table F-2. It is evident that dissolved oxygen is sensitive to the value of K_a in the model (Run 1 and 2). The reaeration rate of 0.30/day used in the base case was reported in North Carolina Coastal Marina Assessment (NCDEM, 1990). Similarly, the NCDEM DO model is sensitive to SOD values used in the model. If SOD is eliminated in model application (Run 3), then an increase of predicted dissolved oxygen is evident. However, an increase in SOD (Run 4) will cause a decrease in the predicted dissolved oxygen levels. Therefore, these parameters should be evaluated at the proposed marina site when site specific data are not available.

The effects of changing the marina surface area on dissolved oxygen in the marina system is minimum. Doubling and halving the marina surface area (Run 5 and 6) had no effect on dissolved oxygen values. However, changing the tidal range (Run 7 and 8) had a noticeable effect on dissolved oxygen.

TABLE F-2. NCDEM DO Model Sensitivity Analysis Results

Input Parameter	Calibrated Run Beacons Reach	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8
DO_p (mg/L)	4.82	3.75	6.46	6.55	3 23	4.82	4.82	4.02	5.48
K_a (day^{-1})	0.3	*0.05*	*3.00*	0.3	0.3	0.3	0.3	0.3	0.3
SOD (g/L)	2.6	2.6	2.6	*0.0*	*5.0*	2.6	2.6	2.6	2.6
A (ft^2)	101700	101700	101700	101700	101700	*50850*	*203400*	101700	101700
R (ft)	2	2	2	2	2	2	2	*1*	*4*

DO_p = Predicted DO at high tide
K_a = reaeration rate
SOD = sediment oxygen demand
R = tidal range
A = marina surface area

F.4 Sensivitity Analysis for Complex Model (WASP)

Dissolved oxygen processes can be modeled using WASP4/EUTRO4 based on six different complexity levels.- The number of reaction rate coefficients and environmental parameters required by the WASP input file varies according to the complexity level specified by the user. The least complex level (level 1) requires the least number of coefficients. The most complex level (i.e., level 6 which was chosen for the marina applications of WASP4 in this report) requires the most coefficients. The following eight WASP4 reaction rates and constants associated with dissolved oxygen dynamics were tested for their sensitivity on dissolved oxygen concentrations:

- sediment oxygen demand and nutrient benthic flux rates
- wind speed effects
- reaeration rate
- CBOD deoxygenation rate
- phytoplankton death rate
- phytoplankton growth rate
- phytoplankton respiration rate
- carbon-to-chlorophyll ratio

The above parameters were chosen for the sensitivity analysis partly because they are among the eight most important constants needed to model dissolved oxygen dynamics, and partly because existing site specific field data is often not available to estimate their values. Often a model must be calibrated using only literature values or past modeling experience for many of these parameters. Thus, a certain amount of uncertainty may be associated with each of the above parameters and the sensitivity tests are a means of quantifying the impact of each parameter's uncertainty on overall model results. The results of the sensitivity tests can also be useful in designing field sampling programs. For example, if dissolved oxygen is sensitive to variations in sediment oxygen demand and benthic nutrient flux rates, then a field sampling program should be designed to include these benthic flux measurements.

For this sensitivity analysis, WASP4 was applied to the Beacons Reach Marina using the observed data on May 26, 1988. The base run (RUN00) was the calibration run described in Section 6 of this report. A series of sensitivity runs was then made in which the magnitudes of the eight sensitivity parameters were varied within their typical ranges and the model dissolved oxygen results were plotted graphically in Figures F-1 to F-8. The observed data for May 26, 1988, are also presented in the plots for reference. The parameter values used in the various WASP4 sensitivity runs are summarized in Table F-3.

Sensitivity of DO to SOD and benthic flux rates. For the base run (RUN00) the sediment oxygen demand rate was specified as 3.35 gO_2/m^2-day at 20°C. In a study conducted by North Carolina Department of Environmental Management (NCDEM), SOD measurements (corrected to 20°C) made in Beacons Reach Marina, in nearby Gull Harbor Marina, and in Tangle Oaks Marina ranged from 1.89 to 6.15 gO_2/m^2-day (NCDEM 1990). Thus, the calibrated value of

3.35 gO_2/m^2-day is within the appropriate range. No field data were available to estimate benthic flux rates for ammonia or phosphate. Therefore, the benthic flux rates for ammonia and phosphate were assumed to be stoichiometrically related to the sediment oxygen demand rate based on the classical Redfield ratios for O:C:N:P (i.e., 109:41:7.2:1). The results of doubling (RUN01) and halving (RUN02) the SOD and benthic flux rates is shown in Figure F-1. Clearly, dissolved oxygen is quite sensitive to changes in these flux rate parameters.

Sensitivity of DO to wind speed. In the base run, wind speed was set to zero. There may be instances where wind speed may be needed to calibrate a model to data collected from an existing marina where wind was not zero during the sampling period. The WASP4 model can be run in two modes with regard to the reaeration coefficient: (1) the reaeration coefficient can be computed internally by the model based on water velocity speed and wind friction effects, or (2) the reaeration coefficient can be specified. For these two sensitivity runs, the first mode was used in which the reaeration rate was computed by the model. In RUN03 the wind speed was set to 7.5 m/sec and in RUN04 to 15 m/sec. Figure F-2 indicates that DO is very sensitive to these increased wind speeds.

Sensitivity of DO to reaeration rate (K2). Figure F-3 demonstrates the effect of varying the reaeration rate on dissolved oxygen concentrations in Beacons Reach Marina. In RUN05 the reaeration rate was set to 0.3/day, in RUN06 it was 1.0/day, and in RUN07 it was 2.0/day. For the base run (RUN00) the reaeration rate was computed internally by the model based on the hydrodynamic water velocities and the value was approximately 0.7/day. The results show that dissolved oxygen is sensitive to changes in reaeration rate. This is to be expected given the small size and shallow nature of the Beacons Reach Marina system.

Sensitivity of DO to CBOD deoxygenation rate (KDC). The CBOD deoxygenation rate coefficient (KDC) is commonly in the range 0.01 to 5.6/day with a typical value being 0.2/day (at 20°C). KDC was set to 0.2/day in the base run (RUN00), 0.1/day in RUN08, and 0.4/day in RUN09. The dissolved oxygen results shown in Figure F-4 indicate that the model is not highly sensitive to variations in the CBOD deoxygenation rate coefficient. However, halving the KDC coefficient produced greater variations in DO from the base run than did doubling it.

Sensitivity of DO to phytoplankton death rate (K1D). The phytoplankton death rate coefficient (K1D) in the base run (RUN00) was 0.5/day. In RUN10 this coefficient was set to 0.1/day and in RUN11 it was set to 1.5/day. The model sensitivity results indicate that changes in K1D have little impact on dissolved oxygen in Beacons Reach Marina.

Sensitivity of DO to phytoplankton growth rate (K1C). The phytoplankton growth rate (K1C) describes the maximum, or saturated, growth rate that is obtained under non-limiting nutrient and light conditions at a reference temperature of 20°C. K1C was set to 1.0/day in the base run (RUN00), 0.5/day in RUN12, and 1.5/day in RUN13. Figure F-6 shows that dissolved oxygen is not very sensitive to changes in the phytoplankton growth rate for the Beacons Reach Marina.

Sensitivity of DO to phytoplankton respiration constant (K1RC). For the base run, the endogenous respiration rate of phytoplankton (at 20°C) was set to 0.3/day. For sensitivity runs RUN14 and RUN15, K1RC was set to 0.15/day and 0.50/day, respectively. The results shown in Figure F-7 indicate dissolved oxygen is not highly sensitive to variations in this coefficient.

Sensitivity of DO to carbon-to-chlorophyll ratio (CCHL). The carbon-to-chlorophyll ratio commonly falls in the range 20 to 200 mg C/mg Chla. For the base run CCHL was set to 80, and for sensitivity runs RUN16 and RUN17 it was set to 40 and 120, respectively. The results shown in Figure F-8 show that dissolved oxygen is somewhat sensitive to variationsin this parameter.

TABLE F-3. Parameter Values Used for WASP4 Model Sensitivity Analysis

	Input Parameter							
RUN##	SOD gO_2/m^2-day	Wind (m/sec)	K2 (day^{-1})	KDC (day^{-1})	K1D (day^{-1})	K1C (day^{-1})	K1RC (day^{-1})	CCHL (day^{-1})
RUN00	3 35	0.0	computed	0.2	0.5	1.0	0.30	80
RUN01	1.68	0.0	computed	0.2	0.5	1.0	0.30	80
RUN02	6.70	0.0	computed	0.2	0.5	1.0	0.30	80
RUN03	3.35	7.5	computed	0.2	0.5	1 0	0.30	80
RUN04	3.35	15.0	computed	0.2	0.5	1.0	0.30	80
RUN05	3.35	0.0	0.3	0.2	0.5	1.0	0 30	80
RUN06	3.35	0 0	1.0	0.2	0.5	1 0	0.30	80
RUN07	3.35	0.0	2.0	0.2	0.5	1.0	0.30	80
RUN08	3.35	0.0	computed	0.1	0.5	1.0	0.30	80
RUN09	3.35	0.0	computed	0.4	0.5	1.0	0 30	80
RUN10	3.35	0.0	computed	0.2	0.1	1.0	0.30	80
RUN11	3.35	0 0	computed	0.2	1.5	1 0	0.30	80
RUN12	3.35	0.0	computed	0.2	0.5	0.5	0.30	80
RUN13	3.35	0.0	computed	0.2	0.5	1.5	0.30	80
RUN14	3.35	0.0	computed	0.2	0.5	1.0	0.15	80
RUN15	3.35	0.0	computed	0.2	0.5	1.0	0.50	80
RUN16	3 35	0.0	computed	0.2	0.5	1 0	0 30	40
RUN17	3 35	0 0	computed	0.2	0.5	1.0	0 30	120

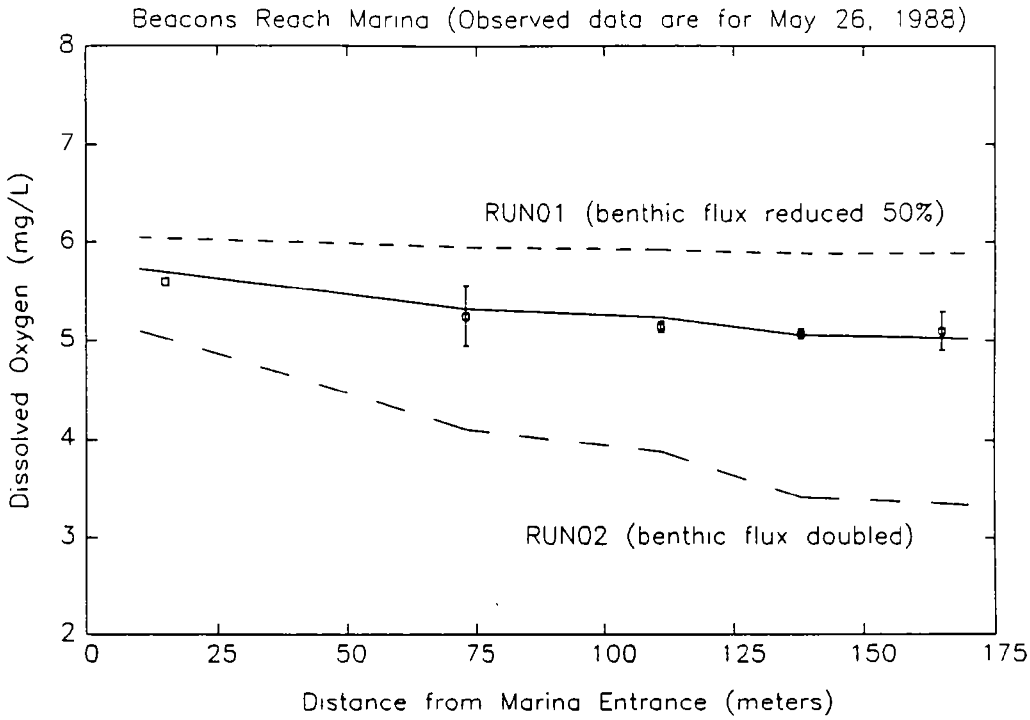

Figure F-1. Sensitivity of DO to SOD and benthic flux rates.

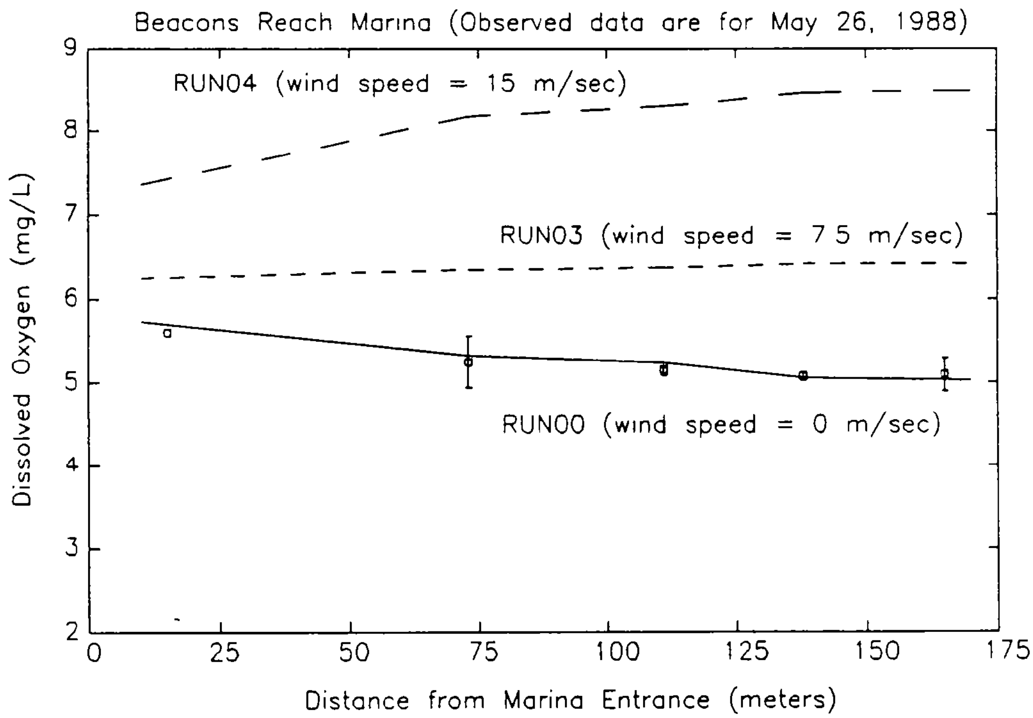

Figure F-2. Sensitivity of DO to wind speed.

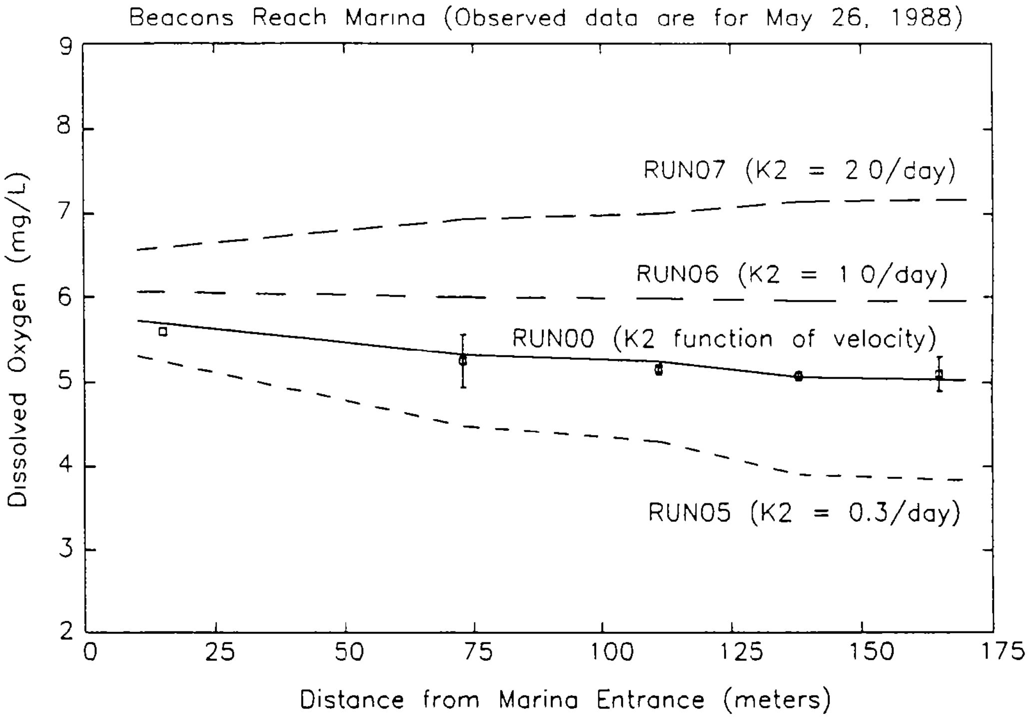

Figure F-3. Sensitivity of DO to reaeration rate (K2).

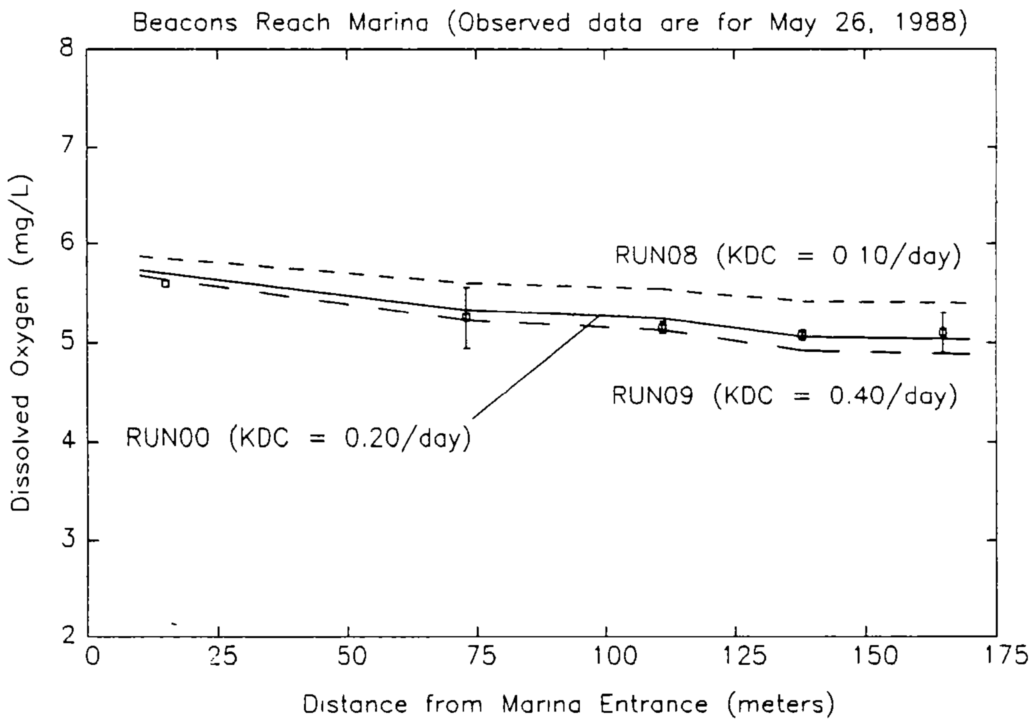

Figure F-4. Sensitivity of DO to deoxygenation rate (KDC).

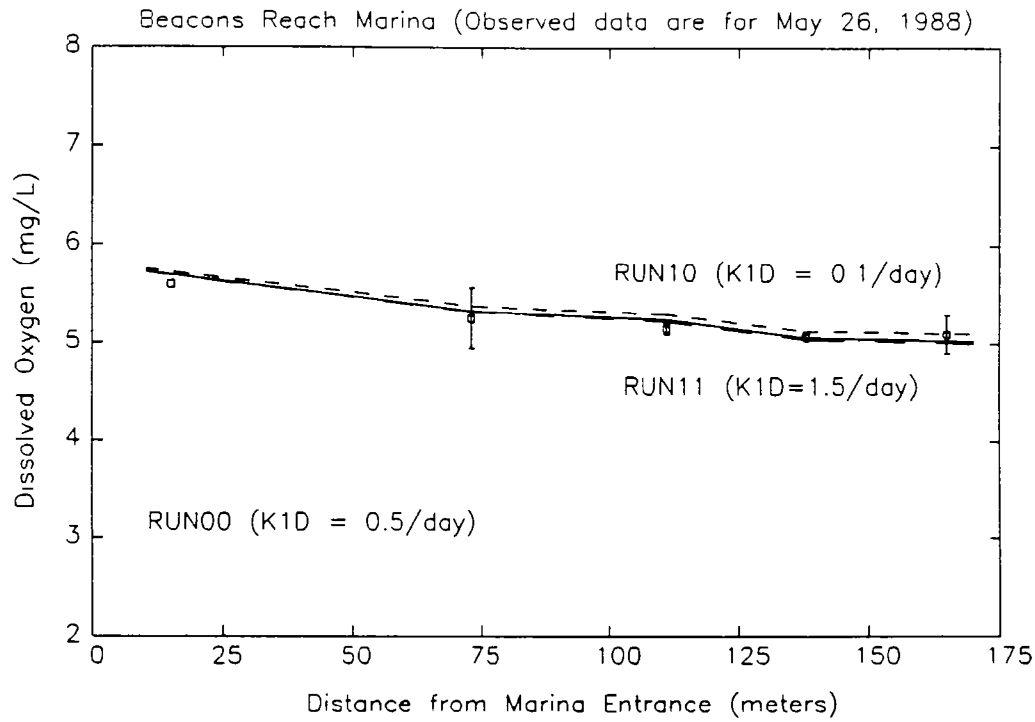

Figure F-5. Sensitivity of DO to phytoplankton death rate (K1D)

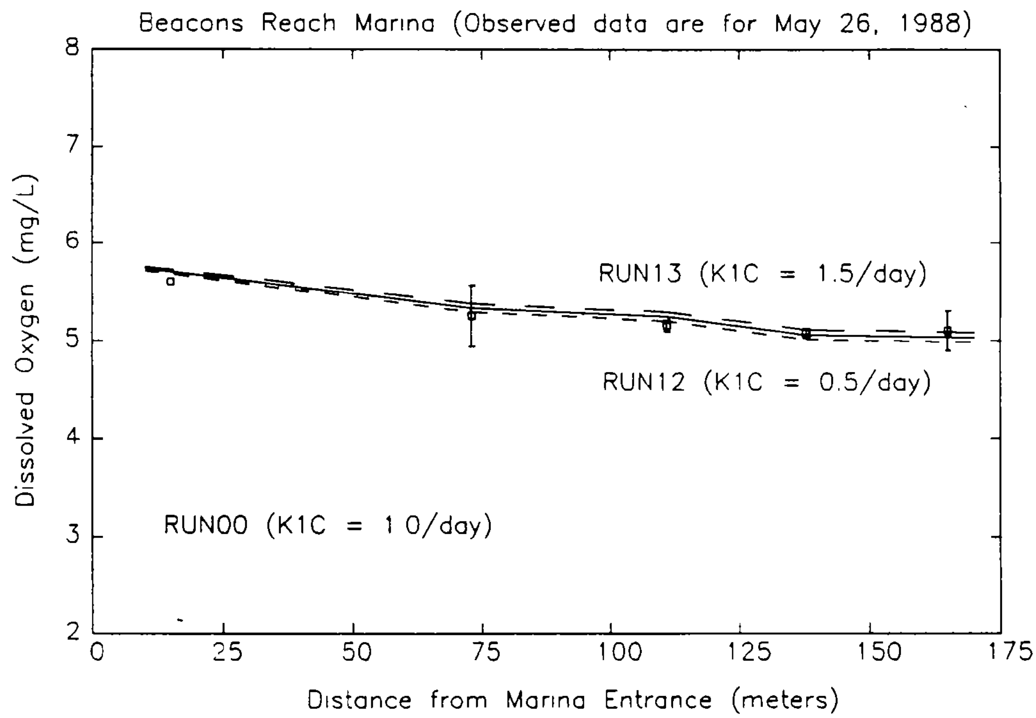

Figure F-6. Sensitivity of DO to phytoplankton growth rate (K1C)

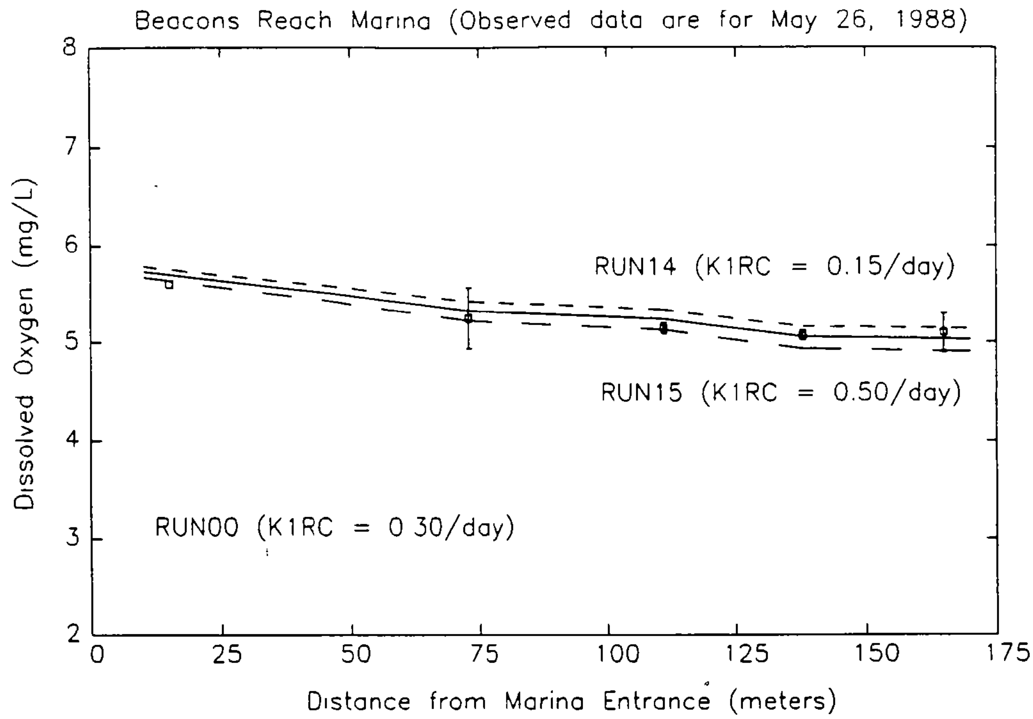

Figure F-7. Sensitivity of DO to phytoplankton respiration constant (K1RC)

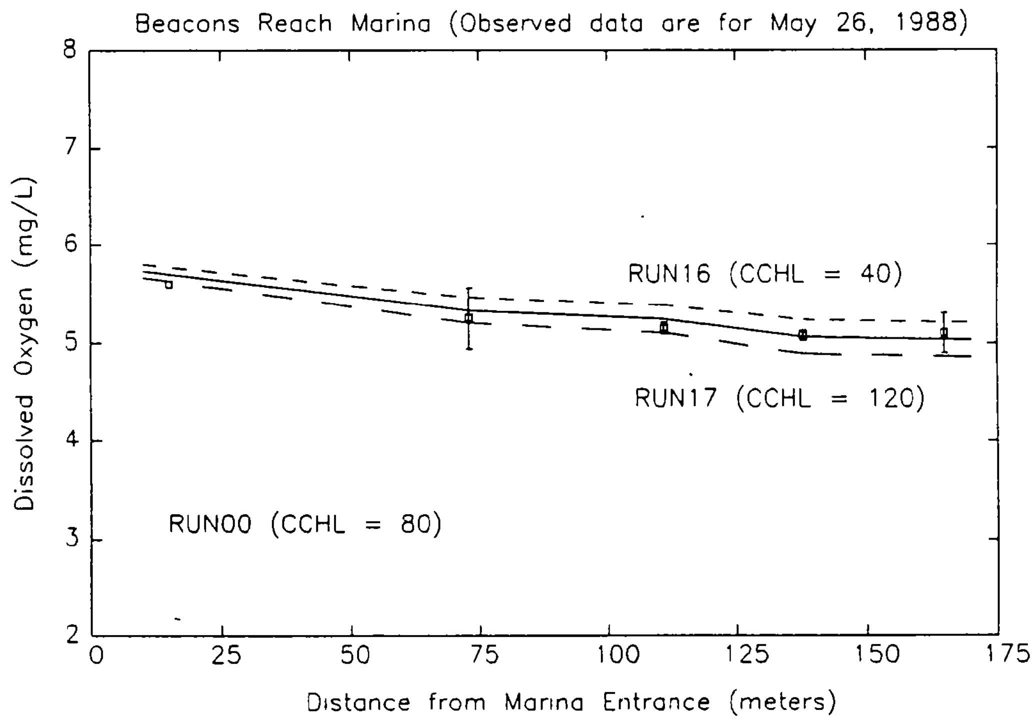

Figure F-8. Sensitivity of DO to carbon-to-chlorophyll ratio (CCHL).