

# **Cumberland Basin Ecosystem Model: Structure, Performance and Evaluation**

P.D. Keizer, D.C. Gordon, Jr., P. Schwinghamer, G.R. Daborn  
and W. Ebenhoeh

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**CUMBERLAND BASIN ECOSYSTEM MODEL:  
STRUCTURE, PERFORMANCE AND EVALUATION**

by

P. D. Keizer, D. C. Gordon, Jr., P. Schwinghamer

Department of Fisheries and Oceans

Bedford Institute of Oceanography

P. O. Box 1006

Dartmouth, Nova Scotia

B2Y 4A2

G. R. Daborn

Acadia Institute for Estuarine Research

Acadia University

Wolfville, Nova Scotia

BOP 1X0

W. Ebenhoeh

Universitat Oldenburg

Fachbereich 6

Mathematik/Informatik

Postfach 2503

D-2900 Oldenburg

West Germany

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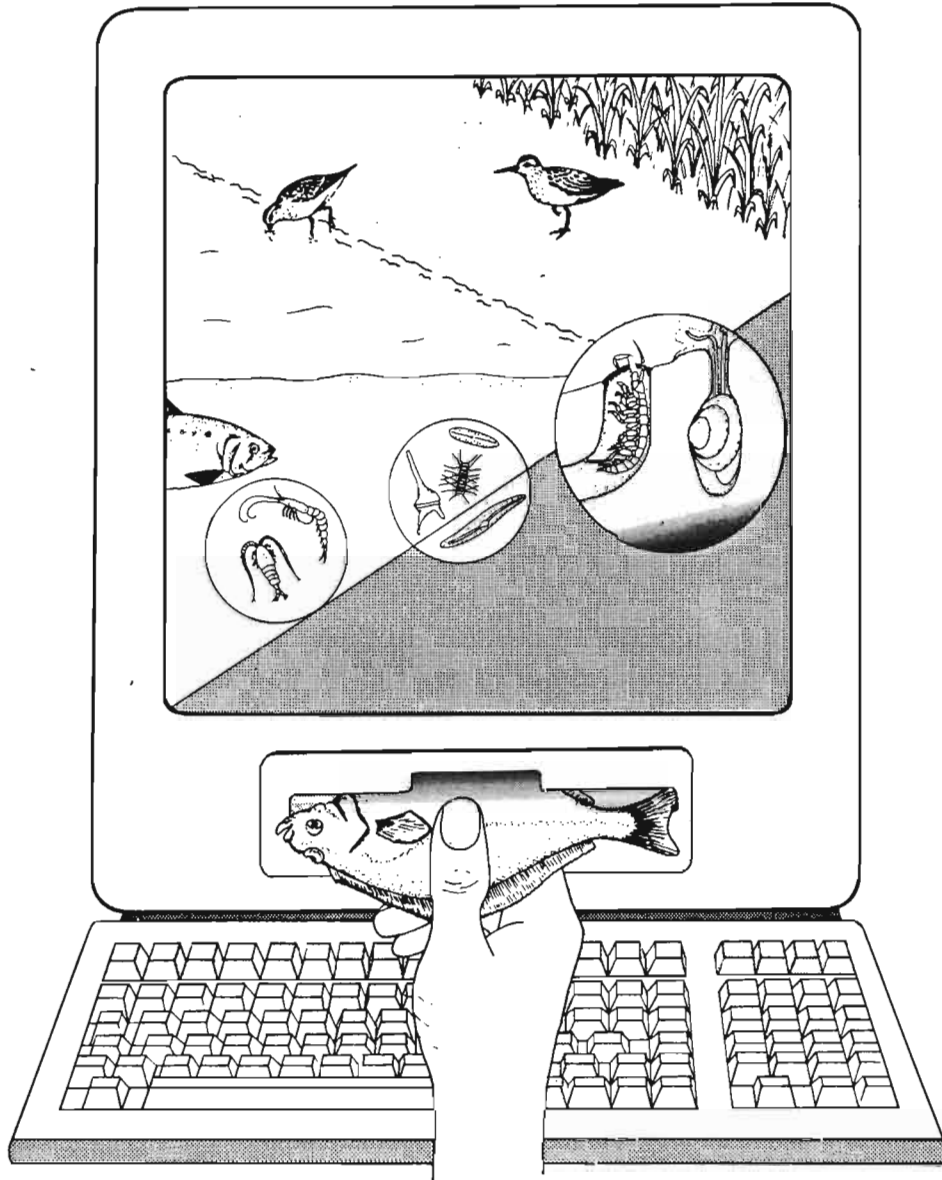
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# THE CUMBERLAND BASIN ECOSYSTEM MODEL





## SUMMARY

Keizer, P. D., Gordon, D. C., Jr., Schwinghammer, P., Daborn, G. R., and Ebenhoeh, W. 1987. Cumberland Basin ecosystem model: Structure, performance and evaluation. Can. Tech. Rep. Fish. Aquat. Sci. No. 1547: xviii + 202p.

This document describes in detail the structure and performance of a holistic ecosystem model of the Cumberland Basin in the upper reaches of the Bay of Fundy, Nova Scotia. The one-dimensional linear box-model was created primarily by the efforts of participants of a series of multidisciplinary, interactive workshops involving scientists from Canada, the Netherlands, the United Kingdom, the Federal Republic of Germany and the United States of America. It was used to bring together, synthesize and help interpret the results of numerous ecological studies in the upper reaches of the Bay of Fundy. The model documented here is by no means the best effort of this group but represents the status of the model at the time the program was terminated.

The report is divided into six sections. Section 1 describes the history of the project, the approaches used and identifies the people who were involved. Section 2 documents the code of the model and is subdivided into sections describing the physical, pelagic and benthic submodels. Wherever possible references are provided for parameters values. Carbon flow diagrams are provided for each biological submodel. The results from a simulation run of the model are described and evaluated in Section 3. General comments about the model and the modelling process as well as an assessment of the success of the project and projections for future development are discussed in Section 4. Sections 5 and 6 contain the references and the numerical output from a three-year simulation run of the model.

## RESUME

Keizer, P. D., Gordon, D. C., Jr., Schwinghammer, P., Daborn, G. R., and Ebenhoeh, W. 1987. Cumberland Basin ecosystem model: Structure, performance and evaluation. Can. Tech. Rep. Fish. Aquat. Sci. No. 1547: xviii + 202p.

Ce document décrit en détail la structure et le comportement d'un modèle d'écosystème holistique du bassin de Cumberland dans les régions en amont de la baie de Fundy, en Nouvelle-Ecosse. Le modèle de la boîte linéaire unidimensionnel a été créé principalement par des personnes qui participaient à une série d'ateliers multidisciplinaires et interactifs qui réunissaient des scientifiques du Canada, des Pays-Bas, du Royaume-Uni, de la République fédérale d'Allemagne et des Etats-Unis d'Amérique. Il a été utilisé pour réaliser l'intégration et la synthèse des données provenant des nombreuses études écologiques réalisées dans les régions en amont de la baie de Fundy et pour en faciliter l'interprétation. Le modèle décrit ici ne constitue nullement le meilleur travail du groupe, mais il représente l'état du modèle au moment où le programme a été achevé.

Le rapport se divise en six sections. La section 1 fait l'historique du projet, décrit les méthodes suivies et énumère les participants au projet. La section 2 explique le code du modèle et se subdivise en sections qui décrivent les sous-modèles physiques, pélagiques et benthiques. Des références ont été fournies, dans la mesure du possible, pour les valeurs des paramètres. Des diagrammes du transport du carbone sont fournis pour chaque sous-modèle biologique. La section 3 décrit et évalue les résultats d'un cycle de simulation effectué à l'aide du modèle. La section 4 contient des observations générales sur le modèle et le processus de modélisation, évalue le succès du projet et indique les perspectives de développement pour l'avenir. Les sections 5 et 6 contiennent des références et les résultats numériques d'un cycle de simulation de trois ans effectué à l'aide du modèle.

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## 1. Introduction

Between 1978 and 1982, a large number of environmental studies were conducted in the Cumberland Basin region at the head of the Bay of Fundy. This research was stimulated by the possibility of tidal power development and the need to acquire scientific information necessary to determine likely environmental impacts (Gordon and Longhurst, 1979). As a result, there now exists an extensive data base for the region (Gordon and Dads-well, 1984; Plant, 1985).

In 1982 we decided to develop a holistic ecosystem model of the Cumberland Basin. The main purpose of the project was to synthesize available data, identify important environmental processes, uncover serious data gaps and indicate preferred directions for future research. The resulting model could also be used to help determine the likely environmental impacts of tidal power development.

The Cumberland Basin is a 124 km<sup>2</sup> estuary. Because of a mean tidal range of about 11 m, 60% of the area is composed of intertidal mudflats and saltmarshes. Freshwater input is small relative to tidal exchange and the water column is well mixed by strong tidal currents. The water is extremely turbid (100-1000mg silt/L) and extensive ice occurs during the winter. Typical temperate/boreal estuarine organisms inhabit the water column, mudflats and saltmarshes. It is rural in setting and relatively unpolluted.

We have succeeded in constructing a one-dimensional, three compartment model that simulates the flow of carbon between major ecological units including pelagic-benthic exchanges. A general description of the model has already been published (Gordon et al., 1986). This report is a much more detailed account prepared for the benefit of the model architects (so we can remember what we did), ecological modellers elsewhere who might be interested in our methods and other research groups thinking of undertaking a similar exercise. The first part is a documentation manual that describes all details of model structure. Physical processes included are explained and the 32 state variables are defined. Processes affecting the biomass of state variables are identified and all equations are thoroughly described. Whenever possible, references are included and assumptions are explained. Carbon pathways are summarized in diagrams. The output of all state variables is presented and carefully evaluated. The report is based on the January 1986 version of the model. It concludes by summarizing what we have learned from the modelling project and offering recommendations for future development.

The methods and history of model development were also covered by Gordon et al. (1986). Some of the highlights are repeated below.

The model uses the BSIM simulation software package which has been expressly designed to develop ecosystem models. It was developed by William Silvert from BAHSIM, a package originally developed at the Biologische

Anstalt Helgoland which was obtained from the Dutch BOEDE group. BSIM is written to strict Fortran 77 standards to ensure portability. Details on BSIM are provided by Silvert (1986 a and b). Currently, both BSIM and the Cumberland Basin model are running on the Marine Ecology Laboratory (MEL) Wicat 160 and on Cyber mainframes at the Bedford Institute of Oceanography (BIO) and Acadia University. Anyone interested in obtaining BSIM should contact William Silvert at MEL.

The project was led by the authors of this report. Such a core group was essential to maintain continuity and to do what had to be done next to keep the project moving. The most important feature of model development however was the series of multidisciplinary workshops involving ten to thirty scientists. These brief but intensive sessions determined the major features of the model.

The main stimulus for starting the project was the support and encouragement of the Dutch BOEDE group with whom we developed personal contact in 1982 when they were in the midst of developing an ecological model of the Ems-Dollard estuary (Ruurdij and Baretta, 1982). The first Cumberland Basin workshop was held in March 1983 at the Netherlands Institute for Sea Research on Texel. The purpose was to see how easily the Ems-Dollard model could be adapted to the Cumberland Basin, and to gain modelling experience. The results convinced us to proceed.

We then began to construct our own model, step by step, beginning with the physical aspects. Wolfgang Ebenhoeh, an applied mathematician from the University of Oldenburg, visited BIO in the fall of 1983 and worked on modelling appropriate transport mechanisms with the assistance of physical oceanographers and sedimentologists. A special transport workshop to review and discuss the results was held at BIO in February 1984. The two biological submodels were first drafted in March 1984 at a workshop held at Acadia University. All three submodels were run interactively for the first time at a large workshop at BIO in July 1984 which was attended by six BOEDE scientists, Wolfgang Ebenhoeh and two scientists from the UK who had been involved in the development of GEMBASE, the ecological model of the Bristol Channel and Severn Estuary. A large number of errors were found and many recommendations offered for continued refinement. A much improved model was tested at the next workshop held back in Texel during March 1985. Further refinements were made at another workshop at BIO in June 1985. Development since then has rested in the hands of the core group and has focussed on preparing this report.

A project of this nature requires the involvement and cooperation of a very large number of people. From overseas, we would like to thank all members of the Dutch BOEDE group, especially Piet deWolf, Job Baretta, Piet Ruurdij and the late Huub Schroeder for their generous and expert assistance throughout the duration of the project. The wisdom and experience of Philip Radford and John Harris helped guide us through some difficult stages for which we are most grateful. More locally, we thank our many Canadian and US colleagues who participated in workshops and discussions and gave so freely of their time, ideas and data. These include: Chris

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## 2. Model Documentation

### 2.1 Variable Name Conventions

The following conventions were reached by consensus and were strictly adhered to in model development in order to prevent confusion and errors.

- a. I to N are integers
- b. B \_\_\_ terms represent benthic state variables  
D \_\_\_ terms are for differentials  
E \_\_\_ terms represent epibenthic state variables  
P \_\_\_ terms represent pelagic state variables  
T \_\_\_ terms are for transport  
X \_\_\_ terms are for boundary conditions
- c. The following prefixes are added to state variable names to represent commonly used variables. This convention makes it easier to work with the code. For example, the net production terms of all state variables begin with PN and the equations can be seen by simply searching for PN.

AS \_ assimilated food  
AV \_ available food  
EF \_ ingested food  
F \_ excretion and fecal production  
G \_ sloppy feeding  
PB \_ temperature and food corrected daily PB  
ratio (net production/biomass)  
PF \_ primary food (other food sources will  
not be used if primary food is absent)  
PG \_ gross production  
PN \_ net production  
R \_ total respiration  
RA \_ activity respiration  
RB \_ basal respiration  
SR \_ temperature corrected specific rate  
TF \_ total available food  
U \_ food uptake  
UM \_ maximum food uptake  
W \_ maturation (such as recruitment)  
Y \_ release (such as spawning)  
Z \_ mortality

d. State variable names and units (names are restricted to four characters each so they can accept two character prefixes defined above).

1. Physical Submodel

SALT - (parts per thousand)  
PSILT - ( $\text{g m}^{-3}$ )  
ESILT - ( $\text{g m}^{-2}$ )  
BSILT - ( $\text{g m}^{-2}$ )  
SILTS - (g)

2. Pelagic Submodel ( $\text{mg m}^{-3}$ )

PLOC - pelagic labile organic carbon  
PIOC - pelagic intermediate organic carbon  
PROC - pelagic refractory organic carbon  
PHYT - phytoplankton  
PBAC - pelagic bacteria  
PHER - planktonic herbivores  
PDET - planktonic detritivores  
PCAR - planktonic carnivores  
PFLR - planktonic fish larvae  
PRFH - resident fish  
PMFH - migratory fish

3. Benthic Submodel ( $\text{mg m}^{-2}$ )

BLCI - intertidal labile organic carbon  
BLCS - subtidal labile organic carbon  
BICI - intertidal intermediate organic carbon  
BICS - subtidal intermediate organic carbon  
BRCI - intertidal refractory organic carbon  
BRCS - subtidal refractory organic carbon  
BDIA - intertidal microalgae  
BACI - intertidal bacteria  
BACS - subtidal bacteria  
BMEI - intertidal meiofauna  
BMES - subtidal meiofauna  
BDFI - intertidal deposit feeders  
BDFS - subtidal deposit feeders  
BSUS - subtidal suspension feeders

4. Three epibenthic state variables are necessary for pelagic-benthic exchanges and to provide food for BSUS. Units are  $\text{mg m}^{-2}$ .

ELOC - epibenthic labile organic carbon  
EIOC - epibenthic intermediate organic carbon  
EROC - epibenthic refractory organic carbon

e. Coefficients are expressed as variables of the form  $C_{nn}X$  where

- C denotes a coefficient
- nn is a two digit number representing the appropriate state variable as follows:

01	BACI	11	BMES	21	PBAC	31	PROC
02	BACS	12	BRCI	22	PCAR	32	PSILT
03	BDFI	13	BRCS	23	PDET	33	SALT
04	BDFS	14	BSILT	24	PFLR	34	SDUM1
05	BDIA	15	BSUS	25	PHER	35	SDUM2
06	BICI	16	SILT5	26	PHYT	36	SDUM3
07	BICS	17	EIOC	27	PIOC	37	SDUM4
08	BLCI	18	ELOC	28	PLOC	38	SDUM5
09	BLCS	19	EROC	29	PMFH		
10	BMEI	20	ESILT	30	PRFH		

- X is a suffix which describe the process involved as follows:

_A	available food
_F	excretion or fecal production
_G	sloppy feeding
_RA	activity respiration
_RB	basal respiration
_S	Michaelis-Menten half saturation constant
_SR	temperature corrected specific rate
_T	Michaelis-Menton feeding threshold
_W	maturation
_Y	release
_Z	mortality

The form for transfer process coefficients is  $C_{ss}X_{dd}$  where ss is the number of the source state variable and dd is the number of the destination state variable.

Examples:

- C25F is the fractional fecal production for herbivores.
- C28A21 is the fraction of PLOC available to PBAC.

## 2.2 Structure of the Model

The model is conceptually divided into three submodels; physical, pelagic and benthic. In order to keep the code in units of reasonable length and to keep the number of variables per subroutine within reasonable limits each submodel is divided into several subroutines as follows:

Submodel	Subroutine	Contents
Physical	ENVDAT	Variable initialization
	ENVIR	Environmental variables, exchange and partition volumes
	PHYS	Daily transport volumes, erosion and silt redistribution
	BTRANS	Physical transport
	SEDRES	General purpose sedimentation-resuspension
	DISVOL	SEDRES utility program
Pelagic	EROS	PHYS utility program
	PELDAT	Variable initialization
	PRIMP	PHYT, PBAC and salt marsh input
	SECP	PHER and PDET
	TERTP	PCAR and PFLR
	FISHP	PRFH and PMFH
Benthic	BENDAT	Variable initialization
	PRIMB	BDIA, BACI, BACS and pelagic-benthic exchanges
	SECIB	BDFI and BMEI
	SECSB	BDFS, BMES and BSUS

## 2.3 Physical Submodel

### 2.3.1 Introduction

The physical submodel includes all the physical factors and processes that are thought to play an important role in the functioning of the Cumberland Basin ecosystem. It provides environmental data and transport mechanisms for the two biological submodels. It is not a detailed physical oceanographic or sedimentological model. For example, there is no stratification or cross-channel variation; compartments are assumed to be uniformly and instantaneously mixed. The submodel is designed only to provide the information required by the ecologists to model the biology at their present level of understanding.

The submodel has evolved over the series of workshops. Originally it was patterned after the Ems-Dollard physical submodel but many modifications have been added, primarily through the efforts of Wolfgang Ebenhoeh, Paul Keizer and Con Desplanque.

The submodel code is contained in the seven subroutines ENVDAT, ENVIR, EROS, DISVOL, PHYS, BTRANS and SEDRES. This documentation however is organized differently and contains the following sections:

- Definition of Compartments
- Flushing and Mixing
- Water Transport
- Sediment Transport
- Environmental Data

### 2.3.2 Definition of Compartments

The Cumberland Basin ecosystem model is a linear, one-dimensional box model with three compartments and three boundaries (Figure 2-1). The original compartments selected at the first workshop in Texel were defined on the basis of our data coverage, geography and the proposed barrage location. Little consideration was given to physical factors. At the transport workshop held in February 1984, the physical oceanographers suggested that we reconsider the compartment boundaries and set them as close to tidal excursion limits as possible.

At the March 1984 workshop, Con Desplanque and Don Gordon estimated the position of tidal excursions using Canadian Hydrographic Charts 4130 and 4010. The approximate position of the head of tidal water at mean low water (MLW) was estimated from soundings at low low water. A line was drawn across the channel at this location. In theory, only freshwater is found above this line on an average low tide. In Cumberland Basin this line is located between the Elysian Fields and Amherst Point (Figure 2-1). In Shepody Bay it is located just above Stoney Creek on the Petitcodiac River. The volume of tidal water above this line (Excursion 1) at mean

high water (MHW) was then calculated. Next, an estimate was made of how far seaward this volume of water would extend at MLW and another line was drawn across the channel. The volume of water between the two lines (Excursion 2) at MLW was calculated and the position of the seaward line was adjusted as necessary so that the MLW volume of Excursion 2 was approximately equal to the MHW volume of Excursion 1. This procedure was repeated step by step down Chignecto Bay to beyond Cape Enrage.

At MHW both Shepody Bay and Cumberland Basin contain three complete tidal excursions which range in length from 15 to 21 km. The three excursions in each estuary total 51 km in length. Current velocities estimated from tidal excursion length and duration of ebb/flood and from tidal prism volume and cross-sectional area ranged from 0.6 to 1.05 m/sec. These estimates compare favourably with observations and estimates from the Greenberg tidal model (Greenberg, 1979, 1983).

After reviewing the results of these calculations, it was agreed to change the compartment boundaries to coincide with the limits of tidal excursions (Figure 2-1). The uppermost tidal excursion in Cumberland Basin, which is empty of seawater at MLW, is defined as Boundary 5. Most of the freshwater discharged into Cumberland Basin enters this boundary (Maccan, Nappan and Hebert Rivers). Compartment 1 of the model is defined as the second tidal excursion, which extends from the base of Amherst Point around the Elysians Fields to Minudie Point. Compartment 2, the third tidal excursion, extends from Minudie Point out to the mouth of Cumberland Basin between Cape Maringouin and Ragged Point Reef, southwest of Joggins. The proposed barrage site at Pecks Point is now near the middle of Compartment 2. Compartment 3 is defined as the fourth tidal excursion extending from Cape Maringouin to about three quarters of the way to Cape Enrage. This compartment is bounded by Shepody Bay (Boundary 6) and Chignecto Bay (Boundary 4) as well as Compartment 2.

Benthic state variables are essentially static relative to the size of the model compartments and therefore their biomass is not transported between model compartments. Pelagic components however are constantly moving back and forth between compartments with the ebb and flood of the tide. Water in one compartment at MLW is transported landward on the flood tide and fills the adjacent compartment at MHW. On the ebb tide, 6.2 hours later, the process is reversed. Therefore it is necessary to identify waterbodies as well as compartments. We arbitrarily defined the waterbodies as the volume of the compartment at low water for a mean tide. Waterbody 1 therefore resides in Compartment 1 at MLW but is transported into Boundary 5 at MHW (Figure 2-1). Waterbody 2 resides in Compartment 2 at MLW but fills Compartment 1 at MHW. Waterbody 3 resides in Compartment 3 at MLW but fills Compartment 2 and the lower part of Boundary 6 at MHW. As discussed later under the silt model, horizontal transport is greater on spring tides and less on neaps. This results in the complex treatment of the exchange volumes described later. In contrast, the Ems-Dollard model defines waterbodies by their position at mid-tide.

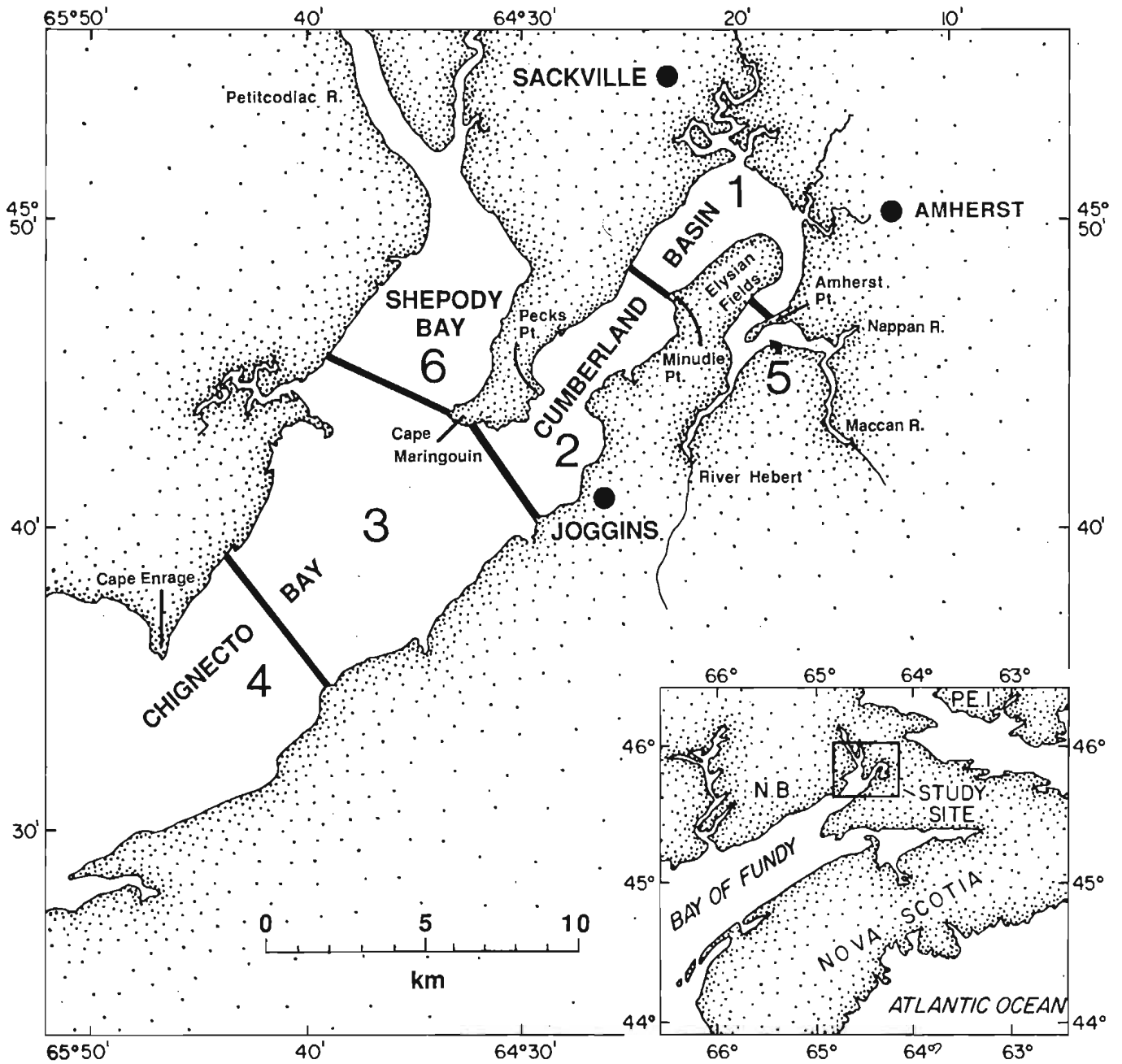


Figure 2-1. Map of Cumberland Basin area with the location of model elements

### 2.3.3 Flushing and Mixing

Water transport is driven by flushing and mixing. These same processes drive the water transport in the Ems-Dollard model (Helder and Ruardij, 1982).

#### 2.3.3.1 Flushing

Flushing represents the one way movement of freshwater, entering from the rivers at the head of the Cumberland Basin and Shepody Bay, through the system to the sea. Monthly average river flow into Cumberland Basin (RIVFL) is entered as a time series in ENV DAT. Units are  $\text{m}^3 \text{ day}^{-1}$ .

TABLE 2-1. DATA RIVFL - Monthly mean river discharge ( $10^6 \text{ m}^3 \text{ d}^{-1}$ ) for Cumberland Basin.

	J	F	M	A	M	J	J	A	S	O	N	D
RIVFL	14.6	2.2	4.9	16.7	4.1	2.2	0.8	0.3	0.3	3.2	2.2	4.6

These data are the monthly average river flows for 1978. April had the greatest discharge and August and September the least. They are based on gauging data for Kelley River (which flows into the River Hebert) and Palmer Creek (near Dorchester) obtained from Inland Waters. The data are scaled up to estimate the total discharge into the entire Basin. Data for 1979 and 1980 are also listed in ENV DAT so the model can be run for different years. A fourth time series in ENV DAT contains estimates of long term average discharge calculated with data in Holloway (1981); namely distributing the mean annual discharge into the Cumberland Basin over the year using the seasonal discharge curve of the Salmon River near Truro.

According to data presented by Holloway (1981), the amount of fresh water discharge entering Shepody Bay (Boundary 6) is 1.263 times that entering Cumberland Basin. Therefore the discharge from Boundary 6 at any time can be estimated by multiplying the discharge into Cumberland Basin by this factor which is called RIVFAC.

The daily freshwater discharge into Cumberland Basin (RIVER5) is calculated from the monthly averages (RIVFL) by a slip function in ENVIR.

$$\text{RIVER5} = \text{SLP}(\text{DAY}, \text{DATES}, \text{RIVFL}, 12)$$

The daily freshwater discharge into Boundary 6 (RIVER6) is

$$\text{RIVER6} = \text{RIVER5} * \text{RIVFAC}$$

### 2.3.3.2 Mixing

Mixing represents the two way exchange of water between model elements. It is driven by a variety of processes which include diffusion, dispersion and advection. The most important is thought to be tidally-driven dispersion (Holloway, 1981). The results of mixing are calculated using exchange volumes (EXVOL) which are based on observed 'steady-state' salinity (RSALT) distributions corresponding to a 'steady-state' river discharge rate (R5). The exchange volumes can be calculated as follows:

Between Compartments 1 and 2

$$\text{EXVOL}(1) = \text{R5} * \text{RSALT}(1) / (\text{RSALT}(1) - \text{RSALT}(2))$$

Between Compartments 2 and 3

$$\text{EXVOL}(2) = \text{R5} * \text{RSALT}(2) / (\text{RSALT}(2) - \text{RSALT}(3))$$

Between Compartment 3 and Boundary 4

$$\text{EXVOL}(3) = (\text{R5} * \text{RIVFAC} + \text{R5}) * \text{RSALT}(3) / (\text{RSALT}(3) - \text{RSALT}(4))$$

Between Compartment 3 and Boundary 6

$$\text{EXVOL}(4) = \text{R5} * \text{RIVFAC} * \text{RSALT}(6) / (\text{RSALT}(6) - \text{RSALT}(3))$$

Since there is no waterbody for Boundary 5, there can be no mixing between Compartment 1 and Boundary 5; the only net water transport across this boundary from one LW to the next is flushing.

R5 is the 'steady-state' freshwater discharge ( $\text{m}^3 \text{ day}^{-1}$ ) into Cumberland Basin which results in the 'steady-state' salinities, RSALT(I). R5 is currently set at the long-term mean discharge rate into Cumberland Basin (Holloway, 1981).

$$R5 = 4.66 \times 10^6$$

RSALT values are estimates of annual average salinity based on data from various sources including samples collected at Nappan, Peck Cove, by helicopter and by ship. The quality of the salinity data from the helicopter program, which sampled along the axis the Cumberland Basin over two seasonal cycles, is poor and so there is considerable uncertainty with the values in Boundary 5 and Compartment 1. These estimates were made in March 1983 Paul Keizer, Con Desplanque and Don Gordon. ENV DAT also c a second set of RSALT estimates for August 1978 which were prepared by Paul Keizer. The values of RSALT must reflect th equilibrium salinity distribution associated with the 'steady state' river flow (R5).

TABLE 2-2. DATA RSALT - Annual average salinities for each of the model elements.

	1	2	3	4	5	6
RSALT	22.	26.	30.	32.	0.	25.

In July 1984, Paul Keizer and Wolfgang Ebenhoh reviewe calculated exchange volumes. They concluded it was better to assign values based on averages of EXVOL(I) calculated for different combinations of R5 and RSALT(I) derived from anchor st tion data during 1978 to 1980. The model currently runs usin the following assigned values for the exchange volumes ( $\text{m}^3$ ):

$$\begin{aligned} \text{EXVOL}(1) &= 30. \times 10^6 \\ \text{EXVOL}(2) &= 91. \times 10^6 \\ \text{EXVOL}(3) &= 430. \times 10^6 \\ \text{EXVOL}(4) &= 88. \times 10^6 \end{aligned}$$

Further information on mixing and flushing calculations is contained in Keizer and Gordon (1985).

### 2.3.4 Water Transport

The total volume of water transported each day between adjacent model elements (VOLTR) is calculated in the entry TRFLOW found in the subroutine BTRANS. The arguments in the call are in order: source water body, destination water body, exchange volume, fresh water flow and transport mechanism index.

```
CALL TRFLOW (5,1, EXVOL(5)*RELTR, RIVER5, 1)
CALL TRFLOW (1,2, EXVOL(1)*RELTR, RIVER5, 1)
CALL TRFLOW (2,3, EXVOL(2)*RELTR, RIVER5, 1)
CALL TRFLOW (3,4, EXVOL(3)*RELTR, RIVER5+RIVER6, 1)
CALL TRFLOW (6,3, EXVOL(6)*RELTR, RIVER6, 1)
```

The derivation of exchange volumes (EXVOL) and daily river discharges (RIVERX) were described earlier. In the present model the transport mechanism index is never used and always equals 1. The exchange volume is multiplied by the relative tidal range (RELTR) for a given day. Since tidal dispersion is thought to be the principal mixing mechanism, it is reasonable to assume that exchange volumes are greater during spring tides (RELTR > 1) and smaller on neap tides (RELTR < 1).

The argument list in the entry TRFLOW is

```
ENTRY TRFLOW (IFROM, ITO, EXCHV, SHIFTV, JMECH)
```

Within TRFLOW, flow in the seaward direction is calculated as the sum of the tidally corrected exchange volume plus the river flow

$$\text{VOLTR (IFROM, ITO, JMECH) = ABS(EXCHV) + SHIFTV}$$

Flow in the landward direction equals the tidally corrected exchange volume only

$$\text{VOLTR (ITO, IFROM, JMECH) = ABS(EXCHV)}$$

The function ABS returns the absolute value of its argument (EXCHV)

The values of VOLTR are returned to the subroutine BTRANS where they are used to calculate the transport of state variables. The total amount, XA, of a given state variable, ISTATE, transported is;

$$XA = XC * VTR * SUSC$$

XC is the concentration of the state variable ISTATE in the source element (ICO).

VTR is the volume of water transported from element ICO to element JCO.

$$VTR = VOLTR (IOC, JCO, IMECH)$$

SUSC is the susceptibility of the state variable to water transport. Values for each state variable are set in the pertinent subroutines. Dissolved material (like salt) and fine particles (like phytoplankton) move with the water and have susceptibility constants of 1. Large organisms that are strong swimmers like shad move independently of the water and have susceptibility constants of 0. Weak swimmers will have intermediate values. Benthic organisms also have values of 0 since they are not transported.

After XA is determined, the differentials are calculated. XA is removed from the source element and added to the destination element. For example, in the case of SALT;

for the source element (ICO)

$$DSALT(ICO) = DSALT(ICO) - XA/VOLMLW(ICO)$$

and, for the destination element (JCO)

$$DSALT(JCO) = DSALT(JCO) + XA/VOLMLW(JCO)$$

Transport is calculated for all state variables except those with susceptibility constants of zero (0). State variable concentrations, differentials, boundary conditions and susceptibility constants are stored in and called from 2-dimensional arrays named ST2D, ST2DD, ST2DX and ST2DT which are equivalenced to the state variables in the common blocks STATE, SOURCE, BCS and RUTER respectively.

Transport is calculated for all possible numerical combinations of compartments and boundaries except to and from the same element and among boundaries. Differentials are defined and calculated for compartments only; the boundaries are either assumed to be infinite reservoirs or sinks so concentrations in the boundaries remain constant at the initial values or they are reassigned in the appropriate subroutines where values for transported state variables are entered as time series.

Keizer and Gordon (1985) present nutrient transport estimates calculated using the same equations.

### 2.3.5 Sediment Transport

In the first version of the Cumberland Basin model prepared at Texel in March 1983, silt concentrations were obtained from a time series. However, because of the importance of silt and the requirement to move some biological state variables in a silt-like manner, there was a need to model the transport of suspended particulate material. This silt model was created by Wolfgang Ebenhoeh during his visit to MEL in October 1983. The same subroutines can be used to determine the redistribution of other state variables such as particulate detritus between pelagic, epibenthic and benthic reservoirs.

Carl Amos (AGC) was involved in many of the discussions which took place as the silt model evolved. K. Kranck (AOL) and D. Eisma (NIOZ) have reviewed and provided critiques of the algorithm and its output. The model has been adapted to the Ems-Dollard Estuary (Ebenhoeh, 1985) where it satisfactorily simulates pelagic silt concentrations including the turbidity maximum and sedimentation rates.

#### 2.3.5.1 Terms

The model includes three forms of silt:

PSILT Pelagic silt ( $\text{g m}^{-3}$ ) corresponds to suspended sediment in the waterbodies. It is transported by the residual water motion but is also subject to losses via sedimentation and inputs via resuspension and erosion.

ESILT Epibenthic silt ( $\text{g m}^{-2}$ ) is the resuspendable portion of sedimented silt and can be equated with the higher concentration of suspended sediment in the bottom half meter of the water column. By definition it does not move with the waterbody into other compartments like PSILT. Being a thin layer, concentrations are expressed on an areal basis. After sedimentation PSILT is partitioned into ESILT and BSILT on the basis of the fraction of flat and channel in a compartment. This is not meant to imply that ESILT only exists in the channels. Since the area of channel in Boundary 5 is 0 there is no ESILT there.

BSILT Benthic silt ( $\text{g m}^{-2}$ ) is material which is sedimented onto the intertidal flats and is not resuspendable. BSILT can only re-enter the pelagic system by means of erosion. As with other state variables there is no accounting of BSILT in the boundaries which are assumed to behave as infinite reservoirs. However in order to calibrate the silt model it was necessary to add the state variable SILT5 which models the input and erosion of silt from Boundary 5.

### 2.3.5.2 Origin

New silt enters the model by the erosion of cliffs in Compartments 2 and 3. Daily input (SILTIN) is calculated in ENVIR with the slip function:

$$\text{SILTIN} = \text{SLP}(\text{DAY}, \text{DATES}, \text{SILSRC}, 12)$$

SILSRC, monthly mean input is given in the following data statement contained in ENVDAT.

TABLE 2-3. DATA SILSRC - Monthly mean input ( $10^9$  g d<sup>-1</sup>) of SILSRC.

	J	F	M	A	M	J	J	A	S	O	N	D
SILSRC	8.	8.	4.	2.	1.	1.	1.	1.	2.	4.	8.	8.

These data were obtained from Hildebrand et al. (1980). For the entire Chignecto Bay, Shepody Bay and Cumberland Basin region the total volume of sediment from cliff erosion is  $1 \times 10^6$  m<sup>3</sup> y<sup>-1</sup> which is equivalent to about  $167,000 \times 10^6$  g or  $6,000 \times 10^6$  g d<sup>-1</sup>. Estimates for Compartment 3 only were made by Carl Amos. Approximately half of the sediment input in Compartment 3 is on the northern shore where it is swept out into the outer Bay. This input is accounted for in the Boundary 4 concentration of PSILT.

$$\text{DPSILT}(3) = \text{DPSILT}(3) + 0.5 * \text{SILTIN}/\text{VOLMLW}(3)$$

Based on the maps in Hildebrand et al.(1980) it was estimated that erosion input in Compartment 2 was approximately 10% of that in Compartment 3.

$$\text{DPSILT}(2) = \text{DPSILT}(2) + 0.1 * \text{SILTIN}/\text{VOLMLW}(2)$$

### 2.3.5.3 Transportation

PSILT is moved among compartments and boundaries by the mixing equations like water. ESILT and BSILT are not transported.

#### 2.3.5.4 Redistribution

Exchanges between the three silt types are modelled in the subroutine SEDRES. SEDRES also calculates pelagic/benthic exchanges of other state variables (see Section 2.7). The active processes are sedimentation, resuspension and erosion. PSILT can sediment into ESILT or BSILT while only ESILT can resuspend into PSILT. Eroded BSILT is added to PSILT.

##### 2.3.5.4.1 Sedimentation

Sedimentation occurs at high (Figure 2-2) and low (Figure 2-3) water when the currents are weakest. All internal (1-3) and external (4 and 6) waterbodies are sources of silt deposited into the three model compartments. Erosion of BSILT (SILT5) from Boundary 5 goes directly to PSILT in Compartment 1.

The amount of material sedimented from waterbody I into compartment J is

$$\text{AMOUNT} = \text{CONC} * \text{PVOL}(\text{I},\text{J})$$

CONC is the concentration of sedimented material in each compartment

$$\text{CONC} = \text{PSILT}(\text{I}) * \text{SEDF}$$

or boundary

$$\text{CONC} = \text{XPSILT}(\text{I}) * \text{SEDF}$$

SEDF is the proportion of PSILT sedimented from a waterbody each day which is a function of the mean water depth (DMSL) in the receiving compartment. The deeper the water the smaller the fraction of PSILT that will reach the bottom. SEDF can never be greater than 1.

$$\text{SEDF} = \text{SEDIMI} / \text{DMSL}(\text{J})$$

SEDIMI is the daily (instantaneous) sedimentation rate and is a function of the mean sedimentation rate (SILSED) and the STORM factor.

$$\text{SEDIMI} = \text{SILSED} / \text{STORM}$$

SILSED is the sedimentation rate for silt which is defined in ENV DAT as  $3 \text{ m d}^{-1}$ . This parameter is estimated from several sources of field and laboratory data.

The mean silt particle size (deflocculated sediment) is about  $10 \text{ um}$  (Gordon and Desplanque, 1983). The average settling velocity for particles of this

size is about  $0.5 \text{ m d}^{-1}$  (McCave, 1975). Since flocs do occur the actual sedimentation rate should be greater than this. A value of  $2 \text{ m d}^{-1}$  was set at the July 1984 workshop in consultation with Carl Amos. The value of  $3 \text{ m d}^{-1}$  which is presently used is still considered a reasonable estimate. It agrees with observations of dropping silt concentrations in Chignecto Bay after storm resuspension (Amos and Asprey, 1981). Settling tube experiments (Hildebrand et al., 1980) indicated that more than 90% of the silt mass settled within 1 hour.

STORM, calculated in ENVIR, is a cosine function that reflects the seasonal probability of storms which promote resuspension. It varies from 1.5 in the winter to 0.5 in the summer.

$$\text{STORM} = 1. + .5 * \text{COS} (2.* \text{PI} * (\text{DAY} + 15.)/360.)$$

PVOL(I,J), the partition volume, is the average volume of waterbody I which is in compartment J at high and low tide (Figures 2-2 and 2-3) weighted by the asymmetry factor (ASYM).

$$\text{PVOL(I,J)} = (\text{PVOM(I,J,1)} * (1. - \text{ASYM}) + \text{PVOM(I,J,3)} * (1. + \text{ASYM}))/2$$

PVOM(I,J,1) is the volume of waterbody I in compartment J at low tide (1). For the simplest case, i.e. a mean tide, the entire volume of each waterbody is in its own compartment at low tide.

PVOM(I,J,3) is the volume of waterbody I in compartment J at high tide (3). Again for the simplest case, a waterbody fills up the entire adjacent landward compartment at high tide.

Because of the spring-neap and apogean-perigean tidal cycles values of PVOM vary significantly from the simplest case and several waterbodies may contribute to the contents of a compartment at high and low tide (Figures 2-2 and 2-3).

ASYM is the asymmetry constant. It expresses the asymmetry in any conditions for sedimentation at low and high tide. There are longer periods favourable for sedimentation at high tide than at low tide. For example, there is a longer period of slack water at high tide. Also, at low tide the waterbody is underlain only by coarse subtidal sediments with little stickiness while at high tide a large proportion of the sedimented material spreads over the sticky mudflats. Finally there may also be differences in the resuspension processes on the ebb and flood tides which load the waterbodies with silt to be sedimented at the next slack water. The value of ASYM must be between 0 and 1. If

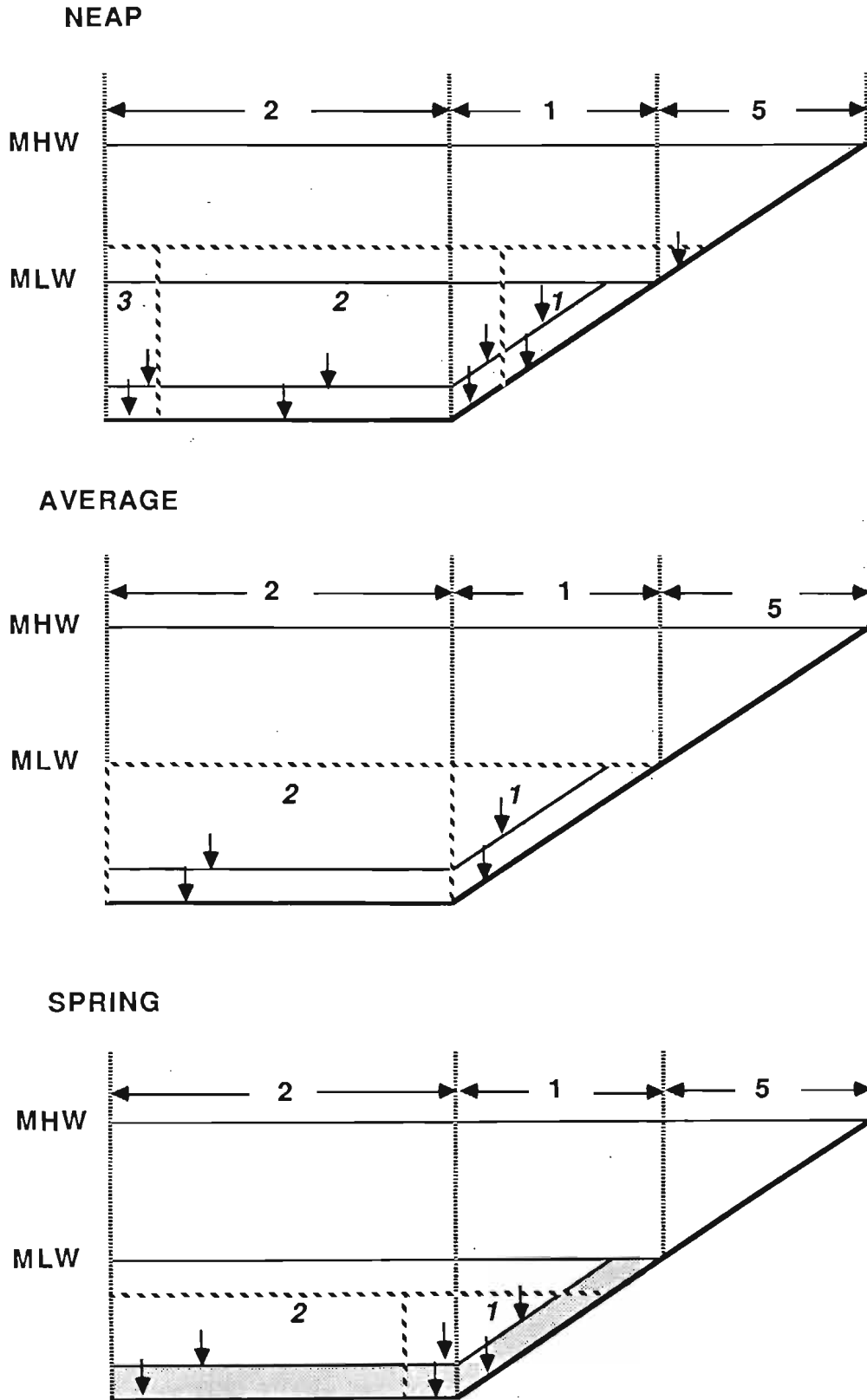


Figure 2-2. Location of waterbodies at neap, average and spring tides at low tide

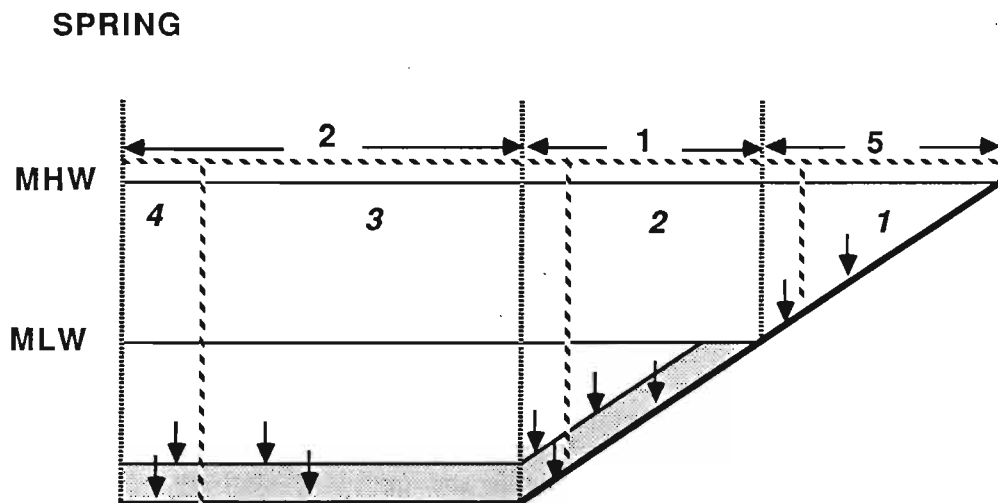
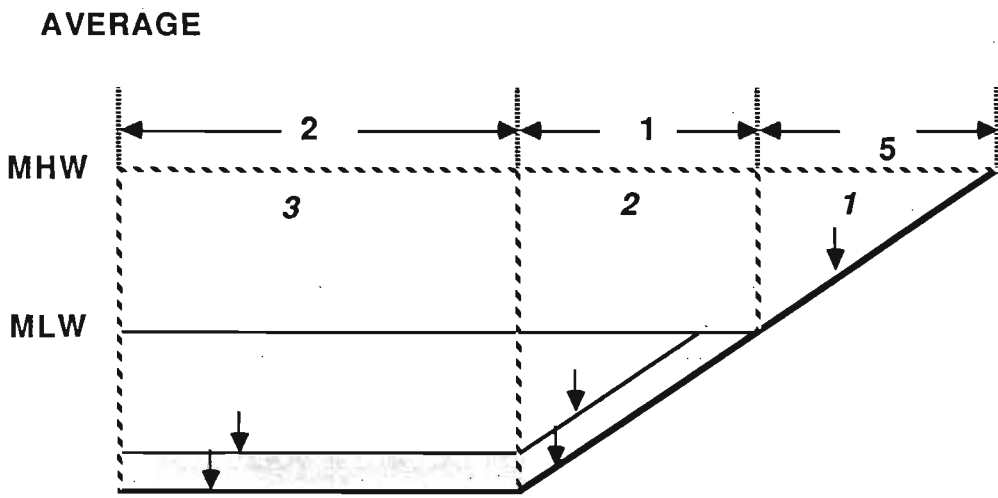
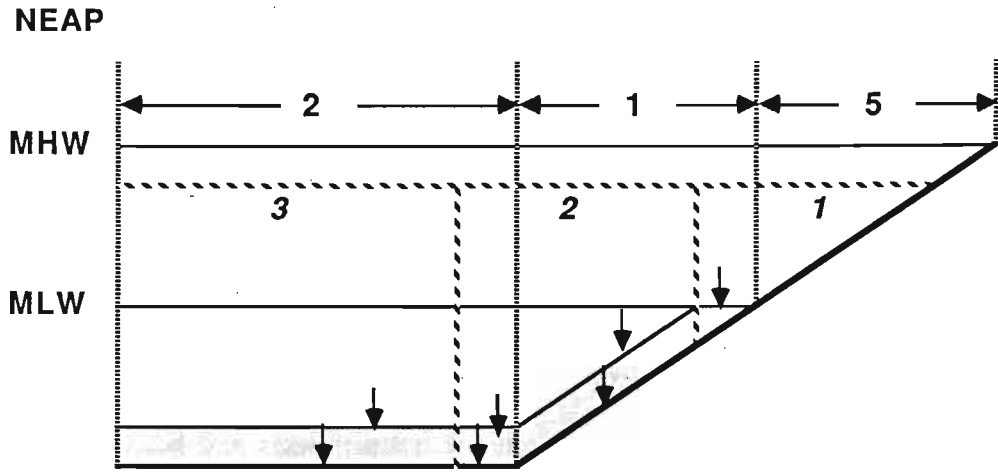


Figure 2-3. Location of waterbodies at neap, average and spring tides at high tide

set at 0 there would be no asymmetry and all silt would be eventually flushed out to sea by the fresh water input. If set at 1 all deposition would take place at high tide. Presently it is set at 0.7. By comparison the value of ASYM in the Ems-Dollard model is 0.57 (Ebenhoeh, 1985).

PVOM is calculated in the subroutine DISVOL using the two local variables

- (1) DIST the volume of the waterbody which by definition is its volume at mean low water. This is defined in ENVDAT as VOLMLW and remains constant throughout the year.
- (2) FREE the volume of compartments and boundaries on a particular day for low, mid and high tide and is calculated using volumes and the relative tidal range given in ENVDAT. The high and low tide volumes change daily with the tidal cycle but the mid-tide volume is constant.

For low tide -

$$\text{FREE(I)} = \text{VOLMLW(I)} + (\text{VOLMLW(I)} - \text{VOLMSL(I)}) * (\text{RELTR} - 1.)$$

For mid tide -

$$\text{FREE(I)} = \text{VOLMSL(I)}$$

For high tide -

$$\text{FREE(I)} = \text{VOLMHW(I)} + (\text{VOLMLW(I)} - \text{VOLMSL(I)}) * (\text{RELTR} - 1.)$$

The water volume (DIST) is distributed among the volumes (FREE) of the model elements in a set sequence starting with the most landward element and proceeding seaward. All numerically possible combinations are included. For example, on a given tide Waterbody 1 is the first used to fill up Boundary 5. DIST is reset to the remaining volume to be distributed, if any, and FREE(I) is reset to the remaining volume of Boundary 5 to be filled (if any). Note that either DIST or FREE(I) will equal 0 at the end of each step. This procedure continues for model elements 1, 2, 3 and 4 in order and then is repeated for Waterbodies 2, 3 and 4 in order. In this manner, the position of each waterbody for each stage of the tide (HT, MT and LT) is calculated for each day.

The horizontal displacement of waterbodies is greatest during spring tides when, for example, part of Waterbody 3 reaches Compartment 1 at high tide and part of Waterbody 1 reaches Compartment 3 at low tide (Figures 2-2 and 2-3). Horizontal

displacement is least during neap tides when the volume of the landward element to be filled is less than the volume of the adjacent waterbody, for example when Waterbody 2 is greater than the available volume of Compartment 1 at high tide.

The total amount (AMOUNT) of material which settles from the water column is then distributed between epibenthic and benthic state variables.

AMTFL is the amount of sediment which settles on and remains on the mudflats.

$$\text{AMTFL} = \text{AMOUNT} * \text{QSFL}(J) * \text{SILSTC} * \text{STCREL}(J)$$

QSFL is the proportion of the waterbody which lies over the mudflats and is calculated in ENVIR.

$$\text{QSFL}(I) = 0.5 * \text{VOLFL}/(\text{VOLFL} + \text{VOLCH})$$

0.5 is included because the mudflats are flooded only about half the time. (Note: This is too high and should be reduced to a more reasonable value in any future versions.)

VOLFL and VOLCH are the volumes of water that cover the mudflats and channels respectively.

$$\text{VOLFL} = \text{AFL}(I) * (\text{TR} - \text{HFL}(I))$$

AFL is the area of the mudflats given in ENV DAT (m<sup>2</sup>)

TR is the daily tidal elevation (m)

$$\text{TR} = \text{TIDER}(I) * (1. + \text{RELTR})/2.$$

TIDER is the mean tidal range given in ENV DAT

RELTR is the relative tidal range calculated daily in ENVIR

HFL is the average elevation of the mudflats (m) given in ENV DAT

$$\text{VOLCH} = \text{AMLW}(I) * (\text{TR} + \text{DMLW}(I))$$

AMLW is the area at mean low water given in ENV DAT

DMLW, calculated in ENVIR, is the average depth at mean low water

SILSTC is the probability that a particle will remain sedimented and is set at 0.1 in ENV DAT. This is a measure of the particle's stickiness and the value used is a very rough estimate.

STCREL reflects the suitability of the compartment bottom for sedimentation and is defined in SEDRES. This is a measure of the substrate's stickiness and the value is a very rough estimate.

TABLE 2-4. DATA STCREL - Values of STCREL for each of model elements.

	1	2	3	4	5	6
STCREL	0.5	1.5	3.0	0.0	0.5	1.5

The material sedimented on the mudflats (AMTFL) is added to the benthic state variable in that compartment.

$$DBSILT(J) = DBSILT(J) + AMTFL/AFL(J)$$

The remaining sedimented material is added to the epibenthic state variable ESILT,

$$AMTEB = AMOUNT - AMTFL$$

with the following exception, if the model element has no volume at MLW (ie Boundary 5) it can have no epibenthic form and the total amount sedimented must be reduced by this impossible loss which stays in suspension (PSILT).

$$AMOUNT = AMOUNT - AMTEB$$

Otherwise AMTEB is added to the epibenthic state variable (ESILT)

$$DESILT(J) = DESILT(J) + AMTEB/AMLW(J)$$

and the net amount sedimented is subtracted from the pelagic state variable (PSILT).

$$DPSILT(I) = DPSILT(I) - AMOUNT/VOLMLW(I)$$

The epibenthic silt is distributed over the area of the compartment at MLW (AMLW(J)) and the pelagic silt is removed uniformly from the waterbody (VOLMLW(I)).

#### 2.3.5.4.2 Resuspension

Resuspension occurs at mid tide when the current velocities are strongest (Figure 2-4). ESILT is resuspended into PSILT.

The concentration of resuspended material (CONC) for internal compartments is

$$\text{CONC} = \text{ESILT(I)} * \text{RESUSI} * \text{STRES(I)}$$

and for external compartments

$$\text{CONC} = \text{XESILT(I)} * \text{RESUSI} * \text{STRES(I)}$$

RESUSI is the daily resuspension rate which is a function of the mean resuspension rate (SILRES) and the STORM factor.

$$\text{RESUSI} = \text{SILRES} * \text{STORM}$$

SILRES is the resuspension constant ( $\text{m d}^{-1}$ ) which is set at 0.1 in ENV DAT. This is a very rough estimate.

STORM (see Section 2.3.5.4.1.)

STRES is the relative bottom current stress factor and is inversely proportional to the depth of the compartments. The values are set in SEDRES.

TABLE 2-5. DATA STRES - Values of STRES for each of the model elements.

	1	2	3	4	5
STRES	3.	1.	.5	.5	3.

The resuspended material from compartment I is then allocated to the various waterbodies, J, present in the compartment at the time of resuspension (Figure 2-4). AMTIJ is the amount of material going from the epibenthic state in compartment I (stationary) into the pelagic state of waterbodies J (moving).

$$\text{AMTIJ} = \text{AMOUNT} * \text{PVOM(J,I,2)}/\text{VOLMT}$$

AMOUNT is the total amount resuspended which is allocated to different waterbodies in proportion to their fraction of the total volume.

$$\text{AMOUNT} = \text{CONC} * \text{AMLW(I)}$$

VOLMT is the total water volume into which resuspension occurs. Its value is the sum of the volumes of waterbodies J in compartment I at mid tide, PVOM(J,I,2) (it should also equal VOLMSL).

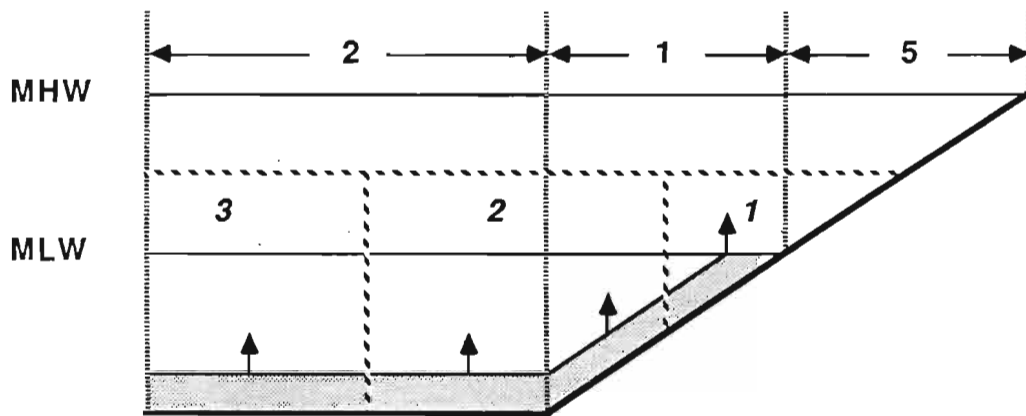


Figure 2-4. Location of waterbodies when resuspension occurs at mid-tide

$$\text{VOLMT} = \text{VOLMT} + \text{PVOM}(\text{J},\text{I},2)$$

PVOM(J,I,2) are the partition volumes calculated in the subroutines ENVIR and DISVOL.

The AMTIJ must be added to the pelagic state variable and subtracted from the epibenthic state variable.

$$\text{DPSILT}(\text{J}) = \text{DPSILT}(\text{J}) + \text{AMTIJ}/\text{VOLMLW}(\text{J})$$

$$\text{DESILT}(\text{I}) = \text{DESILT}(\text{I}) - \text{AMOUNT}/\text{AMLW}(\text{I})$$

VOLMLW is used because by definition the volume of a waterbody is its volume at MLW.

#### 2.3.5.4.3 Erosion

Sediment input by means of erosion has two sources, the cliffs and the mudflats. Cliff erosion has already been discussed above. Over the summer months sediment builds up on the mudflats in the Basin and a portion of this is removed by storms and ice in the winter months (Gordon and Desplanque, 1983). Net annual deposition is in the order of 3 mm ( $6000 \text{ g m}^{-2}$ ) in the Basin although in the upper part it may exceed this. The amount of material eroded is calculated in the subroutine EROS which is called with the following arguments:

**CALL EROS (ERSILT, ERODED, STRM, ICE)**

ERSILT is the erodable material. In the compartments this is the BSILT in excess of 200000.  $\text{g m}^{-2}$ .

$$\text{ERSILT} = \text{BSILT}(\text{I}) - 200000.$$

and in Boundary 5 is the total benthic silt (SILT5).

ERODED is returned as the amount of material eroded which is then added to the pelagic silt pool (PSILT) in the same compartment or in Compartment 1 for mudflat erosion from Boundary 5 and subtracted from the appropriate benthic pool.

$$\text{DPSILT}(\text{I}) = \text{DPSILT}(\text{I}) + (\text{ERODED} * \text{AMLW}(\text{I})/\text{VOLMLW}(\text{I}))$$

$$\text{DBSILT}(\text{I}) = \text{DBSILT}(\text{I}) - \text{ERODED}$$

$$\text{DPSILT}(1) = \text{DPSILT}(1) + \text{ERODED}/\text{VOLMLW}(1)$$

$$\text{DSILTS}(1) = \text{DSILTS}(1) - \text{ERODED}$$

For erosion from Boundary 5, STRM is presently equal to STORM which is calculated in ENVIR. The value of STORM ranges from 0.5 on DAY 165 to 1.5 on DAY 345.

$$\text{STORM} = 1. + .5 * \text{COS}(2. * \text{PI} * (\text{DAY} + 15.) / 360.)$$

ICE, for erosion from Boundary 5, is set at 3 when WTEMPD(1) is less than 0 C. Erosion from Boundary 5 was tuned using this value.

The erosion from the outer compartments was tuned by varying the value of STRM and ICE. The values used do not have any environmental basis and the two factors could easily be replaced by one. To calculate the amount of material eroded the two factors are added together, divided by 360 and multiplied by ERSILT.

$$\begin{aligned} \text{FACTOR} &= \text{STORM} + \text{ICE} \\ \text{ERODED} &= \text{ERSILT} * (\text{FACTOR}) / 360. \end{aligned}$$

### 2.3.6 Environmental Data

Environmental data include the information necessary to describe the physical features of model elements and the daily calculation of numerous physical and environmental variables which affect the biological processes occurring in the Basin. Values for the numerous constants, coefficients and parameters are found in the subroutine ENVDAT while the variables are computed on a daily basis in the subroutine ENVIR.

#### 2.3.6.1 Areas

Areas (m<sup>2</sup>) were determined by Con Desplanque and Don Gordon at the March 1984 workshop using Canadian Hydrographic Chart 4130 and a planimeter.

AMLW is the water area at low tide (MLW) when the flats are completely exposed. It is equivalent to the area of channels which are covered with water at MLW. It also represents the area of the subtidal zone.

TABLE 2-1. DATA AMLW - Values of AMLW (10<sup>6</sup> m<sup>2</sup>) for each of the model elements.

	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>
AMLW	19	51	186	250	0	63

AMSL is the water area at mid tide (MSL) when parts of the flats are flooded.

TABLE 2-2. DATA AMSL - Values of AMSL (10<sup>6</sup> m<sup>2</sup>) for each compartment.

	<u>1</u>	<u>2</u>	<u>3</u>
AMSL	35	64	200

AMHW is the water area at high tide (MHW) when the flats are flooded.

TABLE 2-3. DATA AMHW - Values of AMHW (10<sup>6</sup> m<sup>2</sup>) for each compartment.

	<u>1</u>	<u>2</u>	<u>3</u>
AMHW	50	74	214

AFL (area of flats) is equal to AMHW minus AMLW. It is composed of salt marsh, mudflat and coarser sediments found near MLW. Flats are exposed at low tide and flooded at high tide.

TABLE 2-9. DATA AFL - Values of AFL ( $10^6 \text{ m}^2$ ) for each of the model elements.

	1	2	3	4	5	6
AFL	31	23	28	0	15	60

### 2.3.6.2 Volumes

Volumes ( $\text{m}^3$ ) are defined in ENVDAT.

They were calculated at the March 1984 workshop by Con Desplanque and Gordon using areas and elevations obtained from Canadian Hydrographic Charts 4130 and 4010. Regressions were developed that can be used to estimate compartment volume at any tidal elevation.

VOLMLW is the volume of the model element at MLW which is also the definition of the volume of the waterbody.

TABLE 2-10. DATA VOLMLW - Values of VOLMLW ( $10^6 \text{ m}^3$ ) for each of the model elements.

	1	2	3	4	5	6
VOLMLW	82	457	2299	0	0	290

Volume of the model element at MSL (VOLMSL) is

TABLE 2-11. DATA VOLMSL - Values of VOLMSL ( $10^6 \text{ m}^3$ ) for each of the model elements.

	1	2	3	4	5	6
VOLMSL	235	749	3474	0	22	789

Volume at MHW (VOLMHW) is

TABLE 2-12. DATA VOLMHW - Values of VOLMHW ( $10^6 \text{ m}^3$ ) for each of the model elements.

	1	2	3	4	5	6
VOLMHW	470	1094	4734	0	89	1405

Note that the VOLMHW for Compartment 1 is approximately equal to the VOLMLW of Compartment 2. The VOLMLW for Compartment 3 is approximately twice the volume of Compartment 2 at MHW; the remaining volume of water goes into Boundary 6.

### 2.3.6.3 Average Depth

Average depth at three tidal stages (DMLW, DMSL and DMHW) for each compartment is calculated by dividing volume by area.

### 2.3.6.4 Tidal Range

TIDER, the mean tidal range (m) of each compartment, was calculated by Con Desplanque.

TABLE 2-13. DATA TIDER - Values of TIDER (m)  
for each compartment.

	1	2	3
TIDER	10.6	10.0	9.5

RELTR, the relative tidal range, is a factor which describes daily changes in tidal range caused by predictable astronomical events. It is calculated daily using equations derived by Wolfgang Ebenhoeh and Con Desplanque which describe both lunar and perigean cycles. The perigean cycle, which is especially important in the Bay of Fundy, is not included in the Ems-Dollard model. Daily values of RELTR will vary from year to year and are controlled by the variable DAYFHW which is defined as the day of the year with the highest high tide. It is currently set at 0 (1 January) which approximates conditions in 1978-1979 (see Fig.4 in Gordon and Desplanque, 1983).

$$\text{RELTR} = 1 + \text{ACYCLE} + \text{BCYCLE}$$

ACYCLE is the spring-neap lunar cycle which repeats every 14.76 days. It is caused by changes in the position of the sun and moon relative to the earth.

$$\text{ACYCLE} = 0.16 * \text{COS}(2.0 * \text{PI} * (\text{DAY} - \text{DAYFHW}) / 14.76)$$

BCYCLE is the apogean-perigean cycle which repeats every 27.55 days. It is caused by eccentricity in the lunar orbit around the earth. At perigee, when the moon is closest to earth, the tides are higher.

$$\text{BCYCLE} = 0.23 * \text{COS}(2.0 * \text{PI} * (\text{DAY} - \text{DAYFHW}) / 27.55)$$

These two cycles interact to produce especially high and low tides about every 206 days.

### 2.3.6.5 Elevations

HFL, the average mudflat elevation, is assumed to be approximately half the tidal range.

TABLE 2-14. DATA HFL - Values of HFL (m) for each compartment.

	1	2	3
HFL	5.0	5.0	5.0

EXFAC is an exposure factor used in calculating benthic microalgal production which takes into account the fact that the model assumes mudflat elevation is constant while tidal range increases up estuary.

TABLE 2-15. DATA EXFAC - Values of EXFAC for each compartment.

	1	2	3
EXFAC	0.96	1.00	1.04

### 2.3.6.6 Exposure to Light

The equations for calculating light exposure were prepared by Wolfgang Ebenhoeh during his visit in October 1983. Only minor changes have been made at subsequent workshops.

EXFLLT, the number of hours that the flats are exposed to light each day, takes into account phase differences between light and tidal cycles. Because of high turbidity the flats receive light for photosynthesis only when they are exposed (Hargrave et al., 1983). The amount of light received on a day when high tide occurs at noon will be different from that on a day when low tide occurs at noon.

$$\text{EXFLLT(I)} = \text{EXH} * \text{C2} + \text{EXL} * (1 - \text{C2})$$

EXH is the number of hours of the flats are exposed to sunlight when high tide occurs at noon and typically will equal (DAYL - COVT).

$$\text{EXH} = \text{MIN}(2 * \text{EXPOT}, \text{MAX}(0, \text{DAYL} - \text{COVT}))$$

EXPOT is the number of hours the flats are exposed to the air during a tidal cycle (from high tide to high tide).

$$\text{EXPOT} = 12.6 * \text{EXFACT}(I)$$

EXFACT is the fraction of the day that the inter-tidal flats are exposed to the air which is a function of average flat elevation and tidal range. The tide curve is assumed to be a regular cosine curve and the value of EXFACT ranges from about 0.47 to 0.53.

$$\text{EXFACT}(I) = 1 - \text{ACOS}(X)/\text{PI}$$

$$X = (\text{HFL}(I) * 2 - \text{TR}) / (\text{TR} * \text{RELTR})$$

HFL is the average flat elevation

TR = TIDER(I) or average tidal range

RELTR is the daily relative tidal range.

DAYL is the number of day light hours in a given day. It is smallest (8hr) on 21 December and greatest (16hr) on 21 June.

$$\text{DAYL} = 12 - 4 * \text{COSFAC}$$

$$\text{COSFAC} = \text{COS}(2 * \text{PI} * (\text{DAY} + 10.) / 360.)$$

COVT is the number of hours the flats are covered with water during a tidal cycle.

$$\text{COVT} = 12.6 - \text{EXPOT}$$

The factor C2 describes the phase difference between tidal and light cycles. Its value ranges from 1.0, when high tide occurs at noon, to 0.0, when low tide occurs at noon, with a period of 29.54 days.

$$\text{C2} = (\text{COS}(2 * \text{PI} * (\text{DAY} - \text{DAYFHW}) / 29.54)) ** 2$$

EXL is the number of hours of exposure to light if low tide occurs at noon and will typically equal the shortest of DAYL or EXPOT.

$$\text{EXL} = \text{MAX}(\text{DAYL} - 2 * \text{COVT}, \text{MIN}(\text{DAYL}, \text{EXPOT}))$$

EXWALT is the number of hours a day that a waterbody is exposed to light. Water in the channels is exposed for DAYL hours but over the flats this exposure time is (DAYL-EXFLLT) hours. EXWALT is an average exposure time weighted for the relative areas of channel and intertidal zone in a compartment.

$$EXWALT(I) = (ACH * DAYL + AF *(DAYL - EXFLLT(I)))/(ACH + AF)$$

$$ACH = AMLW(I)$$

$$AF = AFL(I)$$

ALIGHT is the relative light amplitude and is calculated in ENVIR.

$$ALIGHT = 1.0 - 0.6 * COSFAC$$

SFL is a light scaling factor defined in ENVDAT and is the daily mean of the product EXFLLT \* ALIGHT.

TABLE 2-16. DATA SFL - Values of SFL for each compartment.

	1	2	3
SFL	6.36	6.60	6.82

### 2.3.6.7 Temperature

Monthly average water and intertidal sediment temperatures for all model elements were calculated from field data collected at Pecks Cove and by ship and helicopter.

WTEMP is the monthly average water temperature. The monthly means were estimated by Don Gordon from data collected at high tide at Pecks Cove (unpublished data) and at low tide anchor stations at the mouth of Cumberland Basin and off Cape Enrage (Keizer and Gordon, 1985) Data coverage is very patchy and many values were estimated, including all for Compartment 1, assuming temperature decreases up estuary in winter and increases up estuary in summer.

TABLE 2-17. DATA WTEMP - Monthly mean water temperature for each of the model compartments.

Comp.	J	F	M	A	M	J	J	A	S	O	N	D
1	-1.5	-1.5	1.	4.	9.	13.	17.	20.	15.	10.	5.	1.
2	-1.	-1.	1.	3.	8.	12.	15.	18.	14.	10.	6.	2.
3	0.	0.	1.	3.	7.	11.	14.	15.	14.	11.	8.	3.

STEMP is the monthly average intertidal sediment temperature.

The monthly means were estimated by Don Gordon in May 1985 from a smoothed curve of data collected weekly or biweekly beside the buried plates at Pecks Cove between April and December, 1979. They compare very closely with water temperatures measured in cores during production/respiration experiments at Pecks Cove by Hargrave et al. (1983). Values for January to March are guesses. Since the coverage of frozen crust is only about 20% during the winter (Gordon and Desplanque, 1983), it is assumed that monthly means during this period do not drop below zero. Daily temperatures can vary by as much as 10C from the monthly mean but such variations are not included in the model. It is assumed that sediment temperatures are the same in all Compartments.

TABLE 2-18. DATA STEMP - Monthly mean sediment temperature for each of the model compartments.

Comp.	J	F	M	A	M	J	J	A	S	O	N	D
1	0.	0.	3.	6.	12.	18.	23.	22.	17.	12.	8.	3.
2	0.	0.	3.	6.	12.	18.	23.	22.	17.	12.	8.	3.
3	0.	0.	3.	6.	12.	18.	23.	22.	17.	12.	8.	3.

Daily temperatures are calculated from the time series with slip functions.

WTEMPD is the daily water temperature.

$$WTEMPD(I) = SLP (DAY, DATES, WTEMP(1,I), 12)$$

STEMPD is the daily intertidal sediment temperature.

$$STEMPD(I) = SLP (DAY, DATES, STEMP(1,I), 12)$$

## 2.4 Pelagic Submodel

### 2.4.1 Introduction

The growth dynamics of the pelagic organisms are modelled in the following way. A temperature corrected maximum uptake rate is first calculated from a specific growth rate and biomass. This is then used with food concentration in a Michaelis-Menten equation to calculate total food uptake. Respiration, excretion, mortality and other rates are then calculated, usually as a function of food uptake or biomass.

The pelagic submodel is broken down into four subroutines according to approximate trophic level (or size) as follows:

1. PRIMP which includes

PHYT - phytoplankton  
PBAC - planktonic bacteria

2. SECP which includes

PHER - planktonic herbivores  
PDET - planktonic detritivores

3. TERTP which includes

PCAR - planktonic carnivores  
PFLR - fish larvae

4. FISHP which includes

PRFH - resident fish  
PMFH - migratory fish

Biological coefficients are defined in PELDAT. Susceptibility coefficients and boundary conditions are defined at the start of subroutines. Initial values are given in SIMD. All carbon flows are illustrated in Figure 2-5.

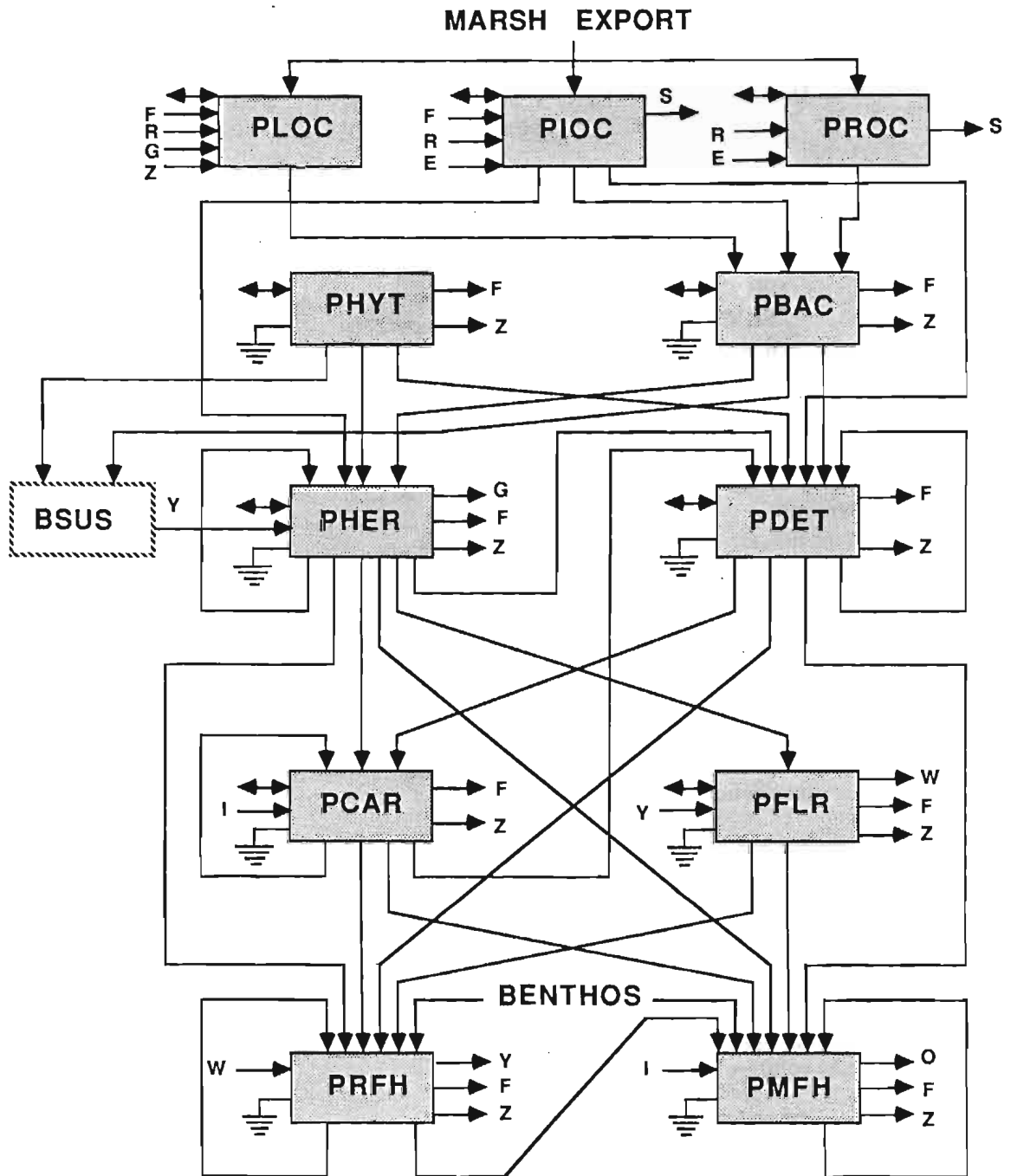


Figure 2-5. Carbon flows in the pelagic submodel.  
 E-erosion, F-excretion, G-sloppy feeding, I-immigration,  
 R-resuspension, S-sedimentation, W-recruitment,  
 Y-spawning, Z-mortality and  $\equiv$ -respiration.

#### 2.4.2 Phytoplankton (PHYT)

The state variable PHYT includes planktonic primary producers (diatoms and flagellates). They are the only autotrophs in the pelagic submodel.

$$\text{DPHYT}(I) = \text{DPHYT}(I) + \text{PGPHYT} - \text{RPHYT} - \text{FPHYT} - \text{ZPHYT} - \text{PREDATION} \pm \text{EXCHANGE}$$

PGPHYT	gross primary production
RPHYT	phytoplankton respiration
FPHYT	phytoplankton excretion added to PLOC and PIOC
ZPHYT	phytoplankton mortality added to PLOC
PREDATION	consumption by PHER, PDET and BSUS
EXCHANGE	transport to and from compartments and boundaries

##### 2.4.2.1 Gross primary production (PGPHYT)

Gross phytoplankton production is calculated with a Michaelis-Menten expression. There is no nutrient limitation on growth but there is nutrient stress which affects excretion and respiration. There are no density dependent biological controls.

Rate determining factors:

- biomass (PHYT)
- temperature (WTEMPD)
- incident light (SUNS)
- interaction of light and tidal cycles (EXWALT)
- extinction coefficient (EXT)

Parameters required:

- specific growth rate at 0 C (C26SR)
- Q10
- half saturation constant (C26S)

PGPHYT(I) is the phytoplankton gross primary production (mgC/m<sup>3</sup>/day) in the euphotic zone which is distributed over the entire water column.

$$\text{PGPHYT}(I) = \text{PHYT}(I) * \text{SRPHYT} * \text{FACL}$$

SRPHYT is the temperature corrected specific growth rate (fraction of biomass/day). It represents the maximum theoretical growth (Vmax) at a given temperature. A value of 1 means that daily growth rate is equal to the biomass.

$$\text{SRPHYT} = \text{C26SR} * \text{EXP} (.0633 * \text{WTEMPD(I)})$$

C26SR is the specific growth rate at 0 C, presently = 1.0.

0.0633 is the temperature coefficient for a Q10 of 1.88.

FACL is the light correction factor which includes the half saturation constant C26S ( $\text{w m}^{-2}$ ).

$$\text{FACL} = \text{SUNZ}/(\text{C26S} + \text{SUNZ})$$

C26S is the light level at which phytoplankton production is half the maximum rate (SRPHYT). A value of 20 was derived from P-I curves measured by Prouse (1983) but during tuning this was increased to 25. The output of the model is very sensitive to the value of this parameter.

SUNZ is the average light level in the water column.

$$\text{A} = \text{EXT} * \text{DMLW(I)}$$

$$\text{SUNZ} = (\text{SUNS} * (1 - \text{EXP} (- \text{A}))) / \text{A}$$

SUNS is the incident radiation in units of  $\text{w m}^{-2}$  (PAR) corrected for the coincidence of tides and daylight periods.

$$\text{SUNS} = (21.3 * \text{DAYL} - 108) * (\text{EXWALT(I)}/\text{DAYL})$$

DAYL is day length in hours and EXWALT(I) is the effective day length for the waterbody (see Section 2.3.6) taking into account the interplay of light and tidal cycles.

EXT is the extinction coefficient which is dependent upon the depth of the euphotic zone.

$$\text{EXT} = 4.6/\text{ZE}$$

4.6 is the value of  $(\ln(100) - \ln(1))$

ZE is the depth of the euphotic zone in meters. It is defined as the depth at which 1% of the incident PAR is present. It is calculated using an empirical equation based upon light data of Prouse (1983) and PSILT concentrations.

$$\text{ZE} = 1 / (0.083 + .0088 * \text{PSILT(I)})$$

DMLW is the depth of the waterbody at mean low water.

#### 2.4.2.2 Phytoplankton respiration (RPHYT)

Phytoplankton respiration has both activity, basal and nutrient stress components. Activity respiration was originally set at 10% of the gross production but it was increased to 30% while tuning the model. Basal respiration is assumed to be 3% of the biomass. Nutrient stress respiration is a function of the nitrate concentration. The algorithm for nutrient stress respiration was adapted from the BOEDE model for the Ems-Dollard.

Rate determining factors:

- gross production (PGPHYT)
- biomass (PHYT)
- nitrate concentration (SDUM1)

Parameters required:

- activity respiration coefficient (C26RA)
- basal respiration coefficient (C26RB)
- nutrient stress threshold

RPHYT is total respiration.

$$\mathbf{RPHYT = RAPHYT + RBPHYT + RNPHYT}$$

RAPHYT is the activity respiration.

$$\mathbf{RAPHYT = C26RA * PGPHYT(I) * RMINU}$$

C26RA is the activity respiration constant, presently = 0.3.

PGPHYT(I) is the gross phytoplankton production.

RMINU is the Michaelis-Menten factor for stress.

$$\mathbf{RMINU = SDUM1(I) / (SDUM1(I) + 14.)}$$

SDUM1(I) is the nitrate concentration which is entered as a time series at the boundaries.

14 is the nitrate concentration (mgN/m<sup>3</sup>) below which nutrient stress occurs.

RBPHYT is the basal respiration.

$$\mathbf{RBPHYT = C26RB * 2.**((WTEMPD(I) -10.)/10.)*PHYT(I)}$$

Note: For puposes of comparison, the formulation

$$RBPHYT = C26RB * EXP ((WTEMPD(I) -10.) *0.0633) *PHYT(I)$$

is an equivalent expression for a Q10 of 1.88 at 10 C.

C26RB is the basal respiration constant at 10C, presently =  
0.03

RNPHYT is the nutrient stress respiration.

$$RNPHYT = 0.9 * EXLOC$$

EXLOC is the excretion under nutrient stress.

$$EXLOC = PGPHYT(I) * 0.9 * (1.-RMINU)$$

0.9 is the fraction of PGPHYT affected by nutrient stress.

#### 2.4.2.3 Phytoplankton excretion (FPHYT)

Dissolved organic carbon is released by phytoplankton and is added to PLOC and PIOC. The algorithm for nutrient stress excretion was adapted from the BOEDE model for the Ems-Dollard.

Rate determining factors:

- gross production (PGPHYT)
- nutrient stress (RMINU)
- nutrient stress excretion (EXLOC)

Parameters required:

- excretion coefficient (C26F)
- fraction of EXLOC to PLOC (0.5)

FPHYT is the dissolved organic carbon release.

$$FPHYT = C26F * PGPHYT(I) * RMINU + 0.5 * EXLOC$$

C26F is the excretion coefficient = 0.1

PGPHYT is the gross primary production.

RMINU is the Michaelis-Menten nutrient stress factor.

EXLOC is the excretion under nutrient stress (see above).

One half of EXLOC goes to PLOC, the other half goes to PIOC .

#### 2.4.2.4 Mortality (ZPHYT)

Originally there was no mortality in the model. It was added in Jan 1985 with approval of Glenn Harrison to help keep phytoplankton under control. It has been changed quite a bit but is currently set at 2% of the biomass.

Rate determining factors

- biomass (PHYT)
- temperature (WTEMPD)

Parameters required:

- mortality coefficient (C26Z)

ZPHYT is the mortality which is added to PLOC.

$$\text{ZPHYT} = \text{C26Z} * \text{PHYT(I)} * \text{EXP}(.0633 * \text{WTEMPD(I)})$$

C26Z is the mortality coefficient, presently = 0.02.

EXP (.0633 \* WTEMPD(I)) is the temperature factor for a Q10 of 1.88.

#### 2.4.2.5 Predation

Phytoplankton are grazed by PHER, PDET, BDFI and BSUS. See other sections.

#### 2.4.2.6 Exchange

Mixing between compartments is calculated in PHYS. The susceptibility constant is set at 1. Boundary values are set by the time series PHYTX.

$$\text{XPHYT(I)} = \text{SLP}(\text{DAY}, \text{DATES}, \text{PHYTX}(1, \text{I}), 12)$$

SLP is a slip function which extrapolates between points in a time series.

DAY is the time in the simulation.

DATES is the time for the data points in the time series.

PHYTX is the time series of PHYT concentrations in the boundaries based upon extensive chlorophyll data (Keizer et al., 1984) using a carbon to chlorophyll ratio of 20.

TABLE 2-19. DATA PHYTX - Monthly mean concentrations  
(mgC m<sup>-3</sup>) for each of the model boundaries.

Bound.	J	F	M	A	M	J	J	A	S	O	N	D
4	20.	22.	18.	14.	17.	20.	22.	24.	22.	20.	18.	19.
5	70.	38.	28.	36.	124.	276.	78.	206.	208.	108.	130.	100.
6	70.	22.	22.	36.	64.	86.	78.	76.	72.	72.	56.	63.

#### 2.4.2.7 Nutrient uptake

Uptake of nutrients by primary production. This is not an attempt to model nitrogen. It is merely a very simplistic check on the potential uptake of nitrogen by primary production in the water column.

$$FLNUTP = \text{MAX}(0, (\text{PGNUT} - \text{RPHYT})) * 0.16$$

0.16 is the N to C conversion factor by weight (C/N = 6).

PGNUT is the gross production less excretory losses.

$$\text{PGNUT} = \text{PGPHYT}(I) * \text{RMINU} - \text{EXLOC}$$

#### 2.4.2.8 Net production

$$\text{PNPHYT}(I) = \text{PGPHYT}(I) - \text{RPHYT}$$

### 2.4.3 Pelagic Bacteria (PBAC)

The state variable PBAC includes both attached and free living bacteria. It is assumed that the dynamics of both are identical. The percentage of attached bacteria (PATBAC) is calculated as a function of PSILT concentration and is passed in the common block ENVBLK. This code is based largely on the research and input of Leon Cammen (Bigelow Laboratory, USA).

$$DPBAC(I) = DPBAC(I) + UPBAC - RPBAC - FPBAC - \\ \text{PREDATION +/- EXCHANGE}$$

UPBAC	food uptake from the three forms of non-living organic carbon (PLOC, PIOC and PROC)
RPBAC	respiration
FPBAC	excretion which is added to PLOC
PREDATION	consumption by PHER, PDET and BSUS
EXCHANGE	transport to and from compartments and boundaries.

#### 2.4.3.1 Food uptake (UPBAC)

The bacteria get their carbon from PLOC, PIOC and PROC. Uptake cannot exceed food availability but all food can be consumed. This is the only pelagic state variable whose uptake is not expressed with a Michaelis-Menton expression.

Rate determining factors:

- food availability (TFPBAC)
- temperature (WTEMPD)
- biomass (PBAC)

Parameters required:

- availability coefficients for PLOC (C28A21), PIOC (C27A21) and PROC (C31A21)
- specific growth rate at 10 C (C21SR)
- Q10

UPBAC is the total food uptake, being the minimum of the food available or the calculated maximum uptake.

$$UPBAC = \text{MIN}(TFPBAC, UMPBAC)$$

TFPBAC is the total food available to bacteria

$$TFPBAC = AVPLOC + AVPIOC + AVPROC$$

Three sources of food are available to the bacteria and different fractions of each are available due to differences in digestibility (i.e. perceived turnover times). These fractions are estimates.

AVPLOC is the available labile organic carbon.

$$AVPLOC = C28A21 * PLOC(I)$$

C28A21 is the fraction of PLOC available, presently = 0.9.

AVPIOC is the available intermediate organic carbon.

$$AVPIOC = C27A21 * PIOC(I)$$

C27A21 is the fraction of PIOC available, presently = 0.01.

AVPROC is the available refractory organic carbon.

$$AVPROC = C31A21 * PROC(I)$$

C31A21 is the fraction of PROC available, presently = 0.0003.

UMPBAC is the maximum allowable food uptake by bacteria.

$$UMPBAC = SRPBAC * PBAC(I)$$

SRPBAC is the temperature corrected specific growth rate.

$$SRPBAC = C21SR * 2. **((WTEMPD(I)-10.)/10.)$$

C21SR, presently equal to 1.0, is the specific growth rate at 10 C. It means that at 10 C the daily maximum growth is equal to the biomass.

The Q10 for bacterial uptake is 2.

The proportion of available food taken up must be known to calculate the differentials.

$$FRAC = UPBAC/TFPBAC$$

#### 2.4.3.2 Bacterial respiration (RPBAC)

This includes both activity and basal respiration.

Rate determining factors:

- food uptake (UPBAC)
- temperature (WTEMPD)
- biomass (PBAC)

Parameters required:

- Q10
- activity respiration coefficient (C21RA)
- basal respiration coefficient (C21RB)

$$RPBAC = RAPBAC + RBPBAC$$

RAPBAC is the activity respiration of bacteria which is assumed to be proportional to food intake.

$$RAPBAC = C21RA * UPBAC$$

C21RA is the activity respiration constant, presently = 0.4.

RBPBAC is the basal respiration which is determined by temperature and biomass.

$$RBPBAC = C21RB * PBAC(I) * 2. **((WTEMPD(I)-10.)/10.)$$

C21RB is the basal respiration coefficient at 10 C, presently = 0.001.

The Q10 for respiration is 2.

#### 2.4.3.3 Bacterial excretion (FPBAC)

A fraction, C21F, of the food uptake is excreted and returned to the pool of PLOC.

Rate determining factors:

- food uptake (UPBAC)

Parameters required:

- excretion coefficient (C21F).

FPBAC is the exudate production.

$$FPBAC = C21F * UPBAC$$

C21F is the excretion coefficient for PBAC, presently = 0.2.

#### 2.4.3.4 Predation

Attached bacteria are grazed by herbivores, detritivores and benthic suspension feeders. The fraction of attached bacteria (PATBAC) is calculated from the concentration of PSILT using the following empirical relationship based upon the data of Cammen and Walker(1982).

PATBAC is the fraction of bacteria which is attached to suspended particulate material.

$$\text{PATBAC}(I) = \text{MAX}(0, (90.9 * \text{LOG10}(\text{PSILT}(I)) - 109.) / 100.)$$

$$\text{PATBAC}(I) = \text{MIN}(1, \text{PATBAC}(I))$$

#### 2.4.3.5 Exchange

Bacteria are exchanged between compartments and boundaries with a transport susceptibility equal to 1. The concentrations of PBAC at the boundaries are determined from a time series.

$$\text{XPBAC}(I) = \text{SLP}(\text{DAY}, \text{DATES}, \text{XPBAC}, 12)$$

SLP is a slip function which extrapolates between points in a time series.

DAY is the time in the simulation.

DATES is the time for the data points in the time series.

XPBAC is the time series of mean monthly concentrations of PBAC at each of the boundaries (Cammen and Walker, 1982, plus unpublished data).

TABLE 2-20. DATA PBACX - Monthly mean concentrations (mgC m<sup>-3</sup>) for each of the model boundaries.

Bound.	J	F	M	A	M	J	J	A	S	O	N	D
4	5.	5.	5.	6.	5.	5.	5.	5.	5.	5.	4.	5.
5	40.	40.	40.	40.	40.	50.	70.	100.	100.	50.	40.	40.
6	10.	10.	10.	10.	11.	12.	13.	14.	10.	11.	10.	10.

#### 2.4.3.6 Net production

$$\text{PNPBAC}(I) = \text{UPBAC} - \text{RPBAC}$$

Note that excretion of carbon is included in production since consumed carbon was taken into the cell and probably altered biochemically before release.

#### 2.4.4 Pelagic herbivorous zooplankton (PHER)

The zooplankton are modelled as if they all behave like the estuarine herbivore *Acartia*. They are assumed to be omnivorous and have the same potential food sources as detritivores but they feed primarily on phytoplankton.

$$\text{DPHER(I)} = \text{DPHER(I)} + \text{ASPHER} - \text{RBPHER} - \text{RAPHER} - \text{PREDATION} \pm \text{EXCHANGE}$$

ASPHER	assimilated food (PHYT, PBAC, PIOC, PHER)
RBPHER	basal respiration
RAPHER	activity respiration
PREDATION	consumption by higher animals and cannibalism
EXCHANGE	transport to and from compartments and boundaries

##### 2.4.4.1 Food uptake (UPHER)

Herbivores feed on PHYT, PBAC, PIOC and PHER. Food uptake is calculated using a Michaelis-Menten expression which includes a feeding threshold. An upper limit is also placed on feeding (saturation level).

Rate determining factors:

- temperature (WTEMPD)
- food availability (TFPHER)
- biomass (PHER)

Parameters required:

- specific growth rate at 0 C (C25SR)
- Q10
- feeding threshold (C25T)
- food concentration at half the maximum feeding rate (C25S)
- feeding saturation level
- availability coefficients for PHYT, PBAC, PHER and PIOC (C26A25, C21A25, C25A25, and C27A25)

$$\text{UPHER} = \text{UMPHER} * ((\text{AVMHER} - \text{C25T}) / (\text{C25S} + \text{AVMHER})) * \text{PHER(I)}$$

UMPHER is a temperature corrected maximum uptake rate.

$$\text{UMPHER} = \text{C25SR} * \text{EXP}(0.0693 * \text{MAX}(0, \text{WTEMPD(I)}))$$

C25SR is the maximum specific uptake rate at 0C, presently = 0.45.

0.0693 is the temperature coefficient for a Q10 of 2.

WTEMPD(I) is the daily water temperature.

Note that when the temperature drops below zero, the rate remains equal to that at zero.

C25T is the feeding threshold, presently = 40.

C25S is the food concentration at half the maximum feeding rate, presently = 600.

AVMHER is the maximum amount of food available.

$$\text{AVMHER} = \text{MIN}(\text{TFPHER}, 1000.)$$

The feeding saturation level is 1000. Copepods cannot graze more than this even if more food is available.

TFPHER is the total biomass of all food types available to herbivores.

$$\text{TFPHER} = \text{AVPHER} + \text{AVPBAC} + \text{AVPIOC} + \text{AVPHYT}$$

AVPHER is the biomass of herbivores available as food.

$$\text{AVPHER} = \text{C25A25} * \text{PHER(I)}$$

C25A25 is the fraction of herbivores available for cannibalism, presently = 0.1.

AVPBAC is the biomass of pelagic bacteria available. Since only the attached bacteria can be grazed, PBAC must be multiplied by PATBAC which is the fraction of attached bacteria.

$$\text{AVPBAC} = \text{C21A25} * \text{PBAC(I)} * \text{PATBAC(I)}$$

C21A25 is the fraction of PBAC available, presently = 0.25.

PATBAC - see PBAC documentation.

AVPIOC is the biomass of PIOC available to herbivores.

$$\text{AVPIOC} = \text{C27A25} * \text{PIOC(I)}$$

C27A25 is the fraction of PIOC available, presently = 1.0.

AVPHYT is the biomass of phytoplankton available.

$$\text{AVPHYT} = \text{C26A25} * \text{PHYT(I)}$$

C26A25 is the fraction of PHER available to herbivores,  
presently = 1.0

In order to prevent negative food uptake the following equation  
is inserted:

$$\text{UPHER} = \text{MAX}(\text{UPHER}, 0.)$$

and to prevent overgrazing,

$$\text{UPHER} = \text{MIN}(\text{UPHER}, \text{AVMHER})$$

This form of expression occurs quite frequently in the model and  
strictly speaking is incorrect since UPHER and AVMHER do not  
have the same dimensions. AVMHER must be multiplied by  
1./day or

$$\text{UPHER} = \text{MIN} (\text{UPHER}, \text{AVMHER} * 1.)$$

The uptake is also reduced to prevent double filtering when the food  
concentration is low.

$$\text{UPHER} = \text{UPHER} * \text{VOLCL}$$

VOLCL is the fractional volume that will be filtered per day.

$$\text{VOLCL} = 1. - \text{EXP}(-\text{PVOLF})$$

PVOLF is the inverse of the volume which must be filtered to  
obtain the acquired food.

$$\text{PVOLF} = \text{AVMHER} / \text{UPHER}$$

The proportion of available food taken up per day must be known  
to calculate the differentials.

$$\text{FRAC} = \text{UPHER} / \text{AVMHER}$$

#### 2.4.4.2 Sloppy feeding (GPHER)

Copepods are not particularly well-mannered eaters and spill some of  
the grazed food which is added to the pool of labile organic carbon.

Rate determining factors:

- food uptake (UPHER)

Parameters required:

- sloppy feeding coefficient (C25G)

$$\text{GPHER} = \text{C25G} * \text{FRAC} * \text{AVPHYT}$$

C25G is the fraction of phytoplankton uptake lost by sloppy feeding, presently = 0.2.

#### 2.4.4.3 Fecal pellet production (FPHER)

Some of the ingested food is not assimilated but is passed out as fecal pellets and added to the pools of labile and intermediate organic carbon.

Rate determining factors:

- food uptake (UPHER)
- sloppy feeding (GPHER)

Parameters required:

- assimilation coefficients for PHYT, PBAC, PIOC and PHER

$$\text{FPHER} = \text{EFPHER} - \text{ASPHER}$$

EFPHER is the food ingested.

$$\text{EFPHER} = \text{UPHER} - \text{GPHER}$$

UPHER and GPHER are defined above.

ASPHER is the biomass of ingested food actually assimilated.

$$\text{ASPHER} = \text{FRAC} * \text{ASPHER}$$

$$\text{ASPHER} = (0.80 * \text{EFPHYT}) + (0.9 * \text{AVPBAC}) + (0.01 * \text{AVPIOC}) + (0.90 * \text{AVPHER})$$

The estimated assimilation coefficients are ;

0.80 for PHYT.

0.90 for PBAC.

0.01 for PIOC

0.90 for PHER.

EFPHYT is the biomass of phytoplankton ingested

$$\text{EFPHYT} = \text{AVPHYT} - \text{GPHER}$$

AVPHYT and GPHER are defined above.

#### 2.4.4.4 Respiration (RBPHER and RBPHER)

Respiration has two components: basal (RBPHER) which is a function of temperature and biomass, and activity which is a function of food uptake (UPHER).

Rate determining factors:

- food uptake (UPHER)
- biomass (PHER)
- assimilated food (ASPHER)
- temperature (WTEMPD)

Parameters required:

- basal respiration coefficient (C25RB), presently = 0.01.
- activity respiration coefficient (C25RA), presently = 0.45.

$$\text{RBPHER} = \text{PHER(I)} * \text{C25RB} * \text{EXP}(0.0693 * \text{MAX}(\text{WTEMPD(I)}, 0.))$$

$$\text{RAPER} = \text{C25RA} * \text{ASPHER}$$

#### 2.4.4.5 Predation

Copepods are preyed upon by themselves (cannibalism), PDET, PCAR, PFLR, PRFH and PMFH. The equations for cannibalism are given above under UPHER. See documentation on other state variables for uptake equations.

#### 2.4.4.6 Exchange

Mixing with other compartments is calculated in PHYS. The susceptibility constant is set to 0.1 (very limited motility). PHER concentration in Boundary 4 is constant at 150mg C m<sup>-3</sup>; Boundary 5 is 0. and Boundary 6 is equated to Compartment 2.

#### 2.4.4.7 Net production

$$\text{PNPHER(I)} = (\text{ASPHER} - \text{RBPHER} - \text{RAPER})$$

$$\text{PBPHER} = \text{PNPHER(I)}/\text{PHER(I)}$$

Note that fecal matter is not included in production because it was never assimilated.

#### 2.4.5 Detritivores (PDET)

Detritivores represent large omnivorous crustaceans which are assumed to have similar food sources as the herbivores but different availabilities. They are better able to utilize detritus (PIOC).

$$\text{DPDET(I)} = \text{DPDET(I)} + \text{UPDET} - \text{FPDET} - \text{RAPDET} - \text{RBPDET} - \text{ZPDET} - \text{PREDATION} \pm \text{EXCHANGE}$$

UPDET	food uptake from PIOC, PHYT, PBAC, PHER, PDET and PCAR
FPDET	fecal pellet production added to PLOC(25%) and PIOC(75%)
RAPDET	activity respiration
RBPDET	basal respiration
ZPDET	mortality added to PLOC
PREDATION	consumption by other organisms and cannibalism
EXCHANGE	transport to and from compartments and boundaries

##### 2.4.5.1 Food uptake (UPDET)

Originally the detritivores were assumed to feed only on PIOC but problems were encountered. The functioning of the model improved considerably when phytoplankton were added to their food supply. The code was later expanded to add PBAC, PHER, PDET and PCAR. The original empirical equation derived from Prouse's data also gave some problems and detritivore biomass always exploded. Therefore, a Michaelis-Menten equation was introduced and seems to work very well. It includes a feeding threshold.

Rate determining factors:

- biomass (PDET)
- food availability (TFPDET)
- temperature (WTEMPD)

Parameters required:

- specific growth rate at 0 C (C23SR)
- Q10
- feeding threshold (C23T)
- food concentration at half the maximum feeding rate (C23S)
- availability coefficients for PIOC, PHYT, PBAC, PHER, PCAR and PDET. (C27A23, C26A23, C21A23, C25A23, C22A23 and C23A23)

UPDET is the uptake corrected for food availability.

$$UPDET = UMPDET * (TFPDET - C23T)/(C23S + TFPDET) * PDET(I)$$

UMPDET is the temperature corrected maximum uptake rate (fraction of biomass/day)

$$UMPDET = C23SR * EXP(0.069 * WTEMPD(I))$$

C23SR is the maximum specific uptake rate at 0C, presently = 0.10.

0.069 is the temperature coefficient for a Q10 of 2.

TFPDET is the total food available to detritivores.

$$TFPDET = AVPHYT + AVPIOC + AVPBAC + AVPHER + AVPCAR + AVPDET$$

AVPHYT is the biomass of PHYT available

$$AVPHYT = C26A23 * PHYT(I)$$

C26A23 is the PHYT fraction available, presently = 0.1.

AVPIOC is the biomass of PIOC available.

$$AVPIOC = C27A23 * PIOC(I)$$

C27A23 is the fraction PIOC available, presently = 0.1.

AVPBAC is the biomass of PBAC available.

$$AVPBAC = C21A23 * PBAC(I) * PATBAC(I)$$

C21A23 is the fraction available, presently = 0.03.

PATBAC -see PBAC documentation.

AVPHER is available biomass of PHER.

$$AVPHER = C25A23 * PHER(I)$$

C25A23 is the fraction PHER available, presently = 0.1.

AVPCAR is available biomass of PCAR.

$$\text{AVPCAR} = \text{C22A23} * \text{PCAR(I)}$$

C22A23 is the fraction of PCAR available, presently = 0.05.

AVPDET is available biomass of PDET.

$$\text{AVPDET} = \text{C23A23} * \text{PDET(I)/(PDET(I) + 100.)}$$

C23A23 is the fraction of PDET available, presently = 0.1.

C23T is the feeding threshold, presently = 9.

C23S is the food concentration at half the maximum feeding rate, presently = 60.

In order to prevent negative food uptake,

$$\text{UPDET} = \text{MIN} (\text{UPDET}, \text{TFPDET})$$

The uptake is also reduced to prevent double filtering when the food concentration is low.

$$\text{UPDET} = \text{UPDET} * \text{VOLCL}$$

VOLCL is the fractional volume that can be filtered.

$$\text{VOLCL} = 1. - \text{EXP} (-\text{PVOLF})$$

PVOLF is the inverse of the volume which must be filtered to obtain the acquired food.

$$\text{PVOLF} = \text{TFPDET/UPDET}$$

The proportion of available food taken up must be known to calculate the differentials.

$$\text{FRAC} = \text{UPDET/TFPDET}$$

#### 2.4.5.2 Fecal pellet formation (FPDET)

Some of the ingested food is not assimilated but is passed out as fecal pellets and added to PLOC and PIOC. This calculation is much simpler than that for the herbivores which includes assimilation coefficients.

Rate determining factors:

- food uptake (UPDET)

Parameters required:

- fecal coefficient (C23F)

$$FPDET = C23F * UPDET$$

C23F is the fraction of uptake that goes to fecal production, presently = 0.3.

#### 2.4.5.3 Respiration (RBPDET and RAPDET)

Rate determining factors:

- food uptake (UPDET)
- biomass (PDET)
- temperature (WTEMPD)

Parameters required:

- activity respiration coefficient (C23RA), presently = 0.3.
- basal respiration coefficient (C23RB), presently = 0.1.

$$RAPDET = C23RA * UPDET$$

$$RBPDET = C23RB * PDET(I) * EXP(0.0693 * (MAX(0, WTEMPD(I))))$$

#### 2.4.5.4 Mortality (ZPDET)

Mortality is a function of biomass.

Rate determining factors:

- biomass (PDET)
- temperature (WTEMPD)

Parameters required:

- mortality coefficient (C23Z), presently = 0.01.

$$\text{ZPDET} = \text{C23Z} * \text{PDET(I)} * \text{EXP}(0.0693 * (\text{MAX}(0, \text{WTEMPD(I)})))$$

#### 2.4.5.5 Predation

Detritivores are preyed upon by PDET, PCAR, PRFH and PMFH. The latter are only present from June through September.

#### 2.4.5.6 Exchange

Mixing with other compartments is calculated in PHYS. The susceptibility constant is set at 0.1 (strong swimming ability). Concentrations of PDET at Boundary 4 are only 10% of the concentrations in Compartment 3. There are no PDET in the freshwater input (Boundary 5) and the concentration in Boundary 6 is equated to that in Compartment 2.

#### 2.4.5.7 Net production

$$\text{PNPDET(I)} = \text{UPDET} - \text{FPDET} - \text{RAPDET} - \text{RBPDET}$$

#### 2.4.6 Carnivores (PCAR)

These are the planktonic carnivores which include the ctenophores, arrow worms and jelly fish. A pulse is advected into the model from Boundary 4 (the seaward end) during the summer by the physical submodel.

$$DPCAR(I) = DPCAR(I) + UPCAR - FPCAR - RPCAR - ZPCAR - PREDATION +/- EXCHANGE$$

UPCAR	total food uptake from PHER, PDET and PCAR
FPCAR	fecal production which is added to PLOC(25%) and PIOC(75%)
RPCAR	respiration
ZPCAR	mortality which is added to PLOC
PREDATION	predation including cannibalism.
EXCHANGE	transport to and from compartments and boundaries.

##### 2.4.6.1 Import

New carnivores are advected into the model from the seaward end between Days 165 and 195 by adding PCAR biomass in Boundary 4.

$$XPCAR(4) = SLP (DAY, DATES, PCAR4, 12)$$

SLP is a slip function which interpolates between data points in a time series.

DAY is the time in the simulation.

DATES is the set of dates for the time series.

PCAR4 is a time series of PCAR concentrations for boundary 4.

TABLE 2-21. DATA PCAR4 - Monthly mean concentrations (mgC m<sup>-3</sup>) for PCAR at model boundary 4.

Bound.	J	F	M	A	M	J	J	A	S	O	N	D
4	0.	0.	0.	2.	3.	5.	10.	15.	10.	5.	2.	0.

##### 2.4.6.2 Total food uptake (UPCAR)

The carnivores graze on PHER, PDET and some of their own biomass (PCAR). The food uptake is calculated using a Michaelis-Menten expression. Uptake cannot exceed the food availability.

Rate determining factors:

- biomass (PCAR)
- temperature (WTEMPD)
- food availability (TFPCAR)

Parameters required:

- specific growth rate at 0 C (C22SR)
- Q10
- food threshold (C22T)
- food concentration at half maximum uptake rate (C22S)

UPCAR is total uptake corrected for food availability.

$$\text{UPCAR} = \text{UMPCAR} * (\text{TFPCAR} - \text{C22T}) / (\text{C22S} + \text{TFPCAR}) * \text{PCAR(I)}$$

and to insure uptake does not exceed food available.

$$\text{UPCAR} = \text{MIN}(\text{UPCAR}, \text{TFPCAR})$$

UMPCAR is the temperature corrected maximum uptake rate.

$$\text{UMPCAR} = \text{C22SR} * \text{EXP}(0.069 * \text{WTEMPD(I)})$$

C22SR, presently = 0.1, is the maximum specific uptake rate at 0 C.

0.069 is the temperature coefficient for a Q10 of 2.

TFPCAR is the total available food.

$$\text{TFPCAR} = \text{AVPHER} + \text{AVPDET} + \text{AVPCAR}$$

AVPHER is the biomass of available PHER.

$$\text{AVPHER} = \text{C25A22} * \text{PHER(I)}$$

C25A22 is the fraction of PHER available to PCAR as food, presently = 0.2.

AVPDET is the biomass of available of PDET.

$$\text{AVPDET} = \text{C23A22} * \text{PDET(I)}$$

C23A22 is the fraction of PDET available, presently = 0.1.

AVPCAR is the biomass of available of PCAR.

$$\text{AVPCAR} = 0.05 * \text{PCAR}(I)$$

0.05 is the fraction of PCAR available as food.

C22T is the food threshold constant, presently =0.0.

C22S is the half saturation constant, presently =1.0.

The proportion of available food taken up must be known to calculate the differentials.

$$\text{FRAC} = \text{UPCAR}/\text{TFPCAR}$$

#### 2.4.6.3 Fecal production (FPCAR)

A fraction of the uptake goes into feces.

Rate determining factors:

- food uptake (UPCAR)

Parameters required:

- fecal production coefficient (C22F)

$$\text{FPCAR} = \text{C22F} * \text{UPCAR}$$

C22F is the fraction of uptake that goes to fecal production, presently = 0.3.

#### 2.4.6.4 Respiration (RPCAR)

Presently only activity respiration is calculated.

Rate determining factors:

- food uptake (UPCAR)
- water temperature (WTEMPD)
- biomass (PCAR)

Parameters required:

- activity respiration coefficient

$$RPCAR = C22RA * UPCAR$$

C22RA is the activity respiration constant = 0.30

#### 2.4.6.5 Mortality of the carnivores (ZPCAR)

The mortality of carnivores is a function of temperature and biomass.

Rate determining factors:

- biomass (PCAR)
- temperature (WTEMPD)

Parameters required:

- mortality coefficient (C22Z)

$$ZPCAR = C22Z * EXP(0.069 * WTEMPD(I)) * PCAR(I)$$

C22Z is the mortality coefficient, presently = 0.01.

#### 2.4.6.6 Predation

Both groups of fish, PDET and PCAR feed on the carnivores.

#### 2.4.6.7 Exchange

Susceptibility constant is set at 0.5 (some swimming ability). Transport from Boundary 4 plays a major role in PCAR dynamics. There are no PCAR in Boundary 5 and the concentration of PCAR in Boundary 6 is equated to that in Compartment 2.

#### 2.4.6.8 Net production

$$PNPCAR(I) = UPCAR - FPCAR - RPCAR$$

#### 2.4.7 Pelagic fish larvae (PFLR)

The state variable PFLR represents larvae of pelagic resident fish such as tomcod and smelt. They are not present during January, February or December, but are released in late winter and spring and mature into resident fish in the fall.

$$DPFLR(I) = DPFLR(I) + UPFLR + YPRFH - FPFLR - RPFLR - ZPFLR - WPFLR - PREDATION +/- EXCHANGE$$

UPFLR	uptake of food from feeding on PHER
YPRFH	spawning of resident fish
FPFLR	fecal pellet production added to PLOC (25%) and PIOC (75%)
RPFLR	respiration
ZPFLR	mortality once growth starts, added to PLOC
WPFLR	maturation of larvae
PREDATION	predation by PRFH and PMFH
EXCHANGE	transport to and from compartments and boundaries

##### 2.4.7.1 Spawning resident fish (YPRFH)

Spawning occurs between Day 91 and 180 when 1% of the resident fish biomass (PRFH) is released per day as larvae. There is an immediate 80% mortality which is added to the PLOC pool. These estimates were made by Heath Stone on 7 January 1985.

Rate determining factors:

- biomass of resident fish (PRFH)

Parameters required:

- fraction of PRFH spawned (C30Y)

$$YPRFH = C30Y * PRFH(I)$$

C30Y is the fraction of PRFH that spawn, presently = 0.01.

#### 2.4.7.2 Food uptake (UPFLR)

At the present time the larvae feed only on PHER. Feeding is expressed using a Michaelis-Menten expression. Uptake can not exceed food availability.

Rate determining factors:

- biomass (PFLR)
- temperature (WTEMPD)
- food availability (TFPFLR)

Parameters required:

- specific growth rates at 0 C (C24SR)
- Q10
- food threshold (C24T)
- food concentration at half maximum uptake rate (C24S)

UPFLR is the calculated food uptake

$$UPFLR = UMPFLR * (TFPFLR - C24T)/(C24S + TFPFLR) * PFLR(I)$$

and to insure food uptake does not exceed food supply

$$UPFLR = MIN(UPFLR, TFPFLR)$$

UMPFLR is the temperature corrected maximum uptake rate.

$$UMPFLR = C24SR * EXP(0.069 * WTEMPD(I))$$

C24SR, presently = 0.1, is the maximum specific uptake rate at 0 C.

0.069 is the temperature coefficient for a Q10 of 2.

TFPFLR is the total food available.

$$TFPFLR = AVPHER$$

AVPHER is the biomass of PHER available.

$$AVPHER = C25A24 * PHER(I)$$

C25A24 is the fraction available, presently = 0.25.

C24S is an estimate of the food concentration at half saturation, presently = 1.0.

C24T is the food threshold at which feeding commences, presently set to 0.0.

The proportion of available food taken up must be known to calculate the differentials.

$$\text{FRAC} = \text{UPFLR}/\text{TFPFLR}$$

#### 2.4.7.3 Fecal pellet production (FPFLR)

Fecal pellet production is expressed as a fraction of the uptake and is added to the PLOC and PIOC.

Rate determining factors:

- food uptake (UPFLR)

Parameters required:

- fecal production coefficient (C24F), currently = 0.25.

$$\text{FPFLR} = \text{C24F} * \text{UPFLR}$$

C24F is the fraction of uptake that goes to fecal production.

#### 2.4.7.4 Respiration (RPFLR)

Activity respiration is expressed as a fraction of food uptake. At present basal respiration is not calculated.

Rate determining factors:

- food uptake (UPFLR)

Parameters required:

- activity respiration coefficient (C24RA), currently = 0.5.

$$\text{RPFLR} = \text{C24RA} * \text{UPFLR}$$

#### 2.4.7.5 Mortality (ZPFLR)

A mortality of 80% is assumed immediately after spawning and is covered above under spawning. Thereafter a constant natural mortality of 10% per day is assumed (ie. from Day 91 to Day 330).

Rate determining factors:

- biomass of larvae (PFLR)

Parameters required:

- mortality coefficient for larvae (C24Z)

$$\text{ZPFLR} = \text{C24Z} * \text{PFLR(I)}$$

#### 2.4.7.6 Maturation of larvae (WPFLR)

Larvae mature into PRFH during the month of November (Days 300 to 330) at 5% of the biomass per day. Any larvae remaining on Day 330 are also converted to PRFH.

Rate determining factors:

- biomass (PFLR)

Parameters required:

- rate of maturation (C24W), presently = 0.05.

$$\text{WPFLR} = \text{C24W} * \text{PFLR(I)}$$

C24W is the fraction of PFLR to PRFH per day, presently = 0.05.

#### 2.4.7.7 Predation

Pelagic larvae are preyed upon by PMFH and PRFH. See other documentation for uptake equations.

#### 2.4.7.8 Exchange

Mixing with other compartments is calculated in PHYS. The susceptibility constant is set at 0.7 (weak swimmers). The values for the boundaries are equated to the values in the adjacent compartments.

#### 2.4.7.9 Net production

$$\text{PNPFLR(I)} = \text{UPFLR} - \text{FPFLR} - \text{RPFLR}$$

#### 2.4.8 Pelagic resident fish (PRFH)

This state variable includes those fish that spend their entire life cycle within the model boundaries. Typical species include tomcod, silver-sides and smelt.

$$\text{DPRFH(I)} = \text{DPRFH(I)} + \text{WPFLR} + \text{UPRFH} - \text{FPRFH} - \text{RPRFH} - \text{ZPRFH} - \text{PREDATION}$$

WPRFH	recruitment from PFLR
UPRFH	food uptake from feeding on PDET, PFLR, PHER, PCAR, BMEI, BMES, BDFI, BDFS, BSUS and PRFH
FPRFH	fecal matter production which is contributed to PLOC(25%) and PIOC(75%)
RPRFH	respiration
ZPRFH	mortality added to PLOC
PREDATION	consumption by PMFH and cannibalism

##### 2.4.8.1 Recruitment (WPFLR)

Maturation of larvae into resident pelagic fish which is assumed to occur between Days 300 and 330. See PFLR documentation.

##### 2.4.8.2 Food uptake (UPRFH)

The resident fish presently feed on PDET, PFLR, PHER, PCAR, BDFI, BDFS, BMEI, BMES, BSUS and PRFH. Food uptake is calculated using a Michaelis-Menten expression. Uptake can not exceed food availability.

Rate determining factors:

- biomass (PRFH)
- temperature (WTEMPD)
- food availability (TFPRFH)

Parameters required:

- specific growth rate at 0 C (C30SR)
- Q10
- availability coefficients for BDFI (C03A30), BDFS (C04A30), BMEI (C10A30), BMES (C11A30), BSUS (C15A30), PCAR (C22A30), PDET (C23A30), PFLR (C24A30), PHER (C25A30), and PRFH (C30A30)
- food threshold (C30T)
- food concentration at half maximum uptake rate (C30S)

UPRFH is the uptake corrected for food availability.

$$\text{UPRFH} = \text{UMPRFH} * (\text{TFPRFH} - \text{C30T}) / (\text{C30S} + \text{TFPRFH}) * \text{PRFH(I)}$$

To prevent overgrazing:

$$\text{UPRFH} = \text{MIN}(\text{UPRFH}, \text{TFPRFH})$$

UMPRFH is the temperature corrected maximum uptake rate.

$$\text{UMPRFH} = \text{C30SR} * \text{EXP}(0.069 * \text{WTEMPD(I)})$$

C30SR is the maximum specific uptake rate at 0 C, presently = 0.015.

0.069 is the temperature coefficient for a Q10 of 2.

TFPRFH is the total food available for resident fish from nine sources.

$$\text{TFPRFH} = \text{AVPDET} + \text{AVPHER} + \text{AVPFLR} + \text{AVPCAR} + \text{AVBDFI} + \text{AVBDFS} + \text{AVBMEI} + \text{AVBMES} + \text{AVBSUS} + \text{AVPRFH}$$

AVPDET is the biomass of detritivores available.

$$\text{AVPDET} = \text{C23A30} * \text{PDET(I)}$$

C23A30 is the fraction of PDET available as food, presently = 0.8.

AVPHER is the biomass of herbivores available.

$$\text{AVPHER} = \text{C25A30} * \text{PHER(I)}$$

C25A30 is the fraction of herbivores available, presently = 0.1.

AVPFLR is the biomass of larvae available.

$$\text{AVPFLR} = \text{C24A30} * \text{PFLR(I)}$$

C24A30 is the fraction of larvae available, presently = 0.1.

AVPCAR is the biomass of carnivores available.

$$\text{AVPCAR} = \text{C22A30} * \text{PCAR(I)}$$

C22A30 is the fraction of PCAR available as food,  
presently = 0.1.

AVPRFH is the biomass of resident fish which are prey for  
other PRFH.

$$\text{AVPRFH} = 0.05 * \text{PRFH(I)}$$

0.05 is the fraction of PRFH available as food.

AVBDFS is the available biomass of subtidal deposit feeders.

$$\text{AVBDFS} = \text{C04A30} * \text{BDFS(I)}$$

C04A30 is the fraction of BDFS available as food,  
presently = 0.07.

AVBMES is the biomass of subtidal meiofauna available.

$$\text{AVBMES} = \text{C11A30} * \text{BMES(I)}$$

C11A30 is the fraction of BMES available as food,  
presently = 0.01.

AVBSUS is the biomass of available subtidal suspension  
feeders.

$$\text{AVBSUS} = \text{C15A30} * \text{BSUS(I)}$$

C15A30 is the fraction of BSUS available as food,  
presently = 0.001.

From the intertidal benthos, only one-half of the biomass  
is available since this area is submerged for only one-  
half of the day.

AVBDFI is the biomass of available intertidal deposit  
feeders.

$$\text{AVBDFI} = \text{C03A30} * \text{BDFI(I)} * 0.5$$

C03A30 is the fraction of BDFI available as food,  
presently = 0.07.

AVBMEI is the available biomass of intertidal meiofauna.

$$\text{AVBMEI} = \text{C10A30} * \text{BMEI(I)} * 0.5$$

C10A30 is the fraction of BMEI available as food,  
presently = 0.01.

C30T is the food threshold at which feeding begins, the value is  
presently 0.0.

C30S is an estimate of food concentration at half the maximum  
feeding rate, presently = 1.

The proportion of available food taken up must be known to calcu-  
late the differentials

$$\text{FRAC} = \text{UPRFH}/\text{TFPRFH}$$

#### 2.4.8.3 Fecal production (FPRFH)

Fecal production is expressed as a fraction of the total food uptake  
and is added to PLOC and PIOC.

Rate determining factors:

- food uptake (UPRFH)

Parameters required:

- fecal production coefficient (C30F), presently = 0.3.

$$\text{FPRFH} = \text{C30F} * \text{UPRFH}$$

C30F is the fraction of uptake that goes to fecal production.

#### 2.4.8.4 Respiration (RPRFH)

Activity respiration is expressed as a fraction of the total food  
uptake. At present basal respiration is not calculated.

Rate determining factors:

- food uptake (UPRFH)

Parameters required:

- activity respiration coefficient (C30RA), presently = 0.45.

$$\text{RPRFH} = \text{C30RA} * \text{UPRFH}$$

C30RA is the activity respiration coefficient.

#### 2.4.8.5 Mortality (ZPRFH)

Mortality is estimated by Mike Dadswell to be roughly 25% over a year or about 0.3% daily.

Rate determining factors:

- biomass (PRFH)

Parameters required:

- mortality coefficient (C30Z), presently = 0.003.

$$\text{ZPRFH} = \text{C30Z} * \text{PRFH(I)}$$

#### 2.4.8.6 Spawning (YPRFH)

Spawning starts on 1 March (Day 91) and lasts for 14 days. See PFLR documentation.

#### 2.4.8.7 Exchange

There is no mixing with other compartments since the susceptibility constant is set at 0 (strong swimmers).

#### 2.4.8.8 Net production

$$\text{PNPRFH(I)} = \text{UPRFH} - \text{FPRFH} - \text{RPRFH}$$

#### 2.4.9 Migratory fish (PMFH)

These are the alosid fish such as shad and gaspereau which start to arrive in the Cumberland Basin on 1 June. The residence time of individual fish is not known but is thought to be on the order of several weeks. Numbers decline rapidly in September and most have departed by 1 October. They do not overwinter in the Basin. The reproductive cycle occurs outside the boundaries of the model so only adult fish are included. Their major role in the model is to eat and run. There is no predation or reproduction.

$$DPMFH(I) = DPMFH(I) + UPMFH - FPMFH - RPMFH - PREDATION +/- MIGRATION$$

UPMFH	uptake of food from PDET, PFLR, PHER, PCAR, PRFH, PMFH, BDFI, BDFS, BMEI, BMES, and BSUS
FPMFH	production of fecal matter which is added to PLOC(25%) and PIOC(75%)
RPMFH	respiration
PREDATION	cannibalism
MIGRATION	immigration and emigration

##### 2.4.9.1 Food uptake (UPMFH)

Food uptake is calculated using a Michaelis-Menten expression. The food uptake can not exceed food availability.

Rate determining factors:

- temperature (WTEMPD)
- biomass (PMFH)
- food availability (TFPMFH)

Parameters required:

- specific growth rate at 0 C (C29SR)
- Q10
- availability coefficients for PCAR (C22A29), PDET (C23A29), PFLR (C24A29), PHER (C25A29), BDFI (C03A29), BDFS (C04A29), BSUS (C15A29), BMEI (C10A29), and BMES (C11A29)
- food threshold (C29T)
- food concentration at half the maximum uptake rate (C29S)

$$UPMFH = UMPMFH * (TFPMFH - C29T)/(C29S +TFPMFH) * PMFH(I)$$

To insure uptake does not exceed food availability;

$$UPMFH = \text{MIN}(UPMFH,TFPMFH)$$

UMPMFH is the temperature corrected maximum uptake rate.

$$UMPMFH = C29SR * \text{EXP}(0.069 * WTEMPD(I))$$

C29SR is the maximum specific uptake rate at 0 C, presently = 0.015.

0.069 is the temperature coefficient for a Q10 of 2.

TFPMFH is the total food available for consumption.

$$\begin{aligned} TFPMFH = & AVPCAR + AVPDET + AVPFLR + AVPHER + \\ & AVPRFH + AVPMFH + \\ & AVBDFI + AVBDFS + AVBSUS + AVBMEI + AVBMES \end{aligned}$$

AVPCAR is the carnivore biomass available.

$$AVPCAR = C22A29 * PCAR(I)$$

C22A29 is the fraction available as food for PMFH, presently = 0.1.

AVPDET is the biomass of PDET available.

$$AVPDET = C23A29 * PDET(I)$$

C23A29 is the fraction available which is presently equal to 0.8.

AVPFLR is the biomass of PFLR available.

$$AVPFLR = C24A29 * PFLR(I)$$

C24A29 is the fraction available which is presently equal to 0.1.

AVPHER is the biomass of PHER available.

$$\text{AVPHER} = \text{C25A29} * \text{PHER(I)}$$

C25A29 is the fraction available which is presently equal to 0.05.

AVPRFH is the resident fish biomass available.

$$\text{AVPRFH} = \text{C30A29} * \text{PRFH(I)}$$

C30A29 is the fraction of PRFH available as food, presently = 0.1.

AVPMFH is the migratory fish biomass available.

$$\text{AVPMFH} = \text{C29A29} * \text{PMFH(I)}$$

C29A29 is the fraction of PMFH available as food, presently = 0.05.

AVBDFI is the biomass of BDFI available.

$$\text{AVBDFI} = \text{C03A29} * \text{BDFI(I)} * 0.5$$

C03A29 is the fraction available which is presently equal to 0.5 which reflects the fraction of PMFH that are benthic feeders. Since the fish can only access the BDFI when the flats are covered with water the availability is multiplied by 0.5.

AVBDFS is the available biomass of the subtidal deposit feeders.

$$\text{AVBDFS} = \text{C04A29} * \text{BDFS(I)}$$

C04A29 is the fraction of BDFS available as food, presently = 0.70.

AVBSUS is the subtidal suspension feeder biomass available.

$$\text{AVBSUS} = \text{C15A29} * \text{BSUS(I)}$$

C15A29 is the fraction of BSUS available, presently = 0.001.

AVBMEI is the available biomass of intertidal meofauna.

$$\text{AVBMEI} = \text{C10A29} * \text{BMEI(I)} * 0.5$$

C10A29 is the fraction BMEI available presently = 0.01.  
Since the BMEI are only available when the mudflats are under water, the available biomass is multiplied by 0.5.

AVBMES is the subtidal meiofauna biomass available.

$$\text{AVBMES} = \text{C11A29} * \text{BMES(I)}$$

C11A29 is the fraction BMES available presently = 0.01.

C29T is the food threshold at which feeding begins and it is presently set to 0.0.

C29S is an estimate of the food concentration at half the maximum uptake rate and is presently set at 1.0.

The proportion of available food taken up must be known to calculate the differentials.

$$\text{FRAC} = \text{UPMFH}/\text{TFPMFH}$$

#### 2.4.9.2 Fecal production (FPMFH)

Fecal production is expressed as a fraction of the total food uptake and it is converted to PLOC and PIOC.

Rate determining factors:

- food uptake (UPMFH)

Parameters required:

- fecal production coefficient (C29F).

$$\text{FPMFH} = \text{C29F} * \text{UPMFH}$$

C29F is the fraction of uptake that goes to fecal production, presently = 0.3.

#### 2.4.9.3 Respiration (RPMFH)

Activity respiration is expressed as a fraction of the total food uptake. Basal respiration is included and is not calculated separately since the fish are present only if there is food.

Rate determining factors:

- food uptake (UPMFH)

Parameters required:

- respiration coefficient (C29RA).

$$\text{RPMFH} = \text{C29RA} * \text{UPMFH}$$

C29RA is the activity respiration coefficient, presently = 0.45.

#### 2.4.9.4 Immigration

Adult fish enter the basin from Boundary 4 starting during the month of June.

Parameters required:

- immigration rate (RMIGRN), presently = 2.

$$\text{DPMFH(I)} = \text{DPMFH(I)} + \text{RMIGRN}$$

#### 2.4.9.5 Emigration

Originally fish started leaving the Basin on Sept. 1 at a rate of 5% per day and any remaining fish were removed on Oct. 1. At the Texel 1985 workshop it was decided to key the departure of the fish on the available biomass of detritivores, their preferred food source (Dadswell, personal communication). Fish leave at a rate (C29E) which is modified by the abundance of detritivores relative to a threshold value (C23T29). Fish can now leave as soon as they arrive (Day 150) if there is no food available.

Rate determining factors:

- fish biomass (PMFH)
- detritivore biomass (PDET)

Parameters required:

- emigration rate (C29E).
- threshold biomass of detritivores (C23T29).

$$\text{FSHOUT} = \text{C29E} * \text{C23T29}/(\text{C23T29} + \text{PDET(I)}) * 2$$

$$\text{DPMFH(I)} = \text{DPMFH(I)} - (\text{PMFH(I)} * \text{FSHOUT})$$

29E is the rate at which PMFH leave when there is no food,  
presently = 0.05.

C23T29 is a threshold concentration of detrivores above  
which PMFH leave at a slower rate, presently = 1.0.

#### 2.4.9.6 Exchange

There is no mixing with other compartments since the susceptibility constant is set to 0 (very strong swimmers).

#### 2.4.9.7 Net production

$$\text{PNPMFH(I)} = \text{UPMFH} - \text{FPMFH} - \text{RPMFH}$$

## 2.5 Benthic Submodel

### 2.5.1 Introduction

The intertidal and subtidal benthic organisms are modelled quite differently than pelagic organisms. Net production is calculated using mean annual PB ratios which are adjusted for daily changes in temperature and food supply using Michaelis-Menten equations. Therefore production is fitted to field data and not calculated from food uptake. Total food uptake is determined subsequently in order to calculate differentials.

The benthic submodel is broken down into three subroutines as follows:

1. PRIMB which includes

- BDIA - intertidal microalgae
- BACI - intertidal bacteria
- BACS - subtidal bacteria
- Calls to SEDRES for pelagic-benthic exchanges of labile, intermediate and refractory organic carbon and bacteria

2. SECIB which includes

- BMEI - intertidal meiofauna
- BDFI - intertidal deposit feeders

3. SECSB which includes

- BMES - subtidal meiofauna
- BDFS - subtidal deposit feeders
- BSUS - subtidal suspension feeders

Biological coefficients are defined in BENDAT. Susceptibility coefficients and boundary conditions are defined at the start of the subroutines. Initial values are listed in SIMD. All carbon flows are illustrated in Figures 2-6 and 2-7.

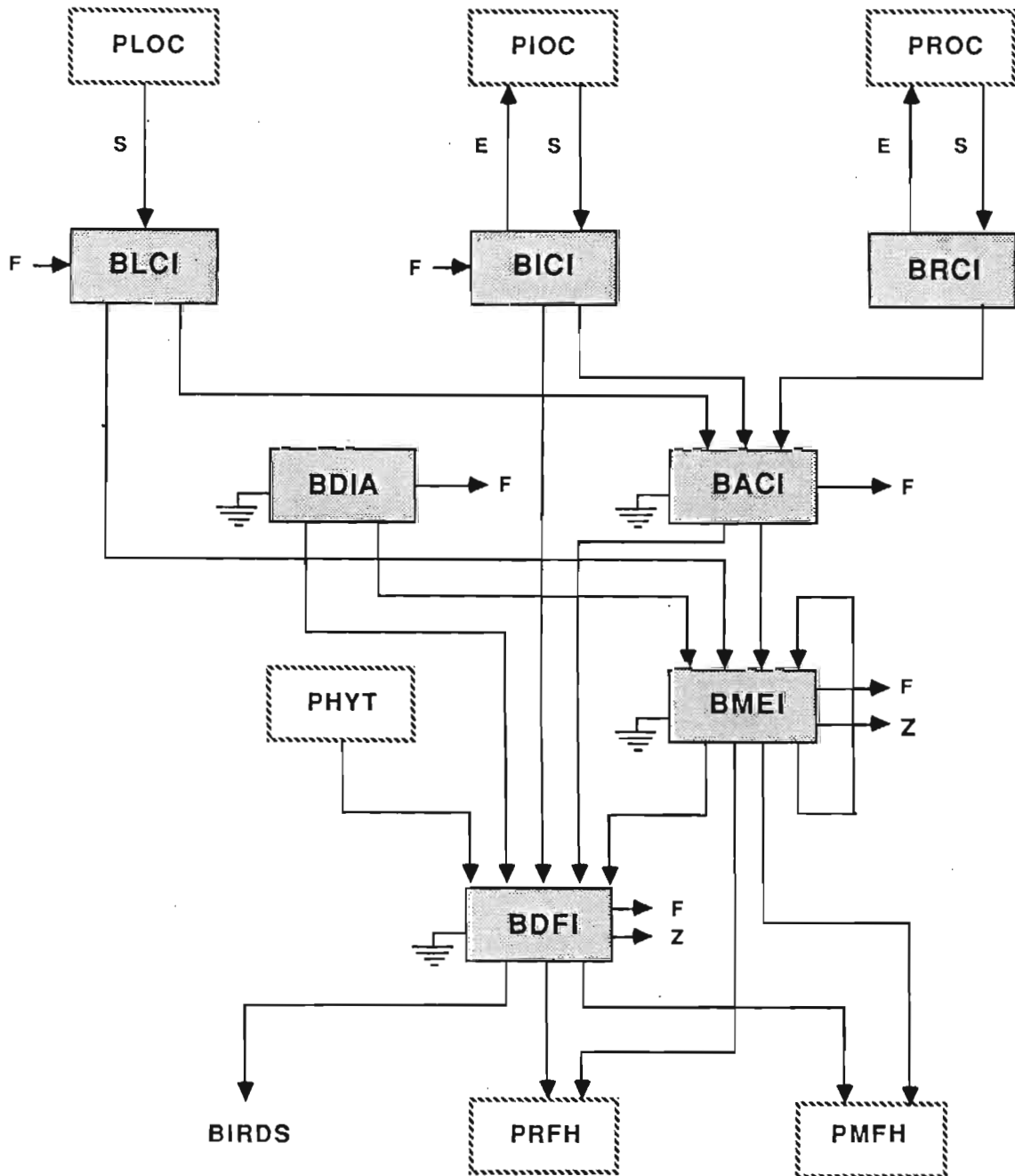


Figure 2-6. Carbon flows in the intertidal benthic sub-model. E-erosion, F-excretion, S-sedimentation, Z-mortality and  $\equiv$  -respiration.

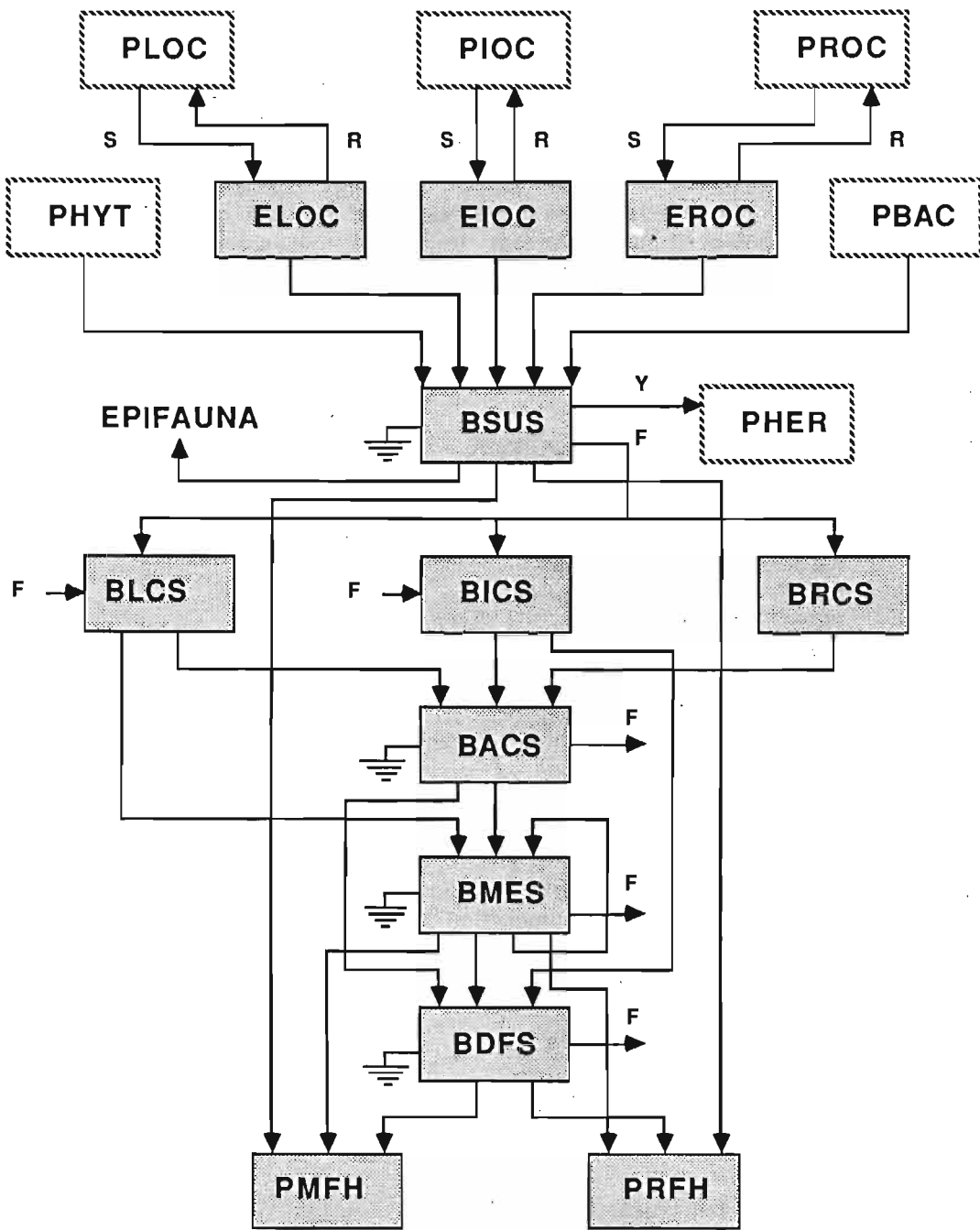


Figure 2-7. Carbon flows in the subtidal benthic sub-model. F-excretion, R-resuspension, S-sedimentation, Y-spawning, Z-mortality and  $\oplus$ -respiration.

## 2.5.2 Benthic microalgae (BDIA)

The state variable BDIA includes the benthic microalgae which reside in the surface layer of intertidal sediments. They are the only autotrophs in the benthic submodel. The role that resuspension and sedimentation play in the distribution of pelagic phytoplankton and benthic microalgae in the water column and surface sediments is not completely resolved (Schwinghammer, unpublished data). Some benthic microalgal species have been identified in water samples from the upper reaches of the Bay of Fundy (Prouse et al., 1984), however, the dominant benthic diatom species have not been found in these samples. Therefore resuspension and sedimentation of BDIA and PHYT are not included in the model. However PHYT is made available as food for benthic suspension (BSUS) and intertidal deposit (BDFI) feeders (Figures 2-6 and 2-7).

$$DBDIA(I) = DBDIA(I) + PGBDIA - RABDIA - FBDIA - PREDATION$$

PGBDIA	gross primary production
RABDIA	respiration
FBDIA	excretion added to BLCI
PREDATION	predation by BMEI and BDFI

### 2.5.2.1 Gross primary production (PGBDIA)

Gross primary production of benthic microalgae is calculated quite differently than the production of phytoplankton. It is based upon the daily average net production rate measured in Cumberland Basin and is independent of microalgal biomass. This mean net production rate is probably an underestimate because grazing took place during the incubation experiments which reduced algal biomass. In the model, grazing occurs on the biomass generated by the production equations.

Rate determining factors:

- exposure to light (FACLB)
- shelf shading (SHADE)

Parameters:

- Q10
- respiration coefficient (C05RA)
- mean daily net production (mg C m<sup>-2</sup>) (C05SR)
- light scaling factor (SFL)
- relative light amplitude (ALIGHT)
- hours of exposure of flats to light (EXFLLT)

$$PGBDIA(I) = PGDAY * SHADE * TEMP * FACLB$$

PGDAY is the normalized mean daily gross production rate (mg C/m<sup>2</sup>).

$$PGDAY = C05SR * EXFAC(I)$$

C05SR is the mean daily gross primary production rate (106 mg C/m<sup>2</sup>) which is obtained by dividing the annual mean daily gross primary production rate in Cumberland Basin of 38 g C/m<sup>2</sup> calculated by Prouse et al.(1984) by 360.

EXFAC, an exposure factor, takes into account the constancy of the average flat elevation in all compartments while the tidal range increases up the estuary. Therefore on every day of the year the flats in the upper compartments should have less production because their exposure time is slightly less. EXFAC is a constant for each compartment and is defined as the annual mean ratio of EXFLLT(I) to the average EXFLLT of all compartments. EXFLLT, which is calculated in the subroutine ENVIR, is the number of hours that the flats are exposed to light each day and varies from 1.56 to 9.88 hours. It takes into account both light and tidal cycles. The values for EXFAC are entered in ENVDAT.

TABLE 2-22. DATA EXFAC - Compartmental values for EXFAC

	1	2	3
EXFAC	0.96	1.00	1.04

SHADE is a correction for self-shading due to light absorption by chlorophyll and shading due to ice. When ice is present on the mudflats from Day 0 to Day 75, SHADE = 0 and there is no production.

IF (DAY .GE. 0 .AND. DAY .LE. 75.) THEN SHADE=0.

otherwise;

$$SHADE = (1 - \exp(-0.8E-3 * BDIA(I)))/(0.8E-3 * BDIA(I))$$

This formulation is a carry-over from the Ems-Dollard model and is dependent on algal biomass.

TEMP is a correction for temperature based on a Q10 of 2.05.

$$\text{TEMP} = 2.05^{((\text{STEMPD}(\text{I}) - 10.5)/10)}$$

10.5 is the mean annual temperature averaged over 12 months.

FACLB is a daily light correction factor which is the ratio of the total light reaching the flats on a given day to the annual average for each compartment.

$$\text{FACLB} = (\text{EXFLLT}(\text{I}) * \text{ALIGHT})/\text{SFL}(\text{I})$$

EXFLLT is the number of hours that the flats are exposed to light each day taking into account both light and tidal cycles.

ALIGHT is the relative light amplitude ranging from a low of 0.4 on December 21 to a high of 1.6 on June 21.

SFL is a light scaling factor which is defined as the annual mean of the product of EXFLLT and ALIGHT for each compartment. The value of the product ranges from 0.63 to 15.8.

TABLE 2-23. DATA SFL - Compartmental values for SFL.

	1	2	3
SFL	6.36	6.60	6.82

#### 2.5.2.2 Respiration (RABDIA)

Microalgal respiration is calculated as a fraction (C05RA) of the gross production. At present, there is no breakdown into activity and basal components.

Rate determining factors:

- gross production (PGBDIA)

Parameters required:

- respiration coefficient (C05RA), present value is 0.1.

$$\text{RABDIA}(\text{I}) = \text{C05RA} * \text{PGBDIA}(\text{I})$$

### 2.5.2.3 Excretion (FBDIA)

Dissolved organic carbon excreted by benthic microalgae is calculated as a fraction (C05F) of the gross production. It is added to BLCI.

Rate determining factors:

- gross production (PGBDIA)

Parameters:

- excretion coefficient (C05F), presently = 0.1

$$FBDIA(I) = C05F * PGBDIA(I)$$

### 2.5.2.4 Predation

Benthic microalgae are grazed by BMEI and BDFI.  
See other documentation.

### 2.5.2.5 Net production (PNBDIA)

$$PNBDIA(I) = PGBDIA(I) - RABDIA$$

### 2.5.3 Intertidal benthic bacteria (BACI)

The state variable BACI represents bacteria that live in the intertidal sediments.

$$DBACI(I) = DBACI(I) + PNBACI - RBBACI - PREDATION$$

PNBACI net production which includes losses by activity respiration (RABACI) and excretion (FBACI) which is split evenly between BLCI and BICI. BLCI, BICI and BRCI are carbon sources for BACI.  
RBBACI basal respiration  
PREDATION predation by BMEI and BDFI

#### 2.5.3.1 Net production (PNBACI)

Net production is calculated as a fraction (C01PN) of the food uptake.

Rate determining factors:

- temperature (STEMPD)
- biomass (BACI)

Parameters required:

- Q10
- assimilation efficiency
- net growth efficiency (C01PN)
- uptake coefficients for three food sources (C06A01, C08A01 and C12A01).

$$PNBACI = C01PN * UBACI$$

C01PN is the net growth efficiency, ie. the fraction of uptake to net growth; presently set at 0.36 (ie 1/CO1SR).

UBACI is the total food uptake which is obtained from BLCI, BICI and BRCI in the ratio of C06A01: C08A01: C12A01 (.901: .09: .009).

$$UBACI = C01SR * PBBACI * BACI(I) * 0.1$$

C01SR is the factor by which net production must be raised to give a relative food uptake of 1 assuming an assimilation efficiency of 80% and a net growth efficiency of 45%. That is  $1/(0.8*0.45) = 2.78$ . The activity respiration (never calculated) is covered by this factor.

PBBACI is the daily PB ratio of bacteria and is set equal to a maximum of 1 at 20 C.

$$PBBACI = \text{MIN}(1, \text{EXP}(0.0693 * (\text{STEMPD}(I) - 20)))$$

BACI(I) is the bacterial biomass

0.1 is the fraction of bacteria which are active.

The total food uptake is controlled by the concentration of labile carbon (BLCI); there is no food uptake if there is no BLCI.

$$\text{IF } (.901 * UBACI \text{ .GE. } BLCI(I)) \text{ } UBACI = 1.11 * BLCI(I)$$

It is assumed that labile organic carbon (high in nitrogen content) is required by bacteria in order for them to utilize intermediate and refractory organic carbon which are lower in nitrogen content. Cammen and Walker (1986) have demonstrated a relationship between microalgal and bacterial abundance suggesting the importance of extracellular microalgal carbon as a food source.

### 2.5.3.2 Basal respiration (RBBACI)

Rate determining factors:

- biomass (BACI)

Parameters required:

- PB ratio (PBBACI)
- respiration coefficient (C01RB), presently = 0.001.

$$RBBACI = C01RB * PBBACI * BACI(I)$$

### 2.5.3.3 Excretion (FBACI)

Organic carbon excreted from bacteria goes to BLCI.

Rate determining factors:

- food uptake (UBACI)

Parameters required:

- excretion coefficient (C01F), presently = 0.2.

$$\text{FBACI} = \text{C01F} * \text{UBACI}$$

### 2.5.3.4 Predation

Intertidal bacteria are grazed by BMEI and BDFI.  
See other documentation.

#### 2.5.4 Subtidal benthic bacteria (BACS)

The state variable BACS represents bacteria that live in the subtidal sediments.

$$DBACS(I) = DBACS(I) + PNBACS - RBBACS - PREDATION$$

PNBACS	net production which includes losses by activity respiration (RABACS) and excretion (FBACS). The latter is split evenly between BLCS and BICS. BACS feed on BLCS, BICS and BRCS.
RBBACS	basal respiration
PREDATION	predation by BMES and BDFS

##### 2.5.4.1 Net production (PNBACS)

Net production is calculated as a fraction (C02PN) of the food uptake. (Same as for BACL.)

Rate determining factors:

- temperature (WTEMPD), subtidal sediment temperatures are approximately equal to the water temperature.
- biomass (BACS)

Parameters required:

- Q10
- assimilation efficiency (C02SR)
- net growth efficiency (C02PN)
- uptake coefficients for three food sources (C07A02, C09A02, C13A02)

$$PNBACS = C02PN * UBACS$$

C02PN is the net growth efficiency, ie. the fraction of uptake which goes to growth and presently is 0.36 (i.e. 1/C02SR).

UBACS is the total food uptake which is obtained from BLCS, BICS and BRCS in the ratio of C09A02: C07A02: C13A02 (0.901: 0.09: 0.009).

$$\text{UBACS} = \text{C02SR} * \text{PBBACS} * \text{BACS(I)} * 0.1$$

C02SR is the factor by which net production must be raised to give a relative food uptake of 1 assuming an assimilation efficiency of 80% and a net growth efficiency of 45%. That is  $1/(0.8*0.45) = 2.78$ . The activity respiration (never calculated) is covered by this factor.

PBBACS is the PB ratio of bacteria and is set equal to a maximum of 1 at 20 C.

$$\text{PBBACS} = \text{MIN}(1., \text{EXP}(0.0693 * (\text{WTEMPD(I)} - 20)))$$

BACS(I) is the bacterial biomass

0.1 is the fraction of bacteria which are active.

Food uptake is limited by the availability of labile carbon and stops if there is no BLCS.

$$\text{IF } (.901 * \text{UBACS} \text{ .GE. } \text{BLCS(I)}) \text{ UBACS} = 1.11 * \text{BLCS(I)}$$

It is assumed that labile organic carbon (high in nitrogen content) is required by bacteria in order for them to utilize intermediate and refractory organic carbon which are lower in nitrogen content (See BACI documentation).

#### 2.5.4.2 Basal respiration (RBBACS)

Rate determining factors:

- biomass (BACS)

Parameters required:

- PB ratio (PBBACS)
- respiration coefficient (C02RB), presently = 0.001

$$\text{RBBACS} = \text{C02RB} * \text{PBBACS} * \text{BACS(I)}$$

#### 2.5.4.3 Excretion (FBACS)

Organic carbon excreted from bacteria goes to BLCS.

Rate determining factors:

- food uptake (UBACS)

Parameters required:

- excretion coefficient (C02F), currently = 0.20

$$\text{FBACS} = \text{C02F} * \text{UBACS}$$

#### 2.5.4.4 Predation

Intertidal bacteria are grazed by BMES and BDFS.  
See other documentation.

#### 2.5.4 Intertidal Benthic Meiofauna (BMEI)

This state variable represents the small metazoans and protozoans which live in the intertidal sediment. The dominant group is the nematodes.

$$DBMEI(I) = DBMEI(I) + PNBMEI - RBBMEI - ZBMEI - PREDATION$$

PNBMEI	net production which includes losses by activity respiration (RABMEI) and fecal production (FBMEI) which is added to BLCI (20%) and BICI (80%). BMEI feed on BLCI, BACI, BDIA and BMEI.
RBBMEI	basal respiration
ZBMEI	mortality
PREDATION	predation by meiofauna (BMEI), BDFI, PMFH and PRFH.

##### 2.5.4.1 Net Production (PNBMEI)

The net production is calculated on the basis of PB ratios measured in the Cumberland Basin and simulated biomass. Food uptake is estimated once production is determined.

Rate determining factors:

- temperature and food dependent PB ratio (PBBMEI)
- biomass (BMEI)

Parameters required:

- Q10 maximum PB ratio
- PB ratio at average food concentration (C10SR)
- average food concentration
- half saturation constant (C10S)

$$PNBMEI = PBBMEI * BMEI(I)$$

PBBMEI is the temperature and food corrected PB ratio

$$\text{PBBMEI} = \text{MIN}(0.14, \text{C10SR} * \text{TCORI} * \text{PFBMEI} / \text{C10S})$$

C10SR, the maximum annual PB ratio, is estimated to be 25 or 0.07 per day. The average daily value for the PB ratio is 0.03.

TCORI is the temperature correction factor based upon a Q10 of 2. It equals 1 at the mean production season temperature of 13 C.

$$\text{TCORI} = \text{MAX}(0, \text{MIN}(2, \text{EXP}(0.0693 * (\text{STEMPD}(I) - 13))))$$

PFBMEI is the primary food for BMEI which is assumed to be microalgae. The biomass of BMEI is not considered to be important in determining the PB ratio. The meiofauna are assumed to feed at high rates as long as primary food is abundant.

$$\text{PFBMEI} = \text{BDIA}(I)$$

C10S, presently equal to 1000, is the concentration of PFBMEI at which food uptake is maximal. Note that a simple linear relationship is used and not the conventional Michaelis-Menten formulation.

BMEI(I) is the meiofauna biomass

#### 2.5.4.2 Food Uptake (UBMEI)

Once the net production (PNBMEI) is calculated, the food uptake (UBMEI) must be determined in order to calculate the differentials of food sources.

$$\text{UBMEI} = \text{RABMEI} + \text{RBBMEI} + \text{FBMEI} + \text{PNBMEI}$$

RABMEI is the activity respiration. C10RA, presently = 1.1, is the ratio of activity respiration to net production. (Net growth efficiency of 45%.)

$$\text{RABMEI} = \text{C10RA} * \text{PNBMEI}$$

RBBMEI is the basal respiration. C10RB, presently = 0.01, is the basal respiration coefficient.

$$\text{RBBMEI} = \text{C10RB} * \text{TCORI} * \text{BMEI}(I)$$

FBMEI is the fecal production. C10F, presently = 0.7, is the ratio of fecal production to net production.

$$\text{FBMEI} = \text{C10F} * \text{PNBMEI}$$

PNBMEI is the net production

Fecal production is distributed in the following manner. The fraction of the food which is bacteria,

$$\text{FRBACI} = 0.1 * \text{BACI(I)}/\text{TFBMEI}$$

is returned to the bacterial pool (BACI), while the remainder

$$(1.- \text{FRBACI})$$

goes to BLCI.

The proportion of food consumed to food available is given by the variable FRAC which is used in the differential equations.

$$\text{FRAC} = \text{UBMEI}/\text{TFBMEI}$$

TFBMEI is the total food

$$\text{TFBMEI} = 0.1 * \text{BACI(I)} + 0.8 * \text{BDIA(I)} + 0.1 * \text{BLCI(I)} + .18 * \text{BMEI(I)}$$

The fractions for the first three items reflect the observed depth distribution of the items with respect to the feeding behaviour of BMEI while the fraction of BMEI available is a function of the species composition of the meiofauna in Cumberland Basin (Schwinghamer, unpublished data).

#### 2.5.4.3 Mortality (ZBMEI)

There are three identified causes of mortality;

1. High temperature mortality between Day 180 and 210.

$$\text{ZBMEI} = 0.045 * \text{BMEI(I)}$$

2. Natural mortality of aging cohorts in the fall from Day 270 to 360.

$$\text{ZBMEI} = 0.006 * \text{BMEI(I)}$$

3. Ice related mortality from Day 0 to 75, if the biomass is greater than  $10 \text{ mg C m}^{-3}$

$$\text{ZBMEI} = 0.10 * \text{BMEI(I)}$$

otherwise,

$$\text{ZBMEI} = \text{PNBMEI}$$

ZBMEI is added to intertidal labile carbon (BLCI).

#### 2.5.4.4 Predation

The meiofauna are preyed upon by themselves, BDFI, PMFH and PRFH. See other documentation.

### 2.5.5 Subtidal meiofauna (BMES)

The state variable BMES represents small metazoans which live in the interstices of subtidal sediment. The most dominant group is the nematodes.

$$DBMES(I) = DBMES(I) + PNBMES - RBBMES - PREDATION$$

PNBMES	net production which includes losses by activity respiration (RABMES) and fecal production (FBMES). The latter is added to BLCS (20%) and BICS (80%). BMES feed on BACS, BLCS and themselves.
RBBMES	basal respiration
PREDATION	predation by meiofauna (BMES), BDFS, PMFH and PRFH

#### 2.5.5.1 Net Production (PNBMES)

The net production is calculated on the basis of PB ratios measured in the Cumberland Basin and simulated biomass. Food uptake is not required but is subsequently estimated once production is determined.

Rate determining factors:

- temperature and food dependent PB ratio (PBBMES)
- biomass (BMES)

Parameters required:

- Q10
- maximum PB ratio
- PB ratio at average food concentration (C11SR)
- average food concentration
- feeding threshold (C11T)
- half saturation constant (C11S)

$$PNBMES = PBBMES * BMES(I)$$

PBBMES is the temperature and food corrected PB ratio which is calculated with a Michaelis-Menten function.

$$\text{PBBMES} = \text{MIN}(0.14, \text{C11SR} * \text{TCORS} * \text{PFBMES} / \text{C11S})$$

C11SR, the maximum annual PB ratio, is estimated to be 25 or 0.07 per day, the average value being 0.03.

TCORS is the temperature correction factor based upon a Q10 of 2. It equals 1 at the mean production season temperature of 13 C.

$$\text{TCORS} = \text{MAX}(0, \text{MIN}(2, \text{EXP}(0.0693 * (\text{WTEMPD}(I) - 13))))$$

PFBMES is the primary food for BMES which is assumed to be bacteria. The biomass of BMES is not thought to be important in determining the PB ratio. The meiofauna are assumed to feed at high rates as long as primary food is abundant.

$$\text{PFBMES} = \text{BACS}(I)$$

C11S, presently equal to 300, is the concentration of PFBMES at which food uptake is maximal. Note that a simple linear relationship is used and not the conventional Michaelis-Menten formulation.

BMES(I) is the meiofauna biomass

#### 2.5.5.2 Food Uptake

Once the net production (PNBMES) is calculated, the food uptake (UBMES) must be determined in order to calculate the differentials of food sources.

$$\text{UBMES} = \text{RABMES} + \text{RBBMES} + \text{FBMES} + \text{PNBMES}$$

RABMES is the activity respiration. C11RA, presently = 1.1, is the ratio of activity respiration to net production.

$$\text{RABMES} = \text{C11RA} * \text{PNBMES}$$

RBBMES is the basal respiration. C11RB, presently = 0.01, is the basal respiration coefficient at 13C.

$$\text{RBBMES} = \text{C11RB} * \text{TCORS} * \text{BMES}(I)$$

FBMES is the fecal production. C11F, presently = 0.7 is the ratio of fecal production to net production.

$$\text{FBMES} = \text{C11F} * \text{PNBMES}$$

Fecal production is distributed in the following manner. The fraction of the food which is bacteria,

$$\text{FRBACS} = 0.1 * \text{BACS(I) / TFBMES}$$

is returned to the bacterial pool (BACS), while the remainder

$$(1 - \text{FRBACS})$$

goes to BLCS.

PNBMES is the net production

The proportion of food consumed to food available is given by the variable FRAC which is used in the differential equations.

$$\text{FRAC} = \text{UBMES} / \text{TFBMES}$$

TFBMES is the total food

$$\text{TFBMES} = \text{PFBMES} + 0.5 * \text{BMES(I)} + \text{BLCS(I)}$$

### 2.5.5.3 Predation

The meiofauna are preyed upon by themselves, BDFS, PMFH and PRFH. See other documentation.

### 2.5.6 Intertidal Benthic deposit feeders (BDFI)

The state variable BDFI includes macroscopic invertebrates which live on and in intertidal sediments. It includes crustaceans, molluscs and polychaetes. Dominant species are *Corophium volutator*, *Macoma baltica* and *Heteromastus filiformis*.

$$\text{DBDFI(I)} = \text{DBDFI(I)} + \text{PNBDFI} - \text{RBBDFI} - \text{ZBDFI} - \text{PREDATION}$$

PNBDFI	net production which includes losses by activity respiration (RABDFI) and fecal production (FBDFI). The latter is added to BLCI (20%) and BICI (80%). BDFI feed on BACI, BDIA, BMEI, BICI and PHYT.
RBBDFI	basal respiration
ZBDFI	mortality
PREDATION	predation by PRFH, PMFH and migratory shorebirds.

#### 2.5.6.1 Net Production (PNBDFI)

Net production is calculated on the basis of PB ratios measured in the Cumberland Basin and simulated biomass. Food uptake is subsequently estimated once production is determined.

Rate determining factors:

- temperature and food dependent PB ratio (PBDFI)
- biomass (BDFI)

Parameters required:

- Q10
- maximum PB ratio
- PB ratio at average food concentration (C03SR)
- average food concentration
- average concentration of preferred food (C03S)

$$\text{PNBDFI} = \text{PBBDFI} * \text{BDFI(I)}$$

PBBDFI is the temperature and food corrected PB ratio.

$$\text{PBBDFI} = \text{MIN}(0.066, \text{C03SR} * \text{TCORI} * \text{MAX}(1, (\text{PFBDFI}/\text{C03S})^{**3}))$$

0.066 is the maximum daily PB ratio based on observations at Pecks Cove.

C03SR, the average annual PB ratio, is estimated to be 1.5 or 0.0042 per day. This value and the maximum daily PB ratio are based on data from Hawkins (1986), Hicklin et al. (1980) and Cranford et al. (1985) among others.

TCORI is the temperature correction factor based upon a Q10 of 2. It equals 1 at the mean production season temperature of 13 C.

$$\text{TCORI} = \text{MAX}(0, \text{MIN}(2, \text{EXP}(0.0693 * (\text{STEMPD}(I) - 13))))$$

PFBDFI is the primary food for BDFI which is assumed to be BDIA. The biomass of other food items are not thought to be important in determining PB ratio. The deposit feeders are assumed to feed at high rates as long as primary food is abundant.

$$\text{PFBDFI} = \text{BDIA}(I)$$

C03S, which equals 1000., is the concentration of PFBDFI above which the growth rate is unaffected by food availability. At lower primary food concentrations the growth rate is reduced by the cube of the ratio of PFBDFI to C03S. The choice of the cubed ratio was arbitrary.

BDFI(I) is the deposit feeder biomass

### 2.5.6.2 Food Uptake

Once the net production (PNBDFI) is calculated, the food uptake (UBDFI) must be determined in order to calculate the differentials of food sources.

$$UBDFI = RABDFI + RBBDFI + FBDFI + PNBDFI$$

RABDFI is the activity respiration. C03RA, presently = 1.1, is the ratio of activity respiration to net production.

$$RABDFI = C03RA * PNBDFI$$

RBBDFI is the basal respiration, see details below.

FBDFI is the fecal production

$$FBDFI = (FECES - 1.) * (PNBDFI + RABDFI)$$

(FECES -1.) is the ratio of non-assimilable food to assimilable food.

$$FECES = TFBDFI / (.7 * PFBDFI + .0001 * BICI(I) + .07 * BMEI(I) + .07 * PHYT(I) + .07 * BACI(I))$$

TFBDFI is the total food

$$TFBDFI = PFBDFI + .001 * BICI(I) + .1 * BMEI(I) + .1 * PHYT(I) + .1 * BACI(I)$$

0.7, .001 and .07 are coefficients that combine the assimilation efficiencies of 70% for PFBDFI, BMEI, PHYT and BACI and 10% for BICI with the availabilities of 100, 0.1, 10, 10 and 10% respectively. The availability of BICI reflects its expected half-life whereas the others express the physical availability taking into account food location and the feeding behaviour of BDFI.

FBDFI is distributed in the following manner. The portion of FBDFI which originated as BICI,

$$FRBICI = 0.001 * BICI(I) / TFBDFI$$

is returned to BICI, and the fraction originating as BACI

$$\text{FRBACI} = 0.001 * \text{BACI}(I) / \text{TFBDFI}$$

is returned to BACI and the remainder

$$(1. - \text{FRBACI} - \text{FRBICI})$$

goes to BLCI.

The proportion of food consumed to food available is given by the variable FRAC which is used in the differential equations.

$$\text{FRAC} = \text{UBDFI} / \text{TFBDFI}$$

#### 2.5.6.3 Basal respiration (RBBDFI)

Rate determining factors:

- biomass (BDFI)

Parameters required:

- temperature coefficient (TCORI)
- basal respiration coefficient (C03RB), presently = 0.0005.

$$\text{RBBDFI} = \text{TCORI} * \text{C03RB} * \text{BDFI}(I)$$

#### 2.5.6.4 Mortality (ZBDFI)

Mortality is caused by ice erosion from Day 0 to 75 (Gordon and Desplanque, 1983 ) and is arbitrarily set at 1% daily.

$$\text{ZBDFI} = 0.01 * \text{BDFI}(I)$$

which is added to PLOC.

#### 2.5.6.5 Predation

The intertidal deposit feeders are preyed upon by PRFH, PMFH and migratory shore birds. See other documentation for fish uptake. Grazing of birds occurs from Day 205 to 225 ( Hicklin and Smith, 1984) and is arbitrarily set to equal net production.

$$\text{ZBDFI} = \text{PNBDFI}$$

which is exported from the ecosystem by the migratory birds.

### 2.5.7 Subtidal deposit feeders (BDFS)

The state variable BDFS represents the macroscopic invertebrates which live on and in subtidal sediments. It includes crustaceans, molluscs and polychaetes.

$$DBDFS(I) = DBDFS(I) + PNBDFS - RBBDFS - PREDATION$$

PNBDFS	net production which includes losses by activity respiration (RABDFS) and fecal production (FBDFS). The latter is added to BLCS (20%) and BICS (80%). BDFS feed on BACS, BMES and BICS.
RBBDFS	basal respiration
PREDATION	predation by PRFH and PMFH.

#### 2.5.7.1 Net Production (PNBDFS)

The net production is calculated on the basis of PB ratios measured in the Cumberland Basin and simulated biomass. Food uptake is not required but is subsequently estimated once production is determined.

Rate determining factors:

- temperature and food dependent PB ratio (PBDDFS)
- biomass (BDFS)

Parameters required:

- Q10
- maximum PB ratio
- PB ratio at average food concentration (C04SR)
- average food concentration
- average concentration of preferred food (C04S)

$$PNBDFS = PBBDFS * BDFS(I)$$

PBBDFS is the temperature and food corrected PB ratio.

$$\text{PBBDFS} = \text{MIN}(0.066, \text{C04SR} * \text{TCORS} * \text{MAX}(1, (\text{PFBDFS}/\text{C04S})^{**3}))$$

C04SR, the average annual PB ratio, is estimated to be 1.5 or 0.017 per day.

TCORS is the temperature correction factor based upon a Q10 of 2. It equals 1 at the mean production season temperature of 13 C.

$$\text{TCORS} = \text{MAX}(0, \text{MIN}(2, \text{EXP}(0.0693 * (\text{WTEMPD}(I) - 13))))$$

PFBDFS is the primary food for BDFS which is assumed to be bacteria. The biomass of other food items are not thought to be important in determining the PB ratio. The deposit feeders are assumed to feed at high rates as long as primary food is abundant.

$$\text{PFBDFS} = \text{BACS}(I)$$

C04S, which equals 300., is the concentration of PFBDFS at which the growth rate is unaffected by food availability. At lower primary food concentrations the growth rate is reduced by the cube of the ratio of PFBDFS to C04S. The choice of the cubed ratio was arbitrary.

BDFS(I) is the deposit feeder biomass

#### 2.5.7.2 Food Uptake

Once the net production (PNBDFS) is calculated, the food uptake (UBDFS) must be determined in order to calculate the differentials of food sources.

$$\text{UBDFS} = \text{RABDFS} + \text{RBBDFS} + \text{FBDFS} + \text{PNBDFS}$$

RABDFS is the activity respiration

$$\text{RABDFS} = \text{C04RA} * \text{PNBDFS}$$

C04RA, presently = 1.1, is the ratio of activity respiration to net production. Reference needed.

RBBDFS is the basal respiration, see below for details.

FBDFS is the fecal production

$$\text{FBDFS} = (\text{FECES} - 1) * (\text{PNBDFS} + \text{RABDFS})$$

(FECES - 1.) is the ratio of non-assimilable food to assimilable food.

$$\text{FECES} = \text{TFBDFS} / (.7 * \text{PFBDFS} + .001 * \text{BICS(I)} + .035 * \text{BMES(I)})$$

TFBDFS is the total food

$$\text{TFBDFS} = \text{PFBDFS} + \text{BICS(I)}$$

0.7, .001 and .035 are assimilation efficiencies for PFBDFS, BICS and BMES multiplied by their availabilities of 1, .01 and .5, respectively. The availabilities reflect the turnover time for BICS and the physical availability of PFBDFS and BMES.

FBDDFS is distributed in the following manner. The portion of FBDDFS which originated as BICS,

$$\text{FRBICS} = 0.001 * \text{BICS(S)} / \text{TFBDFS}$$

is returned to BICS, and the fraction originating as BACS

$$\text{FRBACS} = 0.001 * \text{BACS(S)} / \text{TFBDFS}$$

is returned to BACI and the remainder

$$(1 - \text{FRBACS} - \text{FRBICS})$$

goes to BLCS.

The proportion of food consumed to food available is given by the variable FRAC which is used in the differential equations.

$$\text{FRAC} = \text{UBDFS} / \text{TFBDFS}$$

### 2.5.7.3 Basal respiration (RBBDFS)

Rate determining factors:

- biomass (BDFS)

Parameters required:

- temperature coefficient (TCORS)
- basal respiration coefficient (C04RB), presently = 0.0005.

$$\text{RBBDFS} = \text{TCORS} * \text{C04RB} * \text{BDFS(I)}$$

#### 2.5.7.4 Predation

The subtidal deposit feeders are preyed upon by PRFH and PMFH. See other documentation.

### 2.5.8 Subtidal suspension feeders (BSUS)

The state variable BSUS represents the macroscopic invertebrates which live near the surface of subtidal sediments and feed on material suspended in the water column. It is dominated by molluscs and bryozoans.

$$DBSUS(I) = DBSUS(I) + PNBSUS - RBBSUS - YBSUS - PREDATION$$

PNBSUS            net production which includes losses by activity respiration (RABSUS) plus excretion and fecal production (FBSUS). FBSUS is added to BLCS, BICS and BRCS. BSUS feed on PBAC, PHYT, ELOC, EIOC and EROC. basal respiration

YBSUS            spawning which is added to PHER

PREDATION        predation by PRFH, PMFH and epifauna such as starfish.

#### 2.5.8.1 Net Production (PNBSUS)

The net production is calculated on the basis of estimated PB ratios and simulated biomass. Food uptake is subsequently estimated once production is determined.

Rate determining factors:

- temperature and food dependent PB ratio (PBBSUS)
- biomass (BSUS)

Parameters required:

- Q10
- maximum PB ratio
- PB ratio at average food concentration (C15SR)
- average food concentration
- average concentration of preferred food (C15S)

$$PNBSUS = PBBSUS * BSUS(I)$$

PBBSUS is the temperature and food corrected PB ratio

$$PBBSUS = \text{MIN}(0.017, C15SR * TCORS * PFBSUS/C15S)$$

C15SR, the average annual PB ratio, is estimated to be 0.002.

TCORS is the temperature correction factor based upon a Q10 of 2. It equals 1 at the mean production season temperature of 13 C.

$$TCORS = \text{MAX}(0, \text{MIN}(2, \text{EXP}(0.0693 * (WTEMPD(I) - 13))))$$

PFBSUS is the biomass of preferred food

$$PFBSUS = \text{AVPBAC} + \text{AVPHYT} + \text{ELOC}(I)$$

AVPBAC is the fraction (C21A15) of PBAC available as food; presently equal to 0.1.

$$\text{AVPBAC} = C21A15 * \text{PBAC}(I)$$

AVPHYT is the fraction (C26A15) of PHYT available as food; presently equal to 0.1.

$$\text{AVPHYT} = C26A15 * \text{PHYT}(I)$$

ELOC is epibenthic labile organic carbon

BSUS(I) is the suspension feeder biomass

#### 2.5.8.2 Food Uptake

Once the net production (PNBSUS) is calculated, the food uptake (UBSUS) must be determined in order to calculate the differentials of food sources.

$$\text{UBSUS} = \text{RABSUS} + \text{RBBSUS} + \text{FBSUS} + \text{EXCRET} + \text{PNBSUS}$$

RABSUS is the activity respiration and C15RA, presently = 1.1 is the ratio of activity respiration to net production.

$$\text{RABSUS} = C15RA * \text{PNBSUS}$$

RBBSUS is the basal respiration, see below for details.

FBSUS is the fecal production

$$\text{FBSUS} = 6.1 * (\text{RBBSUS} + \text{RABSUS})$$

EXCRET is the excretion of dissolved carbon which is a function of total respiration and is added to ELOC. C15F, presently = 0.4, is the excretion coefficient.

$$\text{EXCRET} = \text{C15F} * (\text{RBBSUS} + \text{RABSUS})$$

The proportion of food consumed to food available is given by the variable FRAC which is used in the differential equations.

$$\text{FRAC} = \text{UBSUS}/\text{TFBSUS}$$

TFBSUS is the total food for BSUS

$$\text{TFBSUS} = \text{PFBSUS} + \text{AVEIOC} + \text{AVEROC}$$

PFBSUS is the preferred food.

AVEIOC is epibenthic intermediate organic carbon available as food to BSUS and C17A15 is the fraction (presently = 1.0) of EIOC available.

$$\text{AVEIOC} = \text{C17A15} * \text{EIOC}(I)$$

AVEROC is epibenthic refractory organic carbon available as food to BSUS and C19A15 is the fraction (presently = 0.001).

$$\text{AVEROC} = \text{C19A15} * \text{EROC}(I)$$

### 2.5.8.3 Basal respiration (RBBSUS)

Rate determining factors:

- biomass (BSUS)

Parameters required:

- temperature coefficient(TCORS)
- basal respiration coefficient (C15RB), presently = 0.0005

$$\text{RBBSUS} = \text{TCORS} * \text{C15RB} * \text{BSUS}(I)$$

#### 2.5.8.4 Spawning (YBSUS)

There are two, ten day spawning periods; the first starting on Day 130 (May 10), the second starting on Day 300 (Oct. 1). Larval production is assumed to be a fraction, C15Y, of the BSUS biomass. Larval production is added directly to PHER. C15Y is presently set at 0.025.

$$YBSUS = C15Y * BSUS(I)$$

#### 2.5.8.5 Predation

The subtidal suspension feeders are preyed upon by PRFH, PMFH and epifauna. See other documentation for fish predation. Predation by epifauna, which are not modelled, is handled in the following equation. The carbon consumed is removed from BSUS but just disappears.

$$EPIF = .066 * TCORS$$

The numeric value is a predation coefficient estimated by Mike Dads-well.

## 2.6 Non-living organic carbon

### 2.6.1 Labile organic carbon (PLOC, BLCL, BLCS)

This pool of organic carbon represents those non-living compounds which are decomposed/assimilated at a very rapid rate. Their turnover time is on the order of one day. It represents the very labile compounds like simple sugars, amino acids and fatty acids which are quickly consumed. It has a very large number of sources.

Labile organic carbon is introduced into the pelagic pool (PLOC) by export from the salt marshes, import across the boundaries and in the form of exudates, fecal material and dead bodies from various organisms. PLOC is exchanged with the benthic pools (BLCL, BLCS) by calls to SEDRES, the general purpose sedimentation and resuspension subroutine described in section 2.3.5. Carbon pathways are illustrated in Figures 2-5 to 2-7.

#### 2.6.1.1 Sources and sinks of pelagic labile organic carbon (PLOC)

$$\begin{aligned} \text{DPLOC(I)} = & \text{DPLOC(I)} + \text{FPHYT} + \text{FPBAC} + \text{MARSH} + \\ & 0.25 * (\text{FPHER} + \text{FPCAR} + \text{FPFLR} + \text{FPRFH} + \text{FPMFH}) + \\ & \text{ZPHYT} + \text{ZPDET} + \text{ZPCAR} + \text{ZPFLR} + \text{ZPRFH} + \text{ZBDFI} + \\ & \text{GPHER} + 0.8 * \text{YPRFH} - \\ & \text{UPTAKE} - \text{DEPOSITION} + \text{RESUSPENSION} +/- \text{EXCHANGE} \end{aligned}$$

FPHYT	phytoplankton excretion
FPBAC	bacterial excretion
FPHER	herbivore fecal pellets
FPCAR	carnivore fecal pellets
FPFLR	fish larvae fecal pellets
FPRFH	feces of resident fish
FPMFH	feces of migratory fish
ZPHYT	phytoplankton mortality
ZPDET	detritivore mortality
ZPCAR	carnivore mortality
ZPFLR	larval mortality
ZPRFH	resident fish mortality
ZBDFI	intertidal deposit feeder ice mortality.
GPHER	sloppy feeding by herbivores
YPRFH	larvae released by resident fish
MARSH	release from marshes (see Section 2.6.4)
UPTAKE	utilization by pelagic bacteria
DEPOSITION	loss to ELOC, BLCL and BLCS (see Section 2.7)
RESUSPENSION	resuspension from ELOC (see Section 2.7)
EXCHANGE	mixing with other compartments (see Section 2.3.4)
	The susceptibility constant is set to 1.

The concentration of PLOC at the boundaries is determined by a time series; daily values being calculated by a slip function.

$$XPLOC(I) = SLP (DAY, DATES, PLOCX(1,I), 12)$$

SLP is a slip function which extrapolates between points in a time series.

DAY is the time in the simulation run.

DATES is the times for the data points in the time series.

PLOCX is the time series of PLOC concentrations for the boundaries consisting of 12 monthly mean values for each compartment based upon extensive POC and DOC data (Keizer et al., 1984)

TABLE 2-22. DATA PLOCX - Monthly mean concentrations (mgC m<sup>-3</sup>) for each of the model boundaries.

Bound.	J	F	M	A	M	J	J	A	S	O	N	D
4	54.	63.	81.	99.	87.	75.	63.	57.	51.	45.	36.	42.
5	98.	91.	98.	138.	146.	131.	81.	131.	125.	136.	143.	100.
6	66.	120.	78.	108.	66.	72.	54.	82.	74.	92.	74.	70.

2.6.1.2 Sources and sinks of intertidal benthic labile organic carbon (BLCI)

$$\text{DBLCI(I)} = \text{DBLCI(I)} + \text{FBDIA} + \text{FBACI} + \\ (1. -\text{FRBACI}) * \text{FBMEI} + (1. -\text{FRBACI} - \text{FRBICI}) * \text{FBDFI} + \\ \text{ZBMEI} + \text{DEPOSITION} - \text{UPTAKE}$$

FBDIA	microalgal excretion
FBACI	bacterial excretion
FBMEI	meiofaunal fecal pellets, less the fraction that was BACI (FRBACI) in the total food.
FBDFI	deposit feeders fecal pellets, less the fractions that were BACI (FRBACI) or BICI (FRBICI) in the total food.
ZBMEI	intertidal meiofauna mortality
DEPOSITION	deposition of pelagic labile organic carbon (PLOC) when the flats are flooded.
UPTAKE	utilization by BACI

2.6.1.3 Sources and sinks of subtidal benthic labile organic carbon (BLCS)

$$\text{DBLCS(I)} = \text{DBLCS(I)} + \text{FBACS} + (1. - \text{FRBACS}) * \text{FBMES} + \\ (1. - \text{FRBACS} - \text{FRBICS}) * \text{FBDFS} + 0.25 * \text{FPDET} + \\ (\text{FBSUS} - \text{FRAC} * \text{AVEROC}) * (\text{PFBSUS}/\text{TFBSUS}) - \text{UPTAKE}$$

FBACS	bacterial excretion
FBMES	meiofaunal fecal pellets, less the fraction that was BACS (FRBACS) in the total food.
FBDFS	deposit feeders fecal pellets, less the fractions that were BACS (FRBACS) or BICS (FRBICS) in the total food.
FBSUS	a fraction of suspension feeder fecal pellets. All EROC consumed is added to BRCS and the fraction of the remaining FBSUS that was PFBSUS is added to the BLCS.
UPTAKE	uptake by BACS

## 2.6.2 Intermediate organic carbon (PIOC, BICI, BICS)

This pool of organic carbon represents those non-living compounds which are decomposed/assimilated at a moderate rate. Their turnover time ranges between a day and a year. It represents those compounds that are used at a slower rate than labile organic carbon but are not refractory. It has a number of sources.

Intermediate organic carbon is introduced into the pelagic pool (PIOC) from the salt marshes and across the boundaries. It is also produced as part of the fecal production of various organisms as PIOC, BICI or BICS. PIOC is exchanged with BICS and BICI by calls to SEDRES, the general purpose sediment transport routine. Carbon pathways are illustrated in Figures 2-5 to 2-7.

There are no direct connections between labile, intermediate and refractory organic carbon. Organic matter is visualized as having a certain percentage of PLOC, PIOC and PROC at the outset. The PLOC disappears rapidly, the PIOC more slowly and the PROC stays around for a very long time. Transitions from one form to another can only occur by passing through a state variable. For example, pelagic bacteria take up PIOC and release PLOC.

### 2.6.2.1 Sources and sinks of pelagic intermediate organic carbon (PIOC)

$$\text{DPIOC(I)} = \text{DPIOC(I)} + \text{MARSH} + \text{FLPIOC} + 0.75 * (\text{FPHER} + \text{FPCAR} + \text{FPFLR} + \text{FPRFH} + \text{FPMFH}) - \text{UPTAKE} - \text{DEPOSITION} + \text{RESUSPENSION} +/- \text{EXCHANGE}$$

MARSH	release from marshes (see Section 2.6.4)
FLPIOC	one-half of the nutrient stress excretion of phytoplankton
FPHER	herbivore fecal pellets
FPCAR	carnivore fecal pellets
FPFLR	pelagic fish larvae fecal pellets
FPRFH	feces of resident fish
FPMFH	feces of migratory fish
UPTAKE	consumption by pelagic bacteria, herbivores and detritivores
DEPOSITION	sedimentation (see Section 2.7)
RESUSPENSION	resuspension (see Section 2.7)
EXCHANGE	mixing with other compartments (see Section 2.3.4) The susceptibility constant is set equal to 0.1.

The values of PIOC at the boundaries are set by a time series PIOCX; daily values being determined by a slip function.

$$XPIOC(I) = SLP(DAY, DATES, PIOCX(1,I), 12)$$

SLP is a slip function which extrapolates values between points in a time series.

DAY is the time during the simulation run.

DATES is the list of times for the data points in the time series.

PIOCX is the time series which consists of 12 monthly mean values for each boundary based on extensive data (Keizer et al., 1984)

TABLE 2-23. DATA PIOCX - Monthly mean concentrations (mgC m<sup>-3</sup>) for each of the model boundaries.

Bound.	J	F	M	A	M	J	J	A	S	O	N	D
4	1260	1470	1890	2310	2030	1750	1470	1330	1190	1050	840	980
5	882	810	882	1242	1314	1179	729	1179	1125	1224	1287	1000
6	1320	2400	1560	2160	1320	1440	1080	1640	1480	1840	1480	1400

#### 2.6.2.2 Sources and sinks of intertidal benthic intermediate organic carbon (BICI)

$$DBICI(I) = DBICI(I) + FRBICI * FBDFI - UPTAKE + DEPOSITION$$

FMEII	meiofaunal excretion
FBDFI	a fraction (FRBICI) of deposit feeder fecal pellets. FRBICI is the fraction of the total food that was BICI.
UPTAKE	uptake by BACI and BDFI
DEPOSITION	deposition of PIOC when the flats are flooded (see Section 2.7)

2.6.2.3 Sources and sinks of subtidal benthic intermediate organic carbon (BICS)

$$DBICS(I) = DBICS(I) + FRBICS * FBDFS + (FBSUS - FRAC * AVEROC) * (1 - PFBSUS/TFBSUS) - UPTAKE$$

FMEIS	meiofaunal excretion
FBDFS	a fraction (FRBICS) of deposit feeder fecal pellets. FRBICS is the fraction of the total food that was BICS.
FBSUS	a fraction of suspension feeder fecal pellets. The EROC consumed is added to BRCS and then the fraction of the remainder which was not PFBSUS is added to BICS.
UPTAKE	uptake by BACS and BDFS

### 2.6.3 Refractory organic carbon (PROC, BRCL, BRCS)

This pool of non-living organic carbon contains the refractory components. They are defined as having a turnover time greater than one year. Some of it can be utilized by bacteria but a large fraction is probably buried in the sediments (future gas and oil) or exported. Its palatability is very low.

Refractory organic carbon is introduced into the pelagic pool (PROC) by export from the salt marshes and import across the boundaries. PROC is exchanged with the benthic pools (BRCL, BRCS) by calls to SEDRES, the sediment transport subroutine. PROC is also converted to BRCS by passing through BSUS fecal pellets. Carbon pathways are illustrated in Figures 2-5 to 2-7.

#### 2.6.3.1 Sources and sinks of pelagic refractory organic carbon (PROC)

$$DPROC(I) = DPROC(I) + MARSH - UPTAKE - \\ DEPOSITION + RESUSPENSION +/- EXCHANGE$$

MARSH	release from marshes
UPTAKE	consumption by pelagic bacteria (PBAC)
DEPOSITION	sedimentation to EROC, BRCL and BRCS (see Section 2.7)
RESUSPENSION	resuspension from EROC (see Section 2.7)
EXCHANGE	mixing with other compartments (see Section 2.3.4) The susceptibility constant is set to 0.1.

The concentration of PROC at the boundaries is determined by a time series from which daily values are extrapolated.

$$XPROC(I) = SLP (DAY, DATES, PROCX(1,J), 12)$$

SLP is a slip function which extrapolates between points in a time series.

DAY is the time during the simulation run.

DATES is the time for the data points in the time series.

PROCX is the time series of PROC values for the boundaries consisting of 12 monthly mean values for each compartment based on extensive data (Keizer et al., 1984 )

TABLE 2-24. DATA PROCX - Monthly mean concentrations  
(mgC m<sup>-3</sup>) for each of the model boundaries.

Bound.	J	F	M	A	M	J	J	A	S	O	N	D
4	486	567	729	891	783	675	567	513	459	405	324	378
5	8820	8100	8820	12420	13140	11790	7290	11790	11250	12240	12870	10000
6	1914	3480	2262	3132	1914	2088	1566	2378	2146	2668	2146	2030

2.6.3.2 Sources and sinks of intertidal benthic refractory organic carbon (BRCI)

$$DBRCI(I) = DBRCI(I) - UPTAKE + DEPOSITION$$

UPTAKE            utilization by BACI

DEPOSITION    deposition of PROC when the flats are flooded  
(see Section 2.7)

2.6.3.3 Sources and sinks of subtidal benthic refractory organic carbon (BRCS)

$$DBRCS(I) = DBRCS(I) + (FBSUS) - UPTAKE$$

FBSUS            a fraction of suspension feeder fecal pellets equal to  
the amount of EROC consumed (FRAC\*AVERO C).

UPTAKE            utilization by BACS

#### 2.6.4 Salt marsh export

Although salt marsh occurs within the upper intertidal zone of model compartments, it is not a state variable. The dynamics of above ground salt marsh production are well understood (Gordon et al.,1985) but not modelled. Since the intertidal regions of the model are visualized as being mudflats, the salt marshes are treated more as a boundary condition. Exported organic carbon from the salt marshes is added to the model by time series. It is assumed that all exported organic matter (PLOC, PIOC and PROC) passes into the water that floods the marshes near high tide. There is no direct addition of marsh carbon to the benthic submodel. The benthic submodel receives its marsh-derived organic carbon from the pelagic submodel through calls to the general purpose sedimentation- resuspension sub-routine SEDRES.

Salt marsh organic matter is supplied from the marshes in Boundary 5 and Compartments 1 and 2. Since it is assumed that all export is mediated by water and the marshes are only flooded near high tide, the organic matter is added to the next seaward compartment. For example, marsh export from Boundary 5 is added to Waterbody 1 which moves into Boundary 5 at high tide (Figure 2-1). Mixing of exported detritus between water bodies is driven by the physical submodel. Vegetation is exported only from low marshes. It is assumed that most of the high marsh vegetation decays in place.

TSMCD is the total daily input of salt marsh organic carbon. It is estimated from:

- a. monthly values of the disappearance of vegetation per  $m^2$  from Cumberland Basin low marshes measured by Gordon et al. (1985) Losses from November to April were estimated from the total overwinter loss. In estimating carbon content from total dry weight, percentages of 43% and 30% were used for new and old dead vegetation respectively. Similar monthly losses have been observed in the more complete data base from the Grand Pre low marsh in Minas Basin.
- b. the low marsh area (*Spartina alterniflora*) calculated from data compiled by the Canadian Wildlife Service in Sackville, N.B. The high marshes are assumed not to export appreciable particulate organic carbon.

$$\text{TSMCD} = \text{SLP}(\text{DAY}, \text{DAYSTP}, \text{TSMC}(0, \text{I}), 11)/30.$$

SLP is a slip function which calculates daily from monthly values.

DAYSTP is the time series for the TSMC data (30, 60, . . . days, etc.).

TSMC(0,I) is the total salt marsh organic carbon exported per month into Compartment I in units of tonnes. Division by 30 converts to daily input. TSMC is entered in the following data statements (Jan. to Dec).

TABLE 2-25. DATA TSMC - Monthly mean amounts (tonnesC) of salt marsh detritus input to each model compartment."

Comp.	J	F	M	A	M	J	J	A	S	O	N	D
1	6	8	10	25	26	16	21	33	105	31	12	7
2	26	35	44	110	112	68	91	144	453	136	73	30
3	2	3	3	8	9	5	7	11	35	10	4	2

The TSMCD must be broken down into the three components of labile, intermediate and refractory organic carbon. This is done using very rough estimates prepared by Don Gordon and Peter Cranford based on their marsh studies in the Cumberland Basin and at Grande Pre. The fraction of each form (PPLOC, PPIOC and PPROC) is given for each month in the data statements shown below.

PLOCD is the daily input of PLOC

$$\text{PLOCD} = \text{TSMCD} * \text{SLP}(\text{DAY}, \text{DAYSTP}, \text{PPLOC}, 11)$$

TSMCD is the total daily input

DAYSTP is the data time series

PPLOC is the monthly fraction of labile organic carbon (Jan to Dec)

TABLE 2-26. DATA PPLOC - Monthly fraction of TSMCD which is PLOC.

	J	F	M	A	M	J	J	A	S	O	N	D
PPLOC	0.	0.	0.	0.01	0.02	0.03	0.04	0.05	0.04	0.03	0.02	0.01

PIOCD is the daily input of PIOC

$$\text{PIOCD} = \text{TSMCD} * \text{SLP}(\text{DAY}, \text{DAYSTP}, \text{PPIOC}, 11)$$

TSMCD is the total daily input

DAYSTP is the data time series

PPIOC is the monthly fraction of intermediate organic carbon (Jan to Dec)

TABLE 2-27. DATA PPIOC - Monthly fraction of TSMCD which is PIOC.

	J	F	M	A	M	J	J	A	S	O	N	D
PPIOC	0.2	0.1	0.0	0.1	0.25	0.4	0.55	0.7	0.6	0.5	0.4	0.3

PROCD is the daily input of PROC

$$\text{PROCD} = \text{TSMCD} - (\text{PIOCD} + \text{PLOCD})$$

The organic carbon is added to compartment water bodies using the following equations. The 1.E9 converts tonnes to milligrams. The compartment volumes are in m<sup>3</sup> (see ENV DAT).

The daily input of labile organic carbon (mg m<sup>-3</sup>) is added to DPLOC(I).

$$\text{DPLOC(I)} = \text{DPLOC(I)} + (\text{PLOCD} * 1.E9) / \text{VOLMLW(I)}$$

The daily input of intermediate organic carbon (mg m<sup>-3</sup>) is added to DPIOC(I).

$$\text{DPIOC(I)} = \text{DPIOC(I)} + (\text{PIOCD} * 1.E9) / \text{VOLMLW(I)}$$

The daily input of refractory organic carbon (mg m<sup>-3</sup>) is added to DPROC(I).

$$\text{DPROC(I)} = \text{DPROC(I)} + (\text{PROCD} * 1.E9) / \text{VOLMLW(I)}$$

## 2.7 Pelagic/Benthic Exchanges

Organic matter is exchanged between the benthos and the water column as a result of biological and physical processes.

### 2.7.1 Biological

Biological exchanges are handled in the differentials of the appropriate state variables. Resident (PRFH) and migratory (PMFH) fish, detritivores (PDET), intertidal deposit feeders (BDFI) and suspension feeders (BSUS) are involved in these exchanges.

PDET      excretion goes to BICS (75%) and BLCS (25%).

PRFH      feed on BDFI, BDFS, BMEI, BMES and BSUS.

PMFH      feed on BDFI, BDFS, BMEI, BMES and BSUS.

BDFI      mortality (ZBDFI) in the winter goes to PLOC and BDFI feed on PHYT.

BSUS      feed on PBAC, PHYT, ELOC, EIOC and EROC,  
spawn goes to PHER, and  
excretion (EXCRET) goes to ELOC.

### 2.7.2 Physical

#### 2.7.2.1 Sedimentation and Resuspension

The physical exchanges are handled by calls to SEDRES, the subroutine in the physical submodel which calculates sedimentation and resuspension. Three such exchanges are included in the model involving labile organic carbon, intermediate organic carbon, and refractory organic carbon. Microalgae are not subjected to physical exchange because benthic diatoms can migrate into deeper sediment during flooding and taxonomic studies have shown that the species composition of phytoplankton (PHYT) and benthic microalgae (BDIA) are quite different (Prouse et al., 1984).

For each sedimentation-resuspension process pelagic, epibenthic and benthic forms must be defined for each state variable. The epibenthic state variables have no internal dynamics, i.e. they are abiotic. Epibenthic labile (ELOC) and intermediate (EIOC) organic carbon provide food for the suspension feeders (BSUS). Together with the epibenthic refractory organic carbon (EROC), all three epibenthic state variables provide the necessary pathway for the sedimentation and resuspension of the particular state variable. The mechanism is explained in detail in the sediment transport documentation.

The silt-like transport of non-living carbon is effected by three calls to SEDRES and are made in the subroutine PRIMB.

CALL SEDRES (PC,ELOC,XP,XELOC,DP,DELOC,DBLCI,  
SDRATE,RSRATE,SILSTC,FLAG)

CALL SEDRES (PC,EIOC,XP,XEIOC,DP,DEIOC,DBICI,  
SDRATE,RSRATE,SILSTC,FLAG)

CALL SEDRES (PC,BRCI,XP,XEROC,DP,DEROC,DBRCI,  
SDRATE,RSRATE,SILSTC,FLAG)

The arguments are:

PC the particulate portion of the pelagic state variable  
(PLOC, PIOC or PROC).

$PC = PPC(I) * PLOC(I)$  (or PIOC or PROC)

PPC is the percentage of the state variable which is in a particulate form and will therefore sediment. In Compartment 1, this is assumed to be 70% for the three forms of non-living carbon (PLOC, PIOC and PROC) based on average concentrations of 13.89 mg L<sup>-1</sup> for POC and 4.48 mg L<sup>-1</sup> for DOC obtained from the helicopter samples collected in the Cumberland Basin (Gordon and Keizer, unpublished data) and assuming a ratio of PLOC/PIOC/PROC of 5/15/80. For Compartments 2 and 3 the percentage of particulate carbon drops to 30 and 20% respectively. The percentage of particulate forms in epibenthic state variables is not necessary since it is assumed that dissolved and particulate forms are resuspended together. Since dissolved forms are not sedimented, the resuspension process will gradually leach dissolved organic carbon generated in the benthic submodel into the water column.

EVAR epibenthic state variable (ELOC, EIOC and EROC)

XPVAR boundary conditions of pelagic state variable

XEVAR boundary conditions of epibenthic state variable. Since epibenthic state variables are not subject to water transport, boundary values do not normally have to be set. However since a waterbody can acquire resuspended material from the boundaries, epibenthic state variables which are transported like silt must have boundary concentrations declared in order to function properly. At present concentrations of ELOC, EIOC and EROC are set to 50., 5000. and 19000. respectively in PRIMB. Ideally they should be linked to the dynamic concentrations in the compartments.

DPVAR differential of pelagic state variable

DEVAR differential of epibenthic state variable

DBVAR differential of benthic state variable. At present, for the sake of simplicity, all material is deposited in the intertidal zone (BLCI, BICI or BRCI). Future modifications to the model should distribute some of this material subtidally taking into account the relative areas, depths and current velocities of the subtidal and intertidal areas.

SDRATE sedimentation rate

$$\text{SDRATE} = \text{RELSED} * \text{SILSED}$$

SILSED is the silt sedimentation rate which is set at 3 m day<sup>-1</sup> in ENV DAT. Purely organic particles will settle at a slower rate because of lesser density. Assuming that the density of silt is 2.6 (Danny Andrews, unpublished data from Pecks Cove) and that of organic particles is 1, the rate would be SILSED/2.6. However the rate of sedimentation (RELSED) relative to sediment is presently set at 1.0 for all particles based on the assumption that most of the sedimenting organic material is associated with sediment particles.

RSRATE resuspension rate

$$\text{RSRATE} = \text{RELSUS} * \text{SILSUS}$$

RELSUS is the resuspension rate relative to that for sediment. Organic particles will be easier to resuspend because of lesser density. Using the same assumptions as used for sedimentation rate, the rate becomes SILSUS\*2.6 where SILSUS is the silt resuspension rate which is set at 0.1 m day<sup>-1</sup> in ENV DAT. It is assumed constant for all types of organic particles. Particle size is not taken into account. However, assuming that any particulate organic carbon is resuspended in association with sediment particles RELSUS is presently set at 1.0.

SILSTC probability that sedimented particles will stick to the bottom. At present its value for these three calls is the same as for silt, 0.1.

FLAG dummy variable which must be set at -1 for all calls to SEDRES other than for silt transport.

### 2.7.2.2 Erosion

The benthic state variables BICI and BRCI are eroded like silt (See Section 2.3.5.4.3). The turnover time of BICI is very short relative to the time scale of erosion, therefore the amount eroded would be insignificant and is not calculated.

$$\begin{aligned} \text{DBICI(I)} &= \text{DBICI(I)} - \text{ERODED*ERODIC} \\ \text{DBRCI(I)} &= \text{DBRCI(I)} - \text{ERODED*ERODRC} \end{aligned}$$

ERODIC is the concentration of BICI in the sediment.

$$\text{ERODIC} = \text{BICI(I)/BSILT(I)}$$

ERODRC is the concentration of BRCI in the sediment.

$$\text{ERODRC} = \text{BRCI(I)/BSILT(I)}$$

The eroded BICI and BRCI is added to the PIOC and PROC in the same compartment.

$$\text{DPIOC(I)} = \text{DPIOC(I)} + \text{ERODED*ERODIC*AMLW(I)/VOLMLW(I)}$$

$$\text{DPROC(I)} = \text{DPROC(I)} + \text{ERODED*ERODRC*AMLW(I)/VOLMLW(I)}$$

### **3. Model Output**

#### **3.1 Introduction**

Over the course of this modelling exercise the model was run hundreds of times in its varying forms. Early in 1986 it was agreed to document the model as it existed at that time. This was not a trivial decision. Many people involved in the exercise still had lists of modifications they wanted to try. Nevertheless a cutoff date was chosen and the model at that stage is documented here. Two simulations of that model were run; one for 360 days (1 year) and the other for 1080 days (3 years). Following is the output from these two simulations and a critical assessment of the performance of the model based on these runs.

## 3.2 Assessment of model output

### 3.2.1 Physical Submodel

#### 3.2.1.1 Salinity (SALT)

Salinity is modelled solely as a check on the performance of the water-like transport of the model. At present this state variable is not utilized in any other subroutine. The variation of salinity in the compartments of the model is controlled by its value at the boundaries, the exchange coefficients for transport between model elements and the freshwater flows at Boundaries 5 and 6. Salinities for the boundaries were obtained from the anchor stations at Cape Enrage (Boundary 4) and Shepody Bay (Boundary 6) occupied on five occasions from June 1978 to February 1980 and from 17 helicopter surveys of Cumberland Basin (Boundary 5) in 1979 and 1980. Exchange coefficients were calculated from the salinity distributions derived from the anchor station and helicopter survey data and freshwater discharge estimates derived from flow data for the Kelley and Salmon Rivers and the work of Holloway (1981). This simulation was run using the mean exchange coefficients for the anchor station periods and the calculated freshwater discharge data for 1978.

There is reasonable agreement between the model output and the available data (Figure 3.1). Salinities from samples collected at high tide at the mouth of Cumberland Basin should be representative of Compartment 3 and samples collected at low tide of Compartment 2. The generally lower values for salinity from the helicopter survey data from the mouth of the Basin reflects the general unreliability of this data set which was obtained with a portable YSI salinity meter. On many occasions the meter was not properly calibrated. Data in Compartment 1 for calculation of the exchange coefficients were obtained by correcting the helicopter data by comparison with data from the anchor stations and field experiments at Pecks Cove. There is one reliable data set from a helicopter survey of the Basin conducted on April 10, 1985. Data for both Compartment 1 and 2 are in excellent agreement with the model output.

The uncertainty in the value of the exchange coefficients is a problem which is basic to the modelling of all state variables which are transported like water but it is particularly apparent in the salinity results. The model uses average exchange coefficients calculated from four sets of data (Keizer and Gordon, 1985) for which exchange coefficients vary by an order of magnitude. The data base is not sufficient to determine whether the variation is due to errors in estimating compartment and boundary salinities and freshwater discharge rates or reflects real changes in rates of exchange. It is highly probable that exchange coefficients vary as a function of tide height, freshwater discharge rate and wind stress but the magnitude of the variation is unknown.

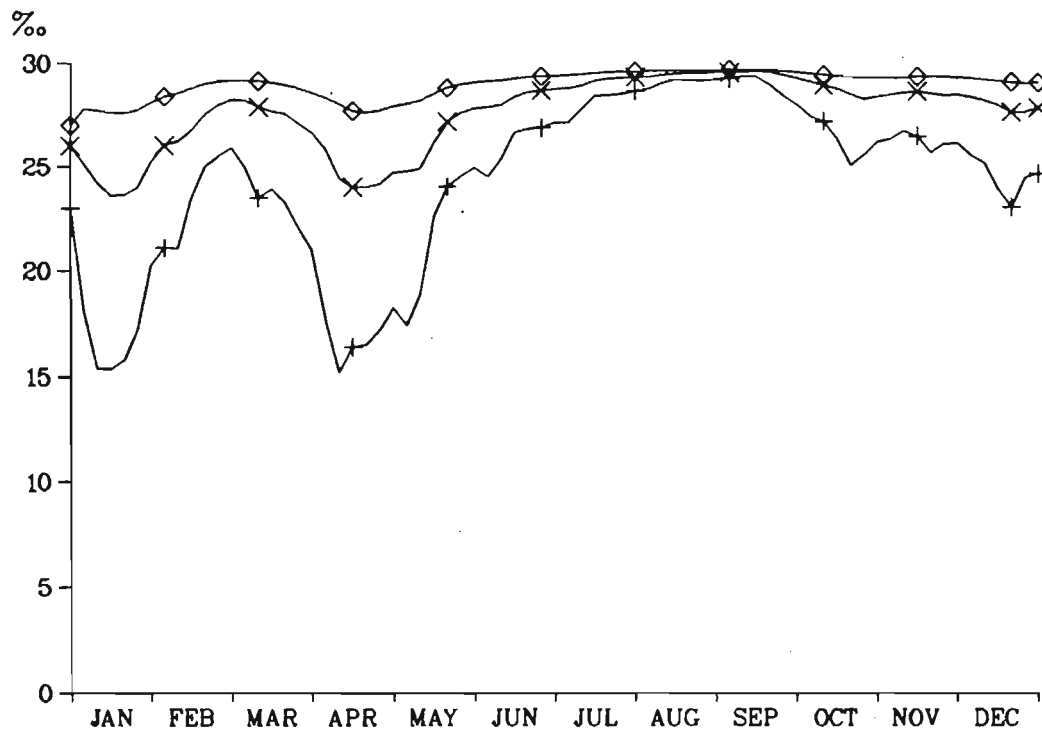


Figure 3-1. Model output for SALT (salinity).

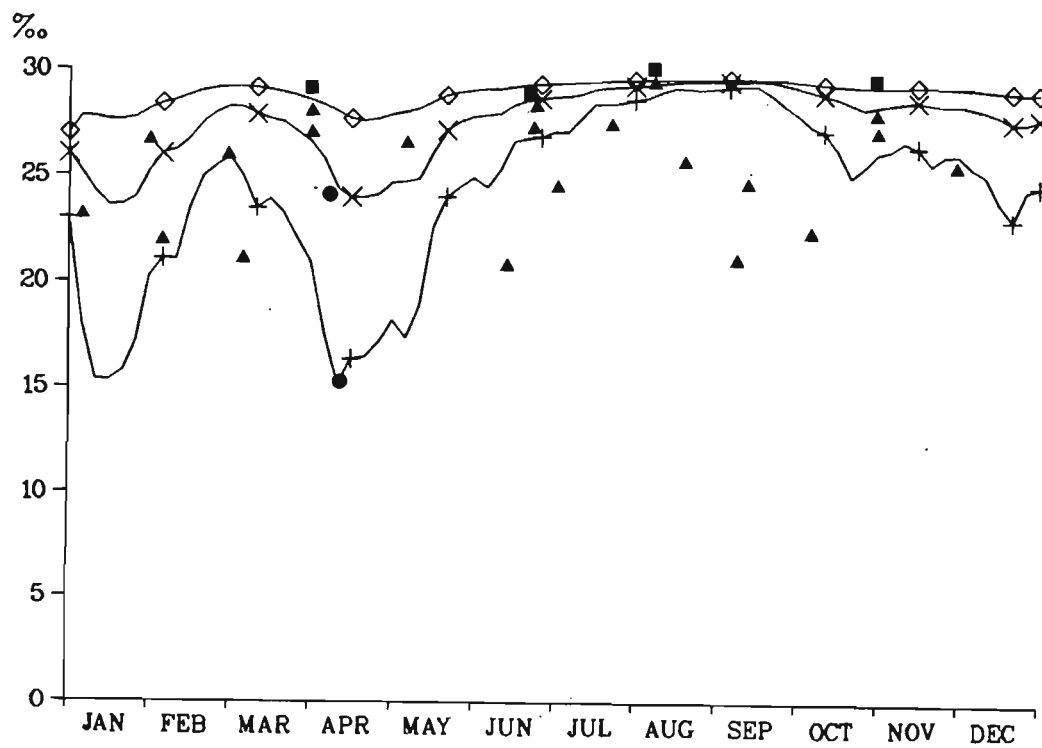


Figure 3-2. Model output with calibration data.

### 3.3.1.2 Silt (PSILT, ESILT, BSILT)

The transport of silt and silt-like substances is modelling using an algorithm described in Ebenhoeh (1985). The basis of the algorithm is the observed net upstream transport of suspended sediment due to the asymmetry in tidal currents coupled with the observed rates of accretion and erosion of sediment from the intertidal zone.

To facilitate coding of the algorithm, silt is divided into three components; pelagic silt (PSILT) which corresponds to the experimentally determined suspended sediment concentration (SSC), epibenthic silt (ESILT) which represents the high concentration of suspended silt close to the bottom of the water column, and benthic silt (BSILT) which is the sediment which accretes on and erodes from the intertidal area. The silt transport submodel was tuned so that PSILT concentrations matched observed SSC and BSILT accumulated at approximately  $6000 \text{ g m}^{-2} \text{ y}^{-1}$  or about  $3 \text{ mm y}^{-1}$ .

As expected there is a very good agreement between data from the anchor stations and the model output for Compartments 2 and 3 (Figure 3.3). Data from the helicopter survey are consistently lower than the model output since the data are for surface water samples and the model output is a depth averaged concentration. SSC increases with depth (Amos and Asprey, 1981) particularly at slack water when these samples were collected.

It is difficult to compare the data for Compartment 1 from the helicopter surveys with the model output. In the shallow and narrow channels of this compartment, the downwash from the helicopter resuspended surface sediments resulting in anomalously high SSC being determined. At the deepest station in this compartment, SSC was consistently much lower than the mean for the four stations in the compartment. The modelled concentrations of PSILT for Compartment 1 are probably too low but without additional data further tuning of the model is not justified.

Another factor which must be considered is the temporal variation in SSC. Seasonal variation appears to be modelled adequately (Figure 3.3). On a shorter time scale, SSC varied by almost a factor of 50 over a 39 hr period at the mouth of Cumberland Basin (Figure 3.4). There is a strong tidal periodicity in this variation. The interaction of this periodicity with the solar and tidal cycles in controlling the PAR for phytoplankton has not been considered. Consideration should be given to using a stochastic expression for the calculation of PSILT because of its highly variable nature.

There are no field data for concentrations of ESILT. It is essentially a conceptual state variable representing a sink of suspended sediment near the bottom of the water column. The seasonal variation (Figure 3.5) is the inverse of PSILT (Figure 3.3) so that in winter ~30% of the silt in the water column is ESILT while in the summer it is 85%. Sedimentologists (Amos, Kranck and Eisma, personal communications) feel that this is a reasonable representation of the silt dynamics.

The areal concentration of BSILT (Figure 3.6) is a product of the net upstream flow of silt from eroded shores and channels in Chignecto Bay. Based on the rate of rise of sealevel and burial of historical artifacts in the Basin, it is estimated that there is a net annual deposition of approximately 3mm of sediment ( $\sim 6,000 \text{ g BSILT m}^{-2}$ ) in the intertidal areas of Cumberland Basin. Data from Pecks Cove (Gordon and Desplanque, 1983) indicate that there is an excessive buildup of sediments in the summer months which is subsequently eroded by the fall storms and winter ice. The sedimentation, resuspension and erosion parameters of the model have been tuned to this net deposition figure.

The major problem with the modelling of silt (PSILT, ESILT and BSILT) is the correspondence of model and environmental parameters. Parameters have been defined (Ebenhoeh, 1985) in such a manner that they are related to a measurable variable but for the most part data are unavailable. Therefore, while tuning has generated the desired model output for silt, the values of the parameters may be wrong and therefore the silt-like transport of other substances may result in improper distributions. Only extensive laboratory and field experimentation can provide the data necessary to evaluate the parameters of this part of the model.

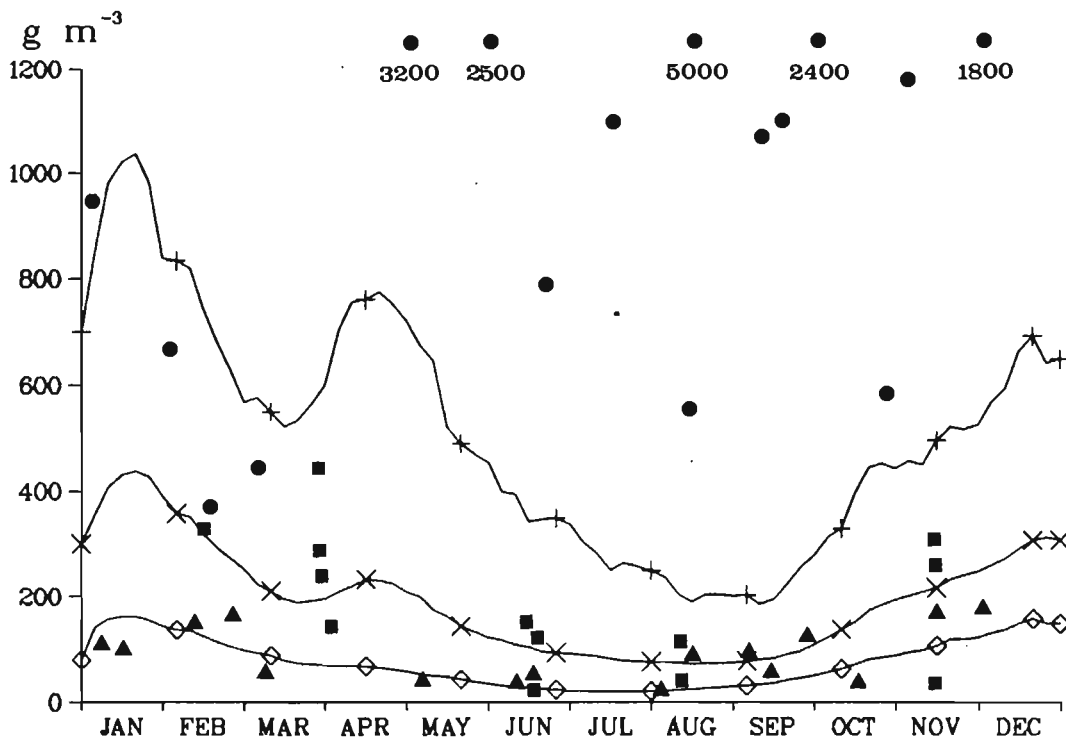


Figure 3-3. Model output of PSILT.

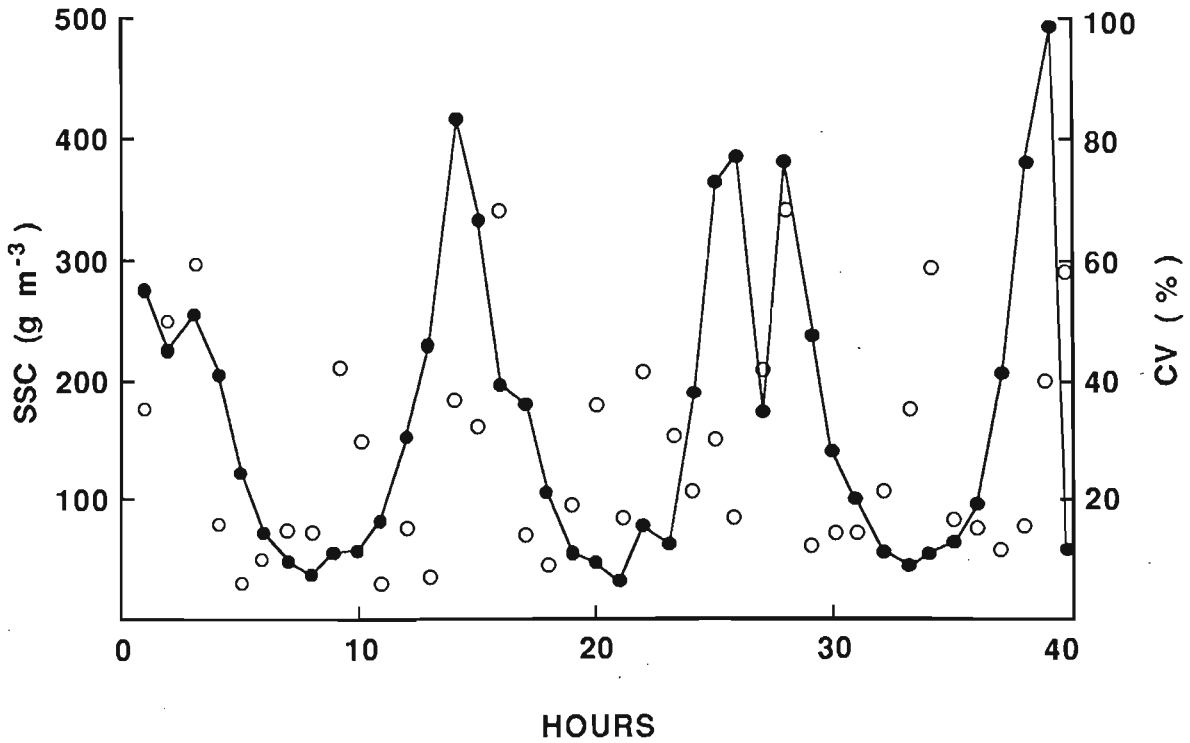


Figure 3-4. Suspended sediment concentrations for 40 h at the mouth of Cumberland Basin.

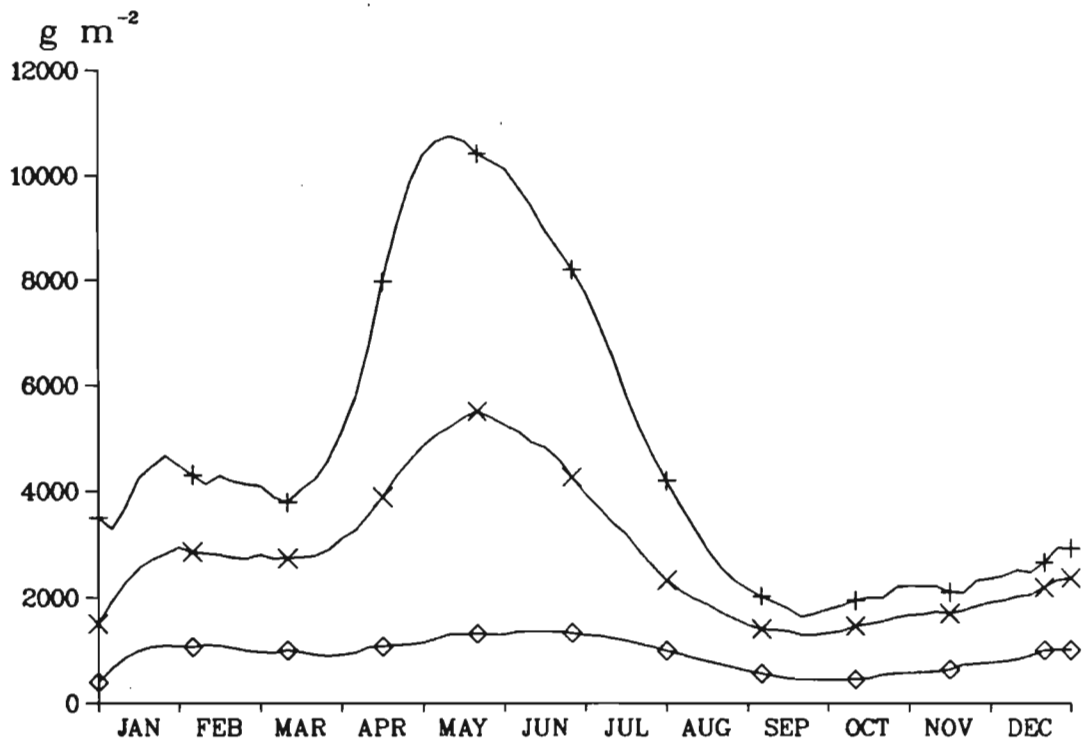


Figure 3-5. Model output of ESILT.

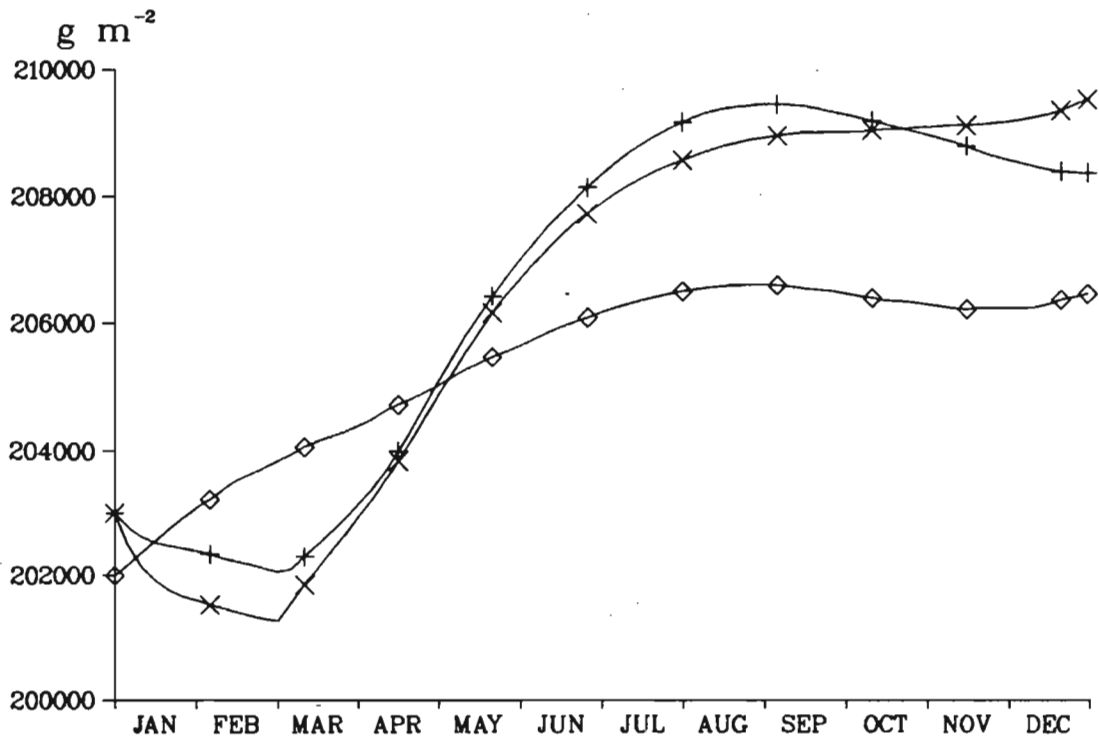


Figure 3-6. Model output of BSILT.

### 3.2.2 Pelagic Submodel

#### 3.2.2.1 Phytoplankton (PHYT)

Phytoplankton biomass shows very strong seasonality (Figure 3.7). It is greatest in late summer when water column turbidity is lowest (Figure 3.3) and drops to very low levels in winter. High turbidity prevents a spring bloom. During the time of maximum biomass, concentrations decrease in the seaward direction, although differences between Compartments 1 and 2 are slight. Net production follows a seasonal cycle very similar to biomass but values increase seaward because of increasing light availability. Net phytoplankton production, calculated using the mean depth of each compartment, is 15, 48 and 86 mg C m<sup>-2</sup> y<sup>-1</sup> for Compartments 1, 2 and 3, respectively.

There is good agreement between model output and available calibration data (Fig. 3-7). The latter are obtained, using a carbon to chlorophyll ratio of 40 based on data summarized by deJonge (1980), from chlorophyll measurements in surface water samples collected along the axis of the Cumberland Basin by helicopter. The seasonal cycle is well represented although the model values are generally lower than calibration data.

The seasonal cycle of net production is very similar to that observed over a two year period in water flooding the Pecks Cove mudflat (Compartment 2) except that the peaks occur in August (Fig. 3-7) instead of June/July (Hargrave et al. 1983). Daily values of net production in the summer are identical to those observed by Hargrave et al. (1983). Values for the rest of the year tend to be somewhat less than measured by Hargrave et al. (1983) at Pecks Cove and by Prouse (1983) in Chignecto Bay and the mouth of Cumberland Basin.

The annual net phytoplankton production in Compartment 1, 15 mg C m<sup>-2</sup> y<sup>-1</sup>, is exactly that estimated by Prouse et al. (1984) for Cumberland Basin. Values for Compartments 2 and 3, 48 and 86 mg C m<sup>-2</sup> y<sup>-1</sup>, are substantially higher than estimated earlier from very limited data by Prouse et al. (1984). Although the earlier estimates may have been too low, these values are thought to be too high by a factor of at least two, especially in Compartments 2 and 3. Estimates of annual phytoplankton production in the Dollard, which is not as turbid as Cumberland Basin, are in the range of 40-80 mg C m<sup>-2</sup> y<sup>-1</sup> (Colijn, 1983).

A number of factors can contribute to errors in PHYT. Because of the high susceptibility to water transport, boundary conditions are very important. These are based upon measurements of chlorophyll. A constant carbon to chlorophyll ratio of 20 was used instead of 40 because it was felt that much of the "chlorophyll", measured by fluorescence, is not functional phytoplankton chlorophyll (Brown et al. 1981), especially in Boundary 5. Assuming a constant carbon to chlorophyll ratio also introduces errors as great as 50% (deJonge, 1980). The values measured in Boundary 5 were scaled down because of resuspension when samples were collected by helicopter.

The parameters governing phytoplankton growth are taken from the literature except for the half saturation constant which is set at a value of 25. This was originally set at 20, a value derived from the P-I curves measured by Prouse (1983). It was increased during tuning to give more realistic biomass and production values.

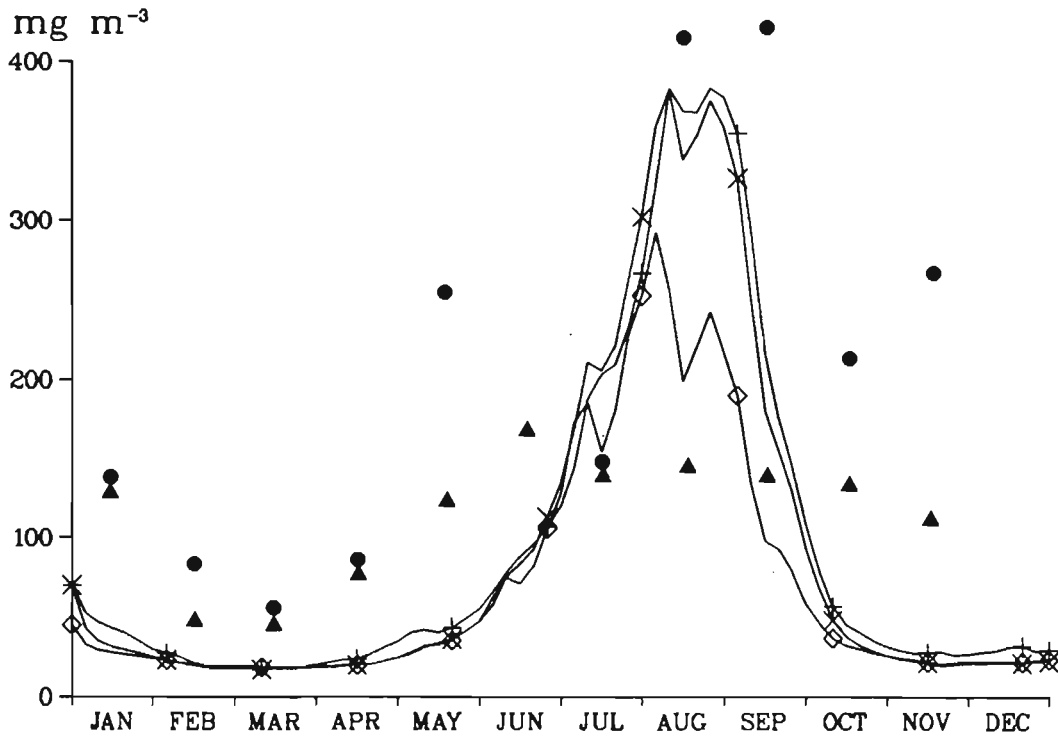


Figure 3-7. Model output for PHYT (Pelagic phytoplankton).

### 3.2.2.2 Pelagic bacteria (PBAC)

Pelagic bacteria biomass peaks in late August (Fig. 3-8) just after phytoplankton biomass and production reach their highest values. This close relationship reflects the dependence of PBAC on the labile organic carbon excreted by phytoplankton which is well documented in the literature (van Es and Meyer-Reil, 1982). Concentrations decrease seaward at all times of the year. The annual production, calculated using the mean depth of each compartment, is 40, 69 and 109 mg C m<sup>-2</sup> y<sup>-1</sup> in Compartments 1, 2 and 3, respectively, which is greater than the phytoplankton net production.

The PBAC biomass simulated by the model is 2-10 times greater than the available calibration data (Fig. 3-8). The latter are based upon direct counts of water samples collected by ship near the mouth of Cumberland Basin (Cammen and Walker, 1982) and by helicopter along its axis (Cammen and Walker, unpublished data read from notebook) assuming each cell contains 10 E-14 g C (Cammen and Walker, 1982). The calibration data do show a seasonal cycle in Compartment 1 very much like that generated in the model in all three compartments. However, bacterial counts in the water flooding the Pecks Cove mudflat (Compartment 2) show little seasonal variation and ranged between 13 and 30 mg C m<sup>-3</sup> (Cammen and Walker, 1986).

Data from the general scientific literature also indicate that PBAC biomass simulated by the model is too high. The review by van Es and Meyer-Reil (1982) reports maximum bacterial concentrations of 200 mg C m<sup>-2</sup> in eutrophic estuaries while Sorokin (1978) reports a range of 10-100 mg C m<sup>-2</sup> in polluted estuaries and lagoons. Standing stock of bacterial carbon is generally 10-40% of the phytoplankton biomass (Ducklow, 1983).

PBAC production has a seasonal curve similar in shape to biomass with maximum values occurring in August. The shape of the curve seems reasonable for Cammen and Walker (1982) report that heterotrophic activity is greatest in the summer when temperature is highest. Since the PBAC biomass is clearly too high, the production values are probably inflated as well. It seems unreasonable for bacterial annual production to exceed that of phytoplankton, especially in Compartment 3 where turbidity and non-living organic carbon concentrations are lowest. Ducklow (1983) reports that bacterial production averages about 5-30% of net phytoplankton production in coastal waters.

There are numerous sources for possible error. Although the values in Boundary 5 may be questionable because of adjustment to correct for resuspension during sampling by helicopter, the boundary conditions do not appear to be a serious source of error at present because the model quickly generates much higher values. The problems must be internal and probably reflect either an overabundance of food (ie. too much PLOC) or too high a specific growth rate. The latter currently equals 1 at 10C with a Q10 of 2 which falls right in the range of generation times summarized by van Es and Meyer-Reil (1982) and Ducklow (1983). However, it is currently assumed that all bacteria are active while van Es and Meyer-Reil (1982) conclude in

their review of the literature that only 6-60% of the bacterial standing stock is active. More realistic bacterial biomass and production values would probably be obtained if only about 30% of the bacteria were set as being active in the model. Also at present 40% of the carbon taken up is assimilated. This figure is much too high, a more reasonable value being 20%.

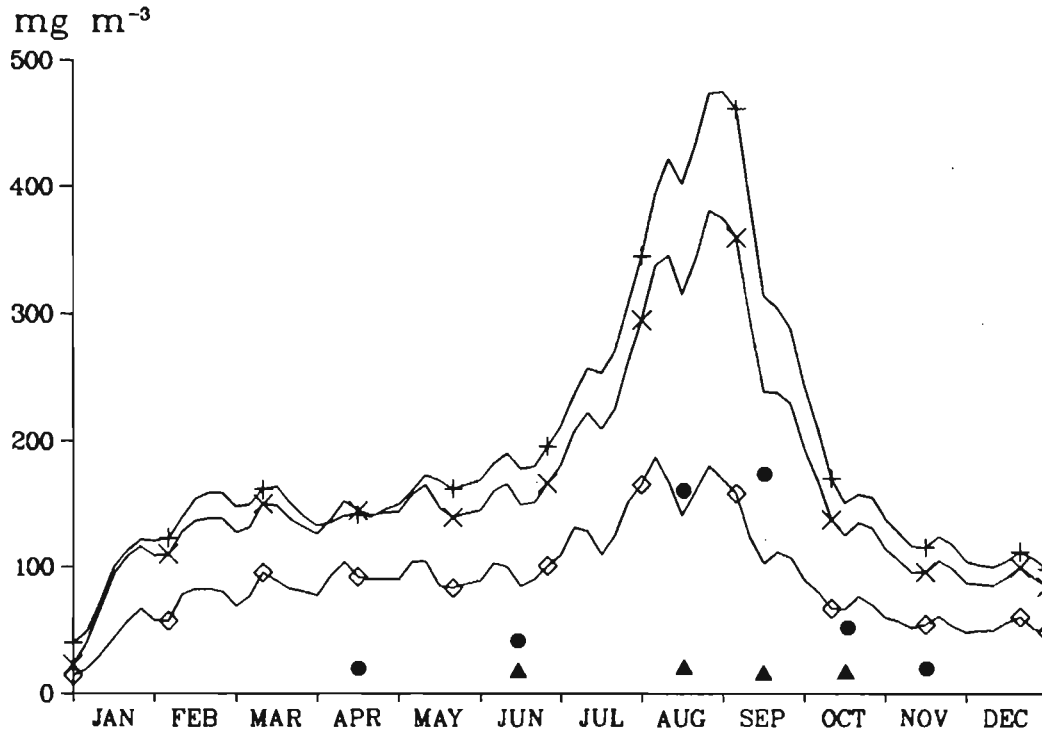


Figure 3-8. Model output for PBAC (Pelagic bacteria).

### 3.3.2.3 Herbivores (PHER)

The seasonal pattern of herbivore biomass (Fig. 3-9) is more or less as expected, with relatively high values in late winter and early spring, and very low values in mid- to late summer. We do not have full seasonal data for Cumberland Basin, but a similar pattern is evident in the Cornwallis Estuary for which biweekly data are available (Brown, 1984). Both our Cumberland Basin (Daborn, 1984) and the Cornwallis data suggest that peak biomass occurs in winter, and is followed by a steep drop during the spring as older and larger individuals decline and are replaced by young of the spring generation (Crawford and Daborn, 1986). The sharp drop in mid-summer biomass is attributable to predation by carnivores and detritivores, both of which peak at this time. The depression of herbivore biomass is also coincidental with the rapid and extensive growth of phytoplankton biomass, suggesting a strong linkage between these two variables. The biomass levels in the three compartments are, however, the reverse of what was expected. According to Brown (1984), and the data from the Dawson cruises of 1978-1980, the more turbid waters generally exhibit higher biomass of copepods (etc.) than the clearer waters to seaward (Daborn, 1984). This is assumed to be a consequence of the protection from predation by visual predators (such as fish) afforded by high silt levels.

Implicit in these observations is the assumption that the herbivores as a group are able to subsist and grow on the bacteria-organic matter complex associated with suspended silt, and that they are really micro-omnivores. This assumption is supported by many published studies (e.g. Poulet 1976, Paffenhofer and Harris, 1976), and our own observations of stomach contents and fecundity of zooplankters in the Cornwallis Estuary (Crawford and Daborn, 1986). The model, however, is not behaving that way since biomass levels in the less turbid Chignecto Bay are much higher than in Cumberland Basin. Added to the close coupling noted between the herbivores and phytoplankton, it seems likely that we have modelled the herbivores as having too high an affinity for phytoplankton and/or too low a utilization rate for bacteria and PIOC. The sharp decline in biomass in upper Cumberland Basin, following a higher initial value supports this interpretation. Given that PHER has been modelled as if it consisted entirely of copepods and PBAC strictly as heterotrophic bacteria without any self-feeding or cannibalism, it is obvious that we have overlooked a potentially important group, the heterotrophic flagellates. Recent studies in estuaries (Kremer and Nixon, 1978; Rheinheimer, 1977) suggest that these are very important, although they are commonly overlooked. It seems more appropriate for the Cumberland Basin modellers to regard these as part of the PHER variable, in which case the extent to which PHER feeds on PBAC and PIOC should probably be increased at the expense of its dependence on PHYT.

Absolute biomass values attained in the model are rather higher than the sporadic field data indicate. On the positive side, however, this portion of the model is stable: end of year biomass values after two and three years are almost identical. Given the availability of food sources that are not fully utilized (e.g., the bacteria), the paucity of field values, and the trophic flexibility of the "herbivores", there seems no reason at

this stage to adjust biomass levels other than to reverse the values within the three compartments.

In Compartment 3 respiration exceeds gross production. The rise in biomass at the end of Year 1 is due to the transport inward from the Boundary 4 where the concentrations of PHER are too high. Production estimates range from 52-56  $\text{mg C m}^{-3} \text{ y}^{-1}$  in Compartments 1 and 2. These values yield P/B ratios of 17.8 for Compartment 1 and 14.5 for Compartment 2 which are well in line with other published values (e.g., Mann, 1982) although somewhat lower than those (24-33) found by Burkill and Kendall (1982) for the Severn Estuary. It is probable that adjustment of bacteria utilization rates would increase the P/B ratio appropriately. Since these ratios are derived from the model rather than explicitly included, they represent a useful internal validation of the model.

The three year run shows that peak PHER values increase in each successive year, and the timing of the peak in Compartment 1 advances from about Day 140 (Year 1) to Day 80 (Year 2) and Day 60 (Year 3). These earlier dates correspond with field observations from the Cornwallis Estuary, and suggest that the model is at least settling down in terms of seasonality .

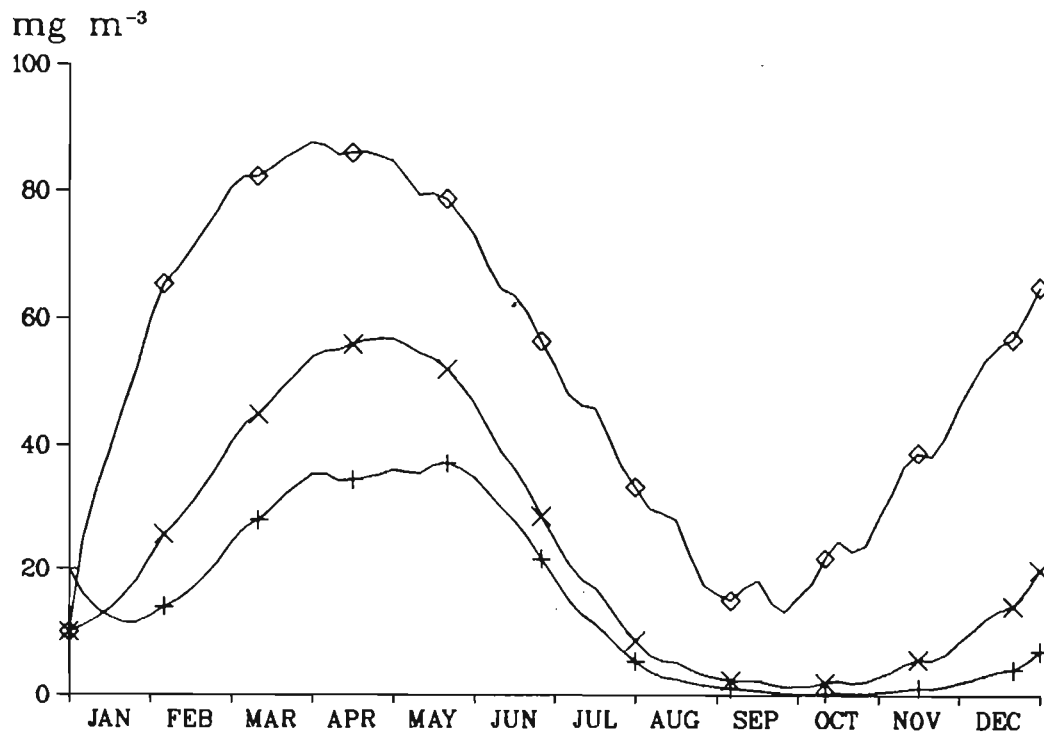


Figure 3-9. Model output for PHER (Herbivores).

#### 3.3.2.4 Detritivores (PDET)

Biomass of epibenthic/pelagic detritivores exhibits a strong seasonal pattern with relatively low winter values in all compartments, a sharp rise in summer, particularly in the inner turbid regions, and an even more precipitous decline in August and September (Fig. 3-10). The latter is coincident with the peak abundance of migratory fish, and reflects the fact that we have coupled these two variables very tightly. Although originally this group was considered to be a major processor of PIOC, it is now also being fed phytoplankton and bacteria, and the mid-summer rise in biomass may partly reflect their increased abundance. When the available phytoplankton is reduced from 0.2 to 0.1 and the available bacteria increased from 0.03 to 0.1, the peak biomass of PDET increases by about 10%, the phytoplankton biomass increases by nearly 20%, and there are slight increases in both the bacteria and carnivores. The herbivores remain essentially unchanged. It is apparent that the detritivores exert a significant impact on phytoplankton.

Peak biomass values in the first year of 50-150 mg C m<sup>-3</sup> seem reasonable. The only data available (20-40 mg C m<sup>-3</sup>) (Prouse, 1984 and 1986) suggest that these values are appropriate, particularly since his collections of mysids may have underestimated biomass because of the tendency for older and larger mysids to remain close to the bottom of the estuary during the day (Crawford, personal communication). Winter values, however, are probably too low. The relative biomass values in the three regions correspond with our general conception that mysids and crangonid shrimp are much more abundant in the turbid portions of the estuary, which has recently been confirmed for the Cornwallis Estuary (Crawford, personal communication).

Production values calculated on the first year run are far too high for organisms of such size, yielding P/B ratios of 40-60. Respiration rates are perhaps a little low at 47-48% of gross production, but the very high P/B values probably arise from unrealistic conversion rates of available food, combined with high availability (0.8) as prey to the migratory fish.

This state variable has always been a difficult one for us to model. It represents a group of larger invertebrate omnivores, including mysids, crangonids, and gammarid crustaceans, that undoubtedly feed extensively on each other as well as detritus and smaller zooplankters. Generation times range from a few weeks in the case of the gammarids to a year for crangonids. Basing rates of turnover on intermediate-sized organisms such as the mysids should provide a reasonable average response time, and increasing the degree of self-limitation to represent cannibalism and/or interference should diminish the high peak at the end of July in Year 1 and allow for an increase in mid-winter biomass.

The three year run, however, shows a dramatic decline in PDET peak biomass in the second and third years: e.g., maximum biomass values are 143, 40 and 18 mg C m<sup>-3</sup> for Years 1-3 respectively in Compartment 1, and similar declines occur in the other two compartments. Winter values in

each year are also approximately one half of the preceding year. Thus, the biomass values in subsequent years fall well below those inferred as occurring in the field. Of their potential food sources, peak values of PHYT, PBAC and PHER progressively increase in the three years, whereas their predators, PCAR and PMFH, both decrease in annual peak biomass. The resident fish, however, undergo substantial increases in biomass over the three years, and since availability of PDET to this group is high (0.8), continued predation by resident fish, particularly over winter months, may be the reason for the steady decline in PDET biomass levels. Consequently, the modelling of PDET seems to be crucial to the equilibrium of the whole model, and much remains to be done to improve it.

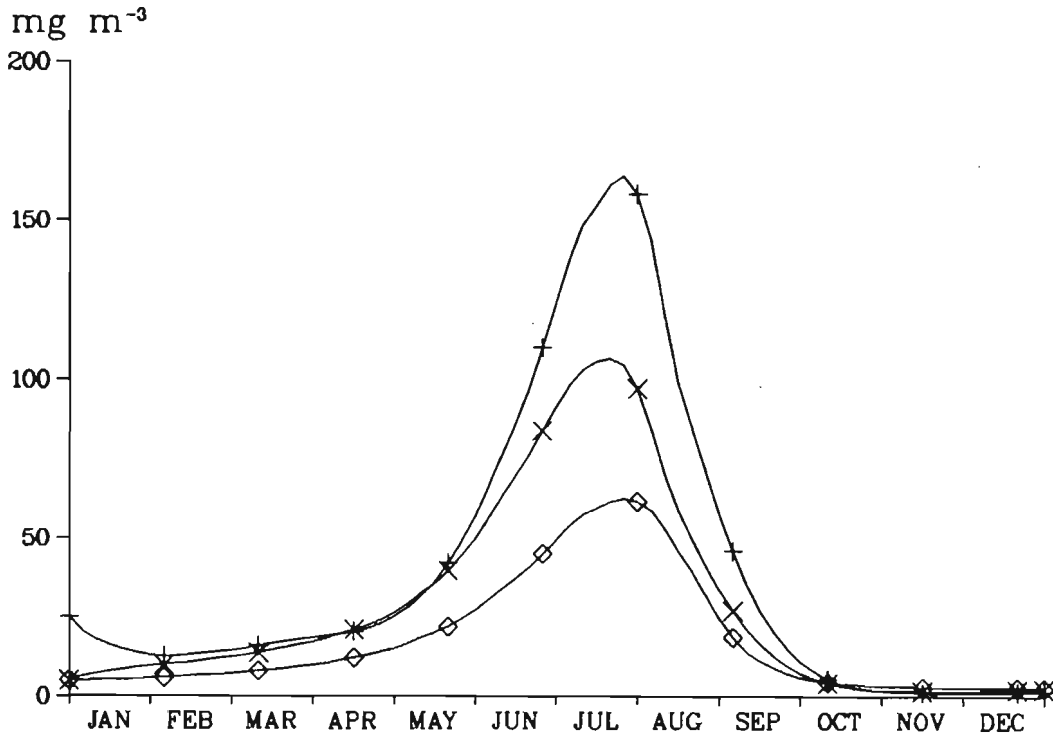


Figure 3-10. Model output for PDET (Detritivores).

### 3.3.2.5 Carnivores (PCAR)

The carnivores have been viewed as a diverse set of largely contact predators that enter Cumberland Basin from the sea and are not resident over the winter. They include chaetognaths, ctenophores, jellyfish and some large predatory copepods. They exhibit a single peak ranging from 25 to 45 mg C m<sup>-3</sup> about Day 220 in the first year (Fig. 3-11), but the three year run indicates the peak occurring earlier (around Day 180) and at much diminished values (15-20 mg C m<sup>-3</sup>) in the next two years. This probably reflects changes in their food supply, particularly a shift from PDET to PHER in the subsequent years.

The sequence of events is as expected, with carnivores arriving from the seaward end in March and April, and being advected into the inner compartments. Rapid growth and higher densities attained in Compartments 1 and 2 are attributable to greater temperatures and increased densities of PDET which are available as food. By the end of the year, biomass of carnivores has decreased satisfactorily through predation and natural mortality, without the group completely disappearing. Its decline during the second and third years probably reflects changes in PDET biomass which forms the bulk of the carnivores' food.

As with PDET, production estimates and maximum biomass values during the first year are far too high, giving P/B ratios of 55-65. They should be less than 10 (Valiela, 1984), and undoubtedly are much lower in the second and third years. Apart from this, this variable seems to be behaving within reasonable limits, although there are no suitable calibration data for comparison.

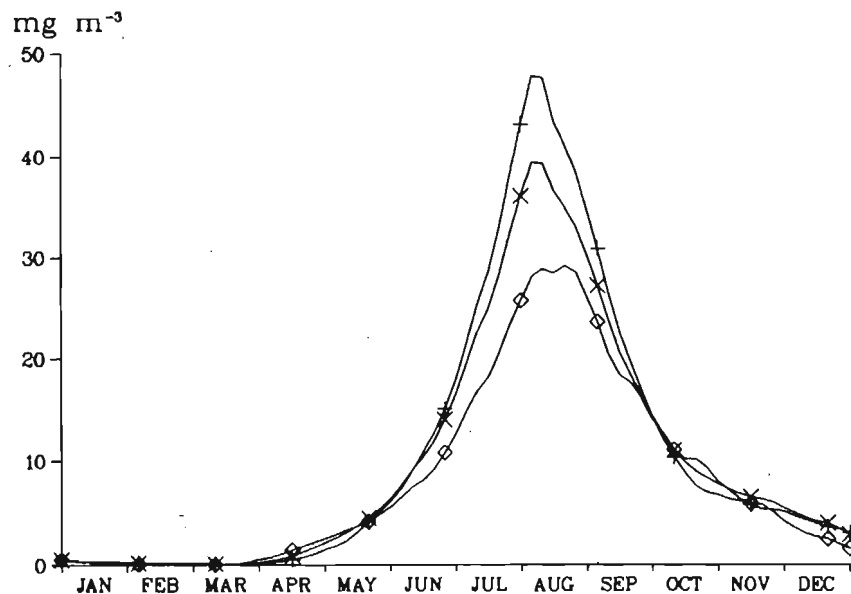


Figure 3-11. Model output for PCAR (Carnivores).

### 3.3.2.6 Pelagic fish larvae (PFLR)

The fish larvae constitute a minor variable that represent larval production by resident fish. We have no suitable calibration data, but the present maximum biomass values of  $<1 \text{ mg C m}^{-3}$  in all three compartments (Fig. 3-12) may be a little too low (Williams, Redden and Brown, unpublished data). Natural mortality of this group is set high (10% per day) which, with development to become juvenile fish (and hence part of PRFH), leads to rapid reductions in larval fish biomass values when spawning ceases in July. This group feeds only on herbivores and is assumed to represent a mixture of tomcod, flounder and silversides larvae, all of which tend to switch to feeding on larger organisms as they mature. Consequently, we may be in error in not allowing them at present to feed on the detritivores.

The three year run shows fish larvae biomass increasing each year in correspondence with increasing resident fish biomass (PRFH). In general, this variable is of minor consequence to the stability of the whole model and behaves in a reasonable manner. It is an important reflection of our own lack of data on Cumberland Basin that we are unable to assess the accuracy of biomass levels.

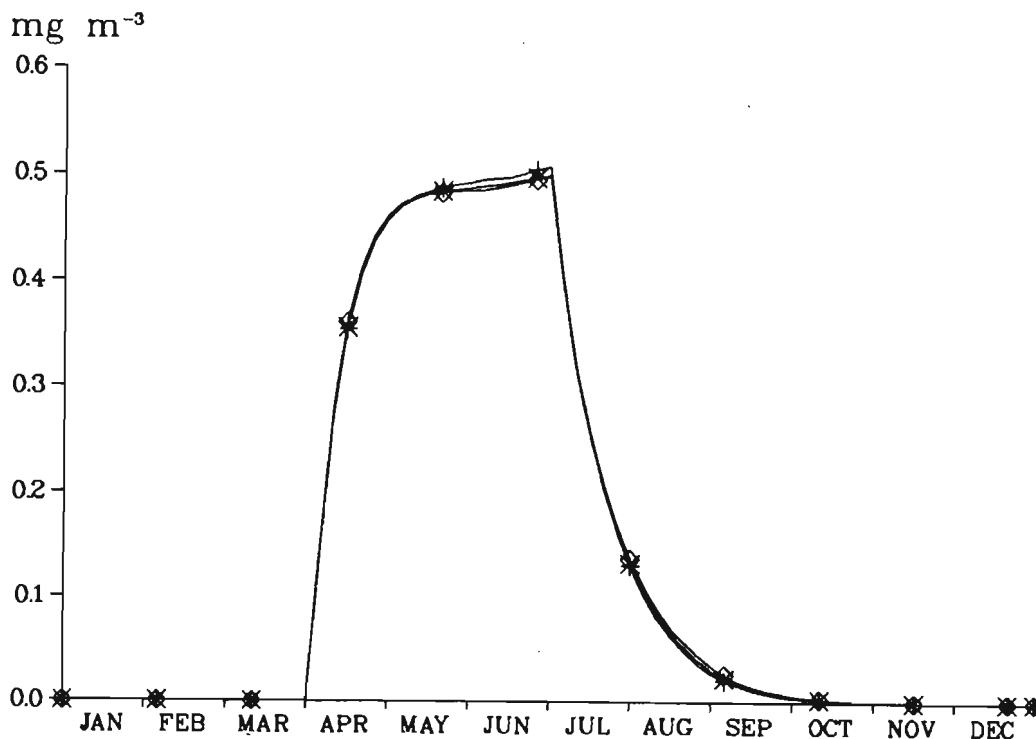


Figure 3-12. Model output for PFLR (Pelagic fish larvae).

### 3.3.2.7 Resident fish (PRFH)

The resident fish of Cumberland Basin (Fig. 3-13) include such species as tomcod, flounder, silversides and smelt. They interact directly with the benthos by feeding on intertidal deposit feeders (BDFI) and meiofauna (BMEI) during summer, and subtidal resources (BMES, BDFS and BSUS) primarily during the winter months. The group should be a relatively important stabilizing force within the model, since it has available to it so many different food sources. In fact, the three year run shows that biomass of resident fish increases by 37-43% by the end of each year. This may well be a response primarily to the explosion of benthic deposit feeders which are highly available to resident fish and which more than double in biomass each year.

Two errors are apparent in the code. The availability of intertidal deposit feeders is set at 70% of the benthic biomass which is calculated per unit area of the intertidal zone, but this is assumed to be available to each cubic meter of water overlying the intertidal zone. A correction for water depth is included in order to calculate differentials of benthic biomass, but not in restricting the resident fish from having access to 70% of the potential prey. Correction for the reduced time for feeding is already included. The second error is in our assumption that resident fish do not leave the area. We have here confused two issues: a group of largely pelagic feeders that do migrate (PMFH), and a group of largely benthic feeders that do not. In reality many of the flounder and tomcod probably leave the Basin and may not return in the next year.

Because of the high levels of production, P/B ratios of 6-7 result from the first year run, which are too high. The increasing biomasses of subsequent years might lower this somewhat, but we are probably also overestimating the net production of this group. At present respiration rates are about 64% of carbon assimilated, which is probably too low since it leaves 25% of food uptake to be added to the fish biomass. Adjustments of these coefficients will undoubtedly reduce the P/B ratio to a more reasonable level and assist in stabilizing this group.

This variable was largely unaffected by changes in PDET biomass resulting from adjustments in the availability of phytoplankton and bacteria, despite the relatively high availability (0.8) of detritivores. This indicates that it is the benthic biomass values that drive the present fish, and hence adjustments to the benthic subroutine are expected to be more effective in stabilizing this variable.

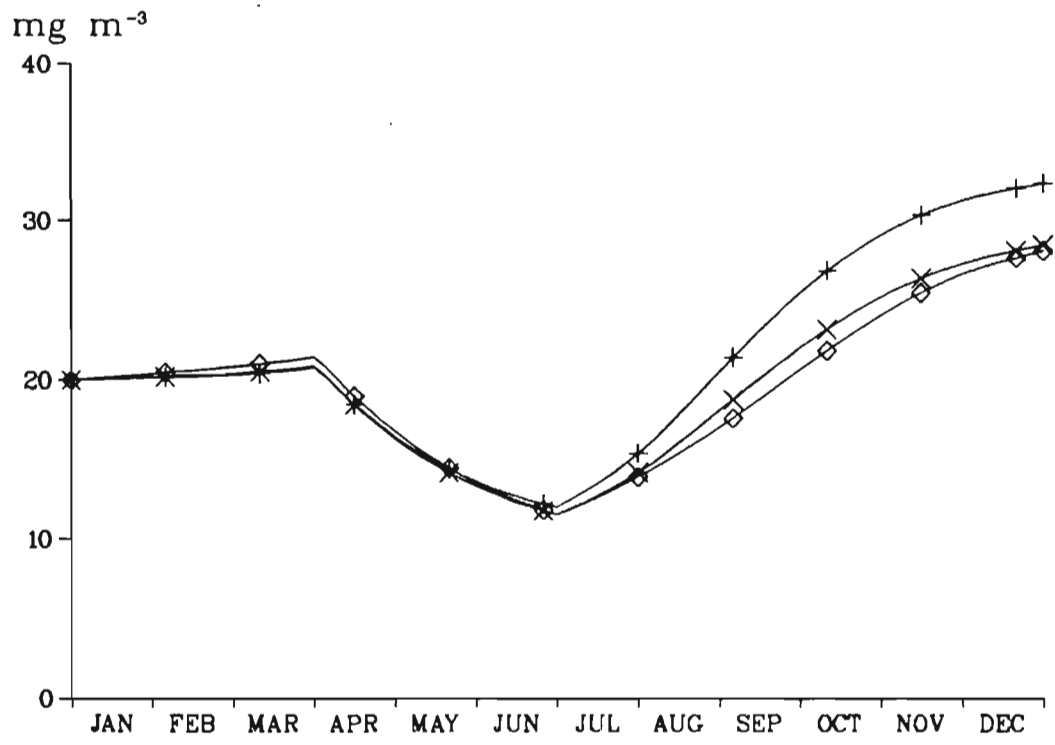


Figure 3-13. Model output for PRFH (Resident fish).

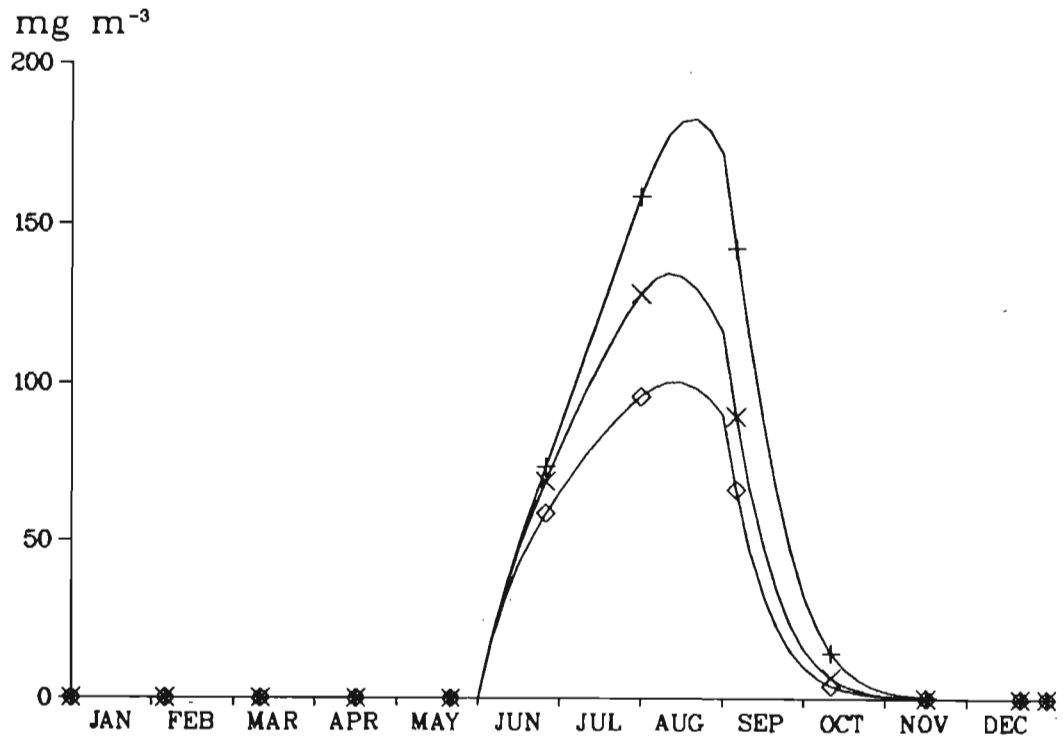


Figure 3-14. Model output for PMFH (Migratory fish).

### 3.3.2.8 Migratory fish (PMFH)

The migratory fish are modelled primarily with the alosids (shad, river herring) in mind, although many other migrant species occur in the region (Dadswell et al., 1984). Their appearance (Fig. 3-14) is determined by a function that adds  $4 \text{ mg C m}^{-3} \text{ d}^{-1}$  for a 90 day period commencing on Day 150 and ending Day 240. It is assumed (Dadswell et al. 1983, 1984) that the fish within the basin are continually leaving and being replaced by new migrants. The rate at which they leave the basin is determined by the concentration of their preferred food, PDET. In this way, no major accumulations of biomass occur, and the standing crop within the Basin conforms fairly well to empirical data obtained by Dadswell et al. (1984). Maximum biomass values occur in August in Compartment 1 as a result of advection, better feeding conditions and higher temperature in the upper part of Cumberland Basin. The peak biomass values of  $100\text{-}165 \text{ mg C m}^{-3}$  appear reasonable. Most of the fish have left the Basin by Day 300.

Migratory fish depend substantially upon the detritivores, to a lesser extent on other pelagic food, and to some degree are able to consume benthic deposit feeders (currently 25% of BDFI biomass is available). They utilize these varied food sources in essentially the same way as the resident fish, with assimilation efficiencies of 70% and respiration representing 64% of gross production (45% of assimilated carbon).

Only 5% of the migratory fish biomass is considered to be cannibalized. This is probably an unreliable estimate since the migratory population includes many larger predators that would feed equally on migratory and resident fish.

The three year run shows that the detritivores and migratory fish are tightly coupled, with reductions in peak fish biomass values 35-55% in the second year and of 14-24% in the third. These correspond to reductions in PDET biomass of 63-72% and 51-55% in the second and third years, respectively. During those three years, benthic deposit feeders (BDFI) more than double their biomass each year, but this does not compensate for the lack of pelagic food, and hence has little direct influence on the migratory fish.

It appears that the migratory fish are behaving reasonably well, since they appear to demonstrate appropriate seasonality, reach biomass levels (at least in the first year) that are acceptable, and respond to variations in available food supply. It could be improved by manipulation of the many coefficients, but in view of the relative instability of other variables this is not warranted at this time.

### 3.3.2.9 Stability of the Pelagic Submodel

The three year run indicates that, although there are significant changes in biomass levels between years, no catastrophic explosions or collapses occur in any of the pelagic variables. A summary of the changes is provided in the accompanying table (Table 3.1).

Increases in peak biomass values occur in the phytoplankton, bacteria, herbivores, resident fish and (hence) larval fish. Phytoplankton and bacteria tend to stabilize in the third year (much smaller increases), whereas the resident fish, larval fish and herbivores increase to the same extent or more in the third year. Decreases occur in the carnivores, detritivores and migratory fish and in all cases these appear to be stabilizing (i.e., smaller decreases in the third than the second year). A longer run would be useful in determining the time course or actuality of stabilization.

Causes of these changes are not obvious. The greatest proportional changes are in the detritivores (negative), and resident fish (positive). Since the available PIOC changes only slightly each year (and in a positive direction) and other major foods also increase (PHYT, PBAC and PHER) the collapse of the detritivores cannot be explained by changes in food supply. It seems likely that resident fish consume the detritivores too effectively, and are themselves inadequately controlled. A sensitivity analysis would be helpful in tracing this problem.

### 3.3.2.10 Production/Biomass Ratios

P/B ratios were not employed to construct the pelagic submodel and therefore can be used as a check of the values obtained. Annual P/B ratios calculated from the first year mean biomass and production values are summarized in Table 3.2. Of these, the phytoplankton and herbivore P/B ratios appear to be reasonable, although a little low, whereas values for the larger organisms are far too high. Since these are based upon the first year values, and significant changes occur as the model settles down in subsequent years of a run, no further comments on P/B ratios are really justified at this time.

TABLE 3-1. Results of 3 yr run on maximum biomass levels.  
(mg C m<sup>-3</sup>) (Expressed as % of previous year)

Variable /Comp.	Year 1			Year 2			Year 3		
	1	2	3	1	2	3	1	2	3
PHYT	317	322	223	457	447	288	492	480	307
				+44	+39	+29	+8	+7	+7
PBAC	440	350	160	540	419	183	566	439	190
				+23	+20	+14	+5	+5	+4
PHER	37	56	86	49	69	94	69	88	103
				+32	+23	+9	+41	+28	+10
PCAR	43	37	28	20	20	18	15	15	18
				-53	-46	-36	-25	-25	0
PDET	143	99	61	40	33	23	18	16	11
				-72	-67	-63	-55	-51	-52
PFLR	0.5	0.5	0.5	0.7	0.7	0.7	1.1	1.1	1.1
				+40	+40	+40	+57	+57	+57
PRFH	32	28	28	57	43	41	100	67	60
				+78	+53	+46	+75	+56	+46
PMFH	165	129	100	75	70	63	57	55	54
				-55	-45	-37	-24	-21	-14

TABLE 3-2. Annual Production/Biomass Ratios\*.

<u>Variable/Comp.</u>	<u>1</u>	<u>2</u>	<u>3</u>
PBAC	86.3	82.3	173.2
PHYT	102.3	139.7	210.0
PHER	17.9	14.5	9.7
PCAR	65.2	54.1	57.7
PDET	59.7	47.7	39.9
PRFH	7.2	6.3	6.3

(\* Based on results of first year run.)

### 3.3.3 Benthic Submodel

#### 3.3.3.1 Benthic microalgae (BDIA)

Because most of the microalgal biomass consists of diatoms, this state variable is called benthic diatoms. Although the model output (Fig. 3-15) agrees well with average expected levels of biomass and gross primary production, the annual dynamics do not follow the same seasonality as that seen in Peck's Cove field data. A spring peak in biomass occurs in the model (April-May) but the actual biomass on the mudflats does not begin to increase dramatically until June. A large fall bloom that occurs on the mudflats could not be attained using the present model structure. There is little difference among the three compartments in the values and dynamics of benthic diatoms. Benthic diatoms are envisioned in the model as existing only at the surface of intertidal sediments. Primary production is modelled as a function of available light and sediment temperature. An annual average gross production rate of  $106 \text{ mg C m}^{-2} \text{ d}^{-1}$  was calculated from data in Hargrave et al. (1983), prorated over the whole mudflat area using helicopter chlorophyll a data. This average was assumed to occur at average light and temperature, with no self-shading. Daily rates were calculated using a Q10 of 2.05 and an average temperature of 10.5 C, and using light level corrected for season and tidal cycle. A small self-shading correction based on a shading function for phytoplankton (W. G. Harrison, pers. com.) was also included for the ice-free season (after Day 75). Shade (by ice) is set to entirely remove any possibility of production between Day 0 and Day 85.

There are many possible sources of error in the model. Even if benthic diatom production is controlled primarily by light and temperature, the values of these parameters at the sediment surface may vary in ways which we cannot describe in this model. In addition, we have not accounted for active behavioural features of diatoms because primary production by benthic diatoms occurs at an interface micro-layer and is probably affected by diatom behaviour, tube-building, photo- and chemo-taxis, facultative heterotrophy, etc. The dynamics may be difficult to properly specify in the present model structure.

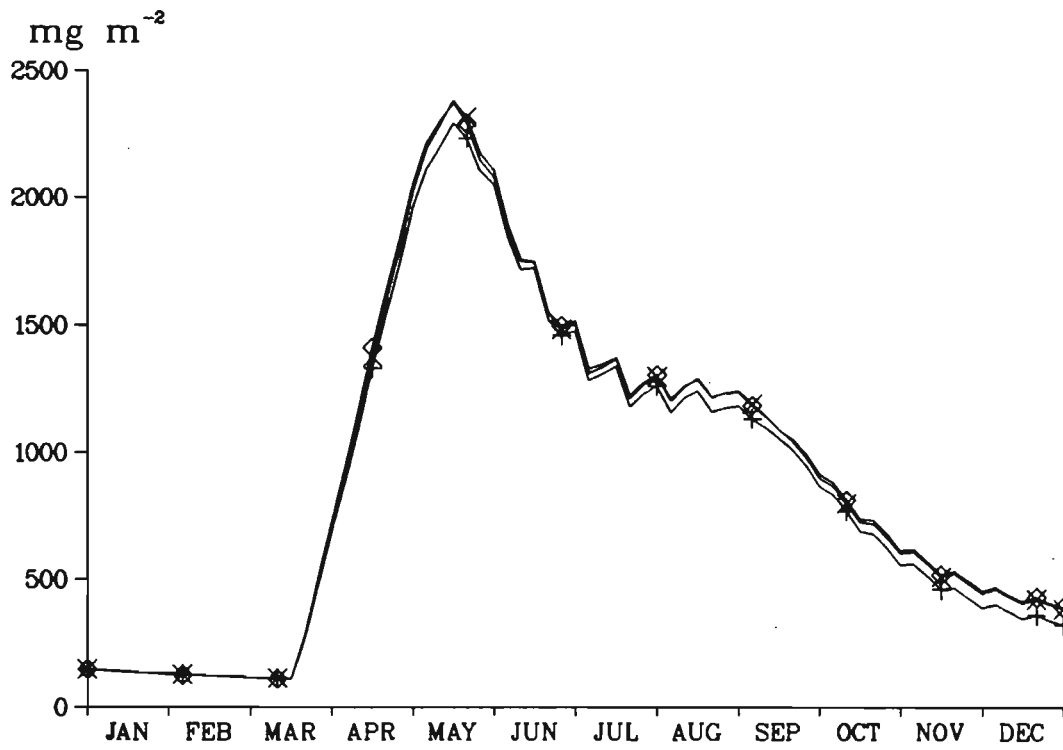


Figure 3-15. Model output for BDIA (Benthic microalgae).

### 3.3.3.2 Intertidal bacteria (BACI)

Intertidal bacteria remain stable over a 3 yr run of the model and, on average, are in the range of 2-5 g C m<sup>-2</sup>. The magnitude of annual variability in biomass (Fig. 3-16) is also approximately in agreement with field observations (Schwinghamer, 1981; Cammen and Walker, 1986). Peak biomass in the model is slow to develop in the ice-free season compared with field observations where high biomass is seen throughout spring and early summer as well as in late summer. Annual production agrees with predicted magnitude of approximately 1% if the population is active (Schwinghamer et al., 1986).

Bacteria is modelled by setting a daily P:B ratio as a function of temperature and labile carbon with a maximum value of 1 (360 yr<sup>-1</sup>). Grazing pressure by meiofauna and deposit feeding macrofauna deplete bacterial biomass. Apparently the growth and loss terms are in good balance but the response time of the bacteria may be somewhat slow.

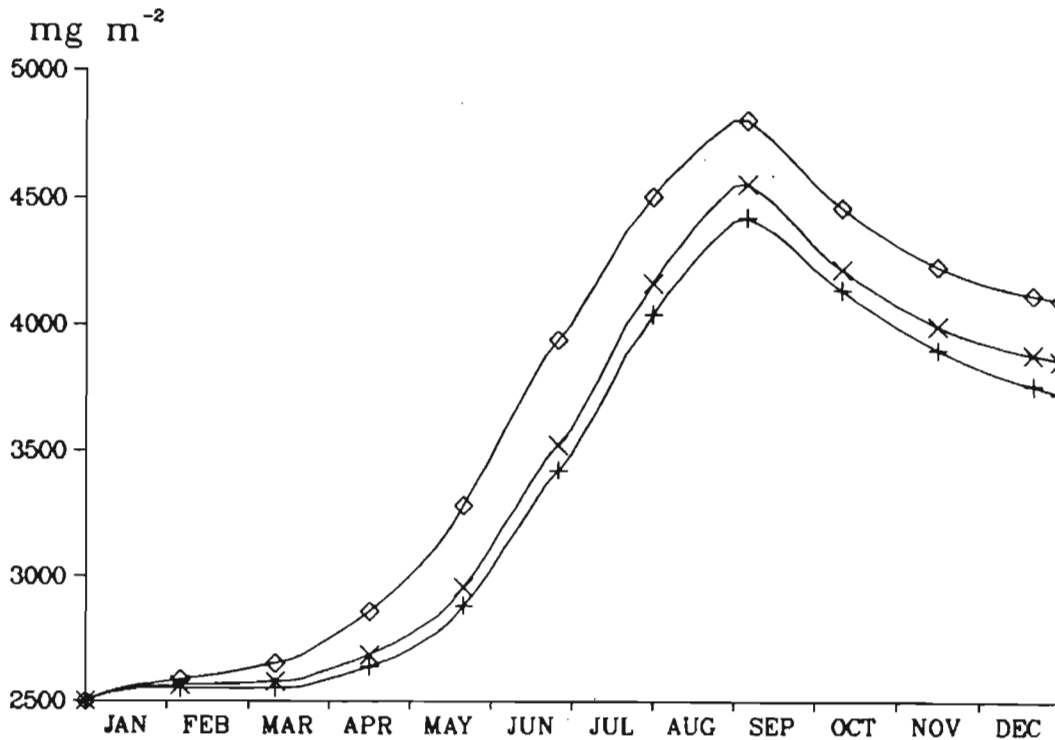


Figure 3-16. Model output for BACI (Intertidal benthic bacteria).

### 3.3.3.3 Subtidal bacteria (BACS)

Although modelled similarly to the intertidal bacteria, the subtidal biomass declines rapidly to unreasonably low levels within the first year of the model run (Fig. 3-17). This decline is probably a result of low input of labile carbon by suspension feeders, which is the only means for suspended organic carbon to enter subtidal sediments in the model. The biomass of bacteria is set approximately an order of magnitude lower than it should be (Schwinghamer, 1981) in the initial conditions of the present model and declines from there. Grazing by meiofauna and deposit feeders is probably not excessive and would not be the prime cause of decline. The modelling of organic carbon input into subtidal sediments by sedimentation must be considered in light of this subtidal component's poor performance in the model.

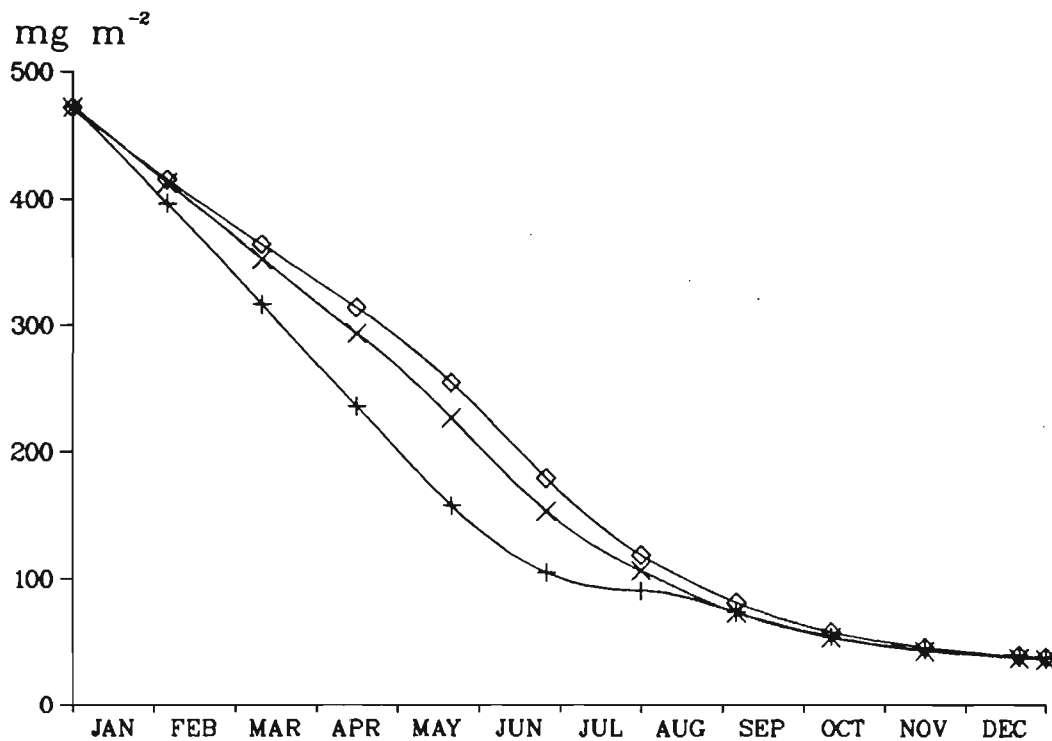


Figure 3-17. Model output for BACS (Subtidal benthic bacteria).

### 3.3.3.4 Meiofauna (BMEI, BMES)

Intertidal meiofauna decline over a 3 year run by more than an order of magnitude. In the first year (Fig. 3-18), the annual cycle is poorly modelled and does not compare well with observed biomass fluctuations. Although summer and fall peaks are present in the intertidal model, an observed early spring peak is not (Schwinghamer, 1981). Response time of meiofauna to favourable conditions is too slow in the model and decay time of the population may also be too slow. The subtidal meiofauna (Fig. 3-19) also declined over three years, especially in Compartments 1 and 2. Although nothing is known about their dynamics, we cannot assume that the subtidal model fits reality any better than does the intertidal one. Biomass levels in Compartment 3 are more than an order of magnitude lower than observed values.

The problems in modelling meiofauna as a single variable may result in the inadequacy of the present benthic submodel. The meiofauna is a whole community comprising many trophic levels, reproductive cycles, life histories, etc. so aggregated dynamics, as desirable as it may seem, may not be useful for modelling the meiofauna. We suspect that this statement may hold for the benthos in general and that a solution may be found in the approach proposed by Bill Silvert using the size spectrum as the typological basis for state variables.

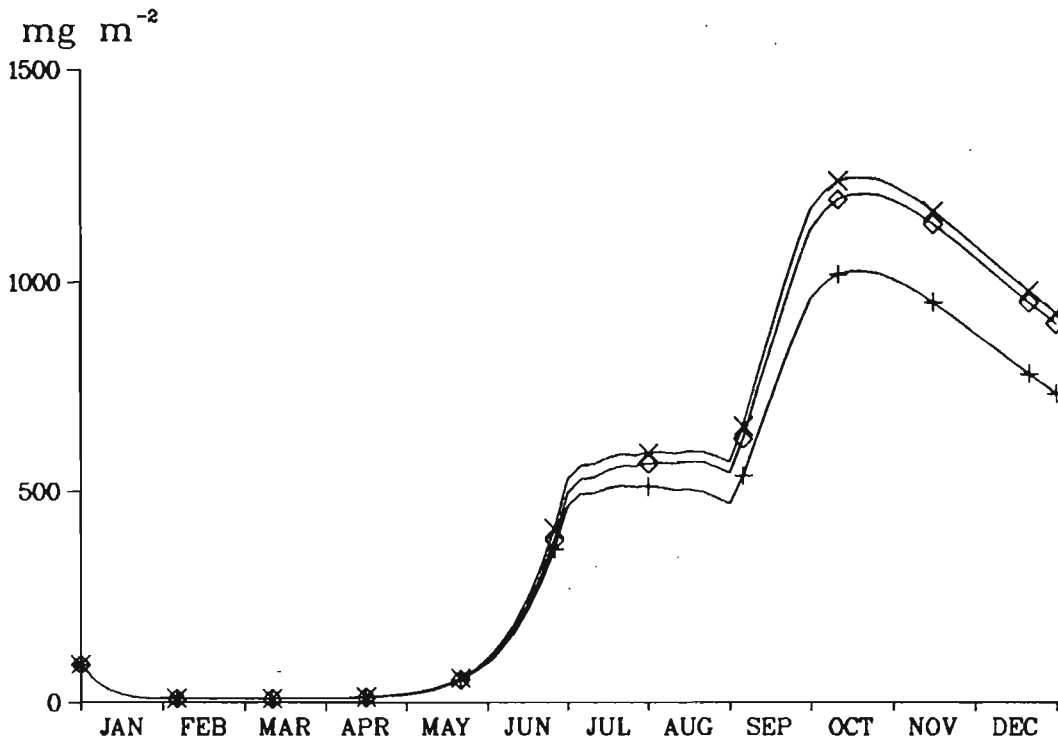


Figure 3-18. Model output for BMEI (Intertidal meiofauna).

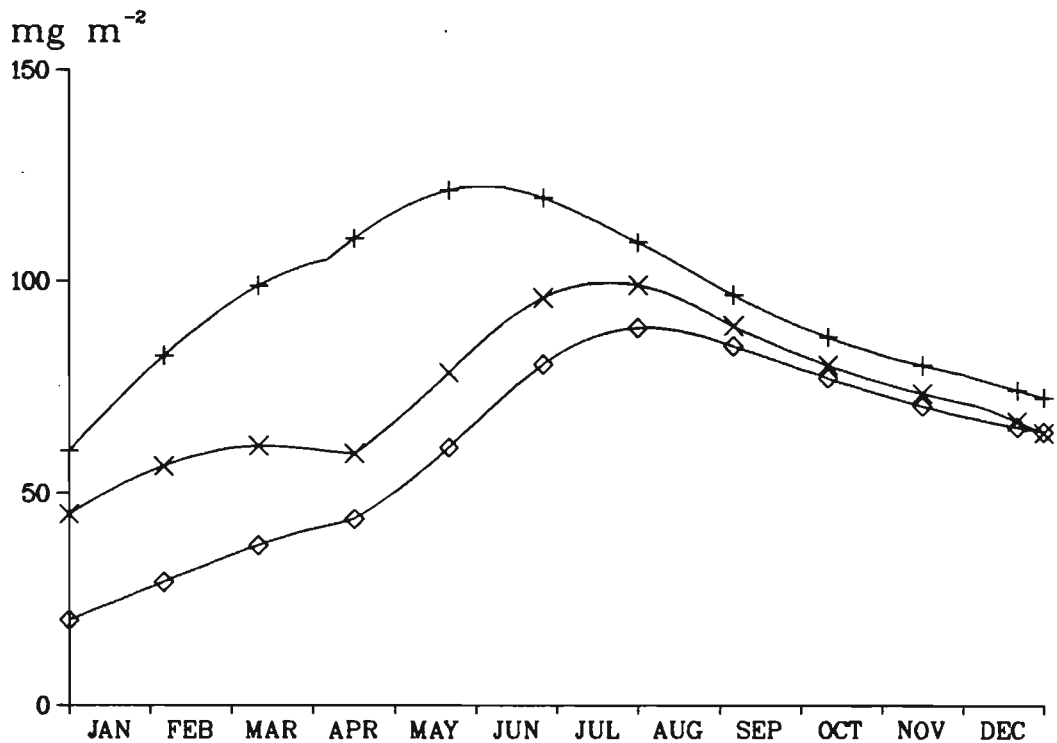


Figure 3-19. Model output for BMES (Subtidal meiofauna).

### 3.3.3.5 Deposit feeders (BDFL, BDFS)

The deposit feeders have not been adequately modelled although growth and loss parameters are derived from a large literature data base (Hicklin et al., 1980; Wildish et al., 1983; Hawkins, 1985; Cranford et al., 1985; Schwingamer, 1983). Intertidal deposit feeders increase in biomass over a 3 year cycle and have a nonsensical annual cycle in the first year (Fig. 3-20). The observed spring and fall biomass peaks are absent from the model and a summer peak is modelled precisely at the time when observed biomass crashed (Schwingamer, 1981). Subtidal deposit feeders merely decline steadily to insignificance (Fig. 3-21). The reasons for the total lack of reality of the deposit feeders' dynamics are obviously many, potentially including incorrect specification of food sources, limiting factors, growth terms, respiration levels, mortality factors, etc. and perhaps failure to include some important behavioural and life-history factors.

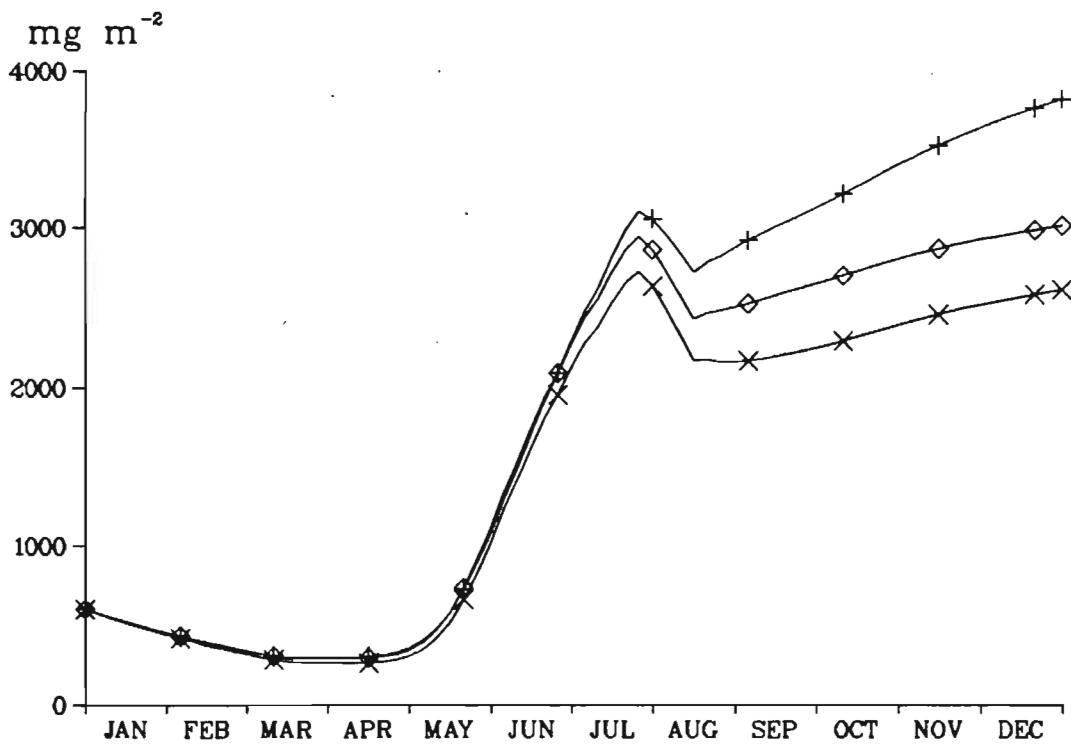


Figure 3-20. Model output for BDFI (Intertidal benthic deposit feeders).

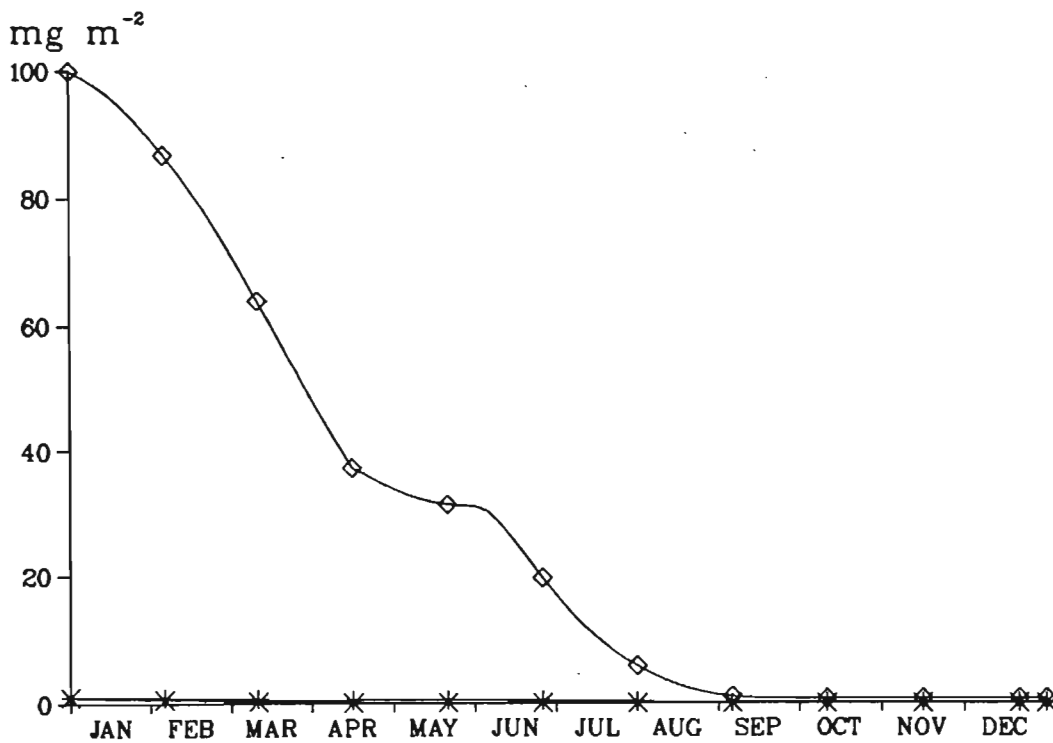


Figure 3-21. Model output for BDFS (Subtidal benthic deposit feeders).

### 3.3.3.6 Suspension feeders (BSUS)

This variable occurs only in the subtidal component of the model and is envisioned as representing primarily a Modiolus population. The initial value was set at  $266 \text{ mg C m}^{-2}$  in Compartment 3 (Schwinghamer, 1981) and should be very stable owing to the longevity of Modiolus. The initial values in the other two compartments were set very low and their real values are not known. The dynamics of BSUS in these two compartments are not of any interest. In Compartment 3, BSUS declines rapidly (Fig. 3-22) to very low biomass owing to our inability to balance incoming organic carbon (as EIOC, PBAC, PHYT) with reasonably estimated energy demands (Ken Freeman, pers. comm.). The reasons for this are probably contained in the interactions between the pelagic and benthic submodel.

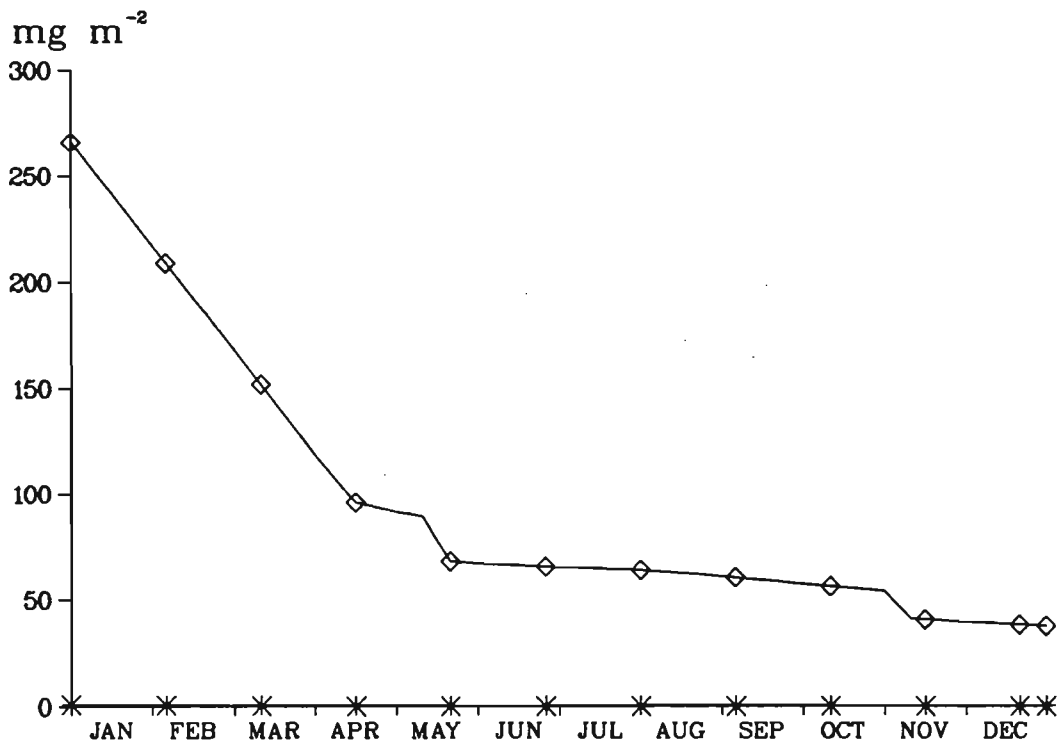


Figure 3-22. Model output for BSUS (Benthic suspension feeders).

### 3.3.3.7 General comments

Given the overall failure of the benthic submodel to even remotely reflect observed dynamics of the real world counterparts of the state variables, it seems that a detailed discussion of the coding or setting of parameter values would be futile. An interesting benthic submodel could be constructed given the full attention of a small group of people but I feel the approach taken should more closely resemble Bill Silvert's size spectral modelling than does the present benthic submodel. However, the modelling exercise has been useful as a heuristic experience, especially in clearly indicating problems encountered when aggregating biological entities into modelling entities. It is quite clear that the major problem of the benthic submodel has been that the parameters and dynamics may have been suitable for the biological entities but not for the model variables. The two were not matched carefully enough.

### 3.3.4 Non-living organic carbon

#### 3.3.4.1 Pelagic labile organic carbon (PLOC)

PLOC shows strong seasonality with maximum values occurring during August in all compartments (Fig. 3-23). For most of the year, concentrations are greatest in Compartment 3 (seaward end). At the time of maximum values, however, the gradient is reversed and greatest concentrations occur in Compartment 1. During August, PLOC reaches 3% of the total pelagic organic carbon. Over the annual cycle, it averages 0.6, 0.8 and 1.2% in Compartments 1, 2 and 3, respectively.

There are no direct measurements of PLOC that can be used as calibration data but the output seems reasonable. See the following section on total pelagic organic carbon for quantitative evaluation.

Major sources of possible error include uncertainty of concentrations in both the three model boundaries and the fecal material of pelagic organisms. Incorrect sedimentation and resuspension rates may also affect model performance.

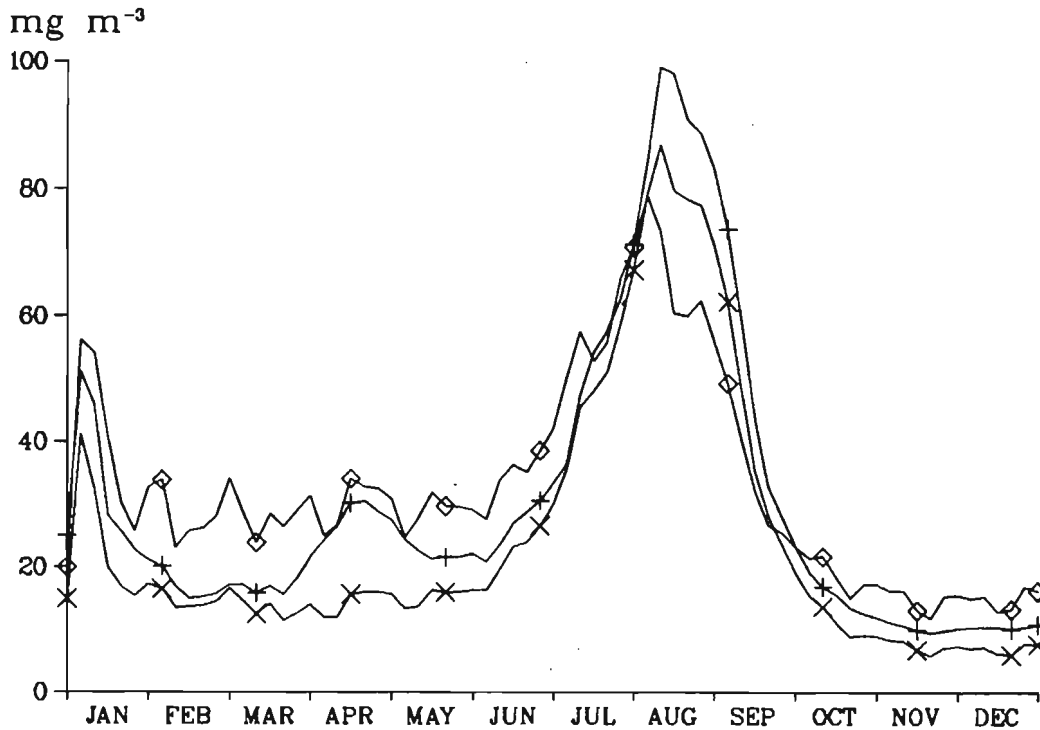


Figure 3-23. Model output for PLOC (Pelagic labile organic carbon).

### 3.3.4.2 Pelagic intermediate organic carbon (PIOC)

PIOC concentrations in all three compartments gradually increase during the winter, reach maximum values in the spring and generally decrease during the summer and fall (Fig. 3-24). Concentrations in Compartment 1 are greatest for most of the year and stay at high levels from May to August. Over the annual cycle, PIOC makes up 35, 45 and 54% of the total pelagic organic carbon in Compartments 1, 2 and 3, respectively.

There are no direct measurements of PIOC that can be used as calibration data but the output seems reasonable. Concentrations are about forty times those of PLOC which is to be expected because of a slower turnover time. The large saltmarsh export peak during August, September and October (Gordon et al., 1985), which is 50-70% PIOC, has no visible impact. The saltmarsh PIOC input into Compartment 2 is 272 tonnes during the month of September, or 9 tonnes daily, while the average total biomass during the same period is about 700 tonnes. The new PIOC is quickly transported to other compartments and sedimented. See the following section on total pelagic organic carbon for quantitative evaluation.

Major sources of possible error include uncertainty of concentrations in both the three model boundaries and the fecal material of pelagic organisms. Incorrect sedimentation and resuspension rates may also affect model performance.

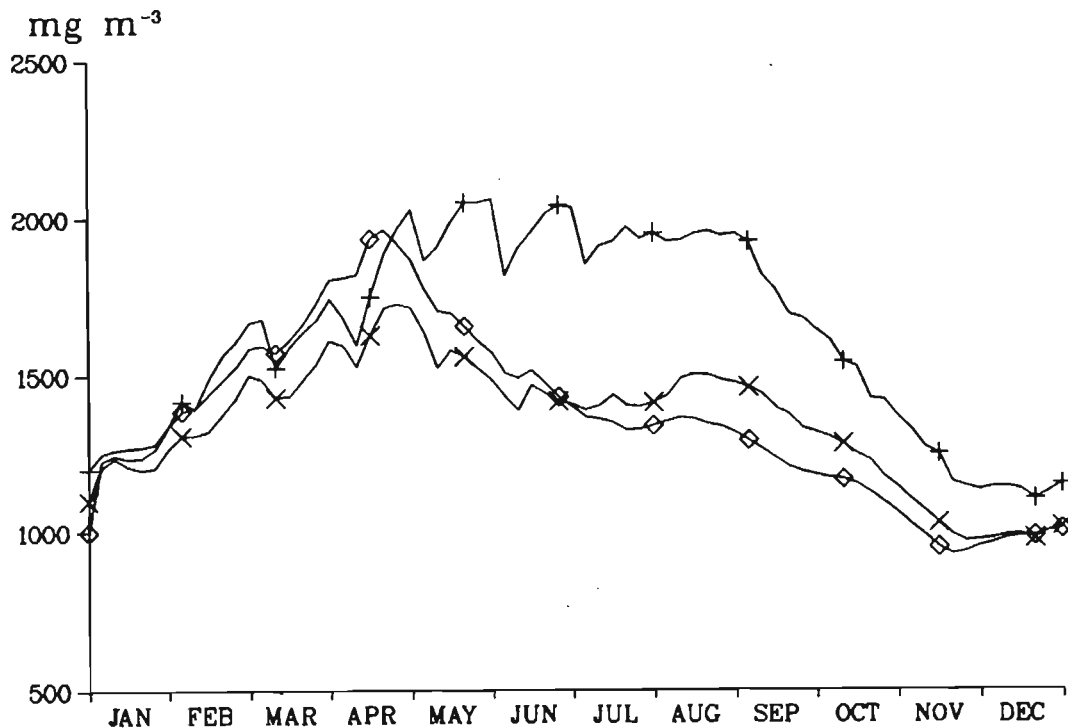


Figure 3-24. Model output for PIOC (Pelagic intermediate organic carbon).

### 3.3.4.3 Pelagic refractory organic carbon (PROC)

Concentrations of PROC show strong seasonality (Fig. 3-25). The two large peaks in the spring are related to freshwater discharge which brings in large amounts of PROC from Boundary 5. Concentrations are lowest in the summer but increase again in the fall. Concentrations increase landward at all times of the year which is to be expected because of increasing freshwater content and suspended load. Over the annual cycle, PROC averages 65, 55 and 45% of the total pelagic organic carbon in Compartments 1, 2 and 3, respectively.

There are no direct measurements of PROC that can be used as calibration data but the output seems reasonable. Concentrations are somewhat greater than PIOC in Compartments 1 and 2 but less in Compartment 3. See the following section on total pelagic organic carbon for quantitative evaluation.

The major source of possible error is uncertainty of concentrations in the three model boundaries. Incorrect sedimentation and resuspension rates may also affect model performance.

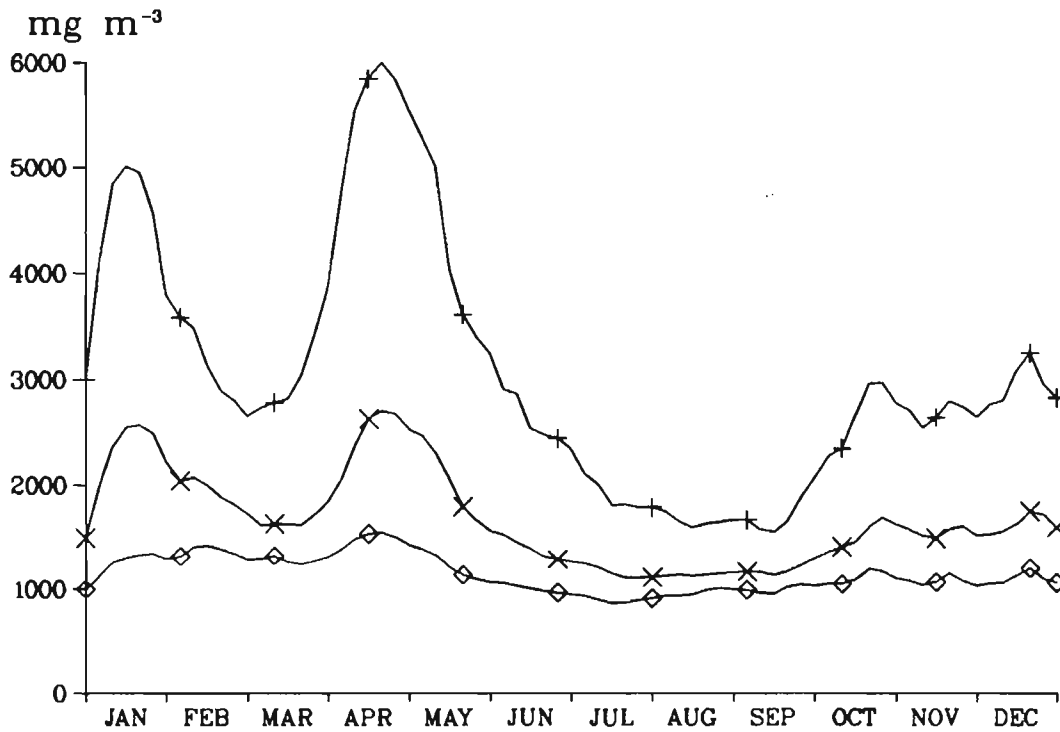


Figure 3-25. Model output for PROC (Pelagic refractory organic carbon).

#### 3.3.4.4 Total pelagic organic carbon

The three forms of pelagic organic carbon are summed and plotted in Fig. 3-26. Also plotted are calibration data for Compartments 1 and 2 which were prepared by adding monthly mean values of DOC and POC in surface samples collected along the axis of Cumberland Basin by helicopter. Calibration data coverage is quite thorough and covers all months of the year except December.

Model output gives total pelagic organic concentrations which are 2-3 times less than observed values. Initial values were originally set higher but it was found necessary to reduce them because of the interactions with epibenthic carbon forms. It is not yet clear why this is so. Perhaps export, sedimentation or utilization rates are too high. The discrepancy may even be greater. Calibration data are based on surface samples and POC concentrations usually increase with depth while the model output reflects the average concentration in the water column. The relative differences between compartments, however, seem accurate and reflect the observed exponential gradient in the up-estuary direction.

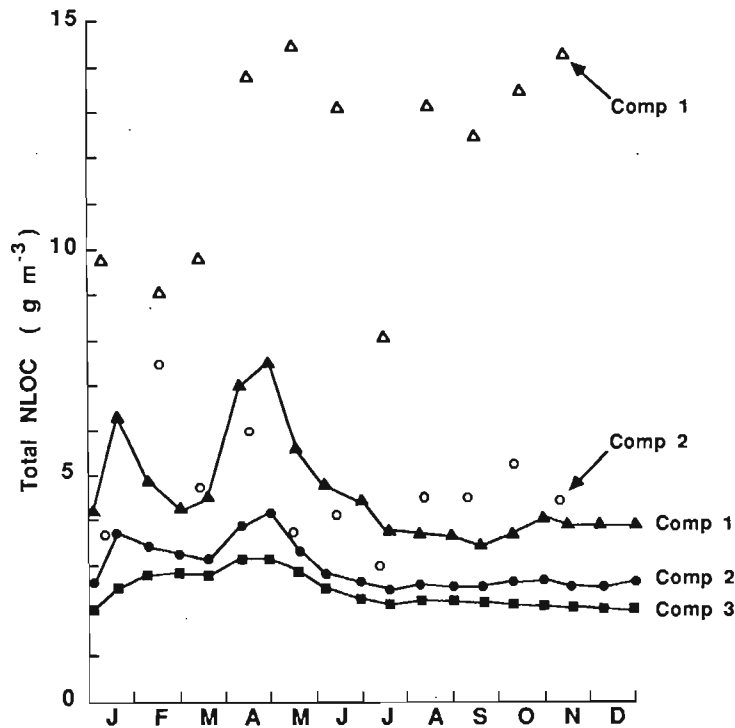


Figure 3-26. Total PLOC, PIOC and PROC from model output with calibration data for DOC plus POC.

### 3.3.4.5 Epibenthic labile organic carbon (ELOC)

The concentrations of ELOC (Fig. 3-27) demonstrate marked seasonality in all compartments and are greatest during the summer, very much like PLOC, when biological activity is greatest. Highest concentrations occur in Compartment 1 during the summer and in Compartment 3 the rest of the year. Over the annual cycle, ELOC averaged 0.9, 1.3 and 2.8% of the total epibenthic organic carbon in Compartments 1, 2 and 3, respectively.

There are no direct measurements of ELOC that can be used as calibration data. Since this state variable is more theoretical than actual, it is difficult to judge the reasonableness of the output. The relatively smooth seasonal cycle is caused primarily by changes in storm frequency which is lowest in the summer.

Major sources of possible error are most likely the sedimentation and resuspension rates.

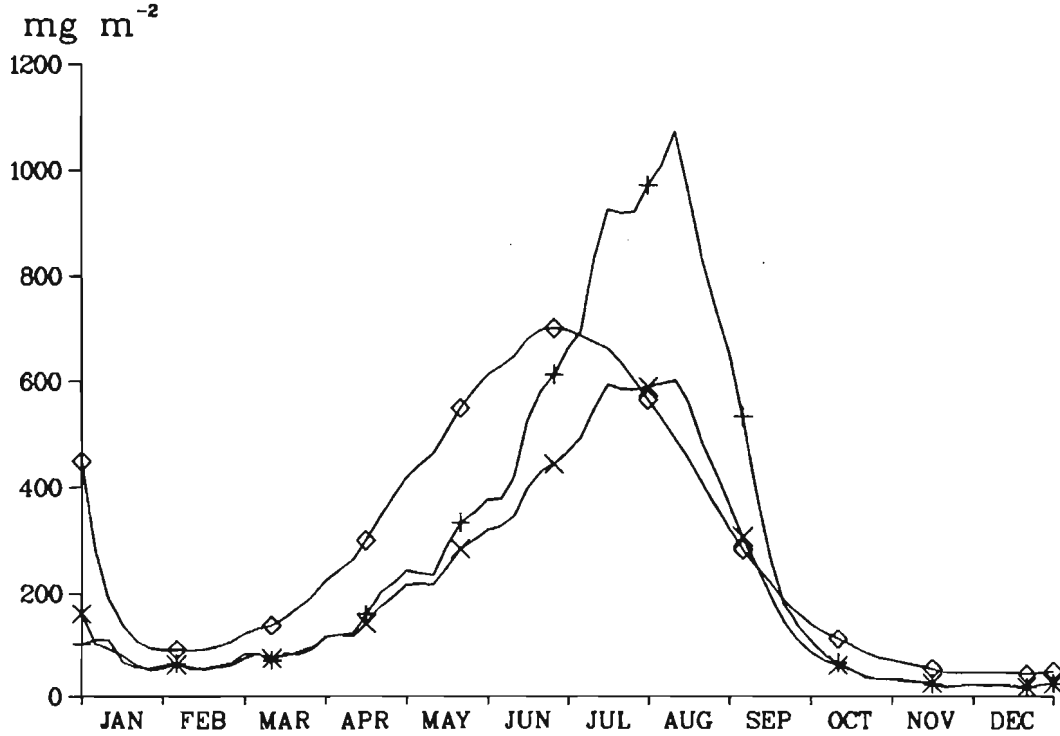


Figure 3-27. Model output for ELOC (Epibenthic labile organic carbon).

### 3.3.4.6 Epibenthic intermediate organic carbon (EIOC)

EIOC demonstrates pronounced seasonality in all compartments with peak values occurring in June (Fig. 3-28), a much stronger seasonal signal than observed with the PIOC. Concentrations are always greatest in Compartment 1 and least in Compartment 3 giving the expected gradient of concentrations increasing in the landward direction. Over the annual cycle, EIOC makes up 46, 54 and 67% of the total epibenthic organic carbon in Compartments 1, 2 and 3, respectively. These percentages are approximately 10% higher than observed in PIOC.

There are no direct measurements of EIOC that can be used as calibration data. Since this state variable is more theoretical than actual, it is difficult to judge the reasonableness of the output. The relatively smooth seasonal cycle is caused primarily by changes in storm frequency which is lowest in summer.

Major sources of possible error are most likely the sedimentation and resuspension rates.

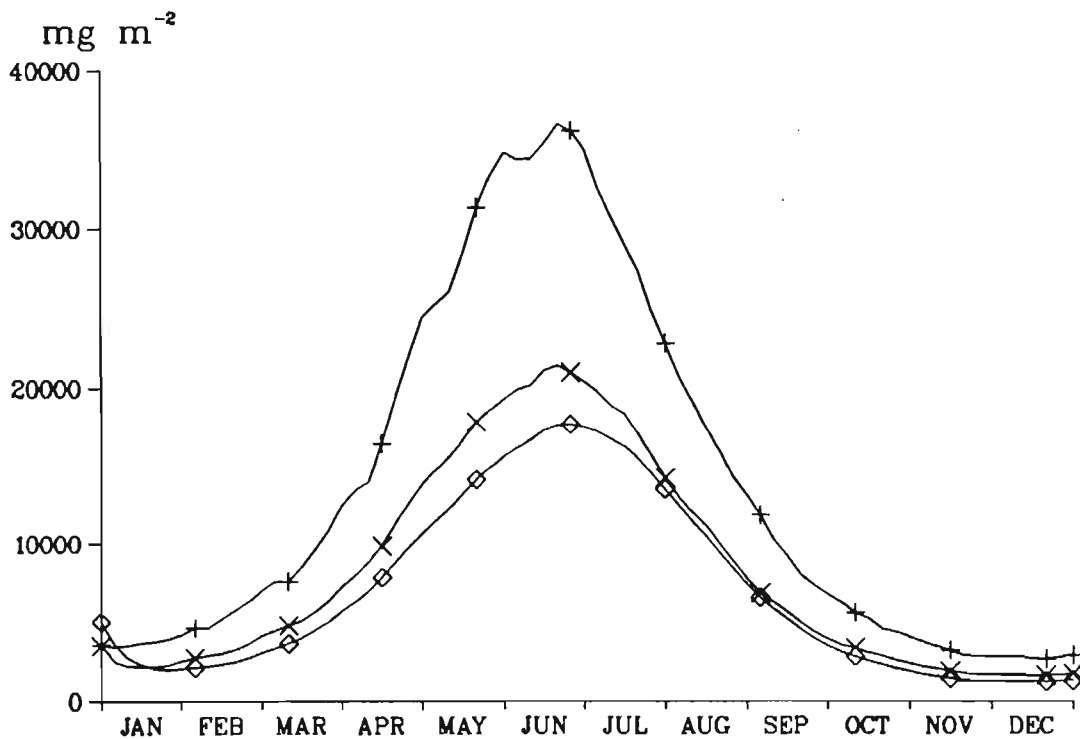


Figure 3-28. Model output for EIOC (Epibenthic intermediate organic carbon).

### 3.3.4.7 Epibenthic refractory organic carbon (EROC)

Like ELOC and EIOC, EROC concentrations show a clear seasonal signal (Fig. 3-29), especially in Compartment 1. Concentrations are always greatest in Compartment 1 and least in Compartment 3. Over the annual cycle, EROC makes up 53, 45 and 31% of the total epibenthic organic carbon in Compartments 1, 2 and 3, respectively. These percentages are about 10% lower than observed for PROC.

There are no direct measurements of EROC that can be used as calibration data. Since this state variable is more theoretical than actual, it is difficult to judge the reasonableness of the output. The relatively smooth seasonal cycle is caused primarily by changes in storm frequency which are lowest in summer.

Major sources of possible error are most likely sedimentation and resuspension rates.

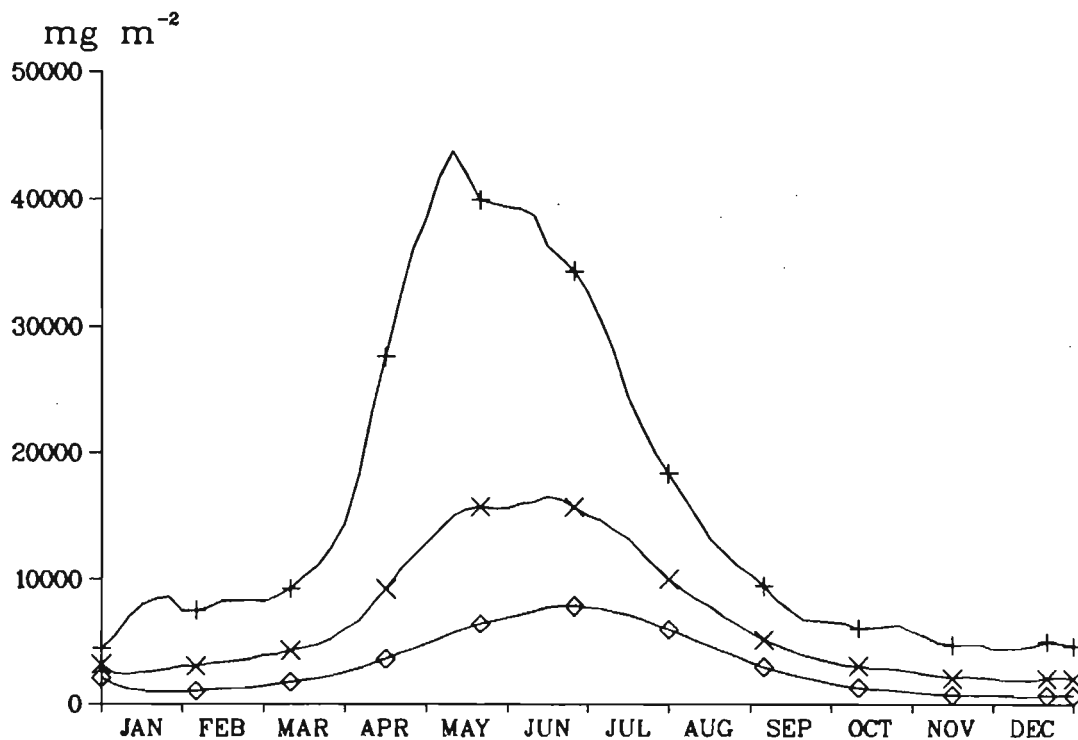


Figure 3-29. Model output for EROC (Epibenthic refractory organic carbon).

### 3.3.4.8 Benthic Intertidal labile organic carbon (BLCI)

Like PLOC and ELOC, BLCI shows strong seasonality in all compartments with highest concentrations in mid summer (Fig. 3-30). Dynamics are controlled by biological processes. Differences between compartments are slight. Winter concentrations are negligible. BLCI concentrations make up a very small amount of the total intertidal benthic organic carbon, about 0.005 % averaged over the annual cycle in each compartment.

There are no direct measurements of BLCI that can be used as calibration data, but the output seems very reasonable. There is no reason to expect major differences between compartments. See the following section on total intertidal benthic organic carbon for quantitative evaluation.

Major sources for possible error are the sedimentation rate and initial values. Because of its very short turnover time, BLCI is not subject to erosion. At first, it was assumed that the initial value should be 1% of the total intertidal benthic organic carbon (similar to pelagic organic carbon) but this was obviously too high. It might be suitable for the very thin surface layer of sediment but not deeper. The model runs well with an initial value of 10 mg C m<sup>-2</sup> which is 0.001 % of the total intertidal benthic organic carbon.

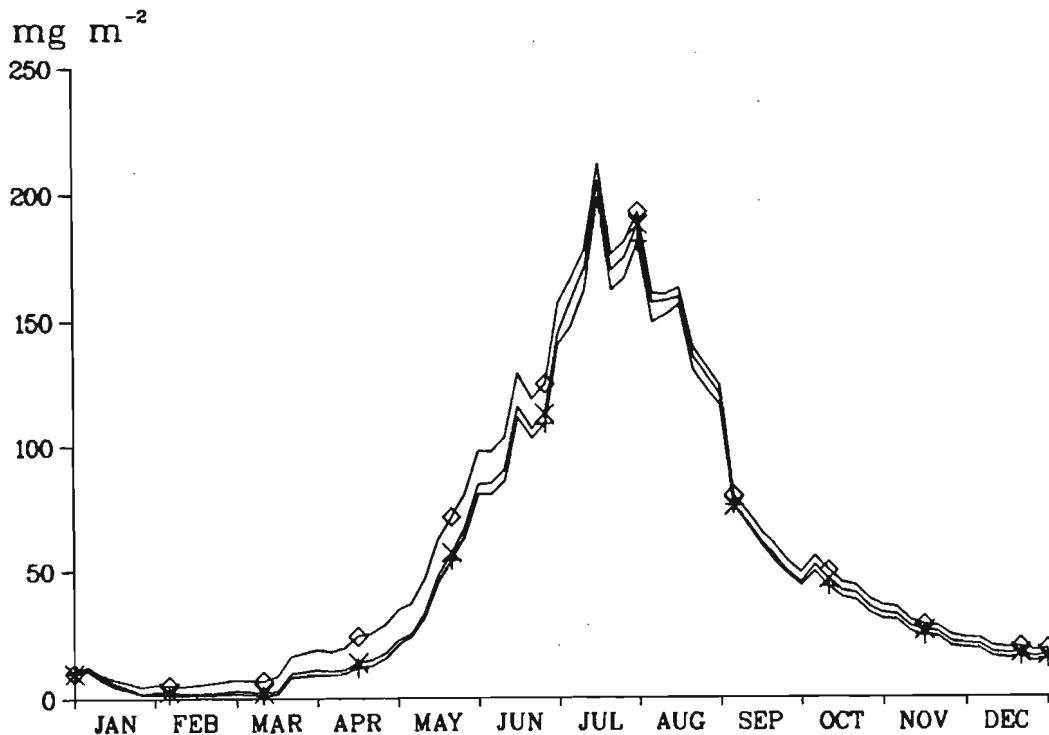


Figure 3-30. Model output for BLCI (Intertidal benthic labile organic carbon).

### 3.3.4.9 Benthic intertidal intermediate organic carbon (BICI)

The concentrations of BICI show a very slight but significant seasonal cycle which is similar in all compartments (Fig. 3-31). This cycle is controlled by physical and not biological processes since annual biotic inputs and utilization are very small compared to biomass. The dynamics follow very closely those of BSILT (Fig. 3-6). Concentrations decrease slightly during the winter and late fall due to ice and storm erosion but increase slightly the rest of the year when there is a net accumulation of sediment. BICI makes up about 21% of the total intertidal benthic organic carbon in each compartment.

There are no direct measurements of BICI that can be used as calibration data but the output seems reasonable. There is no reason to expect major differences between compartments. See the following section on total benthic organic carbon for quantitative evaluation.

Major sources of possible error include sedimentation rate, erosion rate and initial values. In the absence of direct measurements, the initial value of BICI is assumed to be 20% of the total intertidal benthic organic carbon. This may be too high.

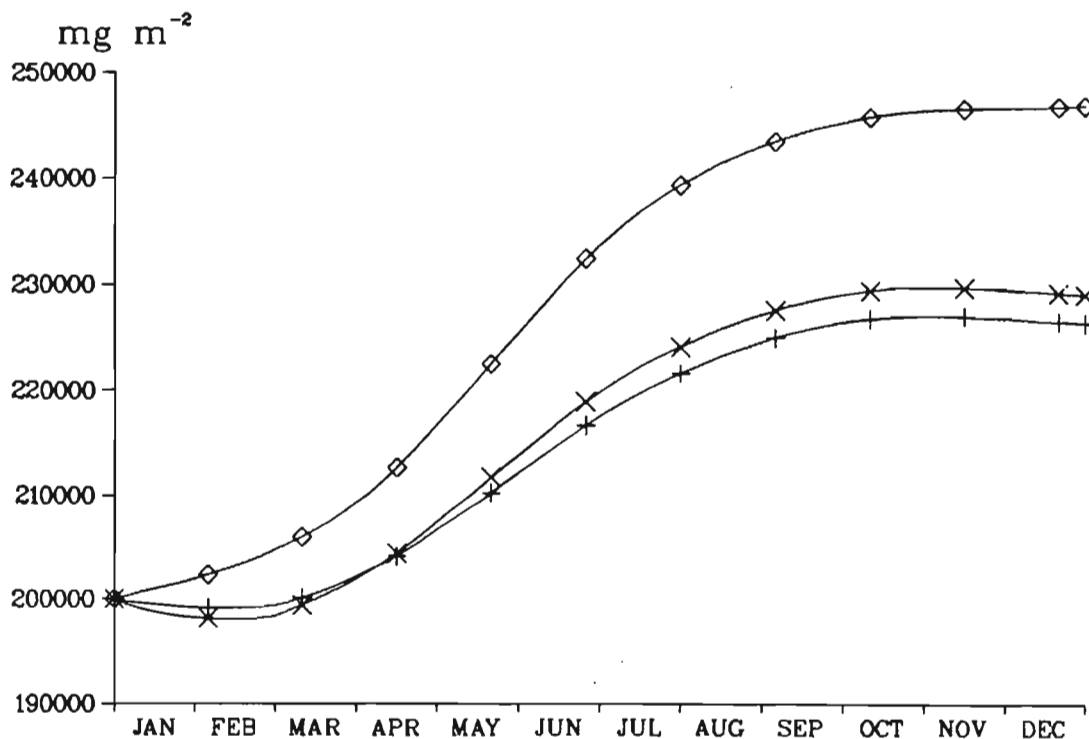


Figure 3-31. Model output for BICI (Intertidal benthic intermediate organic carbon).

### 3.3.4.10 Benthic intertidal refractory organic carbon (BRCI)

BRCI behaves very much like BICI (Fig. 3-32) as is to be expected. It too is controlled by physical processes and therefore follows dynamics like BSILT (Fig. 3-6). Concentrations decrease slightly in the winter and late fall due to ice and storm erosion but increase slightly the rest of the year when there is a net accumulation of sediment. BRCI dominates the total intertidal benthic organic carbon pool, comprising on average about 79%.

There are no direct measurements of BRCI that can be used as calibration data but the output seems reasonable. There is no reason to expect major differences between compartments.

Major sources for possible error include sedimentation rate, erosion rate and initial values. In the absence of direct measurements, the initial value is assumed to be 80 % of the total intertidal benthic organic carbon.

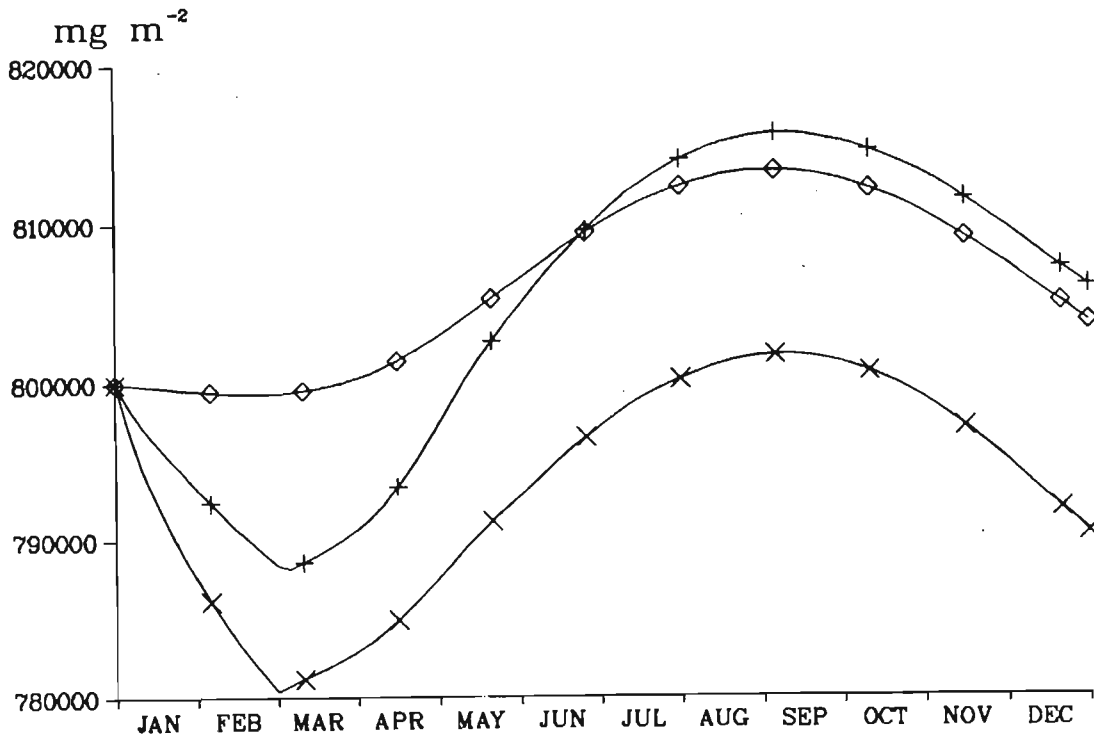


Figure 3-32. Model output for BRCI (Intertidal benthic refractory organic carbon).

#### 3.3.4.11 Total Intertidal Benthic Organic Carbon

The three forms of intertidal benthic organic carbon are summed and plotted in Fig. 3-33 along with calibration data from Compartments 1 and 2. The calibration data are derived from measurements of sediment organic carbon (SOC) in surface sediments collected by helicopter at Allen Creek and Elysian Fields mudflats in Compartment 1 and at Minudie and Pecks Cove mudflats in Compartment 2. Samples collected on foot at Pecks Cove were also included for Compartment 2. All available concentrations from both upper and lower mudflats were averaged by month. The only month without data is December (Compartment 1 only). SOC concentrations, reported in units of  $\text{mg C g}^{-1}$  sediment, were converted to  $\text{mg C ml}^{-1}$  using a sediment density of 2.6 (Danny Andrews, personal communication). Living carbon, which averages about 7% of SOC over the annual cycle, was subtracted. In extrapolating surface concentrations to a depth of 10 cm, it was assumed on the basis of depth profiles in three Pecks Cove sediment cores that concentrations in the 2-10 cm layer were fifty percent lower. The factor to convert  $\text{mg C g}^{-1}$  sediment to  $\text{mg C m}^{-2}$  for a 10 cm layer was therefore  $16.7 \text{ E}04$ .

Model output shows a slight drop in total intertidal benthic organic carbon during the winter in Compartments 1 and 2, a slight increase in all compartments during the spring and summer and a very slight drop in the late fall. These changes are caused by sedimentation and erosion of organic sediment particles. The annual cycle is very similar to that of BSILT (Fig. 3-6). Net accumulation occurs because organic carbon is not removed from the bottom of the 10 cm layer as new material accumulates on top.

As discussed earlier, the silt model has been tuned to give a net annual BSILT accumulation in the intertidal zone of  $3 \text{ mm y}^{-1}$ . The relative rate of organic carbon accumulation generated by the model is excellent. Comparing the accumulation of both silt and organic carbon between Days 60 and 260 yields values of 7.4, 6.7 and  $19.9 \text{ mg C g}^{-1}$  sediment for Compartments 1, 2 and 3, respectively. These match the average annual value for all surface intertidal sediments in Cumberland Basin,  $6 \text{ mg C g}^{-1}$  sediment or 0.6%.

The model output falls right in the middle of the range of calibration data (Fig. 3-33). The calibration data show considerable scatter which is to be expected since they represent very small samples ( $\text{cm}^2$ ) in a heterogeneous environment. They do suggest a slight seasonal cycle with high values during the growing season which is not reproduced in the model.

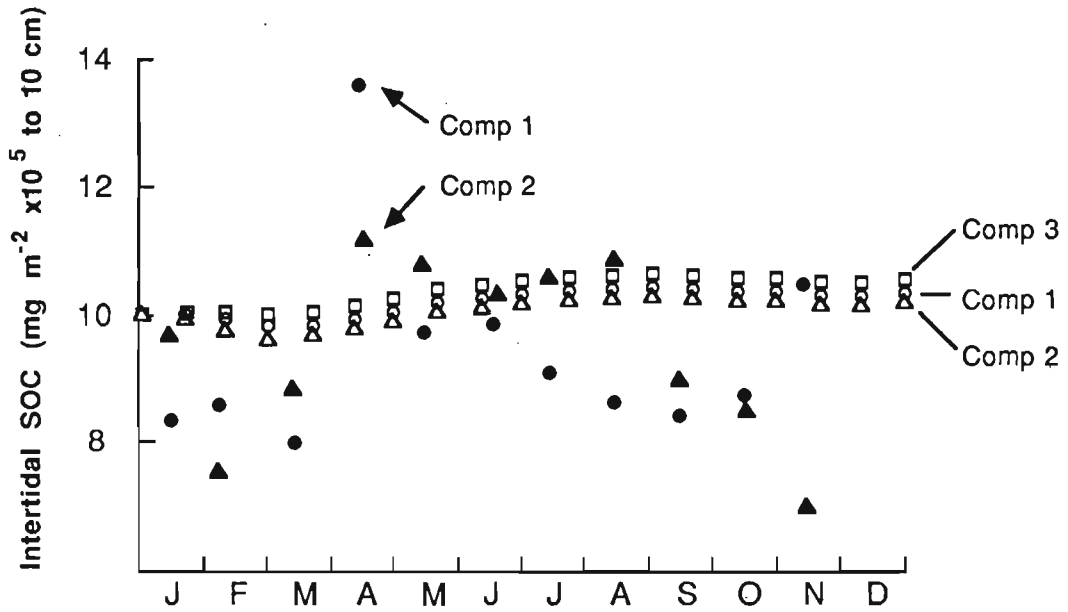


Figure 3-33. Summation of output for BLCI, BICI and BRCI with calibration data.

### 3.3.4.12 Benthic subtidal labile organic carbon (BLCS)

Like BLCI, BLCS shows strong seasonality in all compartments with highest concentrations in mid summer (Fig. 3-34). These dynamics are controlled by biological processes. Concentrations decrease in the seaward direction. BLCS makes up a very small amount of the total subtidal benthic organic carbon, only 0.001% averaged over the seasonal cycle. Concentrations decrease in the seaward direction.

There are no direct measurements of BLCS that can be used as calibration data but the output seems reasonable. See the following section on total subtidal benthic organic carbon for quantitative evaluation.

The major source of error is probably the supply rate which is controlled by PDET and BSUS feces production. The initial value of  $1 \text{ mg C m}^{-2}$  appears to be too high but the model rapidly adjusts.

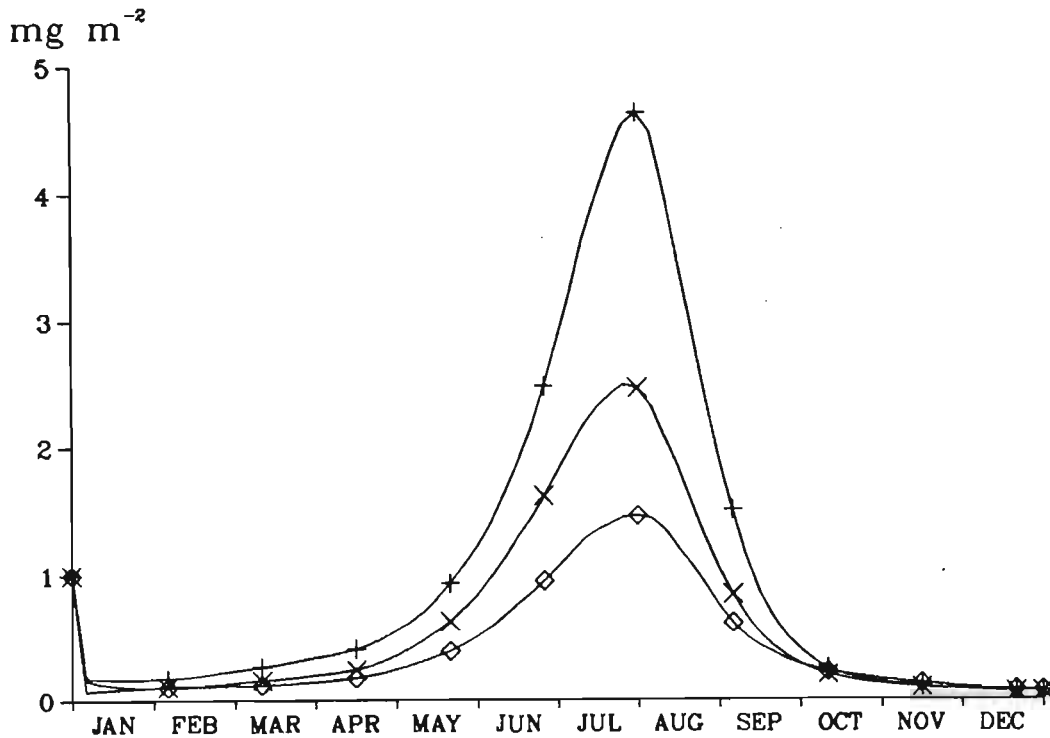


Figure 3-34. Model output for BLCS (Subtidal benthic labile organic carbon).

### 3.3.4.13 Benthic subtidal intermediate organic carbon (BICS)

BICS is far from equilibrium. Supply is greater than consumption so concentrations increase during the year in all three compartments. The net increase in Compartment 1 is almost  $700 \text{ mg C m}^{-2}$  or 3.3% the initial concentration. BICS comprises 20% of the total subtidal benthic organic carbon in each compartment.

There are no direct measurements of BLCS that can be used as calibration data but the output clearly is questionable because of the net accumulation over the year. See the following section on total subtidal benthic organic carbon for quantitative evaluation.

The major sources of error are probably the supply rate, which is controlled by PDET and BSUS feces production, or the rate of utilization by subtidal bacteria (BACS) and deposit feeders (BDFS).

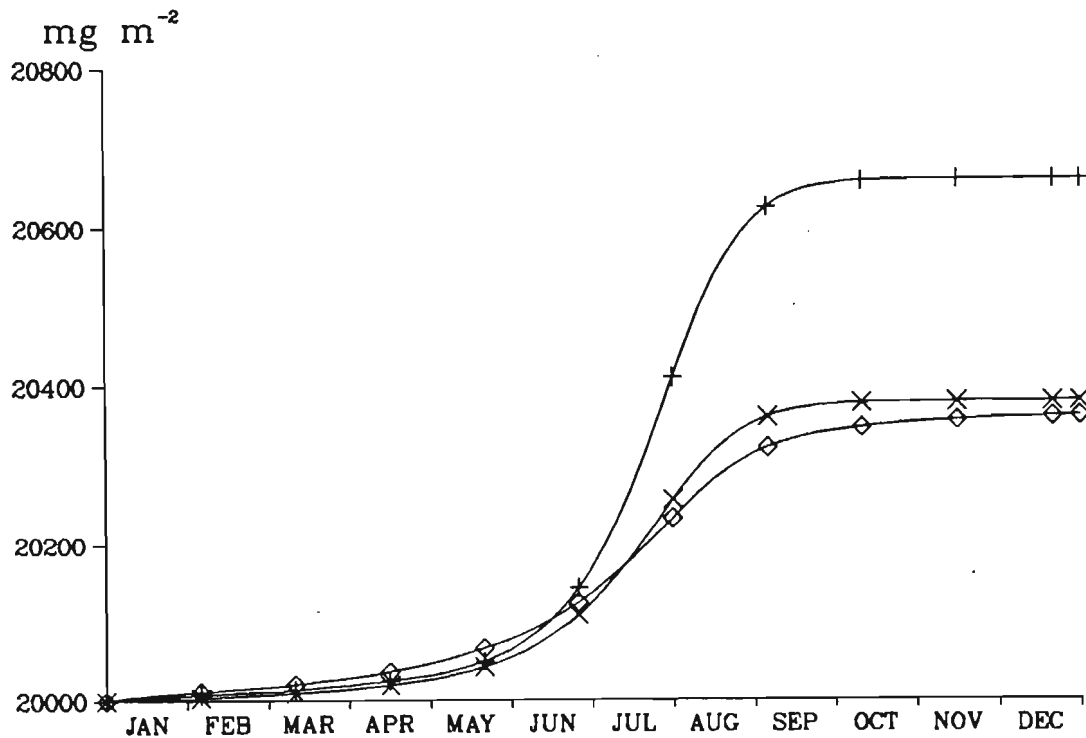


Figure 3-35. Model output for BICS (Subtidal benthic intermediate organic carbon).

#### 3.3.4.14 Benthic subtidal refractory organic carbon (BRCS)

BRCS remains practically constant in all compartments during the annual cycle. It dominates the total subtidal benthic organic carbon pool, comprising 80% in each compartment.

There are no direct measurements of BRCS that can be used as calibration data but the output seems reasonable.

The major source of error is probably the supply rate which is controlled by BSUS fecal production.

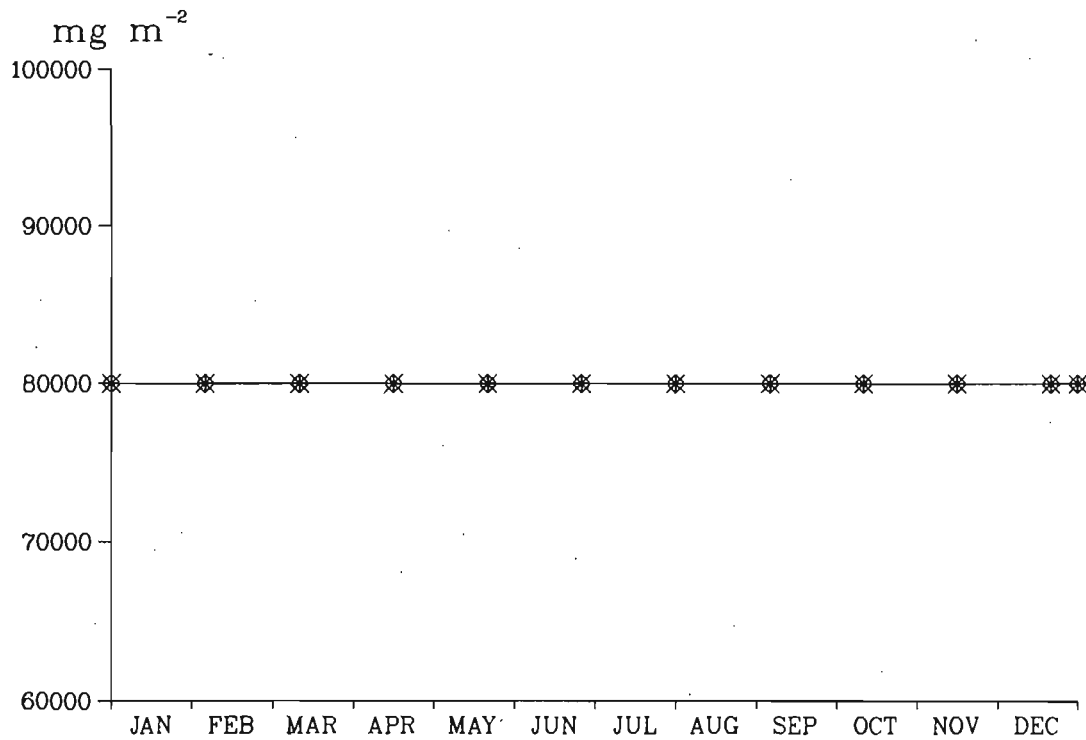


Figure 3-36. Model output for BRCS (Subtidal benthic refractory organic carbon).

#### 3.3.4.15 Total Subtidal Benthic Organic Carbon

Model output is about  $1.E05 \text{ mg C m}^{-2}$  at all times and in all compartments. The only perceptible change is a 1% increase during the year in Compartment 1 caused by the net accumulation of BICS.

Calibration data are available from the month of August 1978 when 23 grab samples were collected from upper Chignecto Bay using the Peer-Longhurst  $0.5 \text{ m}^2$  grab. Fine sediment was subsampled when present. The average carbon concentration was 0.47% or  $4.7 \text{ mg C g}^{-1}$  sediment. This is equivalent to  $12.2E05 \text{ mg C m}^{-2}$  in the top 10 cm assuming no depth gradients in carbon content and a sediment density of 2.6 (Danny Andrews, personal communication). Because fine sediment was relatively scarce in the grabs, it is felt that average values should be at least an order of magnitude less or about  $1.E05 \text{ mg C m}^{-2}$ . The model starts with this concentration and does not significantly depart from it.

#### 3.3.4.16 Total Non-Living Organic Carbon

Annual concentrations are summed and compared in Table 3-3. Only 1-10% of the total organic carbon is in the pelagic form. This percentage increases in the seaward direction as the relative importance of the intertidal zone decreases. Except for Compartment 1, even less organic carbon is in the epibenthic form (about 2-4%). This percentage also increases in the seaward direction. In all compartments the major carbon reservoir is the intertidal sediments. Percentages range from 92% in Compartment 1 to 52% in Compartment 3. Subtidal sediments account for 6 to 34% of the total carbon, increasing in the seaward direction. Intertidal and subtidal sediments together account for 97, 93 and 86% of the total carbon in Compartments 1, 2 and 3, respectively. By dividing the total amount of carbon by the compartment area, an estimate of average concentration is obtained. This ranges from  $688 \text{ g C m}^{-2}$  in Compartment 1 down to  $260 \text{ g C m}^{-2}$  in Compartment 3.

## 4. Conclusions

### 4.1 General comments

Numerical modelling projects generally provide two quite different types of benefits. One is the learning exercise of constructing the model and the other is the resulting model. Their relative importance varies quite substantially depending upon the type of project. If one is building a model of a relatively simple and well understood system to be used frequently for predictive purposes, the emphasis is on the final model. In building a heuristic ecosystem model of an incompletely understood estuary, as we have attempted for the Cumberland Basin, the modelling process is the prime benefit since the model itself is incomplete and unsuitable for quantitative prediction.

Most scientific research projects have a recognizable end-point. The hypotheses being tested are either rejected or accepted. This is not the case in developing an ecosystem model. The model is an ever-changing object which continually expands and improves as new knowledge is incorporated. It has no logical conclusion as long as the comprehension of ecosystem dynamics continues to improve.

One of the most difficult decisions which had to be made during this project was deciding at what point to stop making changes to the model and start preparing this report. The model documented herein is the version that was running as of January 1986. A long list of improvements has quickly grown since then, many of which have been mentioned above in Section 3. A better model could be produced with minor effort. Nevertheless, the model version reported here is adequate to illustrate what we have done and accomplished.

Because the emphasis of the Cumberland Basin modelling project was on the modelling process and not the resultant model, and because the version of the model presented is already out of date, this section does not present conclusions on how well the model works. Instead, we summarize what we have learned and accomplished as well as offer our thoughts for future model development.

#### 4.1.1 The modelling process

The backbone and strength to our modelling approach has been the series of multidisciplinary workshops. These intense but highly rewarding events of 1 - 5 day duration stimulated interaction among scientists of different backgrounds and shaped the major features of the model. The model therefore represents a consensus developed by a large number of scientists who had conducted various research programs in the Cumberland Basin region.

Equally important, however, is to have a dedicated core group consisting of a few individuals who provide leadership and look after the more

mundane aspects of model development such as standardizing and verifying code, improving system utilities, archiving, system maintenance and preparing external documentation. It should include at least one experienced modeller to provide advice and assistance with the formulation of algorithms and their proper coding. The transfer of some concepts to code can be difficult and the approach which is taken can be critical. A good example of the types of difficulties which can evolve can be found by comparing the pelagic and benthic submodels of this model. The pelagic submodel has numerous sensitive parameters but reacts in a useful manner to environmental and biological perturbations. In contrast benthic state variables exhibit little reaction to even major perturbations because their annual production remains constant due to the manner in which the submodel is coded.

The core group must be very careful not to forge ahead on their own and lose contact with the more casual participants. They should be directed by the consensus arrived at workshops. On the other hand, they also must make certain decisions which are necessary to keep the project moving. Interpersonal and conciliatory skills are essential.

Because of their scope, heuristic ecosystem models such as this should be kept highly aggregated and as simple as possible in the early stages of development. Complexity can be added with time after initial formulations are successful. Not all processes of interest to workshop participants can be included, only those with major influence on the entire ecosystem. Compromises have to be made to keep the model balanced and manageable.

Physical exchange processes have a fundamental impact on all but the most isolated ecosystems. These should be examined first and a physical submodel including appropriate exchange mechanisms should be constructed and tested before the first multidisciplinary workshop. It can be modified while the biological submodels are being formulated.

There is a need for very careful record keeping as the model develops. Workshops will generate an overwhelming list of code changes to make. Such modifications must be made in a careful and systematic way in order to avoid confusion which inevitably happens if participants get carried away with unbridled enthusiasm. Two forms of documentation should be maintained.

- [1] Internal documentation within the code explaining each step in computations in enough detail so that submodel authors always understand what they did and why.
- [2] External documentation which describes the entire model. It can take several forms. Ours is contained in Section 2. of this report. The GEMBASE project used a loose leaf form that could easily be updated as changes were made. It should be detailed enough that outsiders can follow what was done and make quality judgements.

Records should be kept of all modifications made to the code. This requires an easy to use and efficient real time software archiving system,

such as UNIX's SCCS, and a daily hardware backup (tape, floppy disc, etc.).

It is very important that everyone involved in the project have the opportunity to write, modify and run the model. A lot can be gained from the experience of individuals between workshops. This means that the model must reside on a computer with a "user-friendly" operating system and the code for the model must be written in a manner such that it is easily transportable to other hardware. The BSIM software modelling package (Silvert, 1986) provides a good basis for a working environment but cryptic mainframe operating systems such as CDC's NOS make it particularly difficult to maintain control over the development of the model. The widely available UNIX operating system has proven to be very suitable for model development and maintenance. A good quality and rapid graphics capability is also essential.

#### 4.1.2 Achievements

The most visible tangible achievement of the project is the model itself as described in this report. Despite its many limitations, it can be used in its current form to run an infinite number of ecological experiments which explore the probable impact of changing specific parameters. For example, how does the ecosystem respond if we change water temperature, reduce exchange coefficients, alter feeding relationships, etc.? Even in its present imperfect form, it could be a valuable tool in environmental impact assessment deliberations if properly used. Other tangible results include publications which describe or apply the Cumberland Basin model. At present these are Keizer and Gordon (1985), Gordon et al. (1986) and Keizer et al. (1986). The list is expected to grow as the model is used further to help analyze and interpret other data from the Cumberland Basin region.

The most important achievements, however, are the intangible ones resulting from the modelling process. The workshops have brought together scientists working on all aspects of ecology in the Bay of Fundy and have provided a forum for the presentation of the results of their research. They have provided a mechanism for evaluating the compatibility of observations, data sets and conclusions of different research programs. The model building exercise has increased our understanding of the relative ecological importance of various physical, chemical and biological processes and the role of various organisms. The processes of defining predator-prey relationships, describing seasonal variations in biomass and modelling processes which control net production of various organisms has identified key questions that can be answered by further research and the time and space scales plus tolerance levels appropriate for data collection. These questions have not all been uniquely identified by this process, but rather that building the model has accentuated the need for a particular data set or the resolution of a particular problem. Some of the major questions which have arisen during the building of the model are:

- [1] Do exchange coefficients vary seasonally or as a function of some other variable (e.g. freshwater discharge)?
- [2] Are sedimentation and resuspension parameters in the model identical for organic matter and silt?
- [3] What is the concentration of biomass of secondary and tertiary producers in the water column? (are these phagotrophs?)
- [4] What are the fish eating/assimilating?
- [5] What is the extent of winter mortalities of the subtidal benthos and how does this vary from year to year?
- [6] Is the salt marsh detritus utilized by organisms other than the bacteria and detritivores?
- [7] What is the activity of the pelagic and benthic bacteria?
- [8] What is the rate of utilization, mineralization and burial of the non-living organic carbon?

This list could go on and on. There are many more questions regarding the modelling of some processes. Many parameters require field observations and/or experiments to establish confidence intervals for their values.

As a result of the modelling project, much has been learned about the dynamics of the Cumberland Basin which is also pertinent to similar environments elsewhere. Examples are as follows.

- [1] Longitudinal mixing is very important. As a result, the dynamics of all state variables within the Basin are heavily influenced by conditions in the boundaries. Therefore the model is quite sensitive to the time series data entered as boundary conditions.
- [2] The first draft of the model suggested considerable sensitivity to the export of organic carbon from the saltmarshes. This led to a more detailed field study of the timing and magnitude of saltmarsh export. The present model is much less sensitive to saltmarsh export since most of the non-living organic appears to come from other sources (fecal production, boundary conditions, etc.). This conclusion is supported by recent field observations that indicate that Spartina detritus constitutes only a small fraction of the suspended particulate organic matter.
- [3] We had always assumed that nutrients are never limiting phytoplankton growth since concentrations don't drop below about 1 mmole/m<sup>3</sup> and turbidity levels are so high. However, phytoplankton did not behave properly until nutrient stress terms were added to the code. We conclude therefore that nutrients can be limiting during the summer when periods of low turbidity and low nutrient concentrations coincide. Phytoplankton production is much more important to the Cumberland Basin than we thought earlier.
- [4] Microbial processes are very important. Because of lack of data and knowledge, we omitted the anaerobic system. This may explain some of our problems with the benthic submodel and in retrospect we should have made an effort to include it. We did have problems in setting the lower boundary (ie. depth) for the benthos which reflects a weakness in understanding benthic processes.

- [5] The subtidal region is entirely dependent upon organic carbon transported downward from the pelagic and intertidal zones. The problems we have encountered in modelling these transfers underlines another serious lack of knowledge.
- [6] At the start of the project, we had assumed that herbivores feed solely on phytoplankton and detritivores feed solely on marsh detritus. These assumptions gave us considerable difficulty in earlier model drafts. The modelling of both grazers improved substantially when we converted them to omnivores and fed them different mixtures of phytoplankton, detritus and bacteria. The greater diversity of food sources has been confirmed by subsequent field observations.

A proper sensitivity analysis has not been conducted on the model. However, during model development we have noted several parameters to which the model is especially sensitive. These include the following:

- [1] Boundary conditions
- [2] Horizontal exchange coefficients
- [3] Activity of pelagic and benthic bacteria
- [4] Half saturation constant for phytoplankton
- [5] Feeding selectivity of herbivores and detritivores

#### 4.2 Future Development

The Cumberland Basin ecosystem model was developed to bring together scientists working in the upper reaches of the Bay of Fundy in a forum which would stimulate the exchange of information and ideas. Hopefully the model will continue to develop as long as scientists continue to conduct research work in the Bay of Fundy and be used to assess the needs for further investigation and the value of new information.

Federal government support of the project through the Department of Fisheries and Oceans has ended. The model has been transferred to the Acadia Centre for Estuarine Research where it resides on the Acadia University Cyber 170. The model is archived on both the Bedford Institute of Oceanography's Cyber 180 and the Marine Ecology Laboratory's Wicat 160. There is tremendous potential for the use of the model at Acadia University both as a teaching tool and as a support for their continuing research in the southern Bight of the Minas Basin. The major obstruction to its use is the Acadia computer. Its NOS operating system is a particularly difficult environment in which to use and maintain the model.

Further development of the model should proceed along the following lines. The model code has been verified once but numerous changes have been made since then so the exercise should be repeated. To date only a limited sensitivity analysis has been conducted in conjunction with tuning the model. It is important that a rigorous and complete sensitivity analysis be conducted to identify those parameters and processes which are particularly sensitive and require the greatest attention in future development. There are also a number of significant improvements that could be made to the model without conducting further research. Many of

these have already been mentioned in Section 3. Others include modelling anaerobic processes, modelling oxygen dynamics as a check against the relative values of input (primary production, reaeration, etc.) and consumption (respiration) and adding more density-dependent relationships to the biological state variables.

Major improvements to the model, however, must await the conduct of new research projects designed to satisfy the serious information gaps that have been identified. The following list of topics should be addressed first.

- [1] Improved knowledge of mixing processes. This includes better data on freshwater runoff, salinity distribution and residual circulation with good resolution of temporal variability. Such information should be used to improve the calculation of exchange coefficients.
- [2] Long term continuous incident light measurements (PAR) should be made within Cumberland Basin to account for temporal variability in cloud cover. Interannual variability could be important.
- [3] More information should be obtained on the importance of storm events so that they can be modelled in more detail.
- [4] Better time series data are required in the three boundary regions for those state variables subject to transport.
- [5] Rudimentary knowledge of gross heterotrophic/autotrophic activity levels is required for both the water column and the sediments.
- [6] The model presently assumes that organic particles have the same parameters as silt. The validity of this assumption should be tested using Cumberland Basin particulate matter.
- [7] Better estimates of carbon to chlorophyll ratios are required to estimate algal biomass from pigment determinations.
- [8] Experiments should be designed and conducted to measure as accurately as possible the relative concentrations of labile, intermediate and refractory organic carbon in source materials (marsh export, algal remains, fecal matter, etc.) and bulk organic carbon in sediments and the water column.
- [9] Very little is known about the migration of resident fish within the Cumberland Basin, both between the intertidal and subtidal areas and with the seaward boundary. It seems to be very important in controlling predation on the benthos. Appropriate field observations would be very valuable.
- [10] Subtidal organisms cannot be modelled satisfactorily until we have a clearer understanding of the biological and physical processes that supply the organic carbon necessary to support them. Improved understanding of the feeding and growth dynamics of Modiolus, the dominant member of the subtidal benthos, would also be valuable.

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## 6. Numerical Output of Model

### 6.1 Output from a three-year run of the model

The following set of tables contain the numerical output in 20 day time steps for a three-year run of the model as it existed on January 17, 1986. The plots in Section 3 were created from the same simulation but the output has a time step of 5 days. The names of state variables are explained in Section 2. PNPBAC and PNPHYT are daily net production values for PBAC and PHYT, respectively. Units for all pelagic state variables are  $\text{mg C m}^{-3}$  and for epibenthic and benthic state variables,  $\text{mg C m}^{-2}$ . The state variable PSILT has units of  $\text{g m}^{-3}$  and for ESILT and BSILT the units are  $\text{g m}^{-2}$ . SALT has units of parts per thousand. SDUM1 is in  $\text{mg N m}^{-3}$  and SILTS(1) is g silt in boundary 5.

STEP	BACI(1)	BACI(2)	BACI(3)	BACS(1)	BACS(2)	BACS(3)
0	2500.	2500.	2500.	472.0	472.0	472.0
20	2548.	2556.	2564.	430.0	438.9	439.1
40	2551.	2565.	2593.	385.2	404.4	407.9
60	2551.	2572.	2628.	339.8	369.9	378.4
80	2559.	2590.	2685.	293.0	335.0	349.7
100	2621.	2665.	2820.	246.9	301.5	321.1
120	2707.	2767.	3003.	201.4	267.3	290.9
140	2883.	2959.	3283.	157.7	226.4	254.3
160	3191.	3286.	3675.	122.5	183.0	211.9
180	3491.	3592.	4008.	99.71	144.5	169.3
200	3884.	4002.	4376.	89.56	116.4	133.4
220	4173.	4307.	4623.	83.55	94.97	107.1
240	4392.	4534.	4805.	71.71	76.07	86.61
260	4300.	4411.	4668.	60.26	62.58	70.27
280	4118.	4207.	4463.	51.18	52.99	58.69
300	3972.	4065.	4316.	44.86	46.38	50.77
320	3855.	3960.	4208.	40.62	41.82	45.18
340	3770.	3891.	4141.	37.62	38.58	41.36
360	3704.	3844.	4098.	35.32	36.14	38.55
380	3978.	4230.	4466.	33.62	34.43	36.57
400	3986.	4278.	4513.	32.09	32.91	34.82
420	3945.	4269.	4517.	30.71	31.56	33.26
440	3902.	4263.	4538.	29.38	30.31	31.87
460	3937.	4319.	4652.	28.12	29.22	30.62
480	4008.	4404.	4810.	26.93	28.30	29.50
500	4137.	4542.	5014.	26.02	27.61	28.46
520	4285.	4692.	5208.	26.22	27.57	27.66
540	4410.	4792.	5310.	28.27	28.67	27.48
560	4538.	4897.	5354.	30.56	30.17	28.08
580	4613.	4953.	5333.	30.33	29.85	28.62
600	4683.	5001.	5321.	29.11	28.69	28.04
620	4622.	4902.	5206.	27.34	27.09	26.56
640	4442.	4725.	5037.	25.36	25.39	24.99
660	4207.	4532.	4852.	23.72	23.96	23.64
680	3951.	4345.	4671.	22.49	22.83	22.52
700	3712.	4184.	4519.	21.55	21.97	21.67
720	3493.	4042.	4389.	20.80	21.27	21.00
740	3466.	4157.	4438.	20.22	20.76	20.49
760	3344.	4108.	4358.	19.69	20.29	20.02
780	3210.	4019.	4271.	19.19	19.87	19.59
800	3079.	3931.	4204.	18.71	19.47	19.20
820	3092.	3955.	4288.	18.26	19.13	18.83
840	3182.	4037.	4443.	17.83	18.86	18.52
860	3354.	4171.	4647.	17.56	18.73	18.25
880	3563.	4320.	4845.	17.89	18.96	18.13
900	3790.	4451.	4985.	19.14	19.80	18.34
920	4001.	4574.	5060.	20.01	20.52	18.92
940	4075.	4641.	5060.	19.83	20.38	19.40
960	4083.	4689.	5057.	19.33	19.96	19.32
980	3883.	4606.	4970.	18.58	19.31	18.78
1000	3520.	4396.	4787.	17.71	18.57	18.14
1020	3079.	4113.	4539.	16.94	17.91	17.56
1040	2643.	3799.	4259.	16.35	17.38	17.06
1060	2289.	3512.	4005.	15.89	16.96	16.67
1080	1995.	3256.	3778.	15.51	16.61	16.35
1100	1965.	3228.	3639.	15.22	16.36	16.10
1120	1872.	3145.	3482.	14.94	16.12	15.88
1140	1745.	3014.	3346.	14.68	15.90	15.67
1160	1630.	2891.	3241.	14.43	15.70	15.47
1180	1703.	2923.	3332.	14.19	15.52	15.29
1200	1867.	3043.	3526.	13.95	15.38	15.14

STEP	BDFI(1)	BDFI(2)	BDFI(3)	BOFS(1)	BOFS(2)	BOFS(3)
0	600.0	600.0	600.0	1.000	1.000	100.0
20	497.2	487.4	496.3	.9700	.8033	93.98
40	411.1	394.0	409.3	.8962	.6025	84.09
60	340.3	317.4	336.7	.7955	.4205	71.29
80	296.8	267.9	290.7	.6743	.2658	56.27
100	300.8	263.3	291.7	.5793	.1578	40.73
120	355.8	306.4	342.5	.5655	.1289	33.91
140	725.5	658.7	735.1	.5673	.1217	31.35
160	1497.	1425.	1537.	.5650	.1124	28.14
180	2292.	2126.	2275.	.4701	.0718	17.03
200	2988.	2659.	2862.	.3469	.0372	8.682
220	2853.	2347.	2581.	.2172	.0145	3.762
240	2913.	2202.	2507.	.1158	.0042	1.322
260	3114.	2268.	2600.	8.6372E-02	2.3565E-03	.7741
280	3298.	2356.	2697.	8.3952E-02	2.1381E-03	.7074
300	3485.	2457.	2799.	8.6499E-02	2.1457E-03	.7073
320	3654.	2548.	2884.	8.9267E-02	2.1769E-03	.7143
340	3797.	2622.	2952.	8.9769E-02	2.1804E-03	.7200
360	3921.	2684.	3008.	8.8313E-02	1.9829E-03	.7241
380	3280.	2229.	2495.	8.6677E-02	1.8053E-03	.6402
400	2740.	1845.	2060.	8.4224E-02	1.5946E-03	.5447
420	2294.	1525.	1695.	8.0863E-02	1.3594E-03	.4433
440	2025.	1324.	1464.	7.6200E-02	1.0969E-03	.3388
460	2085.	1340.	1472.	7.2551E-02	8.5669E-04	.2481
480	2327.	1539.	1687.	7.4138E-02	8.0028E-04	.2256
500	2998.	2175.	2361.	7.6727E-02	8.0418E-04	.2241
520	3910.	3069.	3298.	7.9256E-02	7.9281E-04	.2171
540	5000.	4064.	4337.	7.6600E-02	6.6151E-04	.1751
560	6111.	5039.	5359.	7.2110E-02	5.2312E-04	.1344
580	6141.	4945.	5238.	6.8033E-02	4.1117E-04	.1017
600	6583.	5237.	5525.	6.4470E-02	3.2247E-04	7.6091E-02
620	7173.	5689.	5972.	6.5456E-02	3.0058E-04	6.8577E-02
640	7709.	6057.	6330.	6.8682E-02	3.0762E-04	6.9524E-02
660	8175.	6376.	6634.	7.1724E-02	3.1710E-04	7.1417E-02
680	8585.	6652.	6889.	7.4275E-02	3.2552E-04	7.3172E-02
700	8930.	6880.	7097.	7.5126E-02	3.3017E-04	7.4596E-02
720	9230.	7076.	7275.	7.4581E-02	3.1350E-04	7.5790E-02
740	7728.	5904.	6065.	7.3912E-02	2.9847E-04	7.0400E-02
760	6466.	4918.	5044.	7.2720E-02	2.7956E-04	6.3922E-02
780	5421.	4097.	4187.	7.0879E-02	2.5629E-04	5.6389E-02
800	4796.	3593.	3654.	6.8091E-02	2.2724E-04	4.7777E-02
820	4952.	3675.	3717.	6.6019E-02	1.9794E-04	3.9549E-02
840	5248.	3958.	4013.	6.7788E-02	1.9296E-04	3.7810E-02
860	5955.	4674.	4761.	7.0365E-02	1.9683E-04	3.8215E-02
880	6874.	5610.	5742.	7.3279E-02	1.9920E-04	3.8132E-02
900	8012.	6710.	6882.	7.4003E-02	1.8517E-04	3.4371E-02
920	9197.	7828.	8038.	7.4342E-02	1.6843E-04	3.0182E-02
940	9243.	7741.	7920.	7.5193E-02	1.5338E-04	2.6369E-02
960	9838.	8088.	8268.	7.5946E-02	1.3849E-04	2.2876E-02
980	10721.	8698.	8849.	7.8958E-02	1.3635E-04	2.1986E-02
1000	11511.	9268.	9392.	8.2968E-02	1.4061E-04	2.2522E-02
1020	12190.	9752.	9841.	8.6469E-02	1.4496E-04	2.3158E-02
1040	12786.	10170.	10217.	8.9365E-02	1.4870E-04	2.3719E-02
1060	13286.	10515.	10523.	8.9923E-02	1.5070E-04	2.4173E-02
1080	13721.	10810.	10786.	8.8564E-02	1.4267E-04	2.4553E-02
1100	11481.	9019.	8992.	8.7144E-02	1.3558E-04	2.2790E-02
1120	9596.	7511.	7478.	8.5002E-02	1.2673E-04	2.0683E-02
1140	8037.	6255.	6206.	8.1957E-02	1.1587E-04	1.8230E-02
1160	7098.	5484.	5415.	7.7587E-02	1.0233E-04	1.5422E-02
1180	7315.	5606.	5508.	7.4195E-02	8.8714E-05	1.2743E-02
1200	7601.	5873.	5784.	7.5941E-02	8.6317E-05	1.2174E-02

STEP	BDIA(1)	BDIA(2)	BDIA(3)	BICI(1)	BICI(2)	BICI(3)
0	150.0	150.0	150.0	2.0000E+05	2.0000E+05	2.0000E+05
20	137.1	136.7	135.4	1.9938E+05	1.9854E+05	2.0125E+05
40	127.7	127.1	124.8	1.9913E+05	1.9812E+05	2.0274E+05
60	119.1	118.9	116.2	1.9939E+05	1.9838E+05	2.0471E+05
80	267.8	274.6	278.2	2.0106E+05	2.0058E+05	2.0746E+05
100	1099.	1139.	1174.	2.0342E+05	2.0351E+05	2.1140E+05
120	1961.	2024.	2056.	2.0664E+05	2.0744E+05	2.1671E+05
140	2233.	2316.	2291.	2.1022E+05	2.1171E+05	2.2253E+05
160	1717.	1754.	1750.	2.1394E+05	2.1586E+05	2.2829E+05
180	1478.	1503.	1515.	2.1753E+05	2.1981E+05	2.3367E+05
200	1179.	1211.	1222.	2.2043E+05	2.2296E+05	2.3778E+05
220	1212.	1254.	1258.	2.2276E+05	2.2531E+05	2.4075E+05
240	1177.	1236.	1233.	2.2461E+05	2.2721E+05	2.4299E+05
260	1006.	1039.	1051.	2.2595E+05	2.2858E+05	2.4463E+05
280	763.1	796.4	813.3	2.2674E+05	2.2938E+05	2.4572E+05
300	549.9	596.9	612.3	2.2703E+05	2.2973E+05	2.4633E+05
320	459.9	516.1	529.4	2.2693E+05	2.2965E+05	2.4655E+05
340	368.2	428.2	437.9	2.2664E+05	2.2935E+05	2.4667E+05
360	316.6	382.4	392.3	2.2635E+05	2.2904E+05	2.4683E+05
380	213.5	283.0	278.6	2.2531E+05	2.2696E+05	2.4788E+05
400	154.7	231.1	219.3	2.2478E+05	2.2616E+05	2.4926E+05
420	110.6	190.9	177.1	2.2482E+05	2.2615E+05	2.5113E+05
440	245.9	329.1	323.0	2.2640E+05	2.2831E+05	2.5380E+05
460	988.3	1118.	1141.	2.2872E+05	2.3122E+05	2.5767E+05
480	1541.	1712.	1714.	2.3187E+05	2.3508E+05	2.6290E+05
500	1514.	1685.	1671.	2.3534E+05	2.3924E+05	2.6857E+05
520	1357.	1469.	1469.	2.3897E+05	2.4332E+05	2.7420E+05
540	1290.	1371.	1373.	2.4246E+05	2.4715E+05	2.7937E+05
560	1055.	1118.	1123.	2.4529E+05	2.5017E+05	2.8322E+05
580	1091.	1152.	1154.	2.4763E+05	2.5244E+05	2.8594E+05
600	1042.	1108.	1112.	2.4944E+05	2.5423E+05	2.8792E+05
620	897.6	999.5	1012.	2.5066E+05	2.5543E+05	2.8932E+05
640	632.3	767.2	795.6	2.5122E+05	2.5604E+05	2.9017E+05
660	381.9	519.8	551.4	2.5126E+05	2.5618E+05	2.9054E+05
680	271.9	400.6	430.1	2.5088E+05	2.5587E+05	2.9049E+05
700	176.4	290.6	316.0	2.5033E+05	2.5533E+05	2.9035E+05
720	130.7	231.8	256.6	2.4979E+05	2.5480E+05	2.9025E+05
740	39.45	111.7	120.3	2.4852E+05	2.5236E+05	2.9123E+05
760	12.38	55.87	58.11	2.4776E+05	2.5128E+05	2.9248E+05
780	3.693	27.53	28.97	2.4755E+05	2.5100E+05	2.9422E+05
800	168.0	192.2	200.8	2.4900E+05	2.5308E+05	2.9677E+05
820	781.6	908.8	951.0	2.5123E+05	2.5592E+05	3.0055E+05
840	1254.	1383.	1405.	2.5431E+05	2.5971E+05	3.0568E+05
860	1226.	1344.	1360.	2.5769E+05	2.6377E+05	3.1122E+05
880	1156.	1249.	1267.	2.6122E+05	2.6774E+05	3.1670E+05
900	1134.	1211.	1225.	2.6456E+05	2.7141E+05	3.2165E+05
920	905.6	1007.	1021.	2.6723E+05	2.7425E+05	3.2524E+05
940	840.1	1047.	1056.	2.6931E+05	2.7634E+05	3.2769E+05
960	742.0	1006.	1015.	2.7084E+05	2.7796E+05	3.2944E+05
980	502.1	795.0	841.0	2.7165E+05	2.7895E+05	3.3058E+05
1000	300.3	541.8	594.4	2.7178E+05	2.7929E+05	3.3111E+05
1020	140.9	311.6	363.5	2.7138E+05	2.7915E+05	3.3117E+05
1040	111.7	222.7	265.6	2.7057E+05	2.7855E+05	3.3081E+05
1060	57.61	138.6	172.0	2.6962E+05	2.7773E+05	3.3036E+05
1080	44.05	103.8	132.1	2.6873E+05	2.7694E+05	3.2997E+05
1100	1.390	19.97	28.76	2.6712E+05	2.7411E+05	3.3082E+05
1120	.0639	4.271	6.560	2.6607E+05	2.7272E+05	3.3191E+05
1140	.0027	.9401	1.669	2.6560E+05	2.7219E+05	3.3351E+05
1160	149.3	171.6	180.7	2.6688E+05	2.7417E+05	3.3592E+05
1180	597.3	779.2	835.2	2.6898E+05	2.7693E+05	3.3960E+05
1200	1062.	1230.	1264.	2.7198E+05	2.8068E+05	3.4465E+05

STEP	BIGS(1)	BIGS(2)	BIGS(3)	BLCI(1)	BLCI(2)	BLCI(3)
0	2.0000E+04	2.0000E+04	2.0000E+04	10.00	10.00	10.00
20	2.0004E+04	2.0002E+04	2.0008E+04	3.150	3.979	6.058
40	2.0008E+04	2.0004E+04	2.0012E+04	1.259	1.990	4.791
60	2.0011E+04	2.0007E+04	2.0017E+04	1.685	3.023	7.418
80	2.0016E+04	2.0011E+04	2.0024E+04	8.114	9.610	16.32
100	2.0022E+04	2.0016E+04	2.0033E+04	9.493	10.93	19.62
120	2.0031E+04	2.0025E+04	2.0046E+04	20.78	22.53	34.27
140	2.0047E+04	2.0040E+04	2.0066E+04	54.18	57.11	71.54
160	2.0084E+04	2.0069E+04	2.0093E+04	85.78	90.47	103.6
180	2.0160E+04	2.0120E+04	2.0137E+04	140.5	144.8	156.6
200	2.0294E+04	2.0199E+04	2.0199E+04	161.3	169.0	175.7
220	2.0448E+04	2.0283E+04	2.0268E+04	150.7	156.5	159.9
240	2.0540E+04	2.0333E+04	2.0317E+04	115.3	119.8	123.7
260	2.0573E+04	2.0351E+04	2.0340E+04	53.57	55.72	60.18
280	2.0581E+04	2.0356E+04	2.0351E+04	43.31	46.07	49.64
300	2.0582E+04	2.0357E+04	2.0357E+04	30.52	32.78	35.70
320	2.0583E+04	2.0358E+04	2.0361E+04	23.57	25.46	27.75
340	2.0583E+04	2.0358E+04	2.0364E+04	15.76	17.62	19.92
360	2.0583E+04	2.0359E+04	2.0366E+04	14.58	16.30	18.65
380	2.0584E+04	2.0360E+04	2.0368E+04	17.98	22.36	23.16
400	2.0584E+04	2.0360E+04	2.0370E+04	5.480	6.752	8.508
420	2.0585E+04	2.0362E+04	2.0372E+04	3.990	5.166	8.479
440	2.0587E+04	2.0363E+04	2.0374E+04	9.790	10.58	17.31
460	2.0589E+04	2.0365E+04	2.0377E+04	13.17	13.49	22.54
480	2.0592E+04	2.0369E+04	2.0380E+04	38.06	37.31	50.03
500	2.0600E+04	2.0375E+04	2.0385E+04	65.47	66.97	80.87
520	2.0615E+04	2.0388E+04	2.0394E+04	92.02	94.89	109.4
540	2.0645E+04	2.0409E+04	2.0408E+04	156.5	157.7	171.2
560	2.0681E+04	2.0434E+04	2.0428E+04	151.7	159.0	167.5
580	2.0706E+04	2.0451E+04	2.0448E+04	147.7	152.0	154.8
600	2.0726E+04	2.0464E+04	2.0462E+04	108.0	111.5	115.0
620	2.0735E+04	2.0470E+04	2.0468E+04	62.05	58.17	63.19
640	2.0737E+04	2.0472E+04	2.0471E+04	42.21	42.60	46.32
660	2.0738E+04	2.0472E+04	2.0472E+04	28.37	29.89	32.92
680	2.0738E+04	2.0473E+04	2.0474E+04	20.65	22.42	24.83
700	2.0738E+04	2.0473E+04	2.0474E+04	12.07	14.25	16.68
720	2.0738E+04	2.0473E+04	2.0475E+04	10.90	13.27	15.77
740	2.0739E+04	2.0474E+04	2.0476E+04	14.35	21.17	15.40
760	2.0739E+04	2.0474E+04	2.0476E+04	6.140	8.405	7.704
780	2.0739E+04	2.0475E+04	2.0477E+04	5.690	7.149	8.420
800	2.0740E+04	2.0475E+04	2.0478E+04	12.41	12.38	18.97
820	2.0741E+04	2.0476E+04	2.0479E+04	20.09	18.17	26.77
840	2.0743E+04	2.0478E+04	2.0480E+04	46.01	46.89	59.49
860	2.0747E+04	2.0482E+04	2.0483E+04	72.10	73.56	87.76
880	2.0755E+04	2.0488E+04	2.0487E+04	99.87	102.5	117.8
900	2.0770E+04	2.0499E+04	2.0493E+04	170.1	171.5	185.9
920	2.0784E+04	2.0510E+04	2.0503E+04	166.9	159.3	169.3
940	2.0794E+04	2.0517E+04	2.0512E+04	163.4	154.8	158.6
960	2.0802E+04	2.0522E+04	2.0518E+04	121.9	110.5	114.9
980	2.0806E+04	2.0525E+04	2.0521E+04	78.59	70.07	74.05
1000	2.0808E+04	2.0526E+04	2.0522E+04	49.31	46.01	50.04
1020	2.0808E+04	2.0526E+04	2.0523E+04	28.61	30.05	33.52
1040	2.0808E+04	2.0526E+04	2.0523E+04	21.86	21.49	24.21
1060	2.0808E+04	2.0526E+04	2.0523E+04	12.11	12.44	15.08
1080	2.0808E+04	2.0527E+04	2.0524E+04	10.15	11.20	13.95
1100	2.0808E+04	2.0527E+04	2.0524E+04	28.96	26.63	11.37
1120	2.0808E+04	2.0527E+04	2.0524E+04	8.489	11.16	8.045
1140	2.0809E+04	2.0527E+04	2.0524E+04	7.879	8.574	8.150
1160	2.0809E+04	2.0528E+04	2.0525E+04	17.87	14.83	21.09
1180	2.0810E+04	2.0528E+04	2.0525E+04	28.57	23.58	31.82
1200	2.0811E+04	2.0529E+04	2.0526E+04	45.22	51.21	64.18

STEP	BLCS(1)	BLCS(2)	BLCS(3)	BMEI(1)	BMEI(2)	BMEI(3)
0	1.000	1.000	1.000	90.00	90.00	90.00
20	.1652	.0911	.1067	11.18	11.10	11.17
40	.1791	.1120	.1017	8.991	9.724	8.955
60	.2318	.1395	.1130	8.800	9.433	8.740
80	.2986	.1733	.1308	8.678	9.209	8.595
100	.3734	.2193	.1626	10.55	11.18	10.56
120	.5479	.3472	.2419	18.41	19.61	18.71
140	.9011	.6122	.3895	51.43	56.32	53.53
160	1.549	1.073	.6703	163.4	184.1	171.7
180	2.674	1.729	1.054	465.1	528.5	494.9
200	3.871	2.304	1.421	513.5	588.5	559.9
220	3.325	1.924	1.394	502.6	589.2	565.7
240	1.653	1.004	.7873	468.9	568.2	545.0
260	.5992	.4198	.3946	799.5	980.2	941.1
280	.2329	.1977	.2323	1008.	1228.	1195.
300	.1261	.1224	.1663	996.1	1218.	1194.
320	.0863	.0896	.1223	914.9	1131.	1113.
340	.0662	.0702	.0888	815.7	1023.	1007.
360	.0599	.0619	.0778	718.5	916.6	902.0
380	.0495	.0498	.0592	87.91	114.6	112.8
400	.0515	.0497	.0537	10.67	14.31	14.02
420	.0618	.0548	.0515	9.201	9.171	8.952
440	.0769	.0641	.0524	8.841	8.958	8.708
460	.0956	.0804	.0598	10.41	10.95	10.64
480	.1454	.1243	.0833	16.34	18.19	17.68
500	.2721	.2161	.1286	31.87	39.15	37.65
520	.5281	.3812	.2181	68.52	92.93	88.40
540	.8740	.5867	.3502	155.1	228.6	216.1
560	.7367	.5228	.4443	151.2	239.3	225.7
580	.5822	.3791	.3769	134.3	226.4	213.1
600	.3824	.2400	.2016	113.8	203.5	191.0
620	.1525	.0978	.0933	187.3	350.0	328.8
640	.0549	.0390	.0490	230.2	469.1	448.7
660	.0287	.0230	.0346	213.8	475.4	463.5
680	.0201	.0176	.0259	176.8	430.6	426.2
700	.0164	.0151	.0194	140.0	371.6	372.3
720	.0161	.0151	.0177	109.1	314.5	318.3
740	.0145	.0145	.0152	11.83	36.52	37.05
760	.0169	.0158	.0151	8.482	9.612	8.751
780	.0223	.0198	.0161	7.464	8.854	8.057
800	.0303	.0260	.0187	6.538	8.150	7.434
820	.0402	.0359	.0243	7.051	9.198	8.458
840	.0654	.0588	.0365	9.801	13.57	12.59
860	.1313	.1066	.0597	15.87	23.63	22.08
880	.2649	.1930	.1057	27.83	44.98	42.34
900	.3986	.2834	.1728	51.77	91.05	86.45
920	.2760	.1937	.2070	41.71	80.58	77.16
940	.2264	.1544	.1685	27.20	66.27	63.90
960	.1566	.1024	.0887	15.78	52.60	51.09
980	.0624	.0408	.0396	16.22	79.00	78.72
1000	.0210	.0150	.0198	12.84	88.43	92.36
1020	.0104	.0085	.0137	8.064	75.81	83.05
1040	.0073	.0066	.0102	4.650	58.15	66.70
1060	.0061	.0058	.0076	2.683	43.18	51.63
1080	.0062	.0061	.0071	1.551	31.82	39.55
1100	.0061	.0060	.0063	1.115	8.489	8.669
1120	.0071	.0070	.0064	.8286	7.233	7.418
1140	.0100	.0091	.0070	.6110	6.170	6.405
1160	.0140	.0123	.0084	.4449	5.253	5.547
1180	.0189	.0174	.0113	.4316	5.589	5.998
1200	.0316	.0290	.0175	.5289	7.649	8.359

STEP	BMES(1)	BMES(2)	BMES(3)	BRCI(1)	BRCI(2)	BRCI(3)
0	60.00	45.00	20.00	8.0000E+05	8.0000E+05	8.0000E+05
20	73.43	52.20	25.01	7.9524E+05	7.9070E+05	7.9971E+05
40	85.38	57.58	30.21	7.9153E+05	7.8484E+05	7.9943E+05
60	95.05	60.63	35.26	7.8843E+05	7.8040E+05	7.9938E+05
80	102.0	61.01	39.70	7.8953E+05	7.8201E+05	7.9983E+05
100	107.5	59.57	43.09	7.9234E+05	7.8419E+05	8.0101E+05
120	116.1	66.81	50.29	7.9737E+05	7.8756E+05	8.0295E+05
140	121.3	78.45	60.85	8.0266E+05	7.9122E+05	8.0534E+05
160	121.9	89.89	72.74	8.0692E+05	7.9434E+05	8.0772E+05
180	118.0	97.24	82.61	8.1043E+05	7.9719E+05	8.0998E+05
200	111.8	99.36	88.16	8.1305E+05	7.9943E+05	8.1173E+05
220	104.6	96.88	88.91	8.1474E+05	8.0089E+05	8.1282E+05
240	96.68	90.70	85.96	8.1555E+05	8.0170E+05	8.1331E+05
260	90.05	84.75	81.72	8.1544E+05	8.0160E+05	8.1309E+05
280	84.81	79.85	77.43	8.1457E+05	8.0067E+05	8.1217E+05
300	80.69	75.77	73.43	8.1314E+05	7.9900E+05	8.1066E+05
320	77.48	72.42	69.88	8.1098E+05	7.9650E+05	8.0861E+05
340	74.22	69.35	66.99	8.0848E+05	7.9349E+05	8.0623E+05
360	70.82	63.97	64.59	8.0607E+05	7.9041E+05	8.0380E+05
380	67.99	59.55	59.27	8.0118E+05	7.8095E+05	8.0349E+05
400	65.00	54.77	53.57	7.9732E+05	7.7500E+05	8.0319E+05
420	61.80	49.65	47.57	7.9409E+05	7.7057E+05	8.0313E+05
440	58.10	43.91	41.15	7.9518E+05	7.7218E+05	8.0357E+05
460	54.67	38.26	34.97	7.9798E+05	7.7437E+05	8.0475E+05
480	52.75	36.04	32.70	8.0301E+05	7.7774E+05	8.0669E+05
500	50.59	34.76	31.58	8.0829E+05	7.8140E+05	8.0906E+05
520	48.26	33.50	30.51	8.1254E+05	7.8453E+05	8.1144E+05
540	45.79	32.20	29.38	8.1604E+05	7.8738E+05	8.1370E+05
560	43.30	30.95	28.27	8.1865E+05	7.8962E+05	8.1544E+05
580	40.78	29.67	27.19	8.2034E+05	7.9109E+05	8.1653E+05
600	38.35	28.34	26.12	8.2114E+05	7.9192E+05	8.1701E+05
620	36.52	27.28	25.18	8.2101E+05	7.9184E+05	8.1678E+05
640	35.10	26.41	24.35	8.2012E+05	7.9093E+05	8.1585E+05
660	33.99	25.67	23.62	8.1866E+05	7.8930E+05	8.1433E+05
680	33.12	25.06	22.98	8.1646E+05	7.8684E+05	8.1226E+05
700	32.16	24.47	22.46	8.1393E+05	7.8388E+05	8.0986E+05
720	31.11	23.28	22.01	8.1149E+05	7.8085E+05	8.0742E+05
740	30.22	22.29	20.84	8.0656E+05	7.7153E+05	8.0710E+05
760	29.27	21.21	19.55	8.0265E+05	7.6567E+05	8.0680E+05
780	28.22	19.99	18.12	7.9939E+05	7.6132E+05	8.0674E+05
800	26.96	18.55	16.50	8.0046E+05	7.6293E+05	8.0717E+05
820	25.78	17.05	14.86	8.0326E+05	7.6513E+05	8.0834E+05
840	25.15	16.44	14.24	8.0828E+05	7.6850E+05	8.1028E+05
860	24.43	16.07	13.92	8.1356E+05	7.7216E+05	8.1265E+05
880	23.63	15.67	13.60	8.1780E+05	7.7530E+05	8.1503E+05
900	22.77	15.26	13.25	8.2130E+05	7.7815E+05	8.1728E+05
920	21.86	14.85	12.90	8.2391E+05	7.8040E+05	8.1902E+05
940	20.90	14.41	12.55	8.2559E+05	7.8188E+05	8.2010E+05
960	19.92	13.94	12.19	8.2638E+05	7.8271E+05	8.2058E+05
980	19.17	13.55	11.86	8.2623E+05	7.8266E+05	8.2035E+05
1000	18.59	13.22	11.58	8.2532E+05	7.8178E+05	8.1941E+05
1020	18.12	12.95	11.32	8.2383E+05	7.8017E+05	8.1788E+05
1040	17.75	12.71	11.09	8.2162E+05	7.7776E+05	8.1579E+05
1060	17.29	12.48	10.90	8.1905E+05	7.7485E+05	8.1338E+05
1080	16.75	11.91	10.74	8.1659E+05	7.7187E+05	8.1092E+05
1100	16.28	11.44	10.21	8.1161E+05	7.6268E+05	8.1061E+05
1120	15.77	10.92	9.616	8.0765E+05	7.5690E+05	8.1030E+05
1140	15.19	10.32	8.943	8.0436E+05	7.5262E+05	8.1023E+05
1160	14.48	9.593	8.170	8.0542E+05	7.5424E+05	8.1066E+05
1180	13.83	8.837	7.382	8.0822E+05	7.5644E+05	8.1183E+05
1200	13.56	8.552	7.104	8.1323E+05	7.5981E+05	8.1376E+05

STEP	BRC5(1)	BRC5(2)	BRC5(3)	BSILT(1)	BSILT(2)	BSILT(3)
0	8.0000E+04	8.0000E+04	8.0000E+04	2.0300E+05	2.0300E+05	2.0200E+05
20	8.0000E+04	8.0000E+04	8.0000E+04	2.0247E+05	2.0177E+05	2.0274E+05
40	8.0000E+04	8.0000E+04	8.0000E+04	2.0227E+05	2.0147E+05	2.0338E+05
60	8.0000E+04	8.0000E+04	8.0000E+04	2.0206E+05	2.0127E+05	2.0384E+05
80	8.0000E+04	8.0000E+04	8.0000E+04	2.0270E+05	2.0239E+05	2.0422E+05
100	8.0000E+04	8.0000E+04	8.0000E+04	2.0367E+05	2.0352E+05	2.0461E+05
120	8.0000E+04	8.0000E+04	8.0000E+04	2.0508E+05	2.0486E+05	2.0501E+05
140	8.0000E+04	8.0000E+04	8.0000E+04	2.0642E+05	2.0616E+05	2.0546E+05
160	7.9999E+04	8.0000E+04	8.0000E+04	2.0749E+05	2.0714E+05	2.0584E+05
180	7.9999E+04	7.9999E+04	8.0000E+04	2.0834E+05	2.0788E+05	2.0616E+05
200	7.9998E+04	7.9999E+04	7.9999E+04	2.0895E+05	2.0839E+05	2.0641E+05
220	7.9997E+04	7.9998E+04	7.9999E+04	2.0932E+05	2.0872E+05	2.0655E+05
240	7.9997E+04	7.9998E+04	7.9999E+04	2.0944E+05	2.0892E+05	2.0659E+05
260	7.9997E+04	7.9998E+04	7.9999E+04	2.0937E+05	2.0900E+05	2.0651E+05
280	7.9997E+04	7.9998E+04	7.9999E+04	2.0918E+05	2.0903E+05	2.0638E+05
300	7.9997E+04	7.9998E+04	7.9999E+04	2.0897E+05	2.0908E+05	2.0628E+05
320	7.9997E+04	7.9998E+04	7.9999E+04	2.0870E+05	2.0912E+05	2.0622E+05
340	7.9997E+04	7.9998E+04	7.9999E+04	2.0846E+05	2.0923E+05	2.0623E+05
360	7.9997E+04	7.9998E+04	7.9999E+04	2.0836E+05	2.0951E+05	2.0644E+05
380	7.9997E+04	7.9998E+04	7.9999E+04	2.0252E+05	2.0182E+05	2.0277E+05
400	7.9997E+04	7.9998E+04	7.9999E+04	2.0231E+05	2.0149E+05	2.0340E+05
420	7.9997E+04	7.9998E+04	7.9999E+04	2.0208E+05	2.0128E+05	2.0386E+05
440	7.9997E+04	7.9998E+04	7.9999E+04	2.0273E+05	2.0240E+05	2.0424E+05
460	7.9997E+04	7.9998E+04	7.9999E+04	2.0369E+05	2.0353E+05	2.0463E+05
480	7.9996E+04	7.9998E+04	7.9998E+04	2.0510E+05	2.0487E+05	2.0503E+05
500	7.9996E+04	7.9998E+04	7.9998E+04	2.0644E+05	2.0617E+05	2.0548E+05
520	7.9996E+04	7.9998E+04	7.9998E+04	2.0751E+05	2.0716E+05	2.0586E+05
540	7.9996E+04	7.9998E+04	7.9998E+04	2.0836E+05	2.0789E+05	2.0618E+05
560	7.9996E+04	7.9997E+04	7.9998E+04	2.0897E+05	2.0840E+05	2.0643E+05
580	7.9996E+04	7.9997E+04	7.9998E+04	2.0934E+05	2.0873E+05	2.0657E+05
600	7.9996E+04	7.9997E+04	7.9998E+04	2.0946E+05	2.0893E+05	2.0661E+05
620	7.9996E+04	7.9997E+04	7.9998E+04	2.0939E+05	2.0901E+05	2.0653E+05
640	7.9996E+04	7.9997E+04	7.9998E+04	2.0920E+05	2.0904E+05	2.0640E+05
660	7.9996E+04	7.9997E+04	7.9998E+04	2.0899E+05	2.0909E+05	2.0630E+05
680	7.9996E+04	7.9997E+04	7.9998E+04	2.0871E+05	2.0912E+05	2.0623E+05
700	7.9996E+04	7.9997E+04	7.9998E+04	2.0848E+05	2.0924E+05	2.0625E+05
720	7.9996E+04	7.9997E+04	7.9998E+04	2.0837E+05	2.0952E+05	2.0645E+05
740	7.9996E+04	7.9997E+04	7.9998E+04	2.0252E+05	2.0182E+05	2.0277E+05
760	7.9996E+04	7.9997E+04	7.9998E+04	2.0231E+05	2.0149E+05	2.0340E+05
780	7.9996E+04	7.9997E+04	7.9998E+04	2.0208E+05	2.0128E+05	2.0386E+05
800	7.9996E+04	7.9997E+04	7.9998E+04	2.0273E+05	2.0240E+05	2.0424E+05
820	7.9996E+04	7.9997E+04	7.9998E+04	2.0369E+05	2.0353E+05	2.0463E+05
840	7.9996E+04	7.9997E+04	7.9998E+04	2.0510E+05	2.0487E+05	2.0503E+05
860	7.9996E+04	7.9997E+04	7.9998E+04	2.0644E+05	2.0617E+05	2.0548E+05
880	7.9996E+04	7.9997E+04	7.9998E+04	2.0752E+05	2.0716E+05	2.0586E+05
900	7.9996E+04	7.9997E+04	7.9998E+04	2.0836E+05	2.0789E+05	2.0618E+05
920	7.9996E+04	7.9997E+04	7.9998E+04	2.0897E+05	2.0840E+05	2.0643E+05
940	7.9995E+04	7.9997E+04	7.9998E+04	2.0934E+05	2.0873E+05	2.0657E+05
960	7.9995E+04	7.9997E+04	7.9998E+04	2.0946E+05	2.0893E+05	2.0661E+05
980	7.9995E+04	7.9997E+04	7.9998E+04	2.0939E+05	2.0901E+05	2.0653E+05
1000	7.9995E+04	7.9997E+04	7.9998E+04	2.0920E+05	2.0904E+05	2.0640E+05
1020	7.9995E+04	7.9997E+04	7.9998E+04	2.0899E+05	2.0909E+05	2.0630E+05
1040	7.9995E+04	7.9997E+04	7.9998E+04	2.0871E+05	2.0912E+05	2.0623E+05
1060	7.9995E+04	7.9997E+04	7.9998E+04	2.0848E+05	2.0924E+05	2.0625E+05
1080	7.9995E+04	7.9997E+04	7.9998E+04	2.0837E+05	2.0952E+05	2.0645E+05
1100	7.9995E+04	7.9997E+04	7.9998E+04	2.0252E+05	2.0182E+05	2.0277E+05
1120	7.9995E+04	7.9997E+04	7.9998E+04	2.0231E+05	2.0149E+05	2.0340E+05
1140	7.9995E+04	7.9997E+04	7.9998E+04	2.0208E+05	2.0128E+05	2.0386E+05
1160	7.9995E+04	7.9997E+04	7.9998E+04	2.0273E+05	2.0240E+05	2.0424E+05
1180	7.9995E+04	7.9997E+04	7.9998E+04	2.0369E+05	2.0353E+05	2.0463E+05
1200	7.9995E+04	7.9997E+04	7.9998E+04	2.0510E+05	2.0488E+05	2.0503E+05

STEP	BSUS(1)	BSUS(2)	BSUS(3)	EIOC(1)	EIOC(2)	EIOC(3)
0	1.000	1.000	266.0	3500.	3500.	5000.
20	.9075	.7893	233.6	3698.	2141.	2025.
40	.8110	.6028	200.9	4603.	2854.	2178.
60	.7153	.4433	168.4	6983.	4113.	3034.
80	.6170	.3067	135.4	9699.	5642.	4466.
100	.5419	.2047	103.1	13966.	8834.	6977.
120	.5295	.1792	91.62	24495.	13835.	10661.
140	.4047	.1342	67.92	31368.	17893.	14132.
160	.4031	.1322	66.23	34463.	20217.	16689.
180	.4064	.1317	65.21	35096.	20432.	17582.
200	.4157	.1322	64.28	27406.	17073.	15474.
220	.4295	.1330	62.95	19053.	11942.	11430.
240	.4408	.1325	60.89	12981.	7743.	7434.
260	.4413	.1306	58.46	7955.	4926.	4515.
280	.4367	.1281	56.03	5565.	3308.	2784.
300	.4320	.1259	53.81	4018.	2350.	1837.
320	.3322	9.6155E-02	40.05	2847.	1746.	1302.
340	.3241	9.4015E-02	38.60	2769.	1593.	1201.
360	.3118	8.5341E-02	37.39	2865.	1697.	1268.
380	.3014	7.8069E-02	32.91	3628.	2079.	1647.
400	.2892	6.9888E-02	28.13	4623.	2850.	2137.
420	.2750	6.0971E-02	23.20	7025.	4122.	3032.
440	.2575	5.1056E-02	18.18	9728.	5650.	4471.
460	.2423	4.1663E-02	13.65	13996.	8840.	6984.
480	.2404	3.9113E-02	11.98	24582.	13859.	10672.
500	.1857	2.9917E-02	8.710	31590.	17952.	14150.
520	.1857	2.9668E-02	8.692	34998.	20355.	16718.
540	.1875	2.9622E-02	8.742	36114.	20664.	17626.
560	.1923	2.9810E-02	8.820	28885.	17460.	15536.
580	.2008	3.0157E-02	8.868	20731.	12455.	11507.
600	.2094	3.0361E-02	8.838	13957.	8073.	7495.
620	.2110	3.0146E-02	8.741	8212.	5034.	4544.
640	.2092	2.9718E-02	8.608	5627.	3335.	2795.
660	.2071	2.9295E-02	8.472	4049.	2362.	1842.
680	.1594	2.2454E-02	6.476	2874.	1756.	1304.
700	.1561	2.2082E-02	6.392	2793.	1600.	1203.
720	.1511	2.0672E-02	6.322	2888.	1706.	1270.
740	.1481	1.9577E-02	5.855	3796.	2126.	1653.
760	.1438	1.8326E-02	5.337	4694.	2879.	2141.
780	.1386	1.6865E-02	4.766	7068.	4134.	3035.
800	.1319	1.5128E-02	4.134	9740.	5656.	4473.
820	.1257	1.3349E-02	3.523	14006.	8845.	6986.
840	.1250	1.2842E-02	3.363	24607.	13867.	10674.
860	.0967	9.8733E-03	2.595	31664.	17904.	14154.
880	.0967	9.8149E-03	2.597	35198.	20406.	16725.
900	.0976	9.8100E-03	2.615	36475.	20751.	17637.
920	.1002	9.8782E-03	2.640	29316.	17592.	15551.
940	.1049	1.0006E-02	2.655	21125.	12598.	11526.
960	.1096	1.0090E-02	2.648	14204.	8161.	7509.
980	.1105	1.0023E-02	2.619	8294.	5068.	4551.
1000	.1094	9.8779E-03	2.579	5660.	3348.	2797.
1020	.1082	9.7342E-03	2.537	4075.	2371.	1843.
1040	.0832	7.4590E-03	1.939	2898.	1765.	1306.
1060	.0812	7.3323E-03	1.914	2814.	1607.	1203.
1080	.0782	6.8499E-03	1.893	2909.	1713.	1271.
1100	.0768	6.4943E-03	1.752	3882.	2144.	1654.
1120	.0745	6.0914E-03	1.598	4760.	2907.	2145.
1140	.0715	5.6029E-03	1.427	7107.	4146.	3037.
1160	.0675	5.0182E-03	1.236	9753.	5661.	4474.
1180	.0637	4.4146E-03	1.052	14011.	8849.	6987.
1200	.0633	4.2425E-03	1.004	24621.	13872.	10674.

STEP	ELOC(1)	ELOC(2)	ELOC(3)	FROC(1)	FROC(2)	FROC(3)
0	100.0	160.0	450.0	4500.	3200.	2100.
20	56.10	62.13	108.4	8405.	2685.	1005.
40	51.74	55.72	88.00	7850.	3253.	1136.
60	80.40	73.13	120.2	8250.	3928.	1479.
80	81.06	85.29	173.1	11053.	4810.	2073.
100	120.7	116.3	262.7	23251.	8030.	3256.
120	243.6	216.3	419.1	38459.	12796.	4838.
140	332.6	283.9	550.1	39875.	15702.	6434.
160	414.3	343.5	645.8	38666.	16072.	7472.
180	636.4	460.1	696.8	32688.	15021.	7774.
200	845.3	559.5	631.3	22124.	12010.	6842.
220	932.0	548.2	485.4	14951.	8445.	5090.
240	564.9	331.7	317.2	10327.	5763.	3392.
260	162.6	134.6	185.6	6766.	3891.	2116.
280	63.27	59.07	110.6	6068.	3060.	1339.
300	33.64	33.41	69.49	5814.	2638.	959.9
320	18.19	20.15	47.04	4773.	2193.	744.5
340	21.47	22.78	46.48	4471.	1893.	620.0
360	24.27	25.19	48.73	4615.	2064.	679.4
380	136.5	111.9	76.34	8403.	2670.	861.1
400	130.8	102.4	90.50	7861.	3254.	1119.
420	160.6	114.8	124.6	8255.	3930.	1477.
440	100.9	111.7	178.0	11054.	4812.	2073.
460	124.8	118.9	263.9	23268.	8033.	3258.
480	249.2	218.3	419.5	38462.	12798.	4839.
500	337.5	285.7	550.3	39876.	15702.	6435.
520	417.1	344.9	645.7	38664.	16081.	7474.
540	646.1	464.5	696.9	32689.	15023.	7774.
560	922.1	587.4	633.3	22124.	12011.	6842.
580	1171.	633.9	493.8	14950.	8445.	5090.
600	726.4	397.1	325.7	10325.	5763.	3392.
620	186.9	150.9	189.0	6764.	3891.	2116.
640	64.79	60.59	111.3	6067.	3060.	1339.
660	33.93	33.59	69.57	5813.	2639.	959.9
680	18.46	20.27	47.05	4771.	2193.	744.6
700	21.74	22.89	46.48	4469.	1893.	620.0
720	24.54	25.31	48.73	4614.	2064.	679.4
740	534.9	382.1	114.4	8403.	2670.	861.1
760	289.7	209.0	110.7	7855.	3254.	1119.
780	319.4	192.5	135.1	8249.	3929.	1477.
800	141.9	161.4	187.7	11063.	4813.	2073.
820	131.4	124.2	266.6	23269.	8034.	3258.
840	257.6	221.4	420.6	38461.	12798.	4839.
860	346.4	289.0	551.0	39875.	15702.	6435.
880	423.9	347.7	646.1	38663.	16081.	7474.
900	651.1	467.2	697.3	32687.	15023.	7774.
920	950.2	598.1	634.3	22123.	12010.	6842.
940	1243.	662.5	496.9	14948.	8445.	5090.
960	767.7	415.3	328.3	10323.	5763.	3392.
980	192.7	155.1	190.0	6762.	3890.	2116.
1000	65.44	61.08	111.5	6065.	3060.	1339.
1020	34.40	33.79	69.62	5811.	2638.	959.9
1040	18.91	20.48	47.08	4769.	2192.	744.6
1060	22.15	23.06	46.50	4467.	1893.	620.0
1080	24.95	25.48	48.75	4611.	2064.	679.4
1100	1372.	677.4	150.0	8399.	2669.	861.1
1120	429.9	325.8	133.1	7850.	3253.	1119.
1140	452.6	257.4	144.8	8243.	3928.	1477.
1160	175.5	202.0	195.6	11061.	4813.	2073.
1180	139.2	129.2	268.9	23269.	8034.	3258.
1200	267.8	225.1	421.6	38460.	12798.	4839.

STEP	ESILT(1)	ESILT(2)	ESILT(3)	PBAC(1)	PBAC(2)	PBAC(3)
0	3500.	1500.	400.0	40.00	23.00	14.00
20	4469.	2715.	1062.	113.1	108.5	56.98
40	4133.	2836.	1103.	139.4	127.9	78.12
60	4094.	2806.	974.9	148.5	127.8	68.99
80	4216.	2792.	921.3	151.1	138.5	82.42
100	6765.	3579.	1060.	141.0	152.8	104.4
120	10394.	4862.	1147.	150.0	143.9	90.01
140	10411.	5509.	1321.	163.5	140.7	83.45
160	9426.	4933.	1368.	193.6	168.1	100.5
180	7754.	3953.	1303.	217.0	183.6	109.1
200	5201.	2876.	1124.	273.2	223.2	121.8
220	3322.	1984.	858.8	405.2	326.9	156.5
240	2176.	1487.	620.7	440.5	346.1	157.4
260	1641.	1303.	461.2	286.7	224.7	107.4
280	1948.	1466.	458.1	166.5	134.8	66.15
300	2228.	1675.	576.9	137.6	113.8	59.47
320	2092.	1758.	734.7	123.5	104.7	60.60
340	2523.	2019.	832.5	99.52	85.10	49.33
360	2938.	2375.	1014.	98.28	84.33	48.49
380	4604.	2810.	1140.	196.8	199.5	104.6
400	4174.	2858.	1115.	228.5	207.2	118.0
420	4113.	2815.	977.5	222.5	186.8	94.71
440	4223.	2796.	922.3	193.6	175.3	94.89
460	6771.	3580.	1062.	142.6	155.0	105.6
480	10397.	4863.	1148.	150.1	144.0	90.23
500	10413.	5511.	1321.	163.8	140.9	83.65
520	9424.	4935.	1369.	195.4	169.4	101.0
540	7755.	3953.	1304.	223.0	187.9	110.7
560	5202.	2877.	1124.	297.4	240.9	128.7
580	3323.	1985.	859.0	483.4	386.6	180.2
600	2178.	1487.	620.8	539.4	419.3	182.9
620	1642.	1303.	461.3	326.6	253.4	116.1
640	1949.	1467.	458.1	173.4	139.9	67.62
660	2229.	1676.	577.0	139.0	114.8	59.79
680	2093.	1759.	734.8	124.4	105.4	60.88
700	2524.	2019.	832.5	100.3	85.68	49.54
720	2939.	2375.	1014.	99.00	84.90	48.69
740	4604.	2810.	1140.	299.2	322.9	122.8
760	4174.	2858.	1115.	387.7	353.5	182.8
780	4113.	2815.	977.5	359.6	297.9	141.7
800	4226.	2797.	922.7	273.1	244.6	118.7
820	6772.	3581.	1062.	145.3	158.3	107.1
840	10398.	4864.	1148.	150.3	144.2	90.54
860	10413.	5511.	1321.	164.0	141.1	83.90
880	9424.	4935.	1369.	196.2	170.1	101.4
900	7755.	3953.	1304.	225.7	189.8	111.4
920	5202.	2877.	1124.	305.4	247.1	131.3
940	3323.	1985.	859.0	506.4	404.7	187.7
960	2178.	1487.	620.8	565.6	438.9	189.9
980	1642.	1303.	461.3	336.7	260.7	118.3
1000	1949.	1467.	458.1	175.5	141.5	68.09
1020	2229.	1676.	577.0	140.1	115.7	60.08
1040	2093.	1759.	734.8	125.6	106.3	61.24
1060	2524.	2019.	832.5	101.2	86.40	49.81
1080	2939.	2375.	1014.	99.88	85.59	48.94
1100	4604.	2810.	1140.	302.2	326.3	124.0
1120	4174.	2858.	1115.	522.4	475.9	230.4
1140	4113.	2815.	977.5	472.3	389.0	179.3
1160	4226.	2797.	922.7	335.5	299.1	137.5
1180	6772.	3581.	1062.	147.5	161.0	108.6
1200	10398.	4864.	1148.	151.0	144.8	91.00

STEP	PCAR(1)	PCAR(2)	PCAR(3)	PDET(1)	PDET(2)	PDET(3)
0	.5500	.5500	.5500	25.00	5.000	5.000
20	.2937	.3655	.2167	14.70	8.487	5.361
40	.2065	.2063	.1078	12.61	10.26	6.078
60	.1489	.1270	.0610	14.17	12.07	7.041
80	.0987	.0971	.1046	16.80	14.93	8.652
100	.3023	.5826	1.038	19.01	19.03	11.11
120	1.480	2.105	2.521	24.01	25.28	14.67
140	4.135	4.498	4.195	40.20	37.94	21.27
160	8.990	9.081	7.466	71.86	60.15	33.05
180	17.75	16.38	12.56	114.6	86.20	48.37
200	32.24	27.91	20.44	143.2	99.54	61.12
220	43.15	36.93	28.26	97.31	63.40	53.54
240	31.45	28.51	25.46	49.23	31.64	25.60
260	18.63	17.83	17.54	18.15	12.29	10.11
280	10.16	10.94	11.11	4.986	4.023	4.830
300	6.720	7.833	8.064	1.665	1.944	3.648
320	5.418	6.380	5.899	1.110	1.750	3.261
340	4.391	4.597	3.088	1.245	2.029	2.922
360	3.098	2.979	1.611	1.684	2.498	2.870
380	1.280	1.610	.9191	2.037	3.027	2.862
400	.9182	.9199	.4767	2.895	3.669	2.964
420	.6768	.5762	.2752	4.230	4.529	3.222
440	.4535	.4224	.2608	5.768	5.847	3.809
460	.4859	.8105	1.156	7.197	7.736	4.784
480	1.622	2.259	2.603	9.748	10.59	6.340
500	4.318	4.664	4.275	16.84	16.19	9.258
520	9.090	9.214	7.552	29.55	25.34	14.33
540	16.21	15.46	12.37	39.89	32.68	20.50
560	19.82	20.16	18.17	25.95	22.89	22.80
580	16.66	18.24	20.67	16.92	13.58	16.79
600	14.92	16.49	19.31	11.95	8.921	8.610
620	11.25	12.43	15.00	5.402	4.051	4.078
640	7.654	8.959	10.13	1.644	1.493	2.162
660	5.908	7.123	7.636	.6605	.8523	1.698
680	5.070	6.047	5.685	.4946	.8145	1.536
700	4.204	4.421	2.992	.5840	.9617	1.385
720	2.984	2.874	1.556	.8036	1.196	1.367
740	1.237	1.557	.8885	.9844	1.466	1.375
760	.8946	.8949	.4626	1.423	1.804	1.441
780	.6669	.5665	.2697	2.110	2.260	1.588
800	.4530	.4215	.2606	2.919	2.964	1.904
820	.4916	.8172	1.160	3.685	3.979	2.430
840	1.642	2.280	2.612	5.049	5.497	3.259
860	4.384	4.719	4.298	8.811	8.468	4.795
880	9.182	9.302	7.592	15.43	13.26	7.449
900	14.98	14.78	12.24	18.15	15.90	10.56
920	13.76	15.22	16.57	9.860	8.629	10.91
940	11.84	14.31	18.45	6.751	5.700	7.747
960	11.74	14.00	17.89	5.076	3.974	4.030
980	9.536	11.11	14.33	2.389	1.857	1.963
1000	6.964	8.389	9.823	.7464	.7038	1.060
1020	5.647	6.883	7.489	.3175	.4183	.8406
1040	4.940	5.922	5.607	.2444	.4052	.7635
1060	4.130	4.352	2.955	.2914	.4804	.6904
1080	2.936	2.831	1.534	.4018	.5985	.6826
1100	1.218	1.534	.8756	.4931	.7347	.6874
1120	.8838	.8834	.4562	.7166	.9091	.7228
1140	.6631	.5625	.2672	1.069	1.144	.7991
1160	.4538	.4216	.2602	1.482	1.506	.9614
1180	.4952	.8212	1.162	1.873	2.025	1.230
1200	1.655	2.293	2.618	2.574	2.803	1.654

STEP	PFLR(1)	PFLR(2)	PFLR(3)	PHER(1)	PHER(2)	PHER(3)
0	0.	0.	0.	20.00	10.00	10.00
20	0.	0.	0.	11.52	15.81	46.20
40	0.	0.	0.	14.99	27.79	67.62
60	0.	0.	0.	24.33	40.55	80.44
80	0.	0.	0.	31.99	49.64	85.11
100	.2729	.2740	.2794	34.18	55.08	85.69
120	.4584	.4580	.4611	35.91	56.74	84.68
140	.4870	.4837	.4825	37.04	52.02	78.74
160	.4958	.4896	.4864	29.84	38.88	64.52
180	.5061	.4982	.4973	17.73	24.13	52.14
200	.2019	.2030	.2072	7.755	12.68	39.96
220	7.4081E-02	7.9377E-02	8.6336E-02	1.842	4.382	26.99
240	2.4788E-02	2.7734E-02	3.2329E-02	.8894	2.299	15.63
260	7.4499E-03	8.4963E-03	1.0353E-02	.4012	1.598	14.83
280	2.1675E-03	2.4263E-03	2.8365E-03	.3083	1.963	21.98
300	5.7510E-04	6.4666E-04	7.5196E-04	.4655	2.941	28.13
320	4.9121E-05	5.5413E-05	6.3543E-05	1.099	5.526	38.31
340	1.4152E-05	1.5051E-05	1.5986E-05	3.263	12.12	53.49
360	2.4807E-05	2.5771E-05	2.6725E-05	7.019	19.97	64.81
380	3.9068E-05	4.0031E-05	4.1105E-05	12.94	31.18	75.10
400	6.1836E-05	6.2860E-05	6.4073E-05	24.10	44.82	85.04
420	9.9414E-05	1.0026E-04	1.0127E-04	38.83	58.09	92.45
440	1.6390E-04	1.6453E-04	1.6528E-04	48.59	67.15	94.37
460	.4238	.3977	.3936	47.00	68.98	92.07
480	.6846	.6636	.6578	44.73	66.34	88.88
500	.7234	.7003	.6899	43.27	58.11	80.19
520	.7393	.7096	.6951	31.55	40.71	65.01
540	.7438	.7187	.7120	12.67	20.23	50.76
560	.2544	.2720	.2908	2.157	6.190	36.92
580	8.9394E-02	.1003	.1130	1.295	4.190	26.56
600	3.4804E-02	3.8241E-02	4.3339E-02	1.612	3.285	17.66
620	1.0881E-02	1.2266E-02	1.4699E-02	.6352	2.004	17.11
640	3.1840E-03	3.5628E-03	4.1528E-03	.3503	2.163	23.36
660	8.5538E-04	9.6124E-04	1.1137E-03	.5326	3.211	29.28
680	7.3409E-05	8.2705E-05	9.4605E-05	1.173	5.743	38.74
700	2.1156E-05	2.2484E-05	2.3862E-05	3.371	12.38	53.92
720	3.7112E-05	3.8537E-05	3.9944E-05	7.188	20.30	65.23
740	5.8501E-05	5.9928E-05	6.1510E-05	13.46	32.40	75.75
760	9.2933E-05	9.4369E-05	9.6077E-05	28.57	51.34	88.69
780	1.4997E-04	1.5108E-04	1.5240E-04	51.67	71.93	99.29
800	2.4860E-04	2.4920E-04	2.4991E-04	69.12	87.50	102.8
820	.7041	.6116	.5788	63.24	85.77	98.71
840	1.081	1.011	.9798	55.27	77.41	93.15
860	1.133	1.063	1.029	50.56	64.89	82.35
880	1.163	1.078	1.035	34.44	43.20	65.48
900	1.151	1.085	1.061	9.361	17.48	49.30
920	.3500	.3842	.4241	1.310	4.648	34.93
940	.1257	.1421	.1611	1.215	4.177	26.55
960	5.0414E-02	5.5193E-02	6.2166E-02	1.812	3.562	18.14
980	1.5916E-02	1.7881E-02	2.1339E-02	.7041	2.104	17.61
1000	4.6549E-03	5.2084E-03	6.0667E-03	.3602	2.215	23.67
1020	1.2544E-03	1.4094E-03	1.6314E-03	.5532	3.286	29.57
1040	1.0780E-04	1.2141E-04	1.3878E-04	1.198	5.821	38.93
1060	3.1072E-05	3.3017E-05	3.5031E-05	3.412	12.48	54.11
1080	5.4515E-05	5.6601E-05	5.8659E-05	7.253	20.43	65.41
1100	8.5941E-05	8.8031E-05	9.0348E-05	13.57	32.61	75.95
1120	1.3668E-04	1.3873E-04	1.4117E-04	31.43	55.54	90.52
1140	2.2097E-04	2.2247E-04	2.2427E-04	62.94	83.73	104.4
1160	3.6713E-04	3.6777E-04	3.6849E-04	89.44	106.8	109.9
1180	1.186	.9526	.8594	78.84	101.4	104.3
1200	1.732	1.557	1.474	64.51	87.01	96.46

STEP	PHYT(1)	PHYT(2)	PHYT(3)	PIOC(1)	PIOC(2)	PIOC(3)
0	70.00	70.00	45.00	1200.	1100.	1000.
20	39.82	29.33	26.74	1272.	1199.	1236.
40	24.70	21.10	21.35	1394.	1309.	1397.
60	18.27	17.88	19.34	1667.	1501.	1585.
80	18.14	17.32	18.56	1637.	1484.	1664.
100	23.06	19.01	20.10	1598.	1527.	1823.
120	34.32	24.44	24.32	2030.	1717.	1870.
140	42.55	35.44	35.20	2052.	1561.	1658.
160	74.72	72.30	73.04	1908.	1390.	1493.
180	109.5	123.7	121.1	2041.	1412.	1402.
200	178.7	192.9	163.5	1979.	1406.	1324.
220	317.7	322.0	223.4	1924.	1480.	1359.
240	314.7	302.6	189.8	1927.	1459.	1310.
260	153.8	136.9	85.19	1682.	1367.	1205.
280	53.83	45.84	36.03	1541.	1280.	1167.
300	31.13	25.77	25.64	1371.	1144.	1060.
320	28.22	19.82	20.49	1161.	991.2	926.9
340	28.77	21.52	22.54	1143.	987.8	978.6
360	29.38	22.51	23.31	1154.	1016.	1008.
380	38.10	27.12	25.59	1257.	1181.	1218.
400	24.16	20.48	20.97	1405.	1316.	1397.
420	17.84	17.50	19.16	1681.	1510.	1585.
440	17.73	16.94	18.39	1643.	1489.	1666.
460	22.77	18.66	19.94	1602.	1531.	1825.
480	34.08	24.23	24.24	2039.	1724.	1873.
500	42.54	35.48	35.27	2071.	1573.	1663.
520	77.36	74.97	74.63	1949.	1415.	1504.
540	122.9	137.0	128.5	2127.	1459.	1421.
560	234.7	243.2	189.5	2137.	1493.	1357.
580	457.3	446.7	287.8	2134.	1607.	1408.
600	437.2	409.2	239.6	2094.	1561.	1348.
620	190.3	166.7	96.66	1744.	1407.	1219.
640	57.30	48.60	36.90	1560.	1293.	1172.
660	31.15	25.81	25.64	1383.	1153.	1064.
680	28.05	19.75	20.47	1174.	1001.	932.0
700	28.65	21.46	22.52	1155.	996.3	982.5
720	29.26	22.46	23.30	1165.	1024.	1012.
740	37.98	27.05	25.57	1316.	1232.	1246.
760	23.96	20.31	20.89	1430.	1335.	1407.
780	17.53	17.25	19.06	1695.	1518.	1585.
800	17.24	16.50	18.22	1645.	1490.	1667.
820	22.30	18.13	19.72	1603.	1532.	1826.
840	33.64	23.83	24.09	2041.	1726.	1874.
860	41.98	35.03	35.12	2077.	1577.	1665.
880	77.24	74.98	74.75	1964.	1424.	1508.
900	127.1	141.3	131.0	2157.	1476.	1428.
920	251.6	260.1	199.6	2176.	1516.	1368.
940	491.6	480.2	307.2	2180.	1637.	1422.
960	464.1	434.7	252.2	2136.	1587.	1359.
980	196.1	172.5	99.10	1764.	1421.	1224.
1000	57.26	48.75	36.97	1571.	1300.	1175.
1020	30.77	25.63	25.59	1394.	1160.	1067.
1040	27.64	19.57	20.42	1185.	1009.	936.4
1060	28.37	21.33	22.48	1165.	1004.	985.9
1080	28.96	22.32	23.26	1175.	1032.	1015.
1100	37.72	26.90	25.52	1350.	1265.	1255.
1120	23.71	20.16	20.83	1452.	1353.	1418.
1140	17.22	17.02	18.97	1706.	1526.	1587.
1160	16.76	16.09	18.07	1648.	1492.	1668.
1180	21.83	17.64	19.52	1604.	1533.	1827.
1200	33.26	23.47	23.95	2043.	1727.	1875.

STEP	PLOC(1)	PLOC(2)	PLOC(3)	PMFH(1)	PMFH(2)	PMFH(3)
0	25.00	15.00	20.00	0.	0.	0.
20	25.60	16.78	30.00	0.	0.	0.
40	16.82	13.54	22.88	0.	0.	0.
60	17.18	16.58	34.07	0.	0.	0.
80	15.65	11.49	26.42	0.	0.	0.
100	26.60	12.05	26.61	0.	0.	0.
120	27.58	15.76	30.92	0.	0.	0.
140	21.51	15.90	29.68	0.	0.	0.
160	23.18	19.34	33.56	34.24	33.57	31.44
180	31.94	28.72	41.11	84.16	77.88	65.05
200	51.96	46.43	52.55	130.0	111.6	87.20
220	84.74	75.25	66.69	164.6	128.8	100.4
240	71.25	61.62	51.05	153.5	110.7	91.06
260	29.73	25.76	25.61	54.66	31.87	23.36
280	16.59	13.51	21.60	11.83	6.242	4.516
300	12.02	9.047	17.24	1.899	.9965	.7734
320	9.534	5.977	11.92	.2771	.1494	.1254
340	10.55	7.254	15.34	3.9281E-02	2.1972E-02	1.9614E-02
360	10.90	7.819	16.20	5.5472E-03	3.2304E-03	2.9872E-03
380	57.06	41.77	52.45	5.5472E-03	3.2304E-03	2.9872E-03
400	45.57	34.86	43.03	5.5472E-03	3.2304E-03	2.9872E-03
420	40.86	33.35	47.56	5.5472E-03	3.2304E-03	2.9872E-03
440	16.84	12.44	26.75	5.5472E-03	3.2304E-03	2.9872E-03
460	27.09	12.50	26.88	5.5472E-03	3.2304E-03	2.9872E-03
480	28.07	16.14	31.12	5.5472E-03	3.2304E-03	2.9872E-03
500	21.86	16.12	29.77	5.5472E-03	3.2304E-03	2.9872E-03
520	23.28	19.47	33.71	31.17	30.68	29.21
540	32.12	29.44	41.98	63.82	60.17	53.01
560	57.28	51.97	56.86	75.48	70.08	63.17
580	108.6	95.67	78.51	70.97	64.81	64.68
600	91.99	78.65	59.54	64.59	58.94	58.58
620	33.98	29.31	27.21	13.87	11.55	11.18
640	16.92	13.77	21.73	2.357	1.896	1.873
660	12.14	9.130	17.30	.3506	.2833	.2935
680	9.672	6.072	11.98	4.9517E-02	4.0747E-02	4.4317E-02
700	10.69	7.349	15.41	6.8392E-03	5.7543E-03	6.4933E-03
720	11.04	7.916	16.27	9.3618E-04	8.0632E-04	9.2923E-04
740	170.9	129.6	185.9	9.3618E-04	8.0632E-04	9.2923E-04
760	94.85	79.03	87.44	9.3618E-04	8.0632E-04	9.2923E-04
780	81.87	66.73	71.14	9.3618E-04	8.0632E-04	9.2923E-04
800	19.01	14.12	27.20	9.3618E-04	8.0632E-04	9.2923E-04
820	27.89	13.20	27.26	9.3618E-04	8.0632E-04	9.2923E-04
840	28.85	16.72	31.42	9.3618E-04	8.0632E-04	9.2923E-04
860	22.53	16.54	29.97	9.3618E-04	8.0632E-04	9.2923E-04
880	23.68	19.70	33.85	29.49	29.14	28.15
900	32.26	29.71	42.32	53.94	51.85	47.67
920	59.39	53.98	58.53	57.60	55.38	53.71
940	115.5	101.6	82.21	55.37	52.83	53.88
960	97.11	82.95	61.78	53.26	50.91	50.83
980	34.95	30.14	27.63	9.673	8.779	8.654
1000	17.13	13.90	21.81	1.527	1.361	1.363
1020	12.35	9.263	17.39	.2220	.1985	.2051
1040	9.903	6.220	12.09	3.0959E-02	2.8039E-02	2.9951E-02
1060	10.91	7.494	15.50	4.2278E-03	3.8864E-03	4.2553E-03
1080	11.26	8.062	16.36	5.7046E-04	5.3236E-04	5.9120E-04
1100	456.9	400.2	336.9	5.7046E-04	5.3236E-04	5.9120E-04
1120	137.0	118.0	134.3	5.7046E-04	5.3236E-04	5.9120E-04
1140	116.3	94.80	90.46	5.7046E-04	5.3236E-04	5.9120E-04
1160	20.97	15.60	27.62	5.7046E-04	5.3236E-04	5.9120E-04
1180	28.93	14.02	27.72	5.7046E-04	5.3236E-04	5.9120E-04
1200	29.83	17.42	31.79	5.7046E-04	5.3236E-04	5.9120E-04

STEP	PNPBAC(1)	PNPBAC(2)	PNPBAC(3)	PNPHYT(1)	PNPHYT(2)	PNPHYT(3)
0	0.	0.	0.	0.	0.	0.
20	22.63	16.97	16.23	-.3113	-.1710	.0086
40	18.37	15.75	21.94	-.1242	-.0036	.2430
60	19.43	17.97	21.96	.0924	.1676	.5939
80	18.44	15.29	24.37	.1871	.4302	1.054
100	24.28	15.84	24.63	.1817	.5408	1.634
120	28.04	19.42	28.68	.3907	.9773	2.860
140	24.38	18.32	26.47	1.857	3.147	6.598
160	24.07	18.21	26.41	4.728	10.01	21.60
180	29.35	23.64	30.37	9.283	21.74	43.92
200	39.53	32.87	35.65	26.79	42.95	66.83
220	55.84	49.14	45.43	51.52	75.37	91.05
240	50.14	42.44	36.12	44.09	59.10	58.22
260	26.98	22.59	21.47	13.44	16.39	16.71
280	18.66	15.25	18.83	1.830	2.389	3.587
300	15.23	12.08	16.01	.1427	.3398	1.053
320	12.59	9.435	11.99	-.1682	-.0124	.2599
340	12.96	10.08	14.36	-.0892	-.0454	.1198
360	13.23	10.66	15.19	-.2054	-.1197	.0520
380	39.64	30.56	30.20	-.3006	-.1633	.0731
400	33.98	27.46	33.22	-.1233	-.0176	.2363
420	32.39	27.12	30.17	.0886	.1620	.5868
440	19.27	15.94	24.57	.1823	.4196	1.044
460	24.56	16.11	24.79	.1791	.5301	1.620
480	28.35	19.67	28.81	.3877	.9683	2.850
500	24.69	18.51	26.55	1.854	3.147	6.607
520	24.35	18.42	26.55	4.882	10.36	22.03
540	29.91	24.23	30.89	10.34	23.92	46.40
560	43.04	36.03	37.91	34.63	53.44	76.83
580	69.47	60.84	52.46	74.07	104.2	116.5
600	62.51	52.47	41.11	61.20	79.82	73.35
620	29.81	24.85	22.45	16.63	19.95	19.00
640	18.98	15.49	18.94	1.959	2.548	3.686
660	15.38	12.18	16.06	.1424	.3402	1.053
680	12.74	9.542	12.05	-.1674	-.0125	.2595
700	13.11	10.18	14.42	-.0890	-.0454	.1196
720	13.37	10.76	15.25	-.2046	-.1195	.0519
740	75.56	84.48	34.61	-.2997	-.1628	.0731
760	60.76	51.71	51.37	-.1223	-.0376	.2355
780	54.82	45.40	45.08	.0870	.1597	.5836
800	20.89	17.07	24.83	.1768	.4084	1.034
820	25.00	16.50	25.01	.1753	.5149	1.602
840	28.78	20.00	28.98	.3827	.9523	2.832
860	25.09	18.77	26.67	1.829	3.106	6.577
880	24.67	18.61	26.65	4.869	10.35	22.06
900	30.15	24.46	31.09	10.66	24.60	47.22
920	44.32	37.15	38.78	37.06	57.02	80.71
940	73.30	64.24	54.68	79.56	111.9	124.3
960	65.57	55.01	42.43	64.97	84.80	77.18
980	30.50	25.41	22.72	17.15	20.66	19.49
1000	19.16	15.61	19.00	1.960	2.559	3.696
1020	15.55	12.29	16.13	.1406	.3378	1.050
1040	12.93	9.671	12.14	-.1649	-.0124	.2589
1060	13.29	10.30	14.49	-.0881	-.0451	.1194
1080	13.55	10.88	15.31	-.2025	-.1187	.0518
1100	76.33	85.37	34.94	-.2977	-.1620	.0729
1120	83.71	73.15	64.57	-.1211	-.0370	.2349
1140	73.63	60.79	57.01	.0855	.1576	.5809
1160	22.28	18.06	25.08	.1718	.3983	1.025
1180	25.56	16.95	25.26	.1716	.5006	1.586
1200	29.32	20.38	29.19	.3783	.9380	2.816

STEP	PRFH(1)	PRFH(2)	PRFH(3)	PROC(1)	PROC(2)	PROC(3)
0	20.00	20.00	20.00	3000.	1500.	1000.
20	20.10	20.14	20.28	4948.	2572.	1335.
40	20.19	20.26	20.55	3488.	2072.	1414.
60	20.31	20.42	20.85	2655.	1727.	1290.
80	20.59	20.69	21.21	3036.	1624.	1242.
100	19.28	19.29	19.83	5532.	2382.	1486.
120	16.44	16.33	16.78	5544.	2528.	1431.
140	14.41	14.19	14.49	3605.	1790.	1137.
160	13.00	12.66	12.81	2863.	1453.	1032.
180	12.03	11.55	11.56	2338.	1263.	942.7
200	14.07	13.16	13.04	1811.	1106.	868.3
220	16.98	15.39	14.89	1654.	1138.	934.5
240	20.62	18.15	17.04	1665.	1160.	991.7
260	24.00	20.80	19.43	1652.	1171.	1017.
280	26.93	23.20	21.82	2341.	1411.	1048.
300	29.21	25.20	23.98	2775.	1622.	1101.
320	30.78	26.72	25.83	2795.	1577.	1150.
340	31.78	27.78	27.15	2800.	1554.	1059.
360	32.42	28.49	28.05	2822.	1594.	1057.
380	32.64	28.75	28.44	4951.	2571.	1332.
400	32.86	28.99	28.83	3494.	2075.	1414.
420	33.14	29.28	29.25	2658.	1728.	1290.
440	33.68	29.76	29.76	3037.	1624.	1242.
460	31.62	27.83	27.84	5534.	2384.	1487.
480	27.03	23.61	23.60	5545.	2528.	1431.
500	23.73	20.55	20.40	3606.	1790.	1137.
520	21.43	18.36	18.05	2863.	1453.	1032.
540	19.94	16.82	16.35	2338.	1263.	942.8
560	23.51	19.30	18.53	1811.	1106.	868.3
580	28.75	22.82	21.29	1654.	1138.	934.6
600	35.57	27.32	24.57	1665.	1160.	991.8
620	41.82	31.56	28.16	1652.	1170.	1017.
640	47.05	35.28	31.67	2341.	1411.	1048.
660	51.05	38.33	34.81	2776.	1621.	1101.
680	53.81	40.66	37.50	2795.	1577.	1150.
700	55.57	42.28	39.43	2800.	1553.	1059.
720	56.70	43.39	40.74	2822.	1594.	1057.
740	57.10	43.79	41.33	4953.	2571.	1332.
760	57.49	44.20	41.92	3494.	2073.	1414.
780	58.00	44.67	42.55	2658.	1726.	1290.
800	58.97	45.44	43.33	3039.	1625.	1243.
820	55.39	42.54	40.57	5534.	2384.	1487.
840	47.36	36.12	34.40	5545.	2528.	1431.
860	41.59	31.44	29.75	3606.	1790.	1137.
880	37.58	28.11	26.33	2863.	1453.	1032.
900	35.02	25.80	23.89	2338.	1263.	942.8
920	41.37	29.67	27.11	1811.	1106.	868.4
940	50.71	35.16	31.21	1654.	1138.	934.6
960	62.86	42.18	36.08	1665.	1160.	991.8
980	73.98	48.78	41.38	1652.	1170.	1017.
1000	83.23	54.54	46.53	2341.	1410.	1048.
1020	90.30	59.26	51.16	2775.	1621.	1101.
1040	95.18	62.86	55.11	2795.	1575.	1150.
1060	98.28	65.36	57.94	2800.	1552.	1059.
1080	100.3	67.07	59.87	2822.	1593.	1057.
1100	101.0	67.70	60.73	4953.	2570.	1332.
1120	101.6	68.32	61.60	3494.	2071.	1414.
1140	102.5	69.06	62.53	2657.	1725.	1290.
1160	104.2	70.25	63.68	3038.	1625.	1243.
1180	97.88	65.77	59.63	5534.	2384.	1487.
1200	83.68	55.84	50.56	5545.	2528.	1431.

STEP	PSILT(1)	PSILT(2)	PSILT(3)	SDUM1(1)	SDUM1(2)	SDUM1(3)
0	700.0	300.0	80.00	224.0	210.0	182.0
20	1037.	438.8	162.1	204.4	187.9	178.3
40	820.0	351.7	135.6	189.3	179.7	174.9
60	568.7	250.8	97.87	176.3	171.7	168.0
80	534.6	187.2	74.22	171.3	163.9	158.1
100	756.3	219.1	68.49	157.5	149.6	140.3
120	721.6	208.6	58.17	127.4	124.5	118.6
140	490.9	143.6	43.25	104.8	102.5	98.30
160	394.4	109.1	28.93	92.14	83.15	77.32
180	338.6	91.34	22.33	69.83	61.19	58.59
200	262.5	78.88	19.80	50.77	47.05	47.86
220	203.7	75.72	23.44	45.53	45.00	48.62
240	201.4	75.15	29.71	47.55	47.20	52.27
260	224.6	90.74	41.70	58.26	57.13	61.95
280	328.8	137.1	63.30	74.45	70.57	71.67
300	443.7	193.3	88.77	86.80	82.58	85.40
320	522.1	231.6	118.3	108.2	100.8	105.6
340	593.4	271.9	136.7	146.0	142.2	151.0
360	648.8	307.6	148.6	176.6	171.9	172.3
380	1056.	451.1	165.2	202.7	185.9	177.7
400	826.8	355.0	136.2	189.2	179.6	174.9
420	571.3	251.9	98.05	176.3	171.7	168.0
440	535.2	187.5	74.27	171.3	163.9	158.1
460	756.7	219.3	68.52	157.5	149.6	140.3
480	721.8	208.7	58.19	127.4	124.5	118.6
500	491.0	143.7	43.26	104.8	102.5	98.30
520	394.3	109.1	28.94	92.02	83.01	77.21
540	338.7	91.35	22.33	69.23	60.54	58.15
560	262.6	78.90	19.80	49.87	46.10	47.08
580	203.8	75.75	23.44	44.73	44.17	47.41
600	201.5	75.19	29.72	46.50	46.10	50.90
620	224.8	90.80	41.72	57.16	56.02	61.25
640	329.0	137.2	63.32	74.17	70.34	71.59
660	443.9	193.4	88.79	86.77	82.56	85.40
680	522.4	231.7	118.4	108.2	100.8	105.6
700	593.6	272.0	136.7	146.0	142.2	151.0
720	649.0	307.7	148.6	176.6	171.9	172.3
740	1056.	451.1	165.2	202.6	185.9	177.7
760	826.8	355.0	136.2	189.2	179.6	174.9
780	571.3	251.9	98.05	176.3	171.7	168.0
800	535.6	187.6	74.29	171.4	163.9	158.1
820	756.7	219.3	68.52	157.5	149.6	140.4
840	721.8	208.7	58.19	127.4	124.5	118.6
860	491.0	143.7	43.26	104.9	102.5	98.31
880	394.4	109.1	28.94	92.05	83.03	77.21
900	338.7	91.35	22.33	69.09	60.37	58.02
920	262.6	78.90	19.81	49.60	45.81	46.80
940	203.8	75.75	23.44	44.56	43.99	47.10
960	201.5	75.19	29.72	46.31	45.89	50.60
980	224.8	90.80	41.72	56.96	55.80	61.10
1000	329.0	137.2	63.32	74.12	70.31	71.57
1020	443.9	193.4	88.79	86.77	82.55	85.40
1040	522.4	231.7	118.4	108.2	100.8	105.6
1060	593.6	272.0	136.7	146.0	142.2	151.0
1080	649.0	307.7	148.6	176.6	171.9	172.3
1100	1056.	451.1	165.2	202.6	185.9	177.7
1120	826.8	355.0	136.2	189.2	179.6	174.9
1140	571.3	251.9	98.05	176.3	171.7	168.0
1160	535.6	187.6	74.29	171.4	163.9	158.1
1180	756.7	219.3	68.52	157.5	149.6	140.4
1200	721.8	208.7	58.19	127.4	124.6	118.6

<u>STEP</u>	<u>SILT5(1)</u>	<u>STEP</u>	<u>SILT5(1)</u>	<u>STEP</u>	<u>SILT5(1)</u>
0	10.00	400	2883.	800	4745.
20	1581.	420	3688.	820	6114.
40	2840.	440	4745.	840	7955.
60	3645.	460	6114.	860	9288.
80	4702.	480	7954.	880	10196.
100	6070.	500	9288.	900	10881.
120	7911.	520	10195.	920	11314.
140	9246.	540	10880.	940	11574.
160	10156.	560	11314.	960	11608.
180	10842.	580	11574.	980	11533.
200	11277.	600	11607.	1000	11488.
220	11538.	620	11533.	1020	11524.
240	11572.	640	11487.	1040	11507.
260	11499.	660	11523.	1060	11573.
280	11456.	680	11506.	1080	11763.
300	11494.	700	11573.	1100	1609.
320	11478.	720	11763.	1120	2883.
340	11547.	740	1609.	1140	3688.
360	11738.	760	2883.	1160	4745.
380	1609.	780	3688.	1180	6114.
				1200	7955.