Water Quality Modelling Group Workshop Proceedings

WATER QUALITY MODELLING IN THE ENVIRONMENT AGENCY- PRESENT PRACTICE AND FUTURE CHALLENGES

Editor Dr Linda Pope

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1 INTRODUCTION

The National Centre for Risk Analysis and Options Appraisal (NCRAOA) hosts workshops on topics relating to environmental modelling.

The workshop help on 24th March 2000 was the second in a series on water quality modelling. In the first workshop, Universities and Research Institutes active in water quality modelling described their current research and development

The overall aims of this workshop were to:-

- Give an overview of the current usage and development needs of water quality modelling tools in the Agency
- Present examples of current Agency water quality modelling projects
- Discuss future Agency modelling requirements in the context of the proposed Water Quality Framework Directive

The Environment Agency makes extensive use of water quality modelling in its decision making process, in areas from the issuing of routine discharge consents to the planning of catchment scale improvement schemes and coastal discharges. Modelling is used to ensure that the maximum environmental benefit is obtained from the large-scale investment required for such programmes, and is often the discipline which provides the information required for final decisions on multi-million pound water quality improvement schemes.

Modelling is a fast-moving discipline, and it is essential for the Agency to remain informed about the model development being carried out by academic and commercial institutions, to ensure that the best tool is being used for the task in hand. It is also of benefit to such Institutions to be informed of the practical requirements of the Agency for tools and techniques.

This report provides a summary of the Workshop including papers and overheads prepared by each speaker, together with a brief introduction to the topic of each presentation. A summary of the discussion points and comments made on feedback sheets are included in the form of bullet points.

2 REVIEW OF 1-DIMENSIONAL WATER QUALITY MODELS

Linda Pope

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Steel House, 11 Tothill Street, London SW1H 9NF

The Agency carries out and audits water quality modelling work on most of the major river catchments, estuaries and near-shore coastline in the UK. Consents to discharge are frequently derived using water quality models either in-house or by consultants under contract to the Agency.

It is of great importance that modelling work is carried out consistently across the country, using tools which are well understood and suitable for the modelling required.

Much of the modelling work in the past has concentrated on 'sanitary determinands', using models with few included processes, but with new responsibilities such as the Water Framework Directive and the requirement for nutrient/algal modelling more complex modelling tools are required.

There is therefore a need for the Agency to review the tools which are in use at present and which could potentially be used in the future, to identify which tools are suitable for current tasks, and where development work is required.

To this end, the NCRAOA has undertaken a review of water quality models, the first phase of which is to review the one-dimensional models most commonly used for river and simple estuary modelling.

The review has included:-

1. The development of a database of models
2. Selection of those models which best fit the Agency's requirements
3. Detailed testing of the most commonly used of those models
4. Recommendations for development work

The findings of the review were presented at the workshop prior to the publication of the main report.

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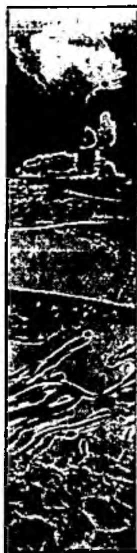

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Review of Water Quality Models Phase 1

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Slide 2

Review of Surface water Quality Models Phase 1

OBJECTIVES

- To Review the Water Quality Models which the Agency are currently using and those which were available for use
- Construct a database of Water Quality Models
- Carry out a Practical Assessment of Selected 1-D Models
- Report
- Recommendations

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GENERAL DATABASE

A BASIC LISTING OF THE CAPABILITIES OF MODELS COMPARED WITH AGENCY REQUIREMENTS FOR:-

- Relevant Functionality
- Availability
- Costs
- Extent of Use and Support
- Adaptability

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MODEL TYPES IN DATABASE -1

- TOT Time of Travel
- RISK Risk
- MZ Mixing Zone
- R In-stream
- E Estuary
- L Lake
- O Ocean
- GW Groundwater
- SH Modelling Shell
- CAT Catchment Model

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MODEL TYPES IN DATABASE -2

- STOCHASTIC
- HYBRID STOCHASTIC/DETERMINISTIC
- STEADY STATE
- DYNAMIC

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Model Functionality Requirements

Stochastic	Deterministic	1st order decay	Conventional Determinands	Nitrate Chemistry	Phosphate Chemistry	Metal with partitioning	Metal with no partitioning	Phytoplankton	Zooplankton	Benthic Algae	Macrophytes	Microbial Processes	Sediment Processes	
+		+	+	+	+	+	+							GQA freshwater improvements
+	+	+	+	+		+	+	+				+	+	GQA Estuary improvements
+		+	+	+	+									AMP34 modelling
+	+	+	+	+	+	+							+	Impact of intermittent discharges
+	+	+	+	+	+			+	+	+	+		+	Eutrophication
+	+	+	+	+	+			+	+	+	+	+	+	Dissolved oxygen – in rivers and lakes
	+													Incident modelling (time of travel)
+		+	+			+	+					+	+	Risk assessment in catchments
+	+													Catchment modelling (diffuse sources)
+	+	+	+	+	+	+	+	+	+	+	+	+	+	Water Framework Directive
+	+		+					+	+	+	+			Habitats Directive

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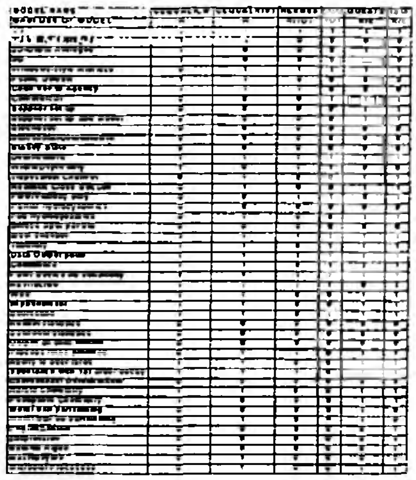

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PRESCREENING

IN A QUERY MODELS CAN BE SELECTED AND SCORED ACCORDING TO THE MATCH TO THE QUERY

Stochastic and Hybrid Models

Restricted to Rivers

SCREENING	MODEL TYPE	MODEL TYPE 2	SCORE
TOMCAT	R	HYBRID	19
SIMCAT	R	HYBRID	19
MINTEQ2	R	HYBRID	16
RQP	R	STOCH	9
DYNTOX	R	STOCH	8

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PRESCREENING

MODELS CAN BE SORTED BY TYPE

AND SCORED ACCORING TO THEIR FUNCTIONALITY

Deterministic Models

Restricted to Rivers/Estuaries and Lakes

SCREENING	MODEL TYPE	SCORE
WASP5	R/L/E	31
TWQM	R	27
QUESTOR	R	27
QUAL2E	R	25
SMPTOX	R	16
WQRRS	R/L/E	14
MICHRIV	R	13
REACHSCAN	R	13
HEC-5Q	R/L	13
RIVMOD	R/L/E	13
DYNHYD3	R/E	11
SLSA	R/L	10
HYDRO3D	R/E	5

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DETAILED DATABASE

The Detailed Database can be Used
to Select Models with Particular Processes

Reaeration relationship	ISIS	MIKE-11	QUESTS	QUESTOR	QUEST
Coefficient				1	1
Owens	1	1	1	1	1
O'Connor & Dobbins	1	1			
Churchill's	1	1			
User defined		1			
Thyssen		1			

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Models Selected For Detailed Assessment

- STOCHASTIC/DETERMINISTIC
- TOMCAT
- SIMCAT

- STEADY STATE
- QUAL2E

- DYNAMIC
- ISIS
- MIKE-11
- QUASAR/QUESTOR
- QUESTS

- SHELL
- ECoS

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Assessment

- Model 'skeleton' assembled for Freshwater Hull Catchment
- Models calibrated using the same reaches and events
- Models calibrated using same datasets
- Models calibrated manually - no autocalibration routines used

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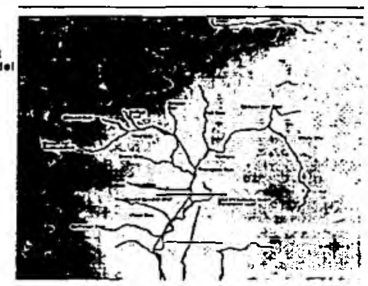
ASSESSMENT

SELECTED MODELS ARE ACQUIRED, CALIBRATED AND VALIDATED FOR THE RIVER HULL OR OTHER SUITABLE CATCHMENT

Figure
Elevation and Extent of Hull Freshwater Model



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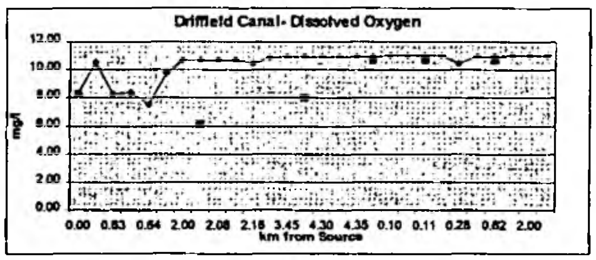
Some Model Plots

MEAN DISSOVED OXYGEN IN DRIFFIELD CANAL

SIMCAT - ANNUAL MEANS (MANUAL CALIBRATION)



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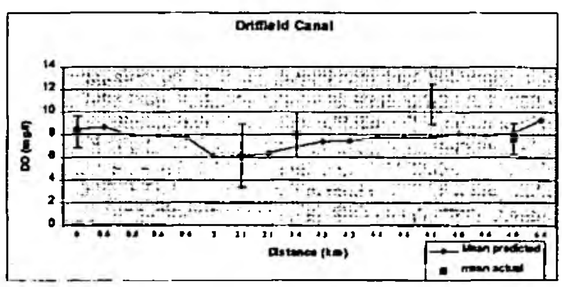
Some Model Plots

MEAN DISSOVED OXYGEN IN DRIFFIELD CANAL

TOMCAT- ANNUAL MEANS



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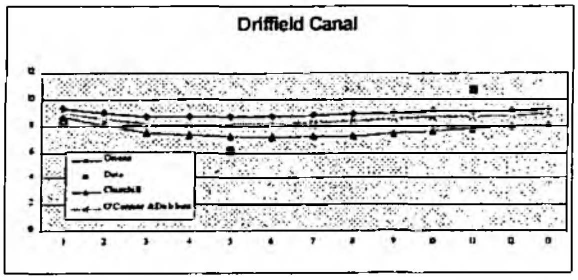
Some Model Plots

MEAN DISSOLVED OXYGEN IN DRIFFIELD CANAL

QUAL2E

EFFECT OF USING DIFFERENT REAERATION EQUATIONS



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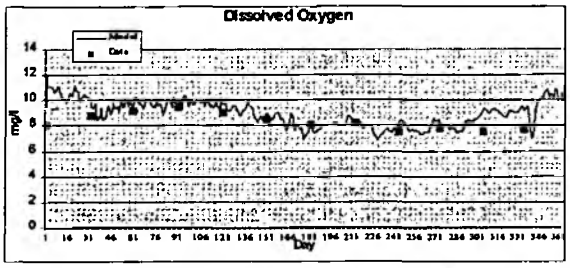
Some Model Plots

MEAN DAILY DISSOVED OXYGEN IN DRIFFIELD CANAL

ISIS - MANUAL CALIBRATION



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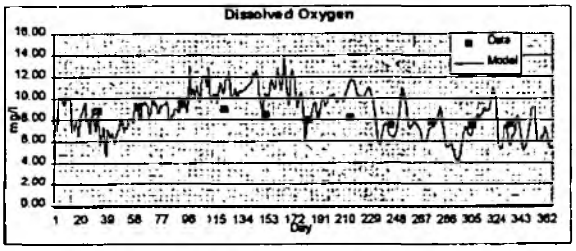
Some Model Plots

MIKE - 11- MEAN DAILY DISSOLVED OXYGEN IN DRIFFIELD CANAL
MANUAL CALIBRATION IN UNSTEADY MODE



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Some Comments on Processes

- Agency Standard Models (SIMCAT, TOMCAT) perform well in matching measured data.
- In more complex models:-
- 'Standard' routines for calculating Nitrate Cycle perform well
- Large diversity in methods of calculating phosphate levels, reflecting complexity of in-stream phosphate chemistry
- Many models represent dissolved oxygen poorly

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What Models do we need?

- Stochastic Model with limited processes
- Intermediate Level Model with a range of processes, partial hydrodynamics and stochastic option
- Access to Fully Hydrodynamic Model with Good Range of Processes

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What else do we need?

- Flexibility in our models - rapid development to meet changing needs, eg linking to catchment models
- Improved model input-output routines
- Improved calibration and uncertainty estimates in all models
- Agency ownership of model codes?

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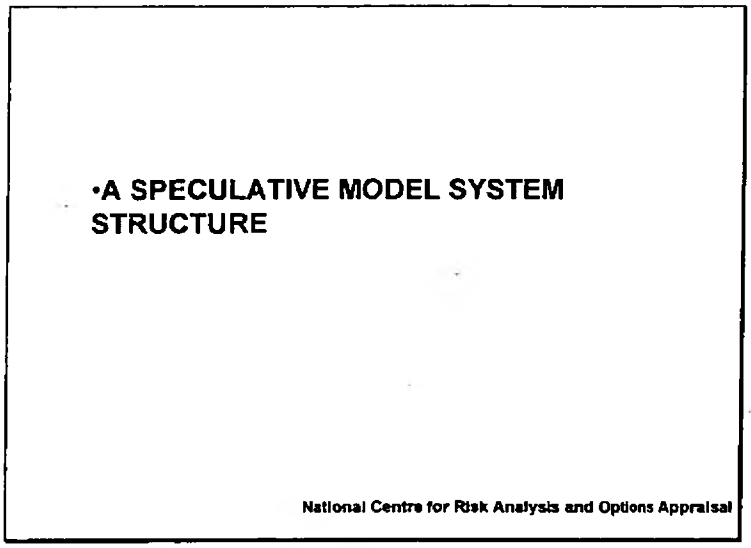

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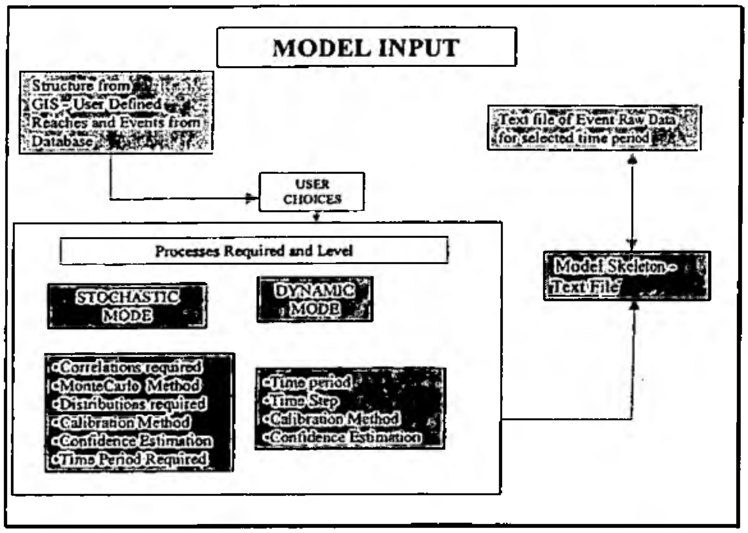

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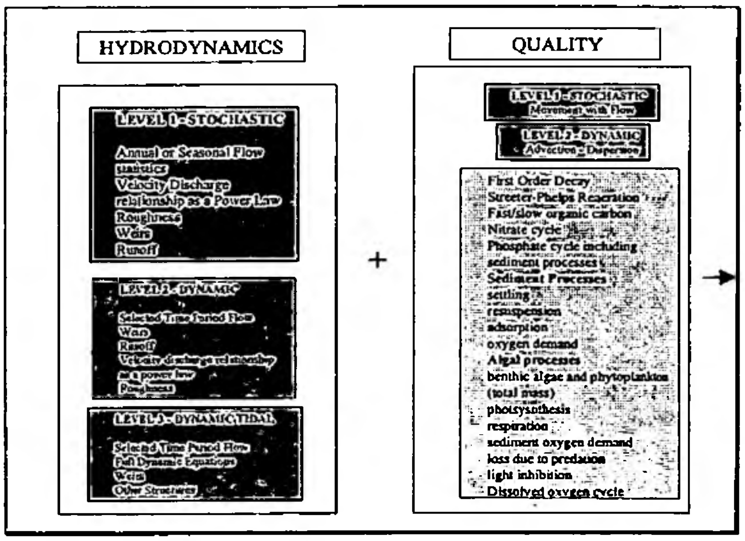

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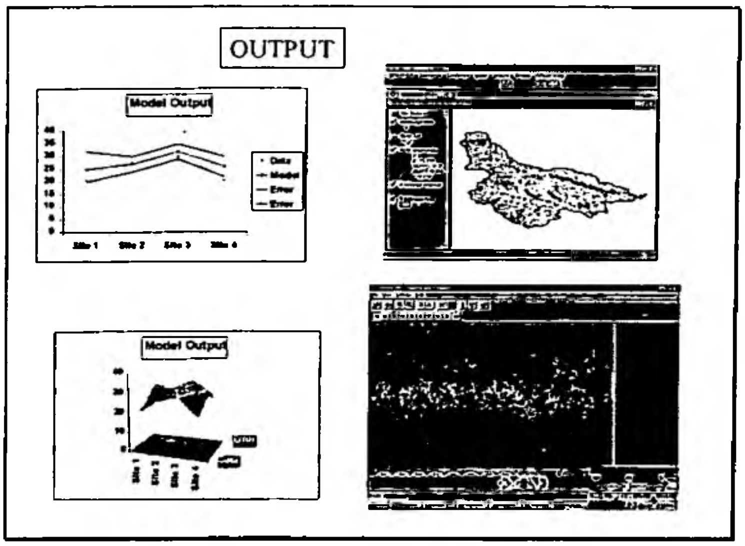

3 NUTRIENT MODELLING :- FUTURE REQUIREMENTS IN THE AGENCY

Geoff Phillips

National Centre for Risk Analysis and Options Appraisal, Environment Agency,
Steel House, 11 Tothill Street, London SW1H 9NF

Modelling the impacts of nutrients on water bodies is a complex task, requiring knowledge of water and sediment chemistry, and the relationship between water chemistry and the biota, particularly algae, macrophytes and fish.

With some sewage treatment works currently being required to introduce phosphate stripping with the aim of reducing eutrophication in receiving waters, there is an increasing requirement on the Agency to predict the impact of such removal both on in-stream levels of phosphates and on algal and macrophyte communities.

The presentation suggests the types of models that the Agency is likely to need and reviews those currently available, including catchment scale, nutrient transport and ecological models.

The importance of taking a catchment scale approach is emphasised and the use of catchment delivery models, based on export coefficient models, is discussed.

Currently there are few ecological models available to Agency modellers and nutrient transport models are largely untested. This is recognised as a barrier to the development of eutrophication control plans and future model development requirements are discussed, including the need for a simple 'toolkit' to assess the risk of eutrophication in water bodies.

Slide 1

Nutrient Modelling
Future Requirements in the Agency

Geoff Phillips.

National Centre for Risk Assessment & Options Appraisal.

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Slide 2

Nutrient Modelling
Future Requirements in the Agency

- Brief overview of eutrophication and approaches to modelling
- Current tools and recent developments
  - Catchment scale models & lake classification
- Future needs

Slide 3

What is Eutrophication ?

- Enrichment of water by nitrogen & phosphorus.
- Algal growth, particularly cyanobacteria.
- Loss of water clarity.
- Loss of submerged aquatic plants & macro-invertebrates.
- Changes to fish populations.

Slide 4

Environment Agency Eutrophication Control Strategy

- Promoting measures to reduce nutrient losses to waters nationally

Slide 5

Environment Agency Eutrophication Control Strategy

- Promoting measures to reduce nutrient losses to waters nationally
- Specific actions in catchments where waters are most at risk
  - Local Environment Agency Plans (LEAP)
  - Eutrophication Control Action Plans

Slide 6

Modelling Needs

- Catchment scale models
  - Quantify sources of nutrients
  - Assess options for control
- Nutrient transport models
  - Quantification of pathway between source and target
- Ecological models
  - Quantify impacts

Slide 7

Ecological Models

- Empirical models widely used to predict phytoplankton growth in lakes
  - Vollenweider (1975) model relates P load to risk of eutrophication

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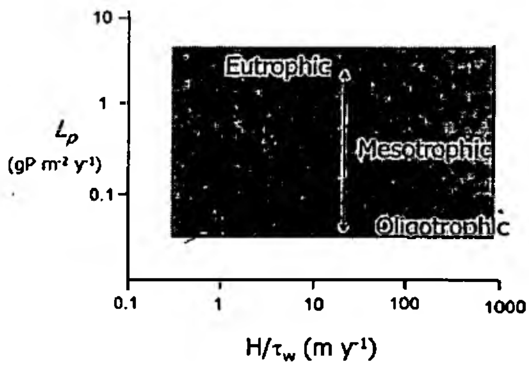
Risk of Eutrophication



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Ecological Models

- Empirical models widely used to predict phytoplankton growth in lakes
  - OECD development of Vollenweider model to predict in lake Total P from TP load

Slide 10

Ecological Models

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    - (Pilot test of SEPA software using Monte Carlo technique to provide error estimates of lake P from P load)

Slide 11

Ecological Models

- Empirical models widely used to predict phytoplankton growth in lakes
  - OECD development of Vollenweider model to predict in lake Total P from TP load
    - (Pilot test of SEPA software using Monte Carlo technique to provide error estimates of lake P from P load)
  - Regression models linking P load to in lake total P & then to chlorophyll concentration.

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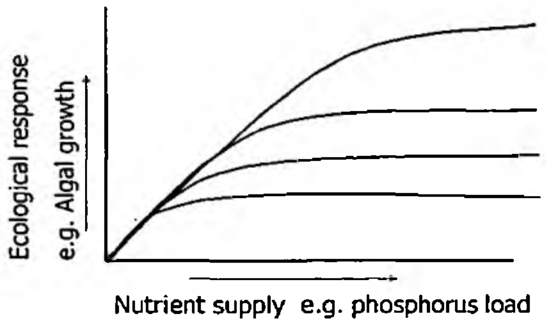
Relationship between Nutrient Supply & Ecological Response



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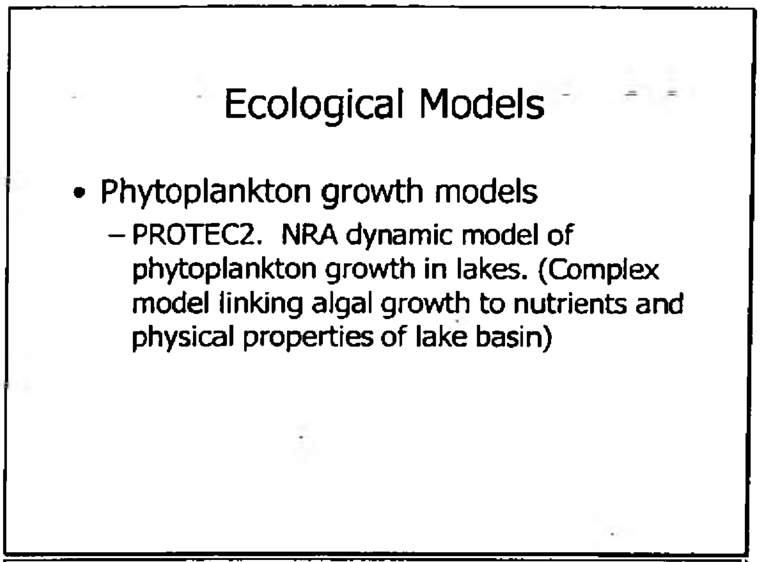

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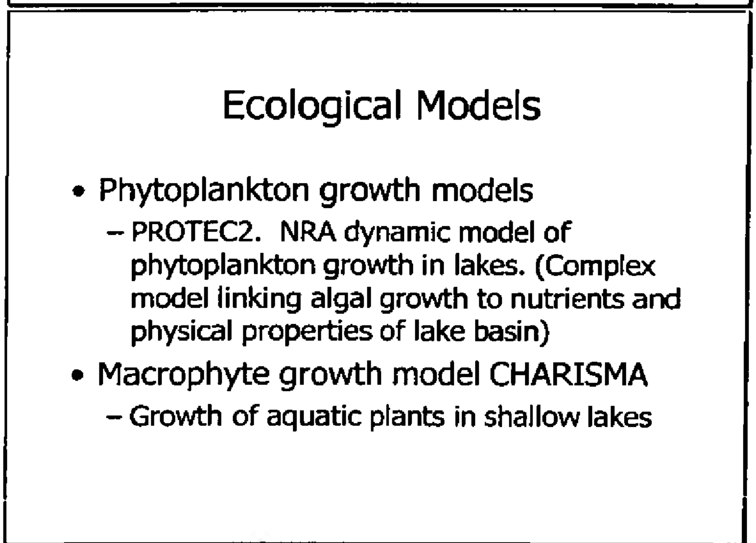

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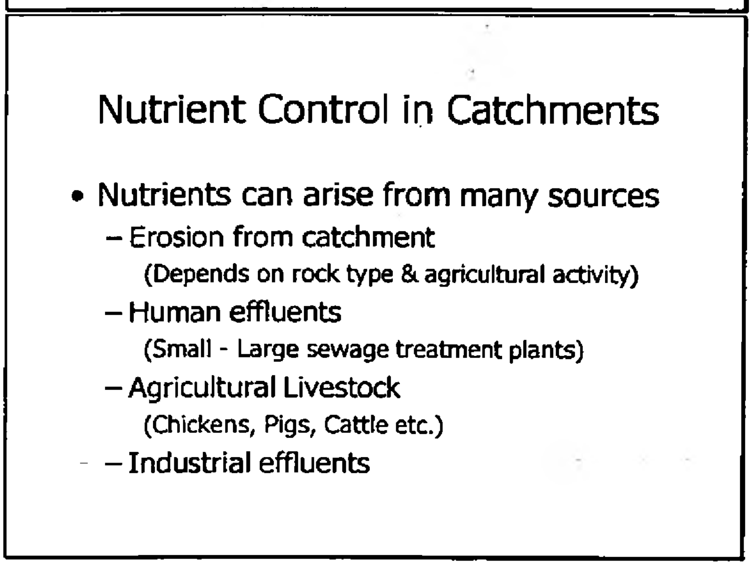

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Nutrient Export Coefficient modelling

- Quantifies nutrient (total P & total N) loads arriving at a water body from all sources in the catchment.

$$L = \Sigma E_i (A_i (I_i)) + p$$

L = Nutrient load lost
E = Export coefficient for nutrient source i
A = Area of catchment occupied by source i
I = Input of nutrients to source i
p = input of nutrients from precipitation

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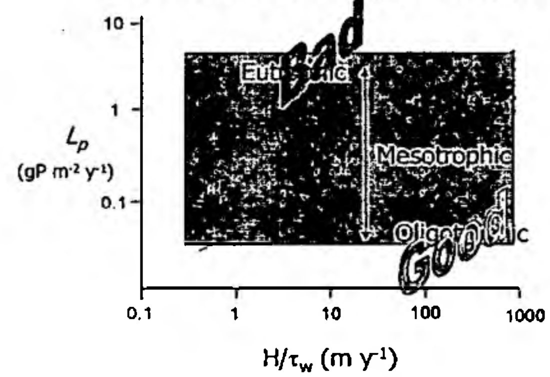
Phosphorus Targets

- Generally accepted concentration thresholds
  - e.g. OECD 35 μgTP.l^{-1} for eutrophic lakes

Slide 18

Risk of Eutrophication



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Phosphorus Targets

- Reference based targets recognise
  - "pristine" lowland lakes may be nutrient rich in comparison with upland lakes

Slide 20

Phosphorus Targets

- Reference based targets recognise
  - "pristine" lowland lakes may be nutrient rich in comparison with upland lakes
- Site (regional) specific targets
  - phosphorus concentration at which "good" ecological quality can be achieved

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Phosphorus Targets

- Site (regional) specific targets require
  - Ecological knowledge (model ?)
  - Reconstruct historic nutrient loads (when ecosystem was in "good" condition)
    - Palaeolimnology - sediment cores
    - "Hindcasting" using nutrient export coefficient models

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Nutrient Export Coefficient Modelling

- Quantifies nutrient (total P & total N) loads arriving at a water body from all sources in the catchment.
  - Nutrient inputs to source (e.g. fertiliser input to a particular crop, P excreted/person)

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Nutrient Export Coefficient Modelling

- Quantifies nutrient (total P & total N) loads arriving at a water body from all sources in the catchment.
  - Nutrient inputs to source (e.g. fertiliser input to a particular crop, P excreted/person)
  - Export potential for each land use type, livestock variety or people (% of input)

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Export Coefficient Model

- Used to identify historic conditions
  - 1930 agricultural activity in England & Wales, (land use and stock density reflect natural features)

Slide 25

Export Coefficient Model

- Used to identify historic conditions
  - 1930 agricultural activity in England & Wales.
  - Remove inputs from people
- Establish a base line (ecological potential)

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Export Coefficient Model

- Use with current land-use data & population estimates to forecast current & future management scenarios
- Contrast :-
  - Base line status (ecological potential)
  - Current status
  - Future status

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Export Coefficient Model

- Must be calibrated and validated on current data
- Provides estimates of mean annual nutrient export as total nutrient eg TP
  - Cannot be used to simulate within year variation
  - Not fully distributed and thus only represents average conditions

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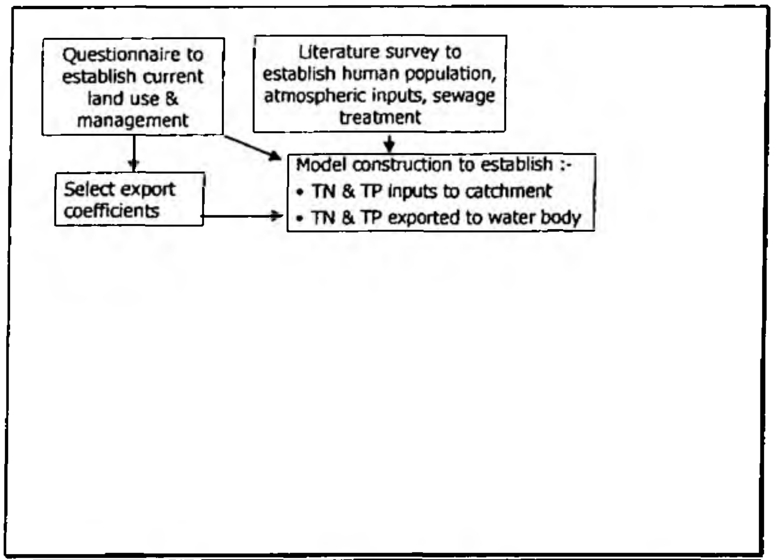

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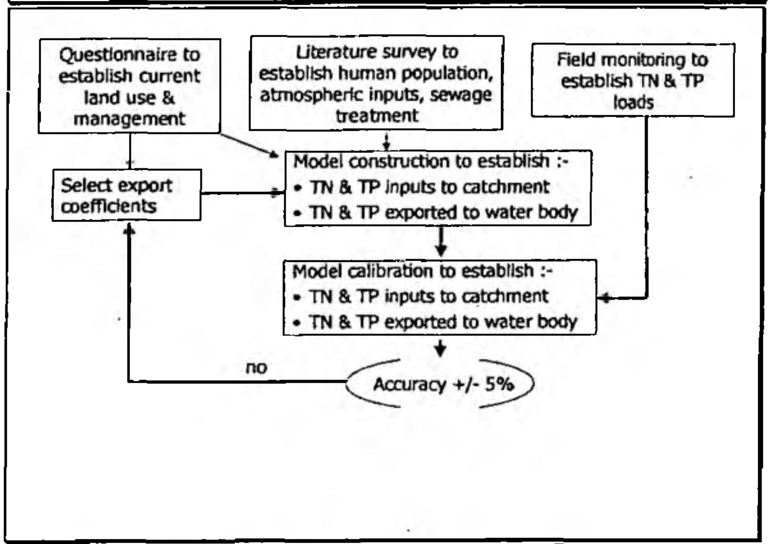

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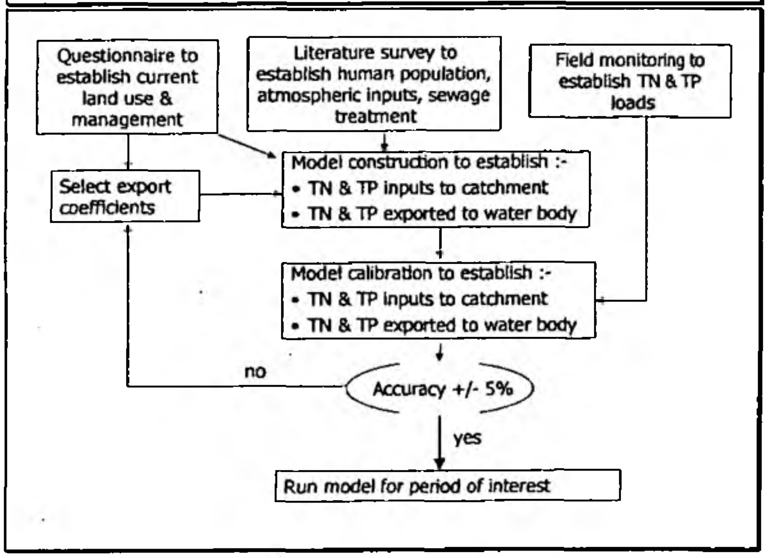

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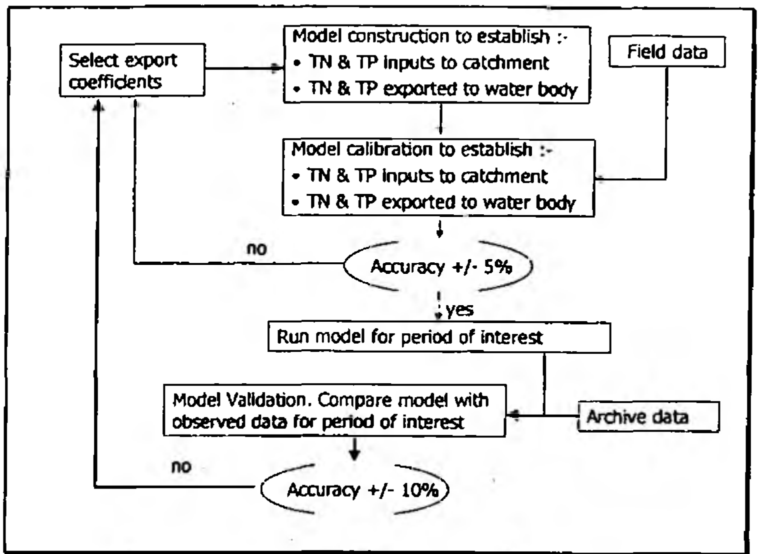

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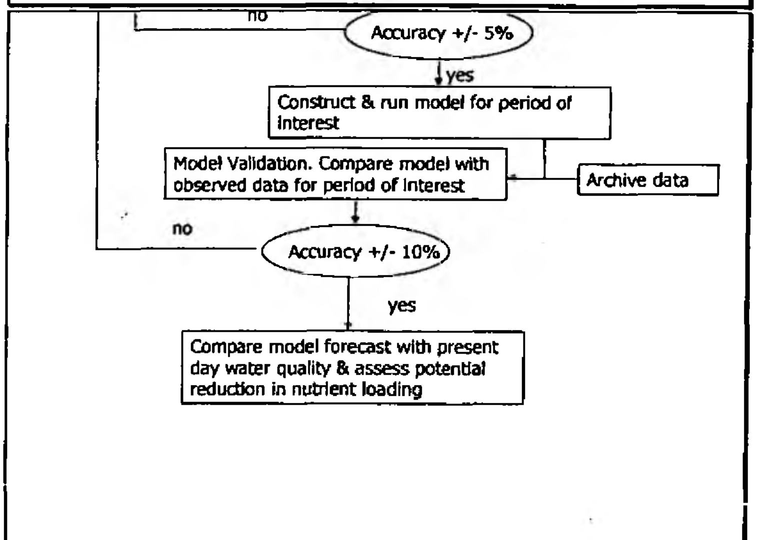

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Precision of Export Coefficient Model

- Depends on geographic scale
  - Catchment model using the "field" as the spatial unit (Johnes 1996)

Slide 34

Precision of Export Coefficient Model

- Depends on geographic scale
  - Catchment model using the "field" as the spatial unit (Johnes 1996)
  - Catchment based model using the "parish" as a spatial unit (10 - 20 km^2)

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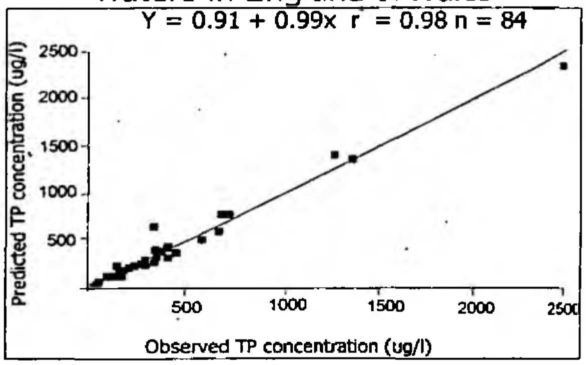
Observed versus predicted total phosphorus concentration for 32 surface waters in England & Wales



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Precision of Export Coefficient Model

- Depends on geographic scale
  - Catchment model using the "field" as the spatial unit (Johnes 1996)
  - Catchment based model using the "parish" as a spatial unit
  - Simplified catchment based model using the "parish" for input data, but land use regions for export coefficients.

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Land Use Regions in England & Wales

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Typical Export Coefficients

Land-use	Region 1 %	Region 2 %	Region 3 %
Perm grass	2.0	6.0	1.0
Cereals	2.5	5.0	2.5
Pigs	1.28	5.1	2.55
etc			

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Current Lake Classification Model

- Hindcast N & P loads for any lake in England & Wales given grid co-ordinates of catchment
- Needs development to link to current agricultural & population database to provide current and future scenarios

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Development Needs

- Development of POPPIE model for nutrient prediction at catchment scale
  - base on existing export coefficient models
- Development of diffuse nutrient risk models
  - used at catchment scale (fully distributed?)
  - collaboration with MAFF and English Nature

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Nutrient Transport Models

- Review has highlighted problems with existing WQ models when used with P
  - non conservative nature of P
- Current R&D to generate P transport model - INCA-P (Reading University)
  - Pilot model test autumn 2000

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Summary

- Development of a "tool kit" to support ECAPs
  - Simple spreadsheet models - OECD
  - Catchment export models
  - Improved P transport model
  - Review of needs for ecological models

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4 NUTRIENT MODELLING USING ECOS

Neil Murdoch and Peter Jonas

Environment Agency, South West Region, 11 Tothill Street, London SW1H 9NF

The South West Region is characterised by many small tidal rivers and bathing beaches. Much of the current modelling work in this Region has been driven by the improvements to sewage treatment works required by the Urban Waste Water Treatment Directive. Many STW in the area have increased loadings in the summer due to he influx of tourists.

Improvements in effluent quality from STW can be expected to improve the quality of bathing beaches both microbiologically and by reducing the risk of eutrophication due to a reduced nutrient load.

If diffuse sources of pollutants are not adequately taken into account, however, the predicted improvements may not be realised despite major investments at STW.

The modelling described here emphasises the necessity of a careful data study of sources of pollutants before model building and calibration.

The model system used in the scenarios described is ECoS, a modelling shell developed at Plymouth Marine Laboratory and used in the academic community (for example for estuary modelling in the NERC LOIS project) and in the Agency. The model shell allows the user to specify the model required based on templates if required.

Two models are described

A simplified 'box' model of Poole harbour used to investigate the relative impact of point and diffuse nutrient sources
A model of Truro-Tresillian used in UWWTD modelling.

Slide 1

Nutrient Modelling Using Ecos

Neil Murdoch & Peter Jonas
EA SW

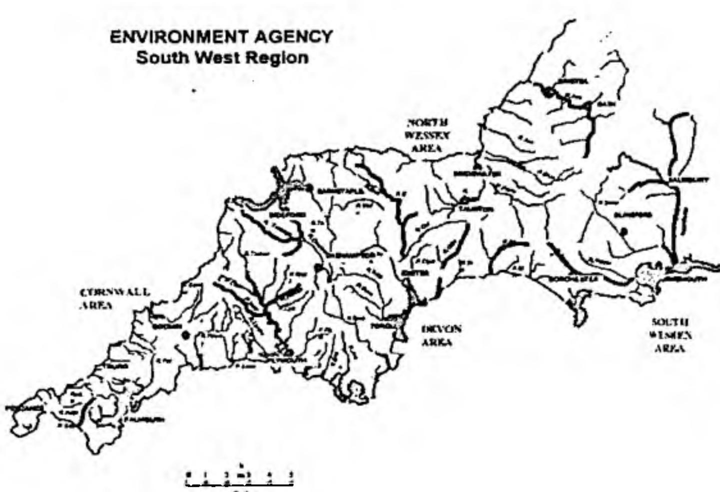
Slide 2

Nutrient Modelling

- Nutrients
  - Nitrates (saline) & Phosphates(rivers)
- Eutrophication
- Statutory drivers
  - Urban Waste Water Treatment Directive
  - (Nitrate Vulnerable Zones, Habitats Dir)

Slide 3

ENVIRONMENT AGENCY
South West Region



Slide 4

UWWTD Issues

- Standards/Regulations
- Relative contributions of diffuse and point sources
- Seasonal variations
- Analysis/modelling
  - input load analysis
  - impact modelling

Slide 5

ECoS

- Estuarine Contaminant Simulator
- Flexible Modelling Tool
  - can put equations in
  - fast simulations (cubature)
- Range of model types
  - box, 1D 2D

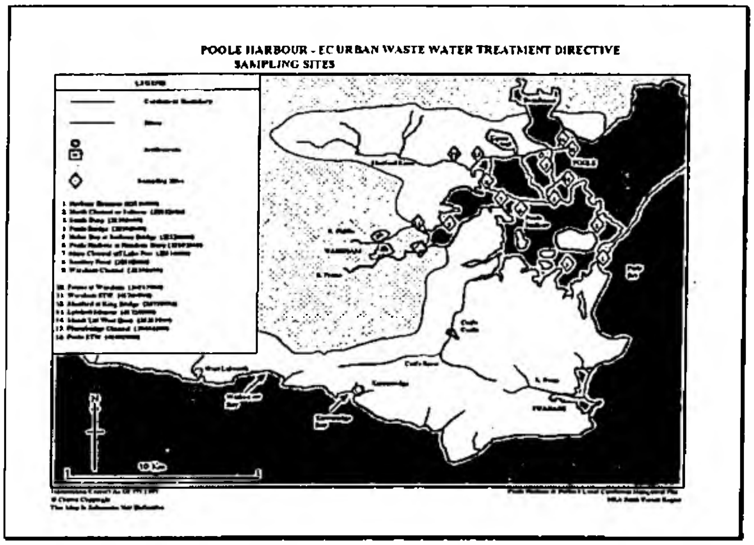
Slide 6

Example 1

Poole Harbour

Box Model

Slide 7



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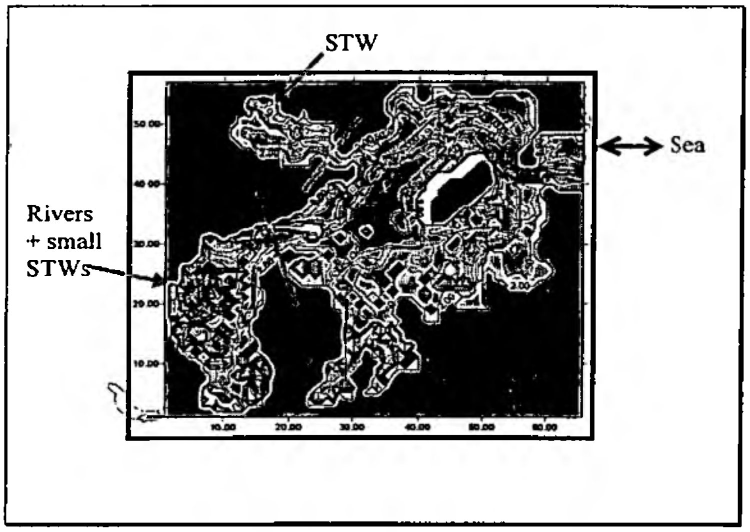

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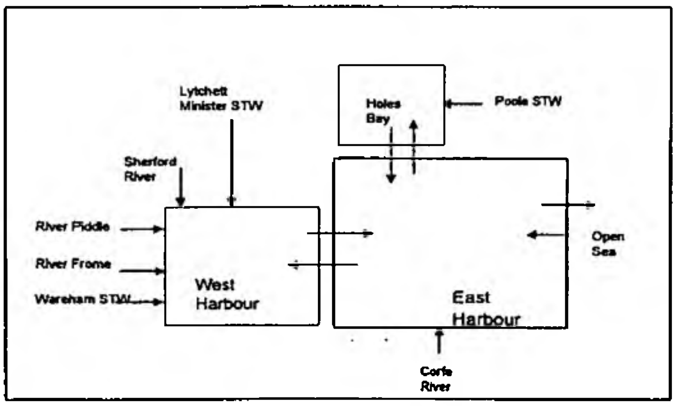
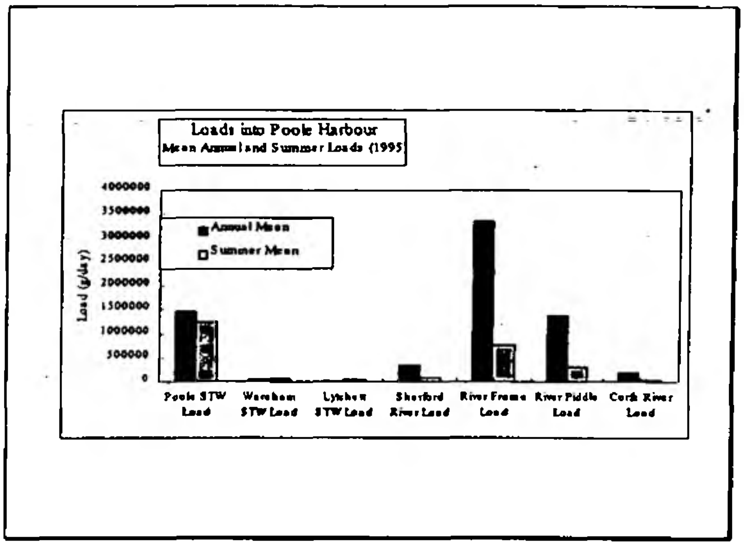


Conceptual representation of Poole Harbour

Slide 10



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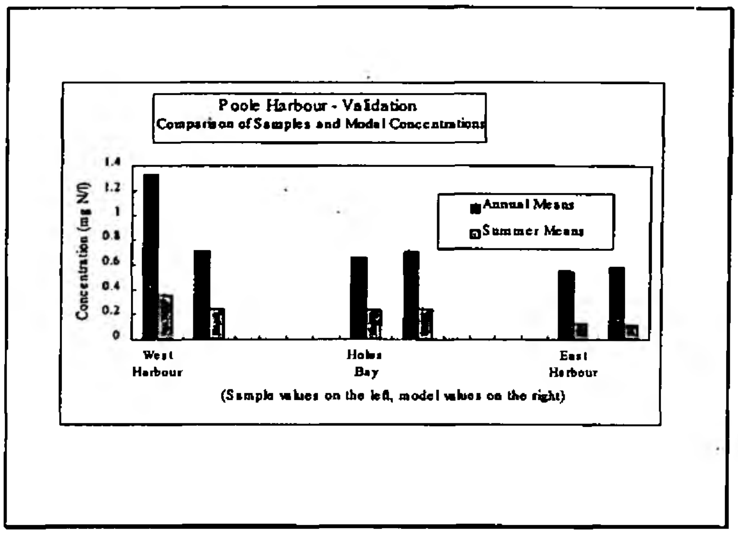

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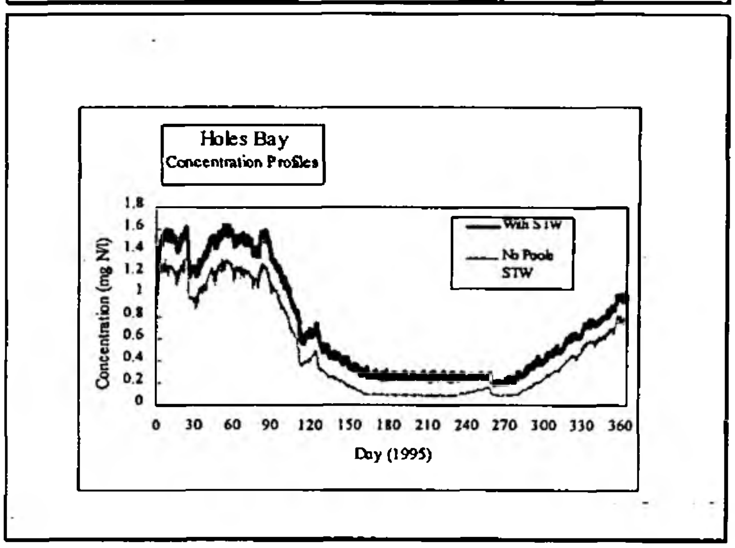
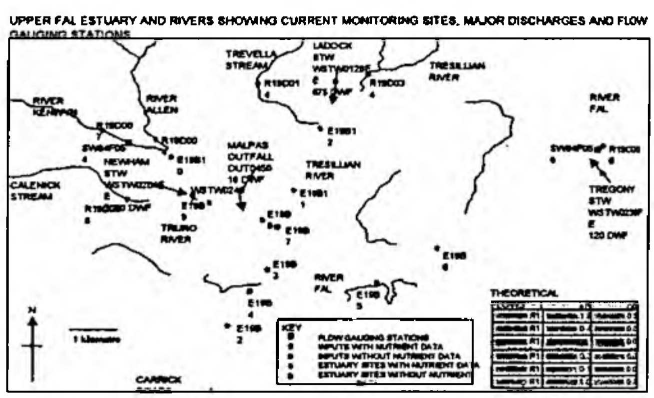


Slide 13

Other example

- Truro-Tresillian
- UWWTD problem
- 1D 'cubature' model

Slide 14



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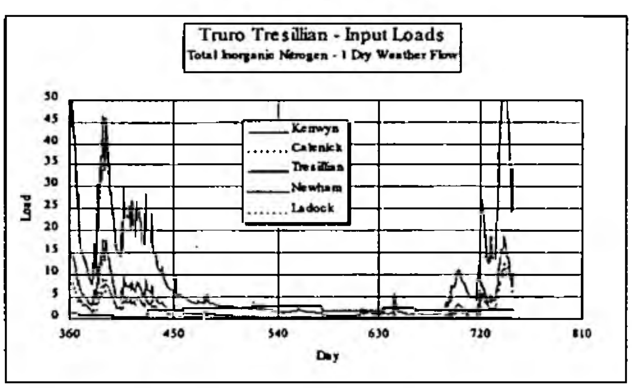

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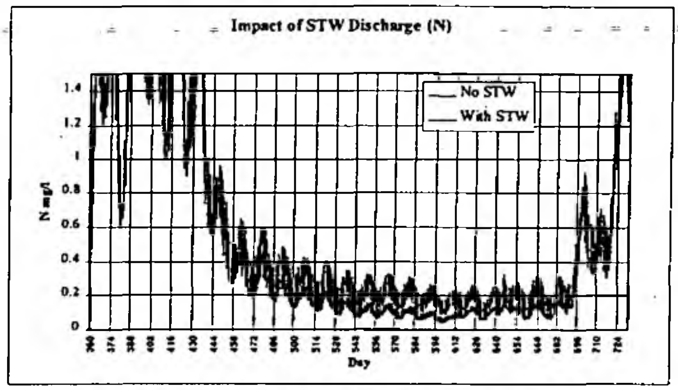

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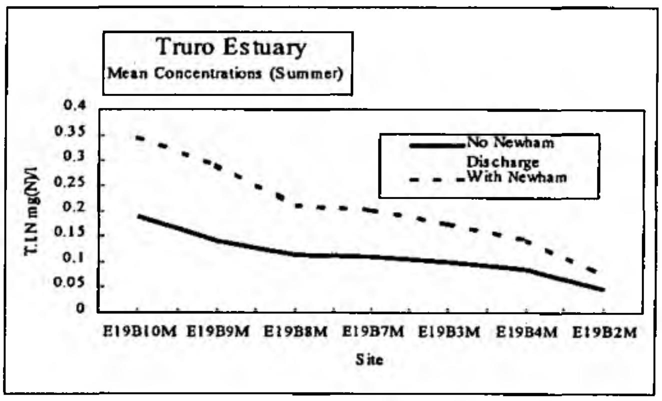


Slide 18

Summary

- Standards/Regulations - Mean values
- Load analysis - scale the problem
- Choose/Design Model - mean values
- Empirically fit to data
- Impact simulation
  - with/without discharge

5 RIVER FLOW INDEXING USING BRITISH BENTHIC MACROINVERTEBRATES: - A FRAMEWORK FOR SETTING HYDROECOLOGICAL OBJECTIVES

C. A. EXTENCE, D. M. BALBI, R. P. CHADD

The Environment Agency of England & Wales, Anglian Region, Northern Area, Waterside House, Waterside North, Lincoln LN2 5HA, U.K.

Definitions of 'good' water quality have generally been expressed in the past in either chemical or ecological terms, with little link between the two types of measurements. The requirement of the proposed Water Framework Directive to define 'good' water quality in both chemically and ecologically requires the development of robust methods to link these disciplines.

The Agency also needs to set low flow limits in rivers which are ecologically meaningful and allow the available water resources to be use without damaging ecological quality.

A method linking qualitative and semi-quantitative change in riverine benthic macro-invertebrate communities to prevailing flow regimes is under development and the results of the first phase of development were presented.

The Lotic-invertebrate Index for Flow Evaluation (LIFE) technique is based on data derived from established survey methods, which incorporate sampling strategies considered highly appropriate for assessing the impact of variable flows on benthic populations. The LIFE method is primarily based on recognised flow associations of different macroinvertebrate species and families.

The LIFE technique offers the prospect of objectively utilising macroinvertebrate data to quantify and assess river flows, and hydroecological links have been investigated in a number of English rivers, after correlating LIFE scores obtained over a number of years with several hundred different flow variables. This process has identified significant relationships between flow and LIFE which has enables those features of flow which are of critical importance in influencing community structure in different rivers to be investigated. Summer flow variables are highlighted as being most influential in predicting community structure in most chalk and limestone streams, whereas invertebrate communities colonizing rivers draining impermeable catchments are much more influenced by short term hydrological events. Biota present in rivers with regulated or augmented flows tend to be most strongly affected by non-seasonal, inter-annual flow variation.

These responses provide opportunities for analysing and elucidating hydroecological relationships in some detail, and it should ultimately be possible to use these data to set highly relevant cost effective hydroecological objectives. Examples of the realtionship between LIFE and hydrographs in various rivers were presented, including rivers affected by flood alleviation schemes. to show how this might be accomplished.

The LIFE technique is considered to have great potential, and could offer considerable advantages over established methods of setting instream flow objectives, such as PHABSIM. These existing methods can be expensive, and may not adequately account for the dynamic nature of an individual site's flow history, when setting hydrological targets.

Key areas of further work include the need to provide robust procedures for setting hydroecological objectives, investigation of habitat quality and LIFE score relationships in natural and degraded river reaches, and evaluation of potential links with other biological modelling methods such as RIVPACS.

The methodology is currently in the second phase of development, which will comprise detailed statistical analysis of the relationships between hydrographs of varying river types and LIFE scores, and the application of the methodoloy to the RIVPACS invertebrate database, which can be used to calculate LIFE scores for a range of clean rivers, using both species-level and family level data.

RIVER FLOW INDEXING USING MACROINVERTEBRATE COMMUNITIES AND THE SETTING OF ECOLOGICAL FLOW REQUIREMENTS

Benthic Freshwater Macroinvertebrate Flow Groups and Ecological Associations

Group	Ecological Flow Association
I	Taxa Primarily Associated with Rapid Flows
II	Taxa Primarily Associated with Moderate to Fast Flows
III	Taxa Primarily Associated with Slow or Sluggish Flows
IV	Taxa Primarily Associated with Flowing (Usually Slow) and Standing Waters
V	Taxa Primarily Associated with Standing Waters
VI	Taxa Frequently Associated with Drying or Drought Impacted Sites

Standard Environment Agency Macroinvertebrate abundance categories

Category		Definition
A	1 – 9	Individuals in Sample
B	10 – 99	Individuals in Sample
C	100 – 999	Individuals in Sample
D	1000 – 9999	Individuals in Sample
E	10000 +	Individuals in Sample

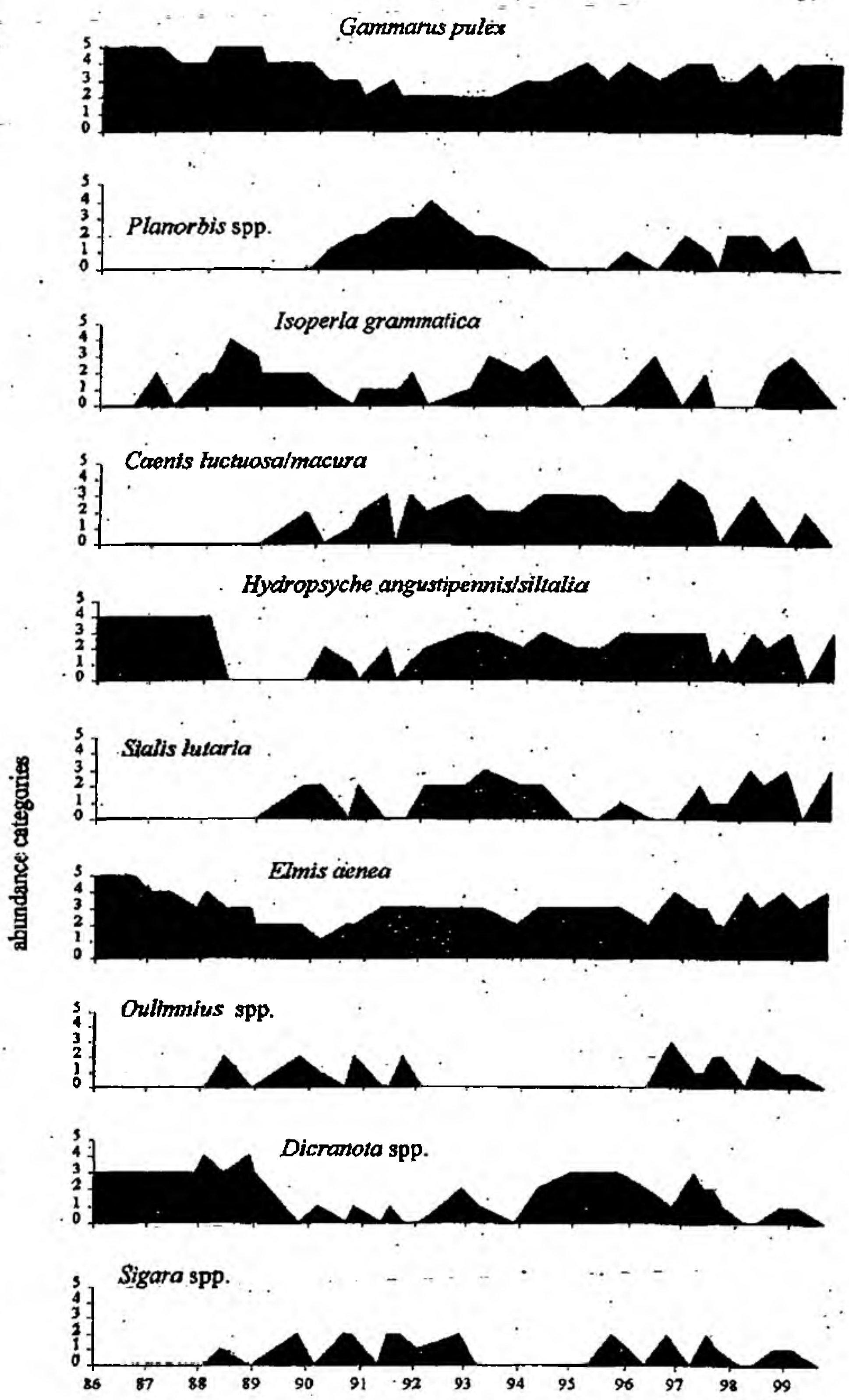
Matrix for Derivation of taxa flow scores
Scores (fs) for different abundance categories of taxa associated with Flow Groups I - VI

		Abundance Categories				
Flow Groups		A	B	C	D	E
I	Rapid	9	10	11	12	12
II	Moderate/Fast	8	9	10	11	11
III	Slow/Sluggish	7	7	7	7	7
IV	Flowing/Standing	6	5	4	3	3
V	Standing	5	4	3	2	2
VI	Drought Resistant	4	3	2	1	1

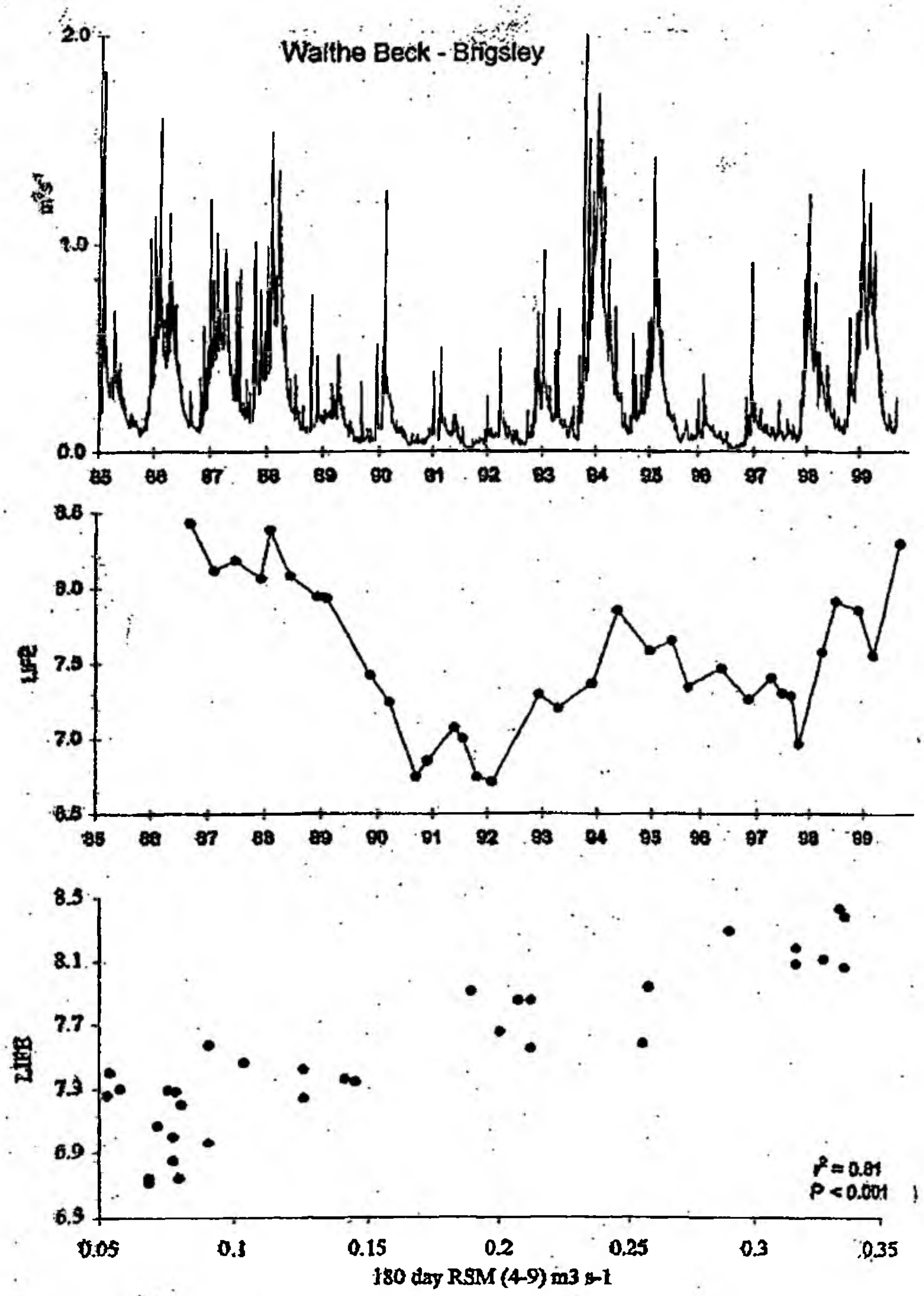
Index calculation

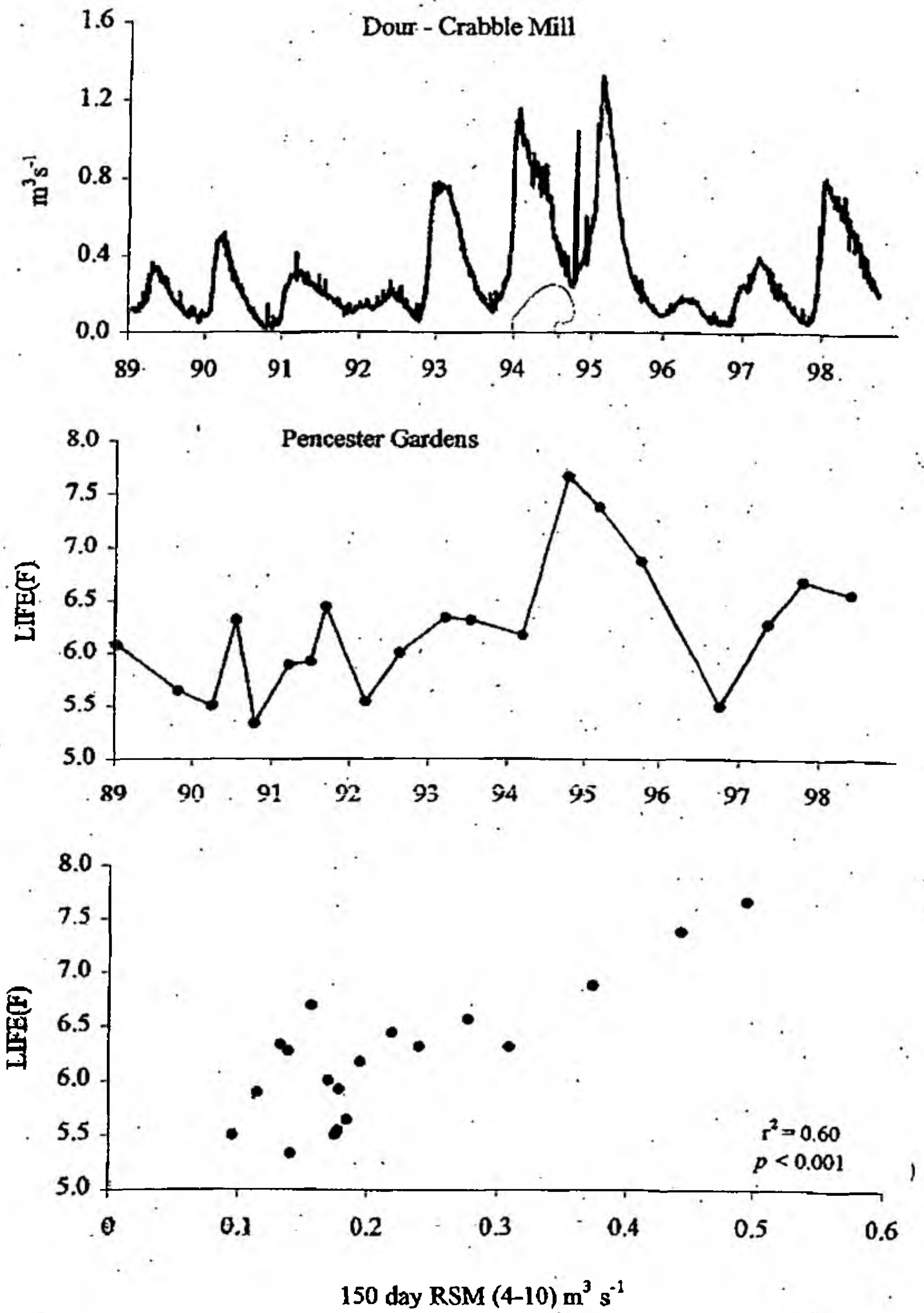
LIFE = SUM (fs) /n

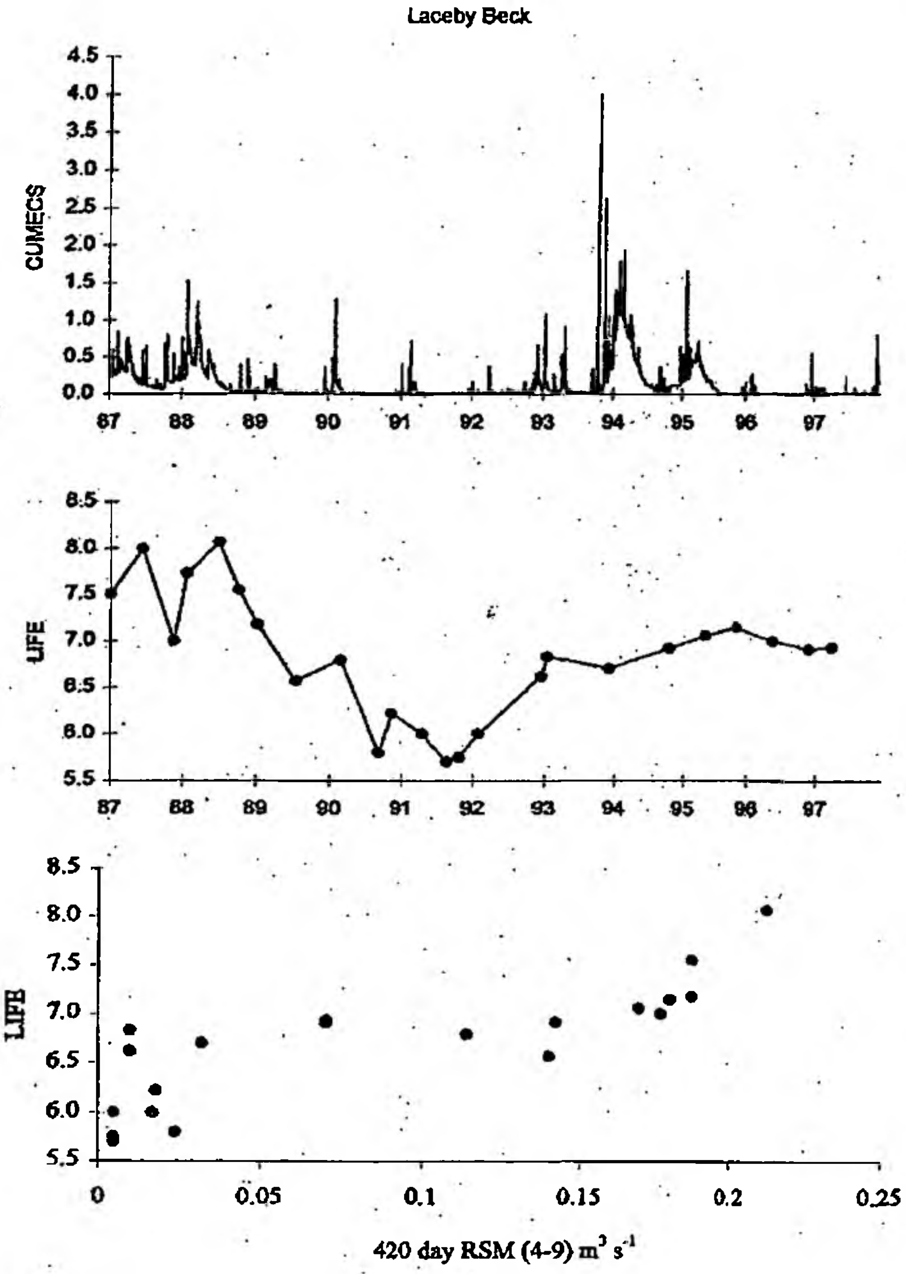
Where SUM (fs) = sum of all the individual flow scores for the whole sample
n = number of families used for the calculation

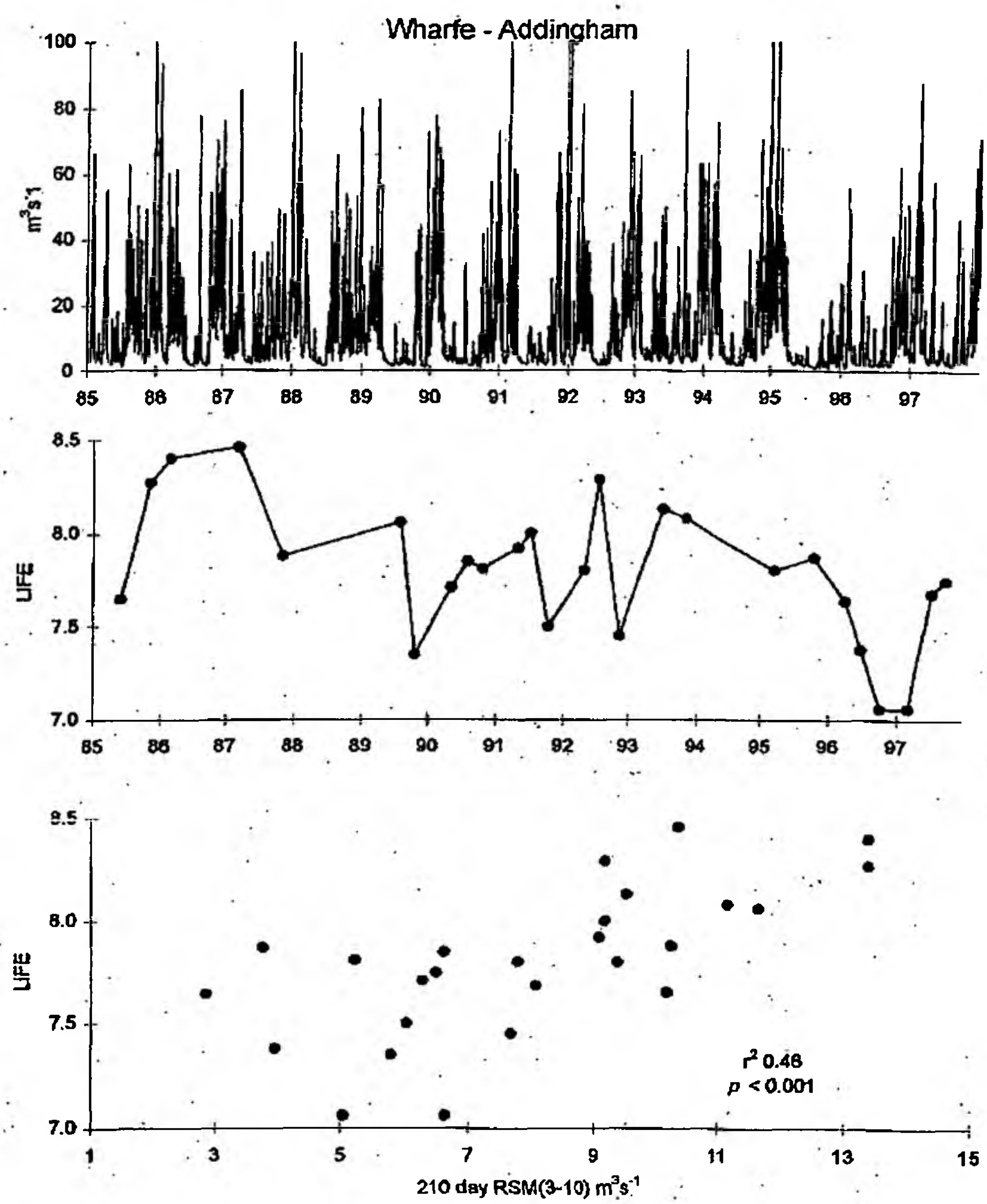


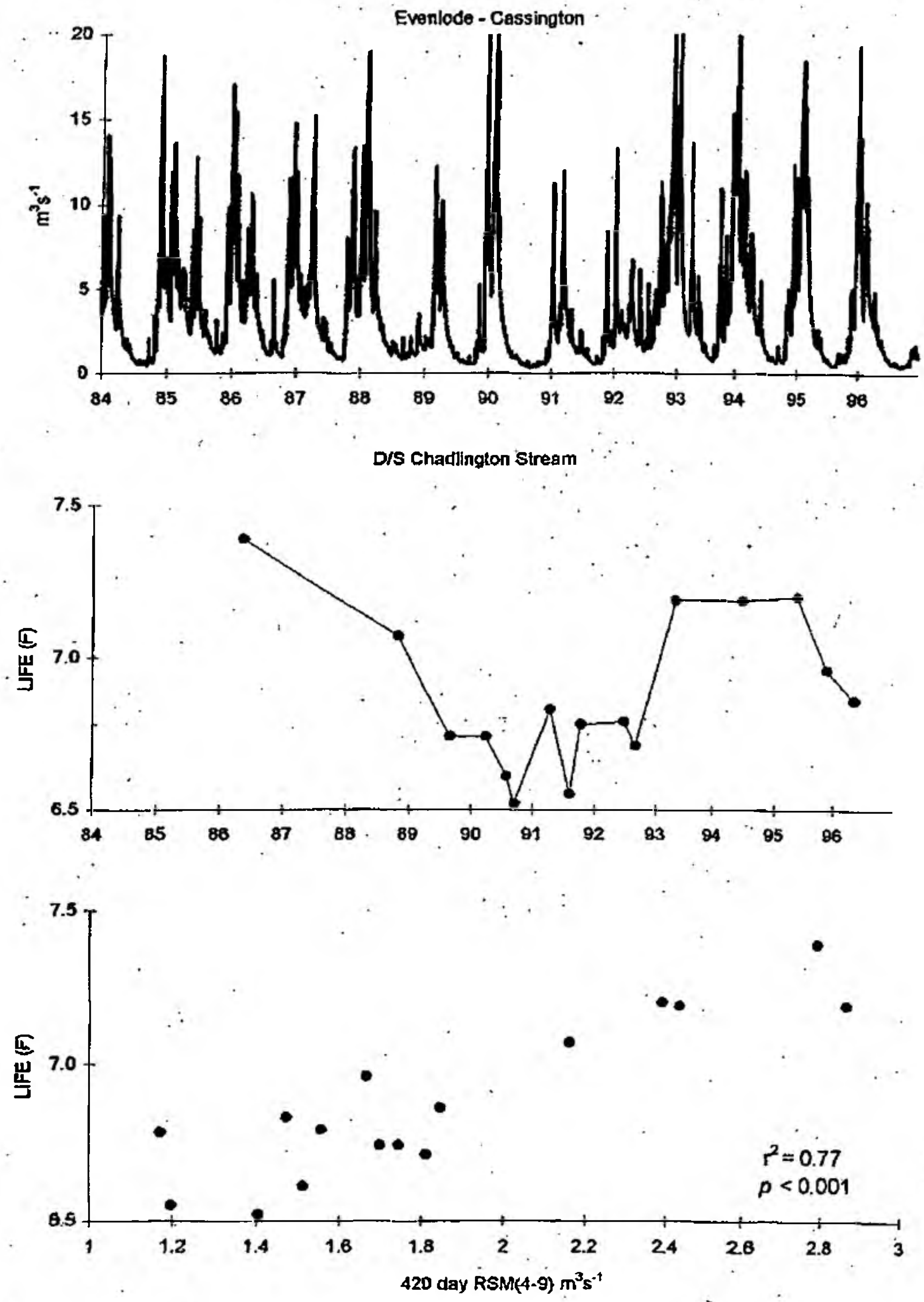
Abundance categories
1 = 1 2 = 2 – 10 3 = 11 – 100 4 = 101 – 1000 5 = >1001

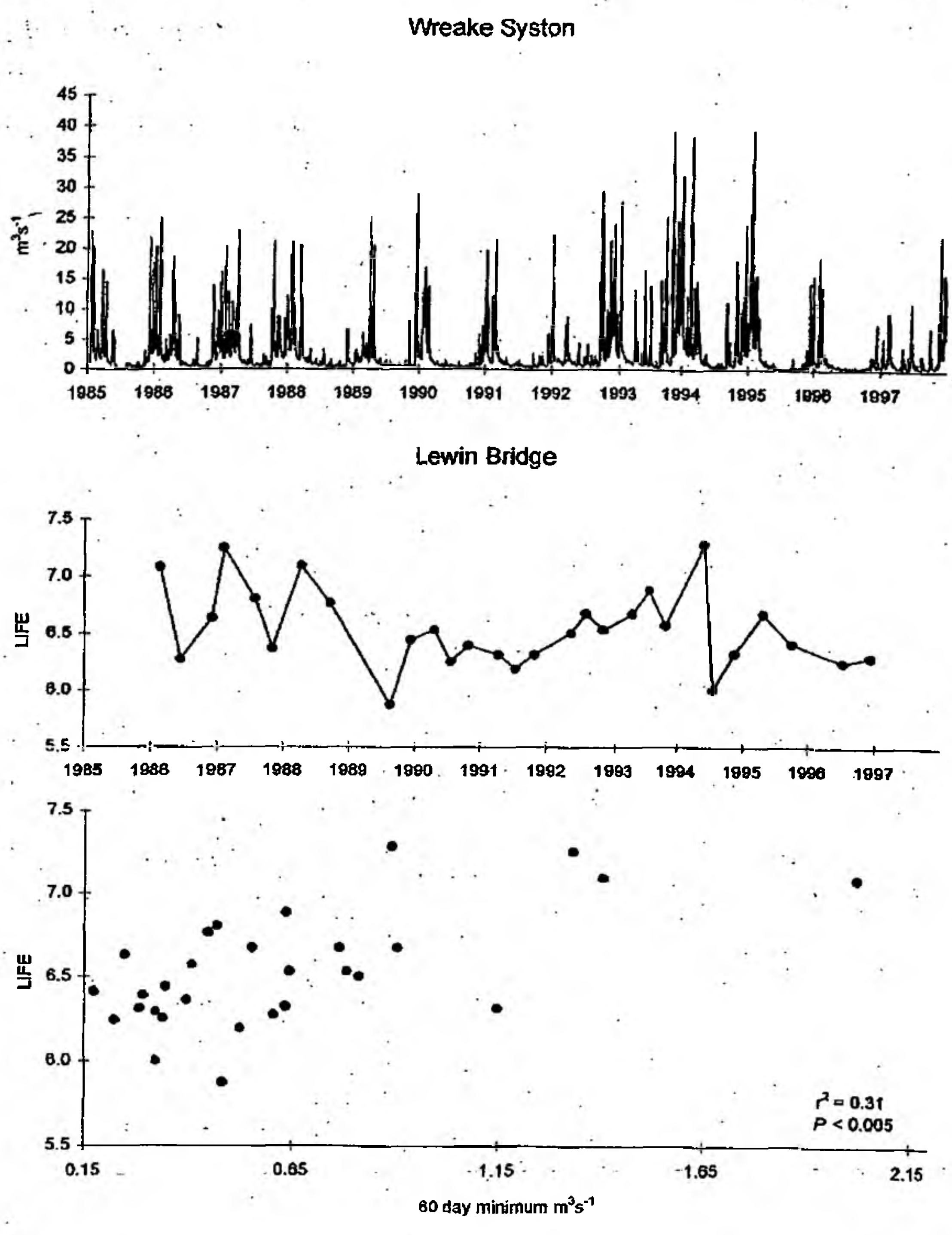

Walthe Beck - Brigsley
2.0
1.0
0.0
85 86 87 88 89 90 91 92 93 94 95 96 97 98 99
8.5
8.0
7.5
7.0
6.5
85 86 87 88 89 90 91 92 93 94 95 96 97 98 99
8.5
8.1
7.7
7.3
6.9
6.5
$r^2 = 0.81$
$P < 0.001$
0.05 0.1 0.15 0.2 0.25 0.3 0.35
180 day RSM (4-9) m3 s-1


Dour - Crabble Mill
m3s-1
1.6
1.2
0.8
0.4
0.0
89 90 91 92 93 94 95 96 97 98
Pencester Gardens
LIFE(F)
8.0
7.5
7.0
6.5
6.0
5.5
5.0
89 90 91 92 93 94 95 96 97 98
LIFE(F)
8.0
7.5
7.0
6.5
6.0
5.5
5.0
0 0.1 0.2 0.3 0.4 0.5 0.6
r2 = 0.60
p < 0.001
150 day RSM (4-10) m3 s-1


Laceby Beck
CUMECS
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
87 88 89 90 91 92 93 94 95 96 97
LIFE
8.5
8.0
7.5
7.0
6.5
6.0
5.5
87 88 89 90 91 92 93 94 95 96 97
LIFE
8.5
8.0
7.5
7.0
6.5
6.0
5.5
0 0.05 0.1 0.15 0.2 0.25
420 day RSM (4-9) m³ s⁻¹


Wharfe - Addingham
m3s-1
100
80
60
40
20
0
85
86
87
88
89
90
91
92
93
94
95
96
97
LIFE
8.5
8.0
7.5
7.0
r2 0.46
p < 0.001
1
3
5
7
9
11
13
15
210 day RSM(3-10) m3s-1


Evenlode - Cassington
m³s⁻¹
20
15
10
5
0
84 85 86 87 88 89 90 91 92 93 94 95 96
D/S Chadlington Stream
LIFE (F)
7.5
7.0
6.5
84 85 86 87 88 89 90 91 92 93 94 95 96
LIFE (F)
7.5
7.0
6.5
r² = 0.77
p < 0.001
1 1.2 1.4 1.6 1.8 2 2.2 2.4 2.6 2.8 3
420 day RSM(4-9) m³s⁻¹


Wreake Syston
45
40
35
30
25
20
15
10
5
0
m³s⁻¹
1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997
Lewin Bridge
7.5
7.0
6.5
6.0
5.5
LIFE
1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997
7.5
7.0
6.5
6.0
5.5
LIFE
0.15 0.65 1.15 1.65 2.15
60 day minimum m³s⁻¹
r² = 0.31
P < 0.005

APPLICATION TO A NEW SITE

- RIVER SWAN
  - Affected by a flood relief scheme
  - Use physical data from unimpacted area upstream to predict target value of LIFE score and compare with observed value from reach experiencing <u>no peak flows</u>

- LIFE SCORE
  - EXPECTED or target value = 7.276
  - OBSERVED or impacted value = 5.710
  - O/E = 0.785

PUTTING LIFE INTO RIVPACS – DELIVERABLES

- ANALYSE VARIATION IN LIFE SCORES OVER ALL RIVPACS REFERENCE SITES
- SET A TARGET FOR UNIMPACTED SITES
- INVESTIGATE SAMPLING VARIATION IN OBSERVED LIFE SCORES – across a wide range of types and quality of river
- INVESTIGATE OBSERVED/EXPECTEDRATION OF LIFE SCORES IN 5000+ GQA DATA SET - to examine the relationship between LIFE score and the EQI
- ADD LIFE SCORES TO THE RIVPACS PACKAGE
- SUBSIDIARY INVESTIGATION TO EXAMINE "HYDROLOGICAL HISTORY" OF ALL SITES WITH SUITABLE DISCHARGE DATA – to determine whether invertebrate samples were taken during a low flow period.

6 WATER QUALITY MODELLING IN THE NORTH EAST REGION

Julia Jarvis

Environment Agency, North East Region, Phoenix House, Global Avenue, Leeds Ls2 5HA.

The North East region of the Environment Agency extends from Chesterfield (the Don and Rother River Catchment) in the south to the Scottish Border (the Tweed catchment) in the North. The area includes river catchments, such as the Don and Aire, which receive a high proportion industrial and sewage effluent relative to their flow, and others such as the Swale which receive proportionally little effluent and are of high quality.

The area also includes three major estuaries (Humber, Tees and Tyne) and the area of coast between the Humber and the Tees.

The Region maintains a small modelling team, and some of their current work is reviewed in this presentation in relation to current legislation and requirements such as AMP3.

A proposal for reviewing the provision of water quality modelling in the Agency is also presented.

Slide 1

Coastal and Estuarine Water Quality Modelling in the NE Region

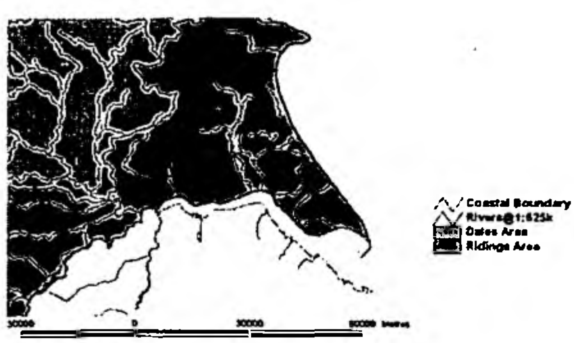
Julia Jarvis

Slide 2

North East Region: Rivers, Estuaries and Coastline

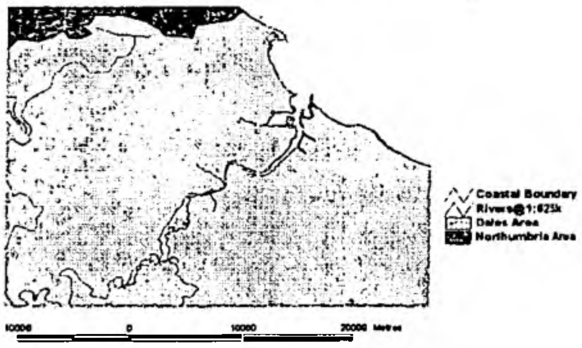
Slide 3

Ridings Area: Humber Estuary and Holderness Coast



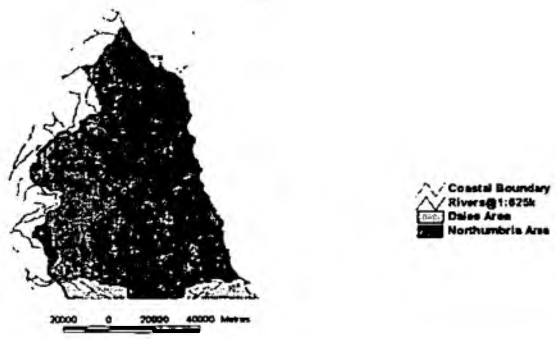
Slide 4

Dales Area: Tees Estuary



Slide 5

Northumbria Area: Tyne Estuary



Slide 6

Current 'in-house' modelling

- ★Operational - an aid to decision making
  - ➡Determination of discharge consents
    - ➡IPC (now IPPC) authorisations
    - ➡AMP (STW intermittent/discontinuous)
  - ➡Emergency (e.g. pollution incidents)
  - ➡Abstraction licensing
- ★Strategic (limited) - e.g. Tees Strategy

Slide 7

Legislative Requirements

★ Water Framework Directive
- ➡Habitat's Directive
- ➡Nitrate Directive
- ➡UWWT Directive
- ➡IPPC Directive

★ Bathing Water's Directive

★ COMAH

Slide 8

Other Drivers...

★ Chemicals in the Environment

★ Human Health Impacts from Chemicals

Slide 9

Water Framework Directive

★ Significant piece of water quality legislation

★ Introduction of objectives set using Ecological standards

★ Cross-functional impact - with effects on water resources, flood defence, conservation, fisheries, planning and environmental monitoring

★ Gaps in tools and expertise need to be filled to ensure timely implementation of the Directive

Slide 10

Implementation of Directive and Reporting requirements

★2000 Directive enters into force

★2003 Member States bring into force laws, regulations and administrative procedures

★2003 MS to provide the Commission with a list of competent authorities, including details of roles and responsibilities; identify River Basin Districts

★2005 Complete summary report detailing the analysis of characteristics of each RBD; including a review of the environmental impact of human activity on the economic analysis of water use

Slide 11

★2007 Repeal existing Directives: Information exchange, Surface Water Abstraction

★2007 Establish surface and groundwater monitoring programmes to establish a comprehensive overview of status within each River Basin District

★2007 Publish, for public consultation, a timetable and work programme for the publication of the River Basin Management Plan (RBMP)

★2007+ 3 months Member States to submit a summary report detailing the established monitoring programme

Slide 12

★2008 Publish, for public consultation, an interim overview of significant management issues in the RBD

★2009 Undertake public consultation on draft RBMP for a minimum of 6 months

★2010 Establish a programme of measures taking account of analyses completed in 2005 with the aim of moving towards meeting environmental objectives

★2010 Publish RBMP

Slide 13

★2013 Repeal existing Directives:Freshwater Fisheries, Shellfish Waters, Groundwater, Dangerous Substances

★2013 Ensure all measures are operational

★2016 Achieve environmental objectives

Slide 14

Good Ecological Status

What role will water quality modelling play in the determination of the Ecological Status of estuaries and coastal waters?

Slide 15

Diffuse Water Pollution

★Results mostly from non-Agency regulated activities - in any case difficult to control by legislation alone

★Nutrients, Pesticides and Herbicides, Soil erosion and sedimentation, Pollution incidents, Urban drainage, Atmospheric input?

★Increase in importance as AMP and IPPC address most point source discharges

★Water Companies and Industry will expect the Agency to address diffuse pollution issues

Slide 16

Identification and quantification of diffuse sources?

What role will water quality modelling play in the identification and quantification of diffuse sources?

Slide 17

Habitat's Directive

- ★ Applicable to SPAs and SACs (birds and flora & fauna respectively)
- ★ 4 Stages
  - ➡ Identify relevant permissions
  - ➡ Assess whether relevant permissions likely to have a significant effect
  - ➡ Appropriate Assessment (i.e. Is affect adverse?)
  - ➡ Revoke, Amend or Affirm
- ★ Apply the same tests of significant effect and adverse affect to new applications

Slide 18

Lindisfarne SPA Monitoring Sites

Slide 19

Primary objectives of the modelling study

★To determine the impact of STWs on in-stream nutrient concentrations

★To determine the impact of individual streams on nutrient levels in the inter-tidal zone

Slide 20

Data received to date

★Hydrological Data
- ●Stage-Discharge
- ●6 sites
- ●Monthly values since July 1999

★Water Quality Data
- ★DO, T, pH, BOD, N, P, Chlorophyll-A, Solids
- ★11 sites
- ★Approx. monthly values between 1990-1999

Slide 21

Data still outstanding...

★Nutrient concentrations in saline waters

★Inter-tidal bathymetry data

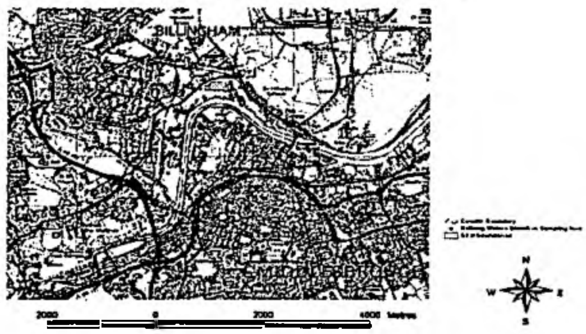
Slide 22

Issues with existing modelling tools...

- ★Variables: Temperature, Salinity, BOD, DO,...
  - ➡What can modelling these variables tell us about the Ecological Status of a water body?
- ★Coverage: Many existing models do not extend to the relevant areas
  - ➡e.g. Tees estuary 2DV model does not extend to the SPA of Seal Sands
- ★Sound Science: Are existing tools adequate?

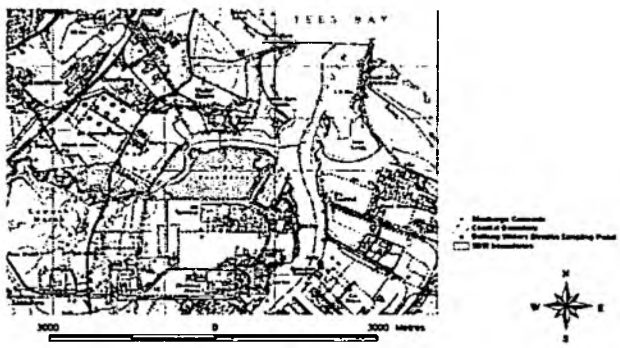
Slide 23

Upper Reach



Slide 24

Lower Tees



Slide 25

The way forward....

To provide a review of the Agency's in-house water quality modelling, with specific regard to:

- Existing legislation and policy
- Current methods and tools
- Scientific basis ('Sound Science')
- Effectiveness (i.e. QA of modelling work)

Slide 26

To formulate proposals for a water quality modelling strategy for the Water Quality Function Group via consideration of:

- Emerging legislation and policy
- Required Effectiveness ('Ideal Standards')
- Scientific Basis
- Related activities of external agencies
- The Agency's IT strategy

Slide 27

To make recommendations for the implementation of such a strategy at Regional Level, taking into account:

- Technical requirements
- Monitoring requirements
- Transition period required for Agency modellers and customers

Slide 28

Benefits to the EA

★ Provide an opportunity to address the deficiencies in the Agency's existing modelling tools, particularly those covering estuaries and coastal waters

★ Provide an opportunity to develop the scientific and technical expertise and widen the experience of the Agency's modellers

★ Consolidate the Agency's in-house modelling capability into a suite of tools, each matching the complexity of the problems they are required to solve

★ Contribute considerably to nationally consistent decision making, based on sound science

Slide 29

Wish List.....

Establishment of a Code of practice for Agency Water Quality Modelling

Establishment of a *virtual* National Centre (or National Service) for Water Quality Modelling

Slide 30

The End

7 AN ANIMATED PARTICLE TRACKING MODEL OF THE FAL ESTUARY

Toby Sherwin, Norman Babbedge, Bethan Jones and Deborah Tyrrell

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Norman Babbedge Environment Agency, Manley House, Kestrel Way, Exeter, EX2 7LQ

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AN 'ANIMATED' POLLUTION MODEL OF FALMOUTH HARBOUR

Toby Sherwin[1], Norman Babbedge[2], Bethan Jones[1] and Deborah Tyrrell[2]

[1] *UCES, UWB Marine Science Laboratories, Menai Bridge, Anglesey, UK, LL59 5EY*
[2] *Environment Agency, Manley House, Kestrel Way, Exeter, Devon, UK, EX2 7LQ*

ABSTRACT

Falmouth Harbour is a large geographically complicated inlet on the south coast of Cornwall. The sewerage system for the town of Falmouth is currently in the middle of a major improvement programme that has included a new outfall just inside the harbour entrance. A computer model of the harbour system was developed to enable the Environment Agency to investigate any number of discharge scenarios easily and in house. Files were provided for each of spring tides, neap tides, wind forcing from four directions and river flow. These files were scaled and combined to form the background flow field for a particular day and input to a particle tracking program that animated the positions of the particles on a computer screen. The method enabled the Agency to rapidly inspect a wide range of different scenarios and determine the consent conditions for the outfall.

1. INTRODUCTION

The Fal Estuary, on the south coast of Cornwall (Fig. 1), is one of the largest natural harbours in Europe. It is also an area of high ecological value, and is designated as a Special Area of Conservation (SAC) under the European Habitats Directive. The town of Falmouth, along with outlying villages, discharges sewage effluent from a population equivalent of about 43,000. Until recently, about 2/3 of this effluent was discharged after screening from the Pennance Point outfall at the western end of Gyllyngvase Bay, and 1/3 was discharged crude from the Middle Point outfall just inside the estuary. Both discharges were inside the SAC and very close to the shore. The Pennance Point outfall was close to two designated bathing waters, whilst the Middle Point outfall was close to one further designated bathing water and to a number of shellfish harvesting areas.

Implementation of the Urban Waste Water Treatment Directive (91/271/EEC) and the Bathing Waters Directive (76/160/EEC) meant that a major improvement scheme was required. Other considerations were the presence of the commercial shellfish beds within the estuary, the (then) impending designation of much of the estuary under the Shellfish Waters Directive, and the high level of recreational use of the waters. The approach eventually put to the Agency by South West Water (SWW) was for the effluent to be treated to a high level, and discharged continuously through a 600 m long outfall (Black Rock outfall) offshore of the original outfall at Middle Point.

The Agency were concerned about the following aspects of the proposals:

- Within the mouth of the estuary, flows were to be increased by a factor of 3, possibly leading to an increase in nutrients discharged into sensitive habitats within the estuary.
- The continuous nature of the discharge might cause deterioration in the bacterial quality of shellfish within the estuary.

In order to evaluate the scheme proposals, the Agency decided to invest in a hydrodynamic model for its own use. The Agency was of the view that a major strength of the modelling approach would be the ability to compare a number of scenarios. Its prime objectives with respect to bacteria were to ensure compliance with Agency Bathing Water Policy and with proposed Shellfish Waters Directive water quality standards. Its objectives with respect to nutrients inside the estuary were primarily that there should be no deterioration as a result of implementation of the scheme. It was assumed that any significant modelling errors would be mitigated by direct comparison between pre-scheme and post-scheme scenarios to give a realistic assessment of any improvement or deterioration.

In response to the Agency's needs, and recognising that one of the drawbacks of many models is the time taken to perform simulations, UCES proposed an approach that would enable potential scenarios to be evaluated quickly. The use of animation would enhance the speed of this evaluation and provide an insight into the hydrodynamic processes involved.

The modelling strategy had two stages:

i) UCES developed a two-dimensional model of the currents in Falmouth Harbour and produced seven files of predictions for: spring and neap tides; forcing by an 8 $m\ s^{-1}$ wind from each of the four cardinal points; and forcing by a mean river flow. In both the wind and river flow cases the tidal amplitude was set to zero.
ii) These files were given to the Agency, along with software that enabled them to linearly construct the currents of any tidal range, wind strength and river flow. This current field was then read by a particle tracking contaminant model that predicted the dispersion of a pollutant for a particular situation. The contaminant model produced an animated display on the computer screen, which allowed a quick evaluation of the changing distribution over a tidal cycle. Situations of particular interest were saved to disc for subsequent processing. The suite is described in detail in Sherwin and Jones (1999).

2. TIDAL REGIME AND METEOROLOGY

Falmouth Harbour is a complex estuary system (Fig. 1). Its main central section (Carrick Road) is about 7 km long and 2 km wide. Most of the Carrick Road is less than 5 m deep at the Lowest Astronomical Tide, but it contains a narrow meandering centre channel with depths of order 25 m. There are also several large creeks and a major branching estuary system at the head of the Carrick road, which extends as far as Truro, about 15 km from the mouth of the Harbour.

There is a moderate tidal range along the south coast of Cornwall and the main M2 semi-diurnal tidal constituent amplitude is about 1.6 m; at the entrance to Falmouth Harbour mean tidal currents are typically 0.25 m s^{-1}. The first harmonic, M4, is reasonably large (about 0.11 m) and on spring tides it combines with MS4 to become nearly 10% of the size of the semi-diurnal signal, although on neaps it is almost non-existent. The large spring tide quarter diurnal signal seems to be generated at St Malo, on the north coast of France (see e.g. Pingree and Maddock, 1978). Currents over Black Rock bank are sensitive to the differences in the tidal curve that result from this effect.

Typical mean wind speeds are about 5 m s^{-1} at Falmouth, with a preponderance of the stronger winds coming from the south west. Sea breezes appear to be weak and the average river flow is small (about 6 m^3 s^{-1}). Further details of the Falmouth Harbour system can be found in Sherwin (1993).

3. THE HYDRODYNAMIC MODEL

The dynamics of Falmouth Harbour were simulated with SPMOD, a standard two-dimensional depth averaged primitive equation shallow water model (see Jones, 1993). Three levels of nesting were used (see Table for the details). At each level the model was run for three tidal cycles, sufficiently long for convergence. During the last tidal cycle the data were extracted at each grid pair and then analysed for the mean, M2 and M4 currents. Higher harmonics were very small and ignored. The values of the M2 and M4 volume flow and elevation were interpolated with a bi-linear method to provide radiating boundary conditions for the finer resolution model.

Nested Models
An Outer model covered the western English Channel from Land's End to Plymouth and for 50 km south of the Lizard (see Table). Non-radiating boundary conditions for the Outer model were taken from tables for M2 elevation derived from the model of Pingree and Griffiths (1979). Since M4 is considerably smaller than M2 it was approximated at the boundary from a figure in Pingree and Maddock (1978). The Outer model forced an Inner model, which in turn forced the fine scale Carrick model.

The dynamics of the finest resolution model were resolved on a 100 m grid covering the area shown in Fig. 1. The upper reaches of some of the inland creeks and rivers do not to have a direct bearing on the dynamics of the central harbour, so their dimensions were approximated. These places acted as reservoirs to ensure that the correct amount of water was pumped in and out through the harbour entrance. Different sized reservoirs were used for the spring and neap tide runs.

Validation
The tidal elevations in the Carrick model were about 6 cm higher than observed, although there was no discernible difference in phase lag. In general there was reasonably good agreement between figures based on drifter and tidal station observations (Sherwin, 1993) and the modelled currents (Fig. 2). Predicted current speeds were generally within 10% of those observed by the Agency at the outfall.

They were also compared with the five Admiralty Tidal Diamond observations in the Harbour (see Fig. 1), which were divided by 1.13 to make them comparable with the depth averaged currents in the model (e.g. Maddock and Pingree, 1978). The average difference was about 0.035 m s^{-1}, compared with typical maximum current speeds of 0.1 to 0.15 m s^{-1}.

Overall the model provided a satisfactory simulation of the flow in Falmouth Harbour. It worked well for the main tidal constituents, but missed some of the detail, for example grid scale eddies on Black Rock bank that observations suggest are produced by Pendennis Point. As a check, float track surveys were simulated to establish how well the model reproduced tidal excursions. As anticipated for a depth integrated model, the modelled excursions lay between those exhibited by surface and deep drogues.

Wind forcing

The Carrick model was also forced with a mesoscale wind model (based on Mass and Dempsey, 1985) which used synthetic 850 mb data to give a steady state surface geostrophic wind field of about 8 m s^{-1}, from the each of the four cardinal points. The wind induced currents were not run to steady state, since wind events do not typically last long enough for this condition to be achieved. The time taken to reach a quasi-steady flow depends on the surface wind and bottom current stresses and the depth of water, and investigations showed that the wind driven currents could be satisfactorily represented with a wind of 8 m s^{-1} blowing for 12 h. Currents at other wind speeds were scaled linearly from these predictions. In general, wind driven currents were less than 0.01 m s^{-1} and tended to be masked by tidal residuals during spring tides, but could be relatively important on neap tides.

Merging of Hydrodynamic Files

The method of linearly adding the different components of tidal, wind and river forced currents was a major factor in helping the Agency conduct its own runs. The technique is not particularly rigorous, since it ignores the effect of non-linear interactions between the different types of current. However, in Falmouth Harbour all currents are small so non-linearities are likely to be unimportant. Furthermore, there are other simplifications that are potentially far more significant, for example, a two-dimensional model cannot reproduce the effects of freshwater driven gravitational circulation. However, it is beyond the scope of this exercise to consider the limitations of the two-dimensional approach.

4. THE CONTAMINANT MODEL

LAGCARTH is a particle tracking model that simulates contaminant dispersion by advecting particles with a pre-determined tidal current field and allowing them to spread using a radial random walk technique. The particles are discharged from a series of outfalls and removed at a rate determined by the decay time of the contaminant. A novel feature is that the positions of particles may be displayed as dots on the computer screen in an animated form that can be tuned to give the appearance of smooth dispersive spreading. The user can then readily see how the position and concentration of an effluent plume varies over a tidal cycle. At regular intervals the model writes a file of particle positions, which can be used for post processing. The model variables were easily changed using a separate interactive program. The program suite ran on a Pentium 100 MHz PC under Windows 95™.

The program proceeds by advancing time in discrete intervals, Δt. At each time step the tidal velocity at the position of a particle, u, is calculated and the particle advected by a distance of approximately $u\Delta t$ (u is actually modified to take account of the tidal velocity at the new position). The particle then makes a random jump. Since LAGCARTH assumes isotropic turbulence, the random walk is effected by fixing the jump distance, r, and randomly selecting its orientation (Hunter, 1987). It can be shown that

$$r = \sqrt{4K\Delta t}$$

where K is the (constant) user defined diffusion coefficient. The variation of depth, h, in the tidal model is accounted for by adding a correction velocity

$$u_2 = \frac{K}{h}\frac{dh}{dx}$$

pointing towards the deeper water. Particles are released at a fixed rate from any number of outfall positions, and removed at a rate that depends on the decay time of the contaminant being represented. When a particle encounters a boundary it is reflected as though it were a perfect ping-pong ball bouncing off a wall. Further information can be found in Sherwin (1999).

5. SIMULATIONS PERFORMED

The flowchart in Fig. 3 illustrates the steps involved in a run of the contaminant model. All simulations used the same mean ($10\ m^3\ s^{-1}$) river flow hydrodynamic field (since the depth mean river currents are almost insignificant), but varied the wind induced hydrodynamic fields. The diffusion coefficient was set to $0.5\ m^2\ s^{-1}$ for all cases, based on model simulations of field spore and dye data.

The model used fixed decay rates to simulate non-conservative pollutant concentrations, but had no water quality module. Instead, a simple 5 day decay rate was used for nutrient concentrations (Dissolved Available Inorganic Nitrogen, or DAIN), based on an empirical appreciation of typical denitrification rates. Comparisons with field data showed this rate to be reasonable. Nutrient simulations were run for 20 tidal cycles (about 10 days), to achieve near steady state. All runs assumed a mean tidal range, since the model was not configured to simulate a spring/neap cycle. This was considered adequate, as the objective was to simulate average concentrations rather than tidal specific concentrations.

Faecal Coliform concentrations were modelled using different values of T_{90} (the time taken for the number of bacteria to reduce by 90%), ranging from 12 h to ∞ h, and runs lasted one tidal cycle, commencing at High Water. These model runs were undertaken for both mean tidal range and neap tidal range (assumed the worst case scenario).

Whilst the model was capable of simulating the influence of many outfalls at once, it was not able to apply different tidal phasing characteristics to each of them. Thus, for multiple outfall scenarios, it was usually necessary to simulate specific phased outfalls separately, and then merge the results to give the combined concentration field. However, given the speed of simulation, this limitation did not prove to be a problem.

A summary of the statistics of the modelling exercise is given below:

- After model set up and testing, the investigations took place over a 2-month period.
- The total duration of model run time was about 75 hours, all undertaken in office time.
- For bacterial modelling, each run took approximately 10 minutes.
- For DAIN modelling, each run took approximately 40 minutes.
- A total of approximately 160 runs were completed.
- A total of approximately 95 scenarios were modelled.

6. RESULTS OF THE CONTAMINANT MODELLING EXERCISE

The modelled annual average DAIN concentrations resulting from all inputs to the estuary (sewage and riverine) are compared with the average DAIN concentrations at the surface obtained from monitoring over a period of 5 years in Fig. 4. There is a good correlation, bearing in mind that the model represents depth-averaged concentrations.

The model proved invaluable in evaluating the impact of the proposed discharge on nutrient concentrations. Early simulations of the continuous discharge strategy that was originally proposed by South West Water indicated an increase in the concentrations of DAIN inside the estuary, resulting from the flood tide phase of the discharge. The proposed discharge is to be fully treated, so it will not be possible to limit the release of effluent to the ebb tide only since the treatment process is continuous and a large storage volume would be required. However, part of the Falmouth scheme includes a large storm storage tunnel in which the crude effluent is collected prior to treatment. This tunnel is larger than required to deliver the Agency's objectives with respect to storm spills, so the Agency considered using the spare capacity of the tunnel to reduce the volume of discharges on the flood tide and increase the volume on the ebb tide. This could be achieved within the variations in flows to the sewage treatment works that occur naturally as a result of diurnal flow variations. The model was successfully used to test a number of different storage scenarios and its speed enabled us to arrive at a solution in a reasonable time scale. With a continuous discharge of effluent, there should be some increase in DAIN concentrations inside the estuary (Fig. 5, top panel). However, by increasing the discharge rate on the ebb tide, and decreasing it on the flood tide, the change in DAIN concentrations inside the estuary should be less than 0.01 mg/l (Fig 5, bottom panel). As a result of the modelling exercise, the tidal phasing of the flow regime was incorporated into the consent issued by the Agency.

The value of using the model to determine the impact of the proposed discharge on Faecal Coliform concentrations in the Fal Estuary was somewhat diminished when it became clear that SWW were proposing to install sand filters and UV disinfection, which should result in very high bacterial standards in the boil. However, the model was of particular value in presenting the scheme to outside bodies and the general public. Firstly, animations demonstrated the behaviour of the discharge plume; and secondly synoptic contour plots such as those presented in Fig. 6 showed the benefit that the scheme will bring by lowering Faecal Coliform concentrations in the Harbour.

7. CONCLUSIONS

In conclusion, the facility for the Agency to control and undertake the model runs itself was a major advantage of the modelling approach described here. The provision of individual hydrodynamic files for various tide, wind, and river conditions enabled a wide range of scenarios to be run rapidly. The ability to view the animated display on a computer screen was of great value in the quick evaluation of a scenario, and for gaining a feel for the behaviour of the system. The empirical approach of using a fixed decay rate to simulate the behaviour of nutrient interactions gave realistic results. Finally, demonstrations of the animations were valuable in explaining the Agency's strategy to the general public.

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TABLE

Details of the Hydrodynamic Models

	Model		
	Outer	**Inner**	**Carrick**
no of longitude elevation grid points	46	69	68
no of latitude elevation grid points	51	85	149
longitudinal grid spacing (mins)	2′	0.5′	0.1′
latitudinal grid spacing (mins)	1′	0.25′	0.05′
longitudinal grid spacing (m)	2375	594	118.75
latitudinal grid spacing (m)	1850	462	92.5
time step (s)	15	1.592	0.484
run duration (h)	37.3	37.3	37.3
westernmost longitude	5° 36′ W	5° 21′ W	5° 5.9′ W
easternmost longitude	4° 06′ W	4° 47′ W	4° 59.2′ W
highest latitude	51° 22′ N	50° 14.5′ N	50° 14′ N
lowest latitude	49° 32′ N	49° 53.5′ N	50° 6.6′ N
viscosity ($m^2 s^{-1}$)	10	10	10
friction coefficient	3.8×10^{-3}	3.8×10^{-3}	3.8×10^{-3}

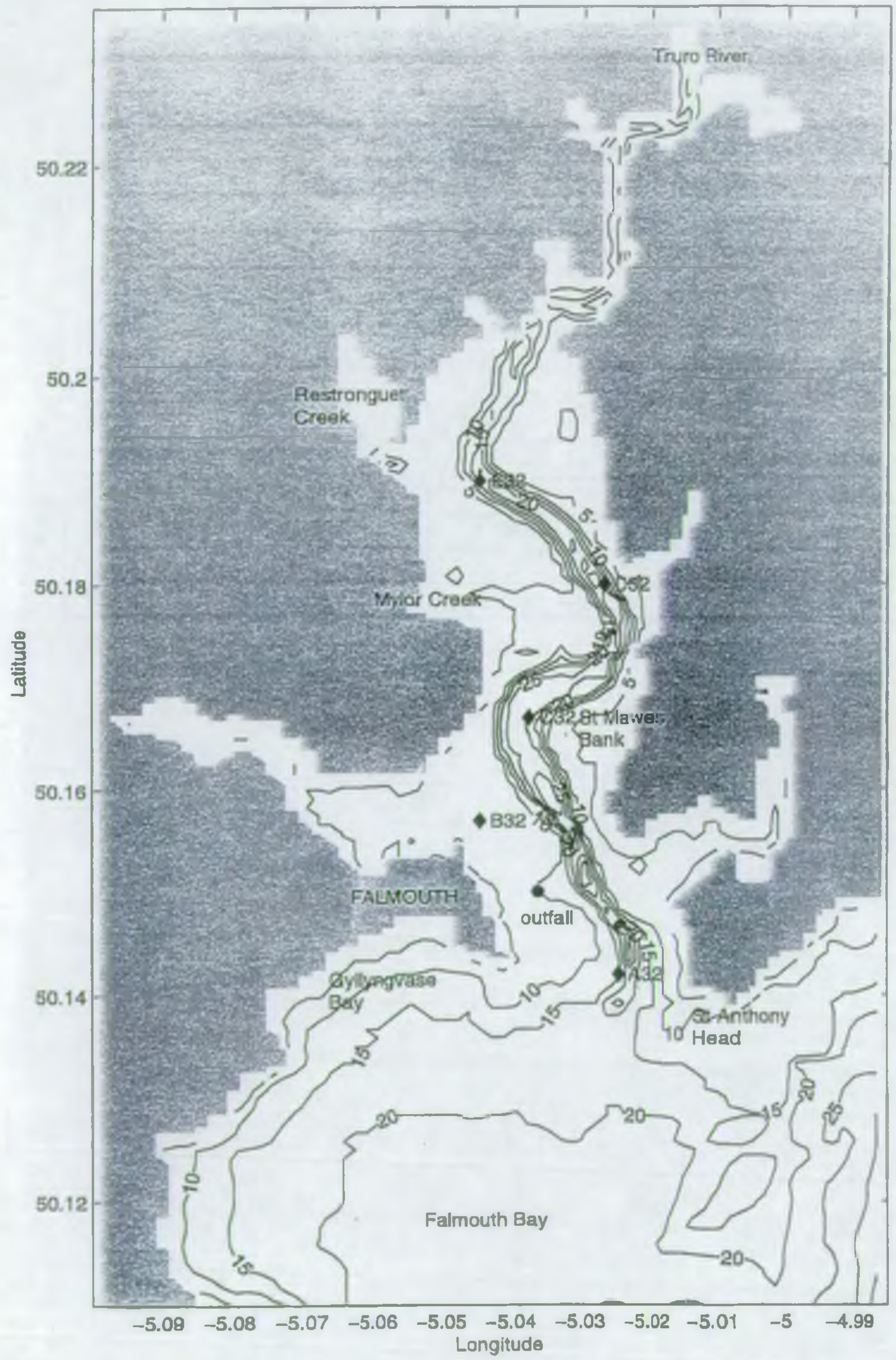


Figure 1. The bathymetry of the fine-scale Carrick Model on neap tides. The positions of the outfall on Black Rock bank and Admiralty tidal diamonds are also shown. The Carrick Road is the wide stretch water north of diamond B32.

Figure 2. Tidal current vectors at hourly intervals in Falmouth Harbour for a mean (M2) tidal range. HW is local high water.

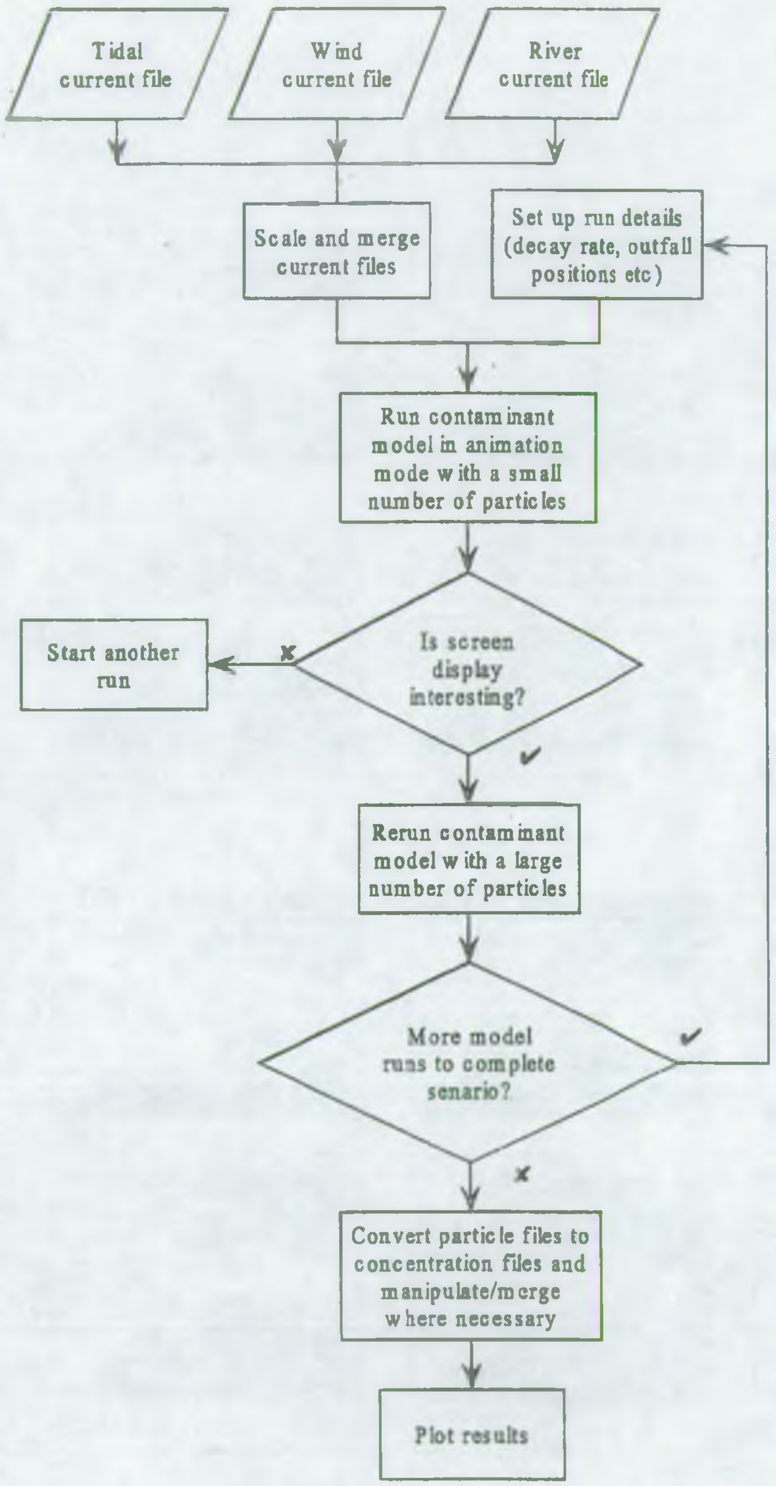
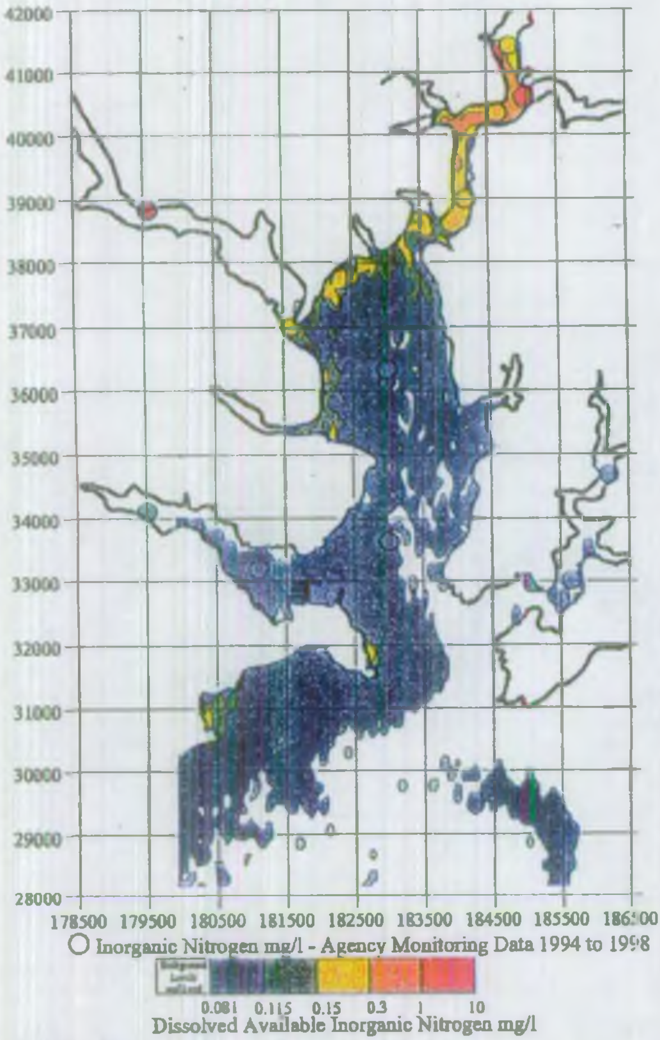
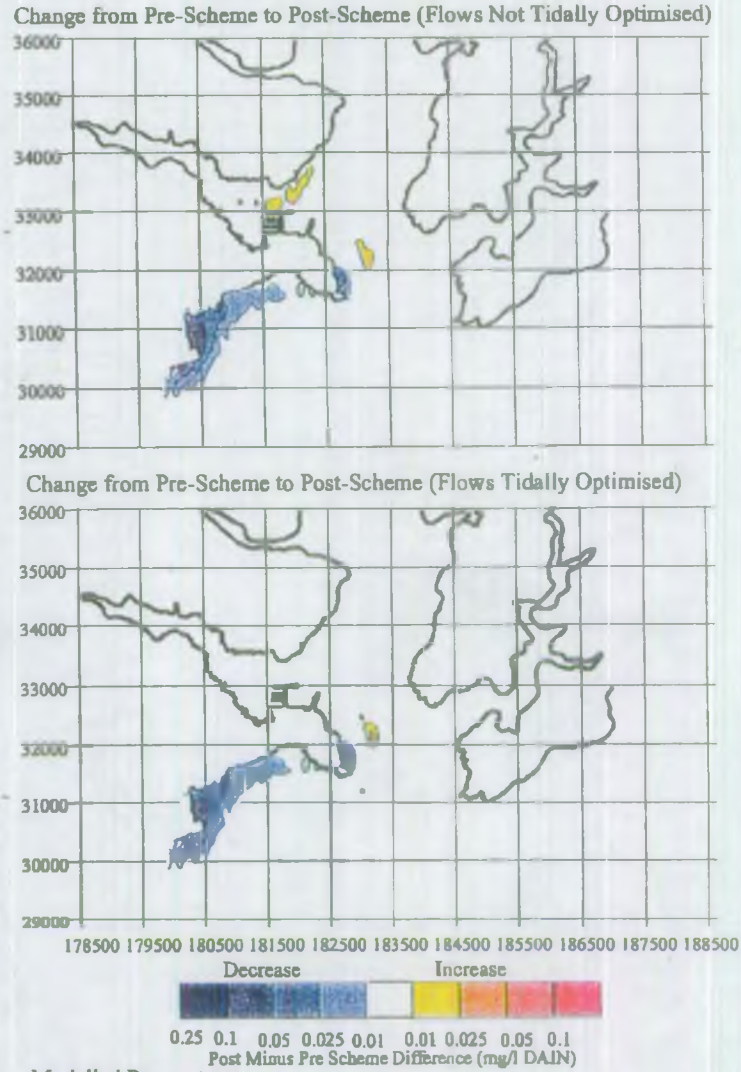


Figure 3. Flowchart illustrating the way in which the Agency used the contaminant model.



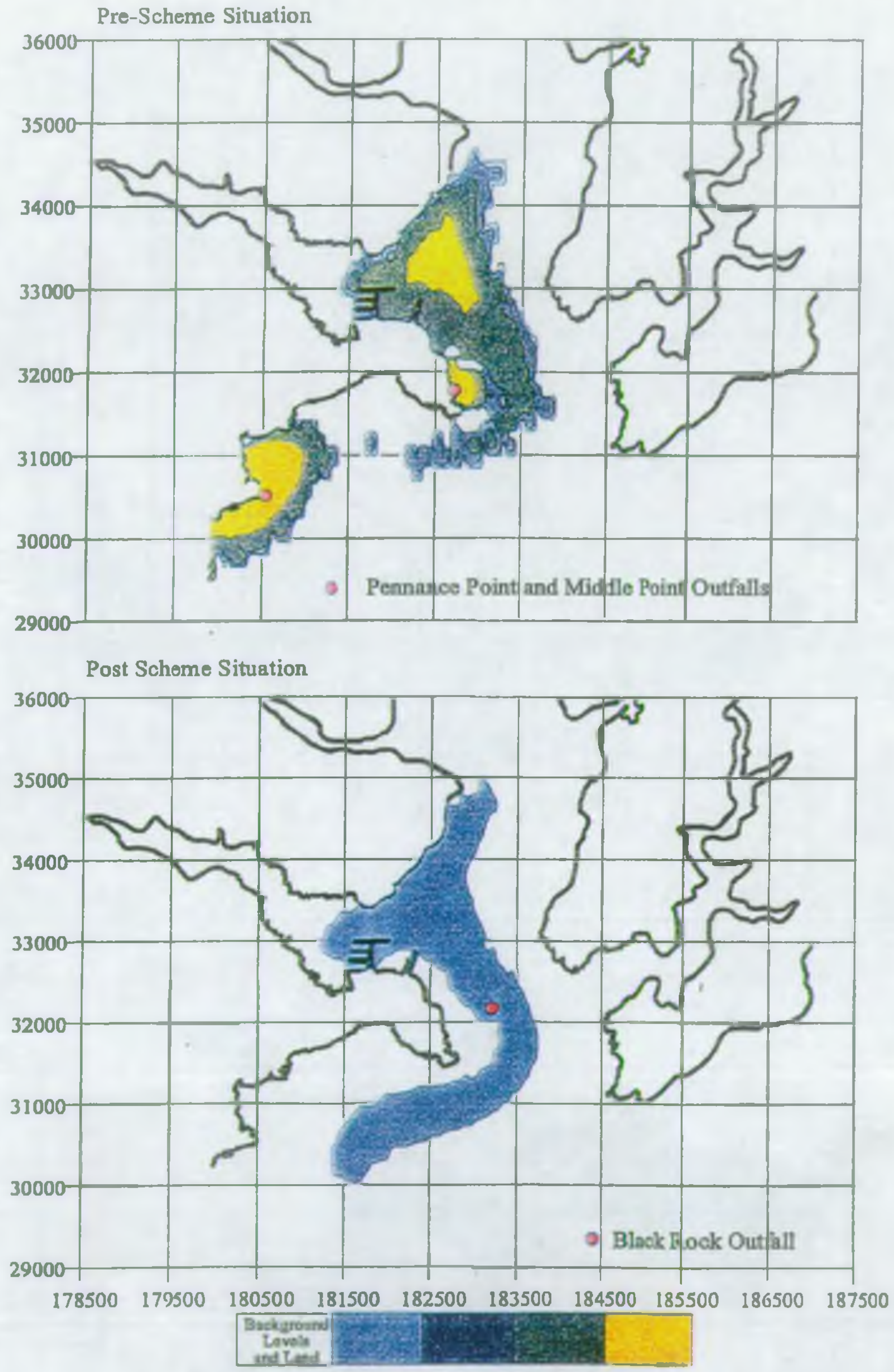
Modelled Parameters:
HW to HW (Discharge for 10 Days), All Inputs (Sewage and Riverine), Summer Flows and Concentrations, Mean Tidal Range, No Wind

Figure 4 DAIN Pre Scheme Modelled Concentrations



Modelled Parameters:
HW to HW (Discharge for 10 Days), Summer flows, Mean Tidal Range, No Wind

Figure 5 Predicted Changes in DAIN Concentrations



Modelled Parameters:
Discharge for 12.4 hours from HW to HW with No Decay,
Pre-scheme Flows Tidally Phased, Effluent Concentration 25,000,000 /100ml
Post-scheme Flows Tidally Optimised, Effluent Concentration 2,500 /100ml
Average Daily Flows, Mean Tidal Range of 3.4 m, No Wind

Figure 6 Modelled Faecal Coliform Concentrations

8 THE ROLE OF MODELS IN DECISION MAKING

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ROLE OF MODELS IN DECISION MAKING

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ABSTRACT

Details are given of the increasing international public concern relating to hydro-environmental issues and cites examples of some of the water quality problems now being considered by hydraulic engineers on a regular basis. The limitations and restrictions of both physical and numerical hydraulic models are discussed and concern is expressed with regard to the increasing use of numerical models being made by non-specialist engineers or scientists - often with little understanding of hydraulics and numerical methods - to assist in the planning and/or design of water quality related studies. General details are given of numerical models used for flow and water quality concentration predictions in coastal and inland hydraulic basins and two example research projects are described. In the first of these studies comparisons are made between dynamically and non-dynamically linked nested models, with the results indicating that in some circumstances non-dynamically linked models can give inaccurate velocity field predictions. In the second example higher order accurate schemes are compared for modelling the advection of abrupt concentration gradients, with computational efficiency and simplicity often being important in hydraulic engineering studies where complex boundaries, often including flooding and drying, can cause added difficulties. Finally, the importance of basic original research is also highlighted, particularly as national and international research funding agencies place increasing emphasis on applied research.

1 INTRODUCTION

1.1 Water Quality Concerns

In recent years there has been a growing international public concern and an increased awareness of pollution problems - particularly with regard to water pollution. This increasing emphasis and concern of hydro-ecological and environmental issues should be welcomed by the hydraulic engineer, since the role and contribution of the engineer in combating water pollution and the importance of accurate hydraulic modelling has not always been fully appreciated by society. In connection with such pollution concerns, hydraulic engineers are now involved in an increasing range of environmental impact assessment studies in most countries, with some typical examples as to the causes and problems of water pollution being given below:

i. Sewage discharge is just one of many different forms of waste disposal to the aquatic environment and can be released in one of three main ways. Firstly, by direct discharge from outfall pipes to coastal and estuarine waters. Secondly by dumping of sewage sludge, usually further offshore. Thirdly, via discharges into rivers and estuaries which, in turn, deposit the sewage into the sea. Sewage waste is not just domestic waste, but can contain typically up to 20% industrial waste and includes organic waste, bacteria and viruses. For the UK alone, over 1.3 million cubic metres of sewage waste are discharged into Britain's coastal waters every day and nine million tonnes of wet sewage sludge are disposed of offshore (Scott, 1988).

ii. Cooling water discharges from coal and oil fired and nuclear power stations, fertilizer plants and desalination works can significantly affect marine life and aquaculture. Such discharges can raise the local water temperature by as much as 5 "C and it is therefore important to ensure that this local temperature rise is minimised, both in terms of protecting the local hydro-ecology and with regard to plant operating efficiency where the inlet is located nearby.

iii. Industrial and radio-active waste from chemical plants and nuclear power stations includes the disposal of potentially dangerous substances such as PCBs, TBT, organochlorines, heavy metals, acidic wastes and radio-active caesium and plutonium 239. Such waste discharges are common along many estuaries and into coastal waters.

iv. Intensive farming of crops on land and fish in nearshore coastal waters has often led to increasing nitrate and phosphate contamination of rivers from fertilizers and relatively high levels of soluble nitrogenous waste products in coastal waters. These waste solutes often lead to nutrient enrichment of the water column which, in turn, acts as a fertilizer and thereby increases the growth of phytoplankton and can lead to algal blooms and eutrophication.

v. Poor flushing of harbours, marinas and coastal basins of natural scenic beauty often leads to undesirable water quality characteristics in the form of low dissolved oxygen levels, with the long term accumulation of toxic, industrial and domestic waste also often being apparent in such basins.

vi. Low retention times and short circuiting in reservoirs and disinfection contact tanks can have deleterious effects on water quality. In reservoirs this can lead to low dissolved oxygen levels, algal blooms and eutrophication, with additional treatment being required at the treatment works, whereas in disinfection tanks short circuiting often requires higher chlorine dosage levels to ensure an adequate bug kill (Falconer and Tebbutt, 1986).

The increased public awareness and concern relating to environmental issues such as those cited above can be attributed to a number of factors. Some of these factors are as follows:

i. In recent years there has been a growing awareness of the health risks associated with various forms of water pollution. For example, recent research in the USA has indicated a higher incidence of cancer of the bladder, colon and rectum in those drinking excess chlorinated water (Perera and Boffetta, 1988).

ii. There has been a significant increase in media coverage of hydro-environmental issues in most countries, with a consequential change in public opinion. For example, in the UK a proposed long sea outfall at Scarborough - a relatively small north eastern coastal resort, with a population of approximately 40,000 -

has had extensive publicity, including one page of coverage in two national UK newspapers and approximately 20 minutes television coverage.

iii. Increased recreation and higher standards of living in many countries have also raised public awareness of most forms of water pollution. Tourism and short break holidays at coastal resorts, waters sports and greater international travel have continually been on the increase and have heightened public concern.

iv. Hydro-environmental issues and concerns are now well up the political agenda in most countries. For example, in Europe concerns over the Greenhouse Effect, EC water quality standards, the emergence of the "Green Party" and the concerns of VIPs have influenced politicians of all political affiliations.

This increased public awareness of hydro-environmental issues and the type of water pollution examples cited above have led to a marked broadening of the role and responsibilities of the hydraulic engineer involved in feasibility and design studies relating to coastal and inland water quality studies. For example, the hydraulic engineer involved in a feasibility study to determine the ideal location of a long sea outfall is increasingly required to apply hydraulic models and interpret the results for complex hydrodynamic and meteorological conditions, and often including complex chemical and biological processes.

1.2 Modelling Restrictions

i. Throughout the past two decades there has been an increasing emphasis on using numerical models for flow and water quality studies, rather than physical models. This increasing emphasis on numerical rather than physical hydraulic models has occurred for a number of reasons, some of which are summarised below:

ii. Physical models have the overriding disadvantage of scaling. This constraint can be particularly critical for water quality studies where, for example, the prototype solute mixing may be strongly influenced by the turbulence level and the decay rate - both of which may be significantly in error in the physical model.

iii. Physical models are increasingly perceived to be more expensive than numerical models, particularly since they generally require large laboratory resources, sophisticated electronic equipment and increasingly specialist technical support staff.

iv. Physical models are not readily transportable, as compared to numerical models which can be distributed via floppy diskettes and high quality colour graphic presentations.

v. Physical models are not adaptable, in that a model of a particular estuary is unique to that estuary and cannot be used for any other estuary. In contrast, a well tested and robust numerical model can be used for a wide range of estuarine studies and conditions, provided that the model limitations are appreciated and realistic.

Hence for these and other reasons numerical models have become increasingly more attractive than physical hydraulic models for water quality and hydro-environmental studies. However, many hydraulic researchers specialising in numerical modelling are becoming increasingly concerned about the misuse and the unrealistic expectations of numerical hydraulic models by clients and some practicing engineers involved in water quality studies. For example, recent studies have been commissioned in the UK where contracts have been proposed and accepted to predict the tidal currents in large complex estuaries to within ± 10% of the field measured data for – between 70 and 100% of the measuring period. Such requirements are unrealistic in most practical cases, since - like physical models - numerical models also have a number of disadvantages. In any coastal or inland hydraulic basin, the true solution of the flow and solute transport rates depends upon how accurately the solution of the model equations, the boundary conditions and the equations themselves reflect the actual physical conditions in the hydraulic basin. In modelling numerically the flow and water quality conditions in coastal and inland waters, there are still a large number of uncertainties included in the models, with some examples being summarised below:

i. In terms of the fluid mechanics most models include a bed friction term derived for steady uniform flow and a wind stress term and a related friction coefficient which, at best, can only be regarded as a simple representation of a complex energy transfer mechanism. Furthermore, only limited information is available about the turbulence transfer of momentum in the vertical plane for coastal, estuarine and river flows.

ii. In terms of the physical processes relating to solute transport fluxes, the value of the coefficients of diffusion and dispersion are still not well known for practical studies (see Fischer et al. 1979) and processes such as the erosion and deposition of cohesive sediments are only now beginning to be understood for idealised laboratory conditions.

iii. The chemical and biological processes of complex water quality indicator equations, such as the nitrogen cycle, are still only understood in their simplest form, with the equations often varying significantly amongst the specialist water quality laboratories. Also, decay rates are generally only included in numerical models as temperature dependent constants, whereas laboratory tests confirm that these rates generally depend upon other parameters such as daylight intensity etc.

iv. The numerical methods included in the models often oversimplify the mathematical solution, such as the numerical treatment of the advective accelerations or the advective transport of a high solute gradient.

v. The boundary conditions included in model studies are often imprecise and limited. For example, bathymetric data are frequently obtained from Admiralty Charts which have not been updated recently and which can be significantly in error - particularly in some estuaries where deep channels can rapidly meander and migrate along the estuary.

With these and other considerations in mind, the hydraulic and/or specialist engineer has a responsibility to appreciate the limitations and restrictions of numerical hydraulic models and to advise clients or non-specialist engineers of their improper use and limitations, particularly in the hands of incompetent users.

2 NUMERICAL MODEL DETAILS

The type of numerical hydraulic models commonly used by hydraulic engineers to assist in environmental impact assessment studies generally involve solving the following equations:

i. For flow modelling:

- The continuity equation - including source inputs from outfalls etc.
- The momentum equations in l,2 or 3 co-ordinate directions - including the effects of the earth's rotation (for 2-D and 3-D flows), the wind stress, bed shear, turbulence and (where appropriate) barometric, density or salinity gradients. In these equations the wind stress is generally represented using a quadratic friction law and a constant friction coefficient at the air-water interface, with field data or a second order parabolic velocity profile being assumed to evaluate the momentum correction factor and modify the advective accelerations in 1-D and 2-D flow simulations (see Falconer and Chen, 1991). For the bed shear stress the Darcy friction factor can be used, together with the Colebrook-White equation, thereby enabling Reynolds number effects to be included where appropriate –such as tidal flood plain flows where low velocities and shallow depths frequently exist. Similarly, for the turbulent shear stresses either simple mixing length models can be used or more refined turbulence models of the κ-ε type.

ii. For water quality modelling:

- The solute transport or advective-diffusion equation - including source load inputs from outfalls etc., bed and/or surface inputs or outputs and kinetic transformation rates.

In terms of the water quality parameters included in such models, these generally include various indicators from the following lists:

i. Physical - including: suspended solids, turbidity, temperature,. radio-activity and colour.

ii. Chemical - including: dissolved oxygen, biochemical oxygen demand, nitrogen, phosphorous, chlorides and metals.

iii. Biological - including: pathogens and algae.

These equations are then generally solved using the finite difference or finite element techniques, with the models described herein generally involving the use of the finite difference technique with the following features: (i) a space staggered grid representation, (ii) an alternating direction implicit scheme, (iii) a hydrodynamic model centred in time and space, including third order upwinding for the advective accelerations with time centring via iteration, (iv) a refined flooding and drying scheme, and (iv) a higher order accurate modified QUICK representation (see Leonard, 1981) for the advection terms of the Advective-Diffusion equation. Further details of the general models described herein are given in Falconer (1986), Falconer and Chen (1991) and Falconer, George and Hall (1990).

3 NUMERICAL MODEL RESEARCH STUDIES

The Computational Hydraulics and Environmental Modelling Research Group at the University of Bradford (lead by the Author) is currently involved in a number of research projects relating to water quality modelling. These projects include: (i) circulation and flushing in harbours and marinas, (ii) 3-D flow and water quality modelling, (iii) 3-D sediment transport modelling, (iv) numerical treatment of high concentration gradients, (v) curvilinear co-ordinate and boundary fitting modelling schemes, (vi) higher order accurate 2-D flow modelling, (vii) turbulence measurement and modelling, and (viii) flow and disinfection process modelling in contact tanks. These research projects are sponsored by several funding agencies including: industry, UK water companies, research councils, the European Commission, government departments and the British Council.

Two typical examples of current research projects are summarised herein:

i. Nested and patched modelling.

A recent research programme has been undertaken to develop, refine and apply two different types of combined coarse and fine grid numerical models (see Falconer and Alstead, 1990), with such numerical models being increasingly used to obtain higher resolution of flow and water quality parameter distributions in regions of particular interest. For example, a fine grid model may be used to obtain a detailed prediction of the velocity and solute distributions within a harbour, whereas a coarse grid model can be used outside the harbour where a lower level of accuracy may be tolerable. Furthermore, nested models are increasingly being used for numerical hydraulic model studies where open boundary data are sparse, or non-existent, and with the coarse grid model being used to provide open boundary conditions in regions of interest. The two main models considered in the current study involved a nested (or non-dynamically linked) and a patched (or dynamically linked) model, with there being advantages and disadvantages of both schemes. In particular, emphasis was also focused on fully including the advective accelerations at the interface between the fine and coarse grid boundaries in the patched model, thereby allowing eddies and fine grid flow features to be advected out of the fine grid domain as accurately as possible. The numerical models were applied to an idealised rectangular harbour laboratory model configuration as shown in Fig. 1. The model harbour was located towards the rear end of a tidal basin, with an oscillating overflow weir being driven by computer and generating tides of varying or constant amplitude and period. The model harbour considered for this study was a distorted scale laboratory model of an idealised prototype square harbour, of length 432 m x 432 m, with a resultant plan surface area of 18.7 ha. The horizontal and vertical scale ratios were 1 : 400 and 1: 40 respectively, with a mean model depth of

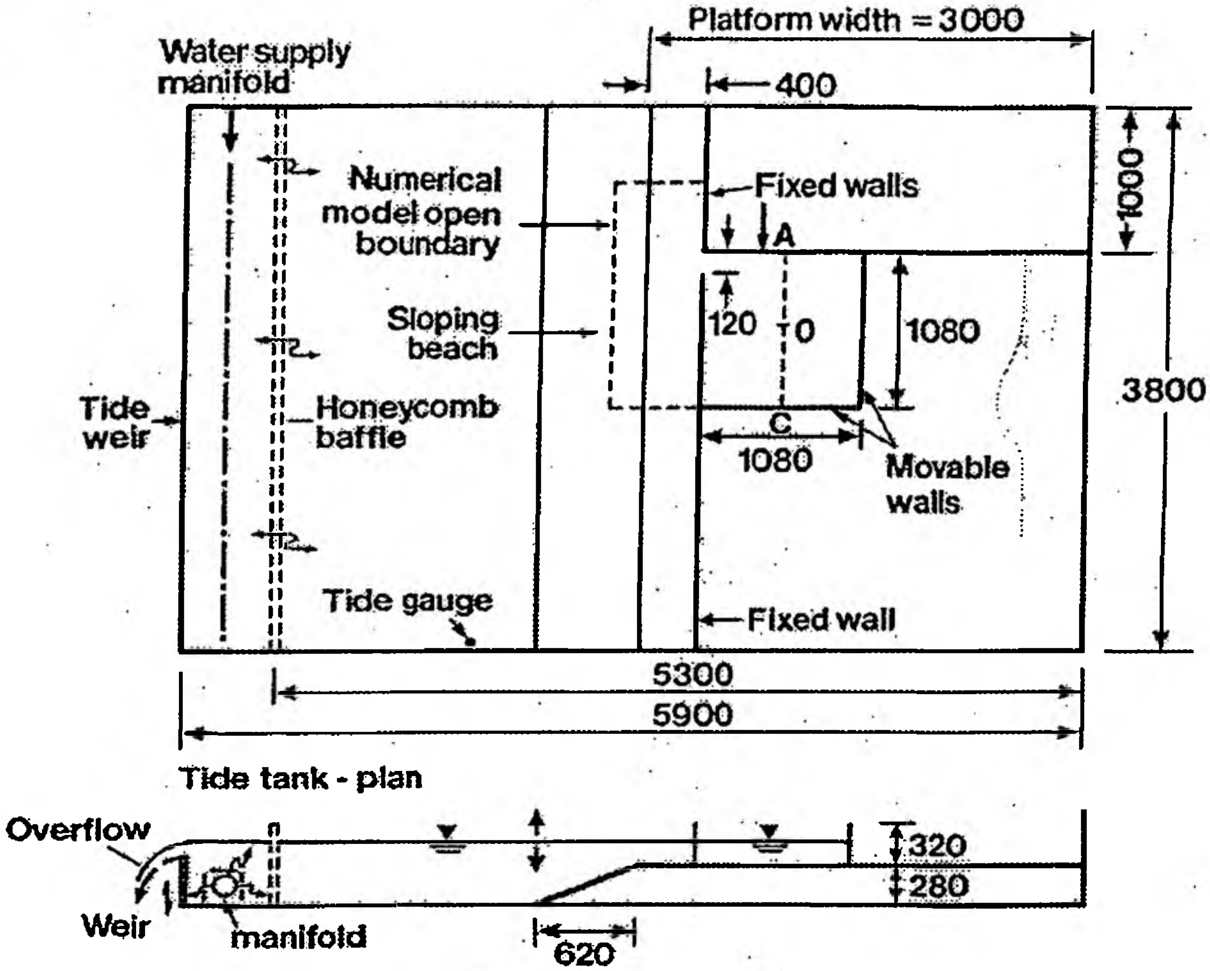
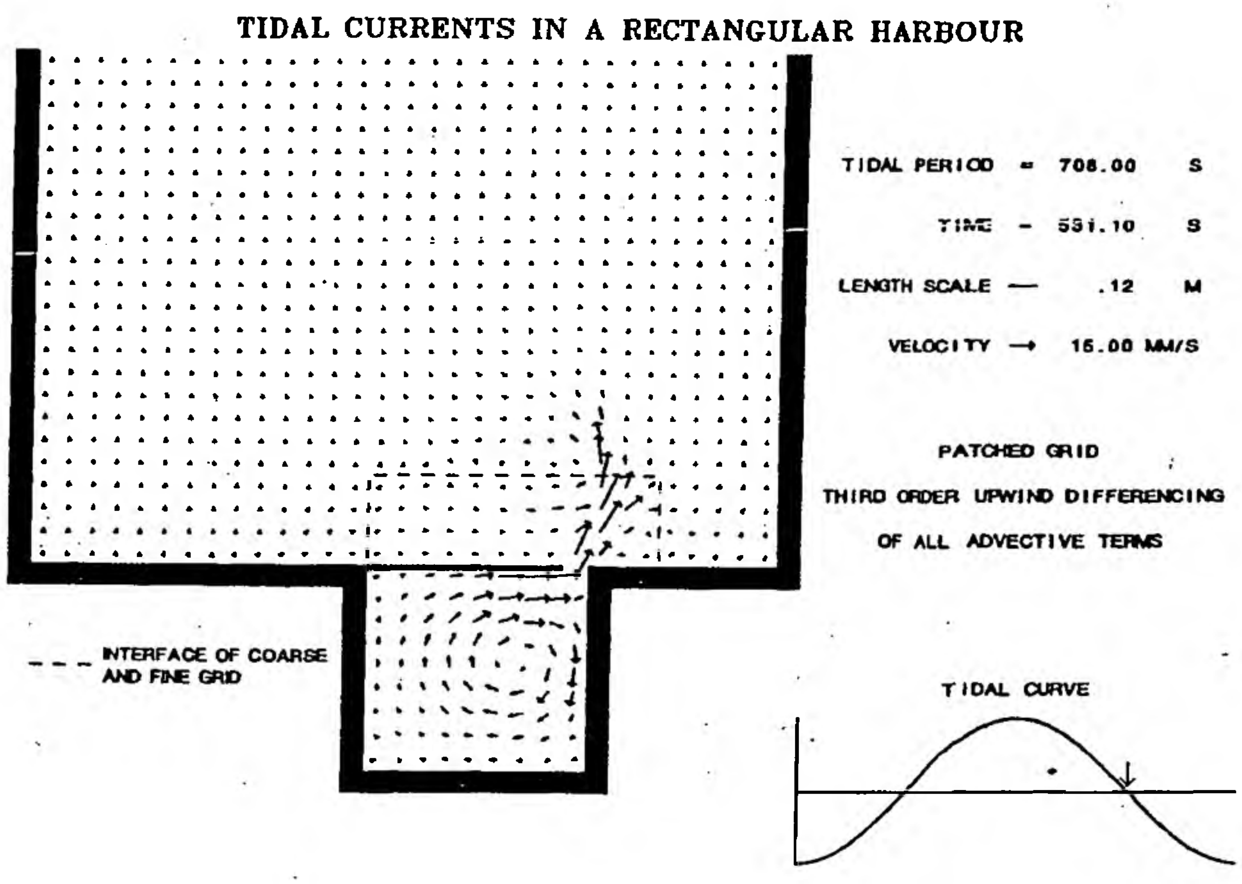


Fig. 1. – Illustration of the tidal basin showing the numerical model open boundaries.

150 mm, a tidal range of 100 mm and a tidal period of 708 s. In the numerical model simulations the tidal basin and the model harbour were reproduced using a coarse grid size of 120 mm. A repetitive sinusoidal tide was specified at the open boundary, coinciding with the honeycomb baffle in the tidal basin (see Fig. 1). The fine grid open boundary was sited 400 mm beyond the harbour entrance, with the corresponding grid size being 40 mm, i.e. one third of the coarse grid size. In the laboratory model tests the depth mean velocities were measured by tracking weighted drinking straws at 10 s intervals, for one minute either side of mean water level, and with dye tracer measurements and observations being recorded to determine the jet efflux characteristics for the ebb tide.

For the nested model investigations it was found that in the coarse grid domain spurious negative velocities were predicted along the harbour entrance streamline as shown in Fig. 2. This anomaly was first thought to be due to the inadequate resolution of the high velocity gradients in the region of the harbour entrance. However, although the use of higher order accurate difference schemes for the treatment of the advective accelerations was found to reduce the spurious velocities, the negative velocities still persisted throughout much of the flood tide. Furthermore, the nested model also predicted an ebb tide jet orientation on leaving the harbour which was normal to the harbour entrance as shown in Fig. 3.

In the patched model investigations, the numerically predicted velocity fields were much more consistent with laboratory measurements and observations. No spurious negative velocities were predicted in the coarse grid region during the flood tide and the ebb tide jet orientation agreed closely with the laboratory model observations. Furthermore, for the patched model, the ebb tide jet was predicted to generate free shear eddies just outside the harbour entrance and these eddies were then advected from the fine grid to the coarse grid and into the tidal tank forebay as shown in Fig. 4. Again these predicted



<u>*Fig. 2. – Predicted coarse grid nested model velocity field for the flood tide showing the spurious velocities beyond the model harbour entrance.*</u>

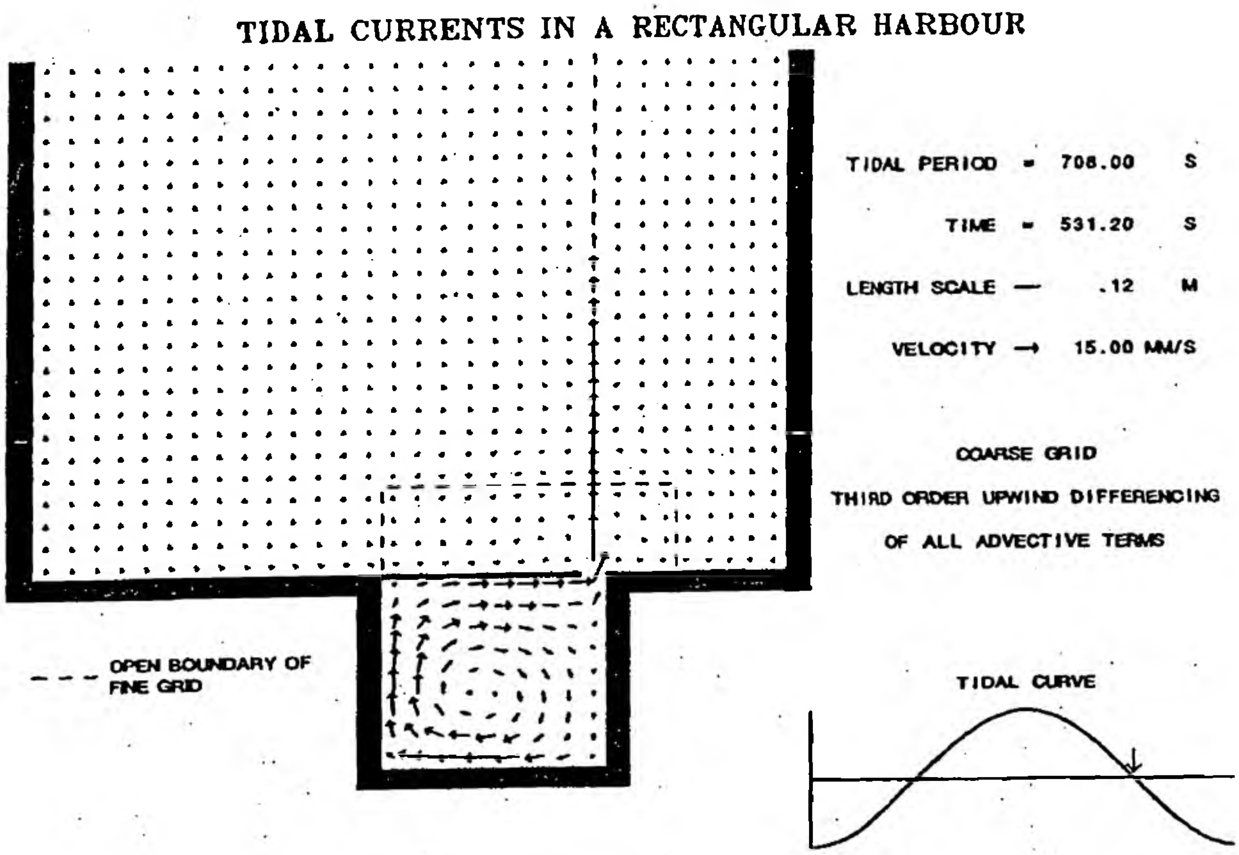


Fig. 3. – Predicted coarse grid nested model velocity field for the ebb tide showing the incorrect orientation.

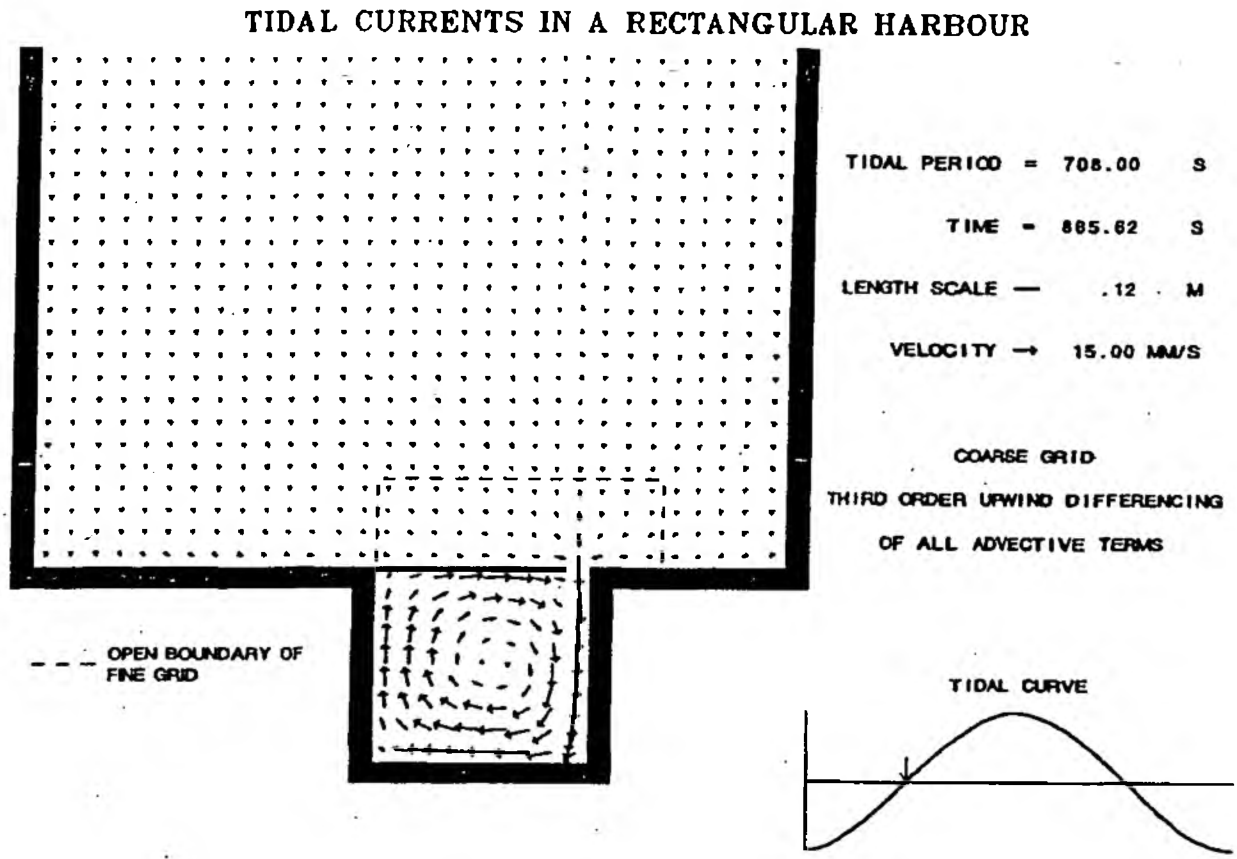


Fig. 4. Predicted coarse grid patched model velocity field for the ebb tide showing the correct orientation.

eddies were in close agreement with the laboratory model results, although they were not predicted in the nested model simulations.

Comparisons were also made of the predicted and measured velocity distributions across the central axes for a first order and third order upwind difference representation of the advective acceleration terms in the momentum equations. As can be seen from the results shown in Fig. 5, the third order upwind differencing of the advective accelerations gave closer agreement with the experimental results obtained by Nece (1990) than the original scheme, although there were some noticeable disparities between the results for velocities less than about 5 mm s-l. However, the velocities were measured by tracking fishing floats and it was difficult to track these floats at low velocities. In particular, for the flood tide velocity profile along the AOC axis shown in Fig. 1, it can be seen that the third order upwind difference scheme has predicted the measured peak jet velocity closely, whereas the first order difference scheme significantly underpredicts this velocity. Other discrepancies between the measured and predicted velocities were predominantly thought to be due to the three-dimensional nature of the velocity field – particularly associated with secondary currents - and the simplicity of the velocity measuring technique.

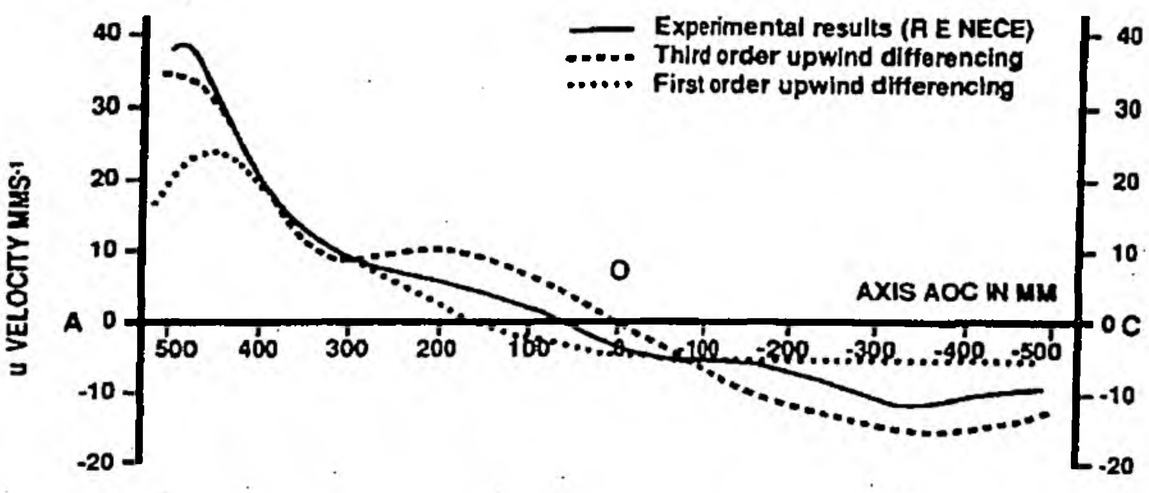


Fig. 5. – Comparison of predicted and measured velocity distributions across the model.

ii. Treatment of high concentration gradients.

In numerical model simulations relating to the transport of conservative or non-conservative water quality indicators, such as coliform or nutrient levels, the advective-diffusion equation is often applied to, and solved for, solute distribution fields where high concentration gradients exist. In modelling numerically this common phenomenon, occurring for example in the close proximity of long sea outfalls, the numerical representation of the advection terms of the advective-diffusion equation is critical in terms of the degree of numerical diffusion introduced into the scheme and the occurrence of grid scale oscillations, or undershoot and overshoot, arising in the vicinity of large concentration gradients. However, although highly accurate and complex difference schemes can be used to represent the advection terms, these schemes are not always computationally efficient and the numerical modeller often has to strike a balance between the level of numerical accuracy and complexity vis-a-vis computational efficiency. This balance is increasingly relevant as numerical models are being run by a growing hydraulic modelling community on workstations and personal computers.

In studying the numerical treatment of the advection terms for modelling high concentration gradients, thirty six different schemes have been coded up and compared for a series of idealised, but severe, test cases. The schemes considered and compared range from the highly diffusive first order upwind scheme to: (i) second order accurate schemes, (ii) TVD and TVB type schemes, (iii) Godunov type schemes, (iv) third order accurate schemes, including QUICK, QUICKEST and ULTIMATE QUICKEST, (v) fourth order accurate schemes, including superbee, MUSC and ULTIMATE fourth order, and (vi) sixth order accurate schemes, including .the six point characteristic method, ULTIMATE sixth order and sixth order accuracy with TVD filters. The test cases considered for the scheme comparisons include for

1-D advection: (i) a plug type profile, (ii) a- semi-elliptic type profile, (iii) a narrow Gaussian distribution, and (iv) a shock front, with comparisons for the case of 2-D advection being focused on the classic test case of pure rotational advection around a square plane of a column source and a Gaussian distribution. Some typical results from these tests and comparisons - which are still being continued – show that schemes such as QUICKEST and sixth order accurate schemes with a modified TVD filter exhibit no overshoot or undershoot, or negative values, for one-dimensional advection and produce accurate predictions for the three severe test cases as shown in Figs. 6 and 7 respectively. In comparing Figs. 6 and 8 it can be seen that the modified TVD filter (Fig. 6) considerably improved the predictions, particularly for the "top hat" or plug profile. Likewise, as can be seen by comparing Figs. 6 and 7 with the modified TVD filter, the sixth order accurate scheme shows an improvement over the third order accurate QUICKEST scheme, with there being less diffusion for the plug profile and a closer prediction of the peak concentration for the narrow Gaussian distribution. For the two-dimensional test cases many of the higher order accurate schemes which performed well for the one-dimensional tests were computationally inefficient and complex to code up, particularly when applied to practical model studies where additional complexities were introduced, such as flooding and drying and irregular and open boundary conditions.

For the initial conditions shown in Fig. 9, it can be seen that using a second order central difference representation for the advection terms gives a significantly erroneous concentration distribution after rotation of the column source around half the plane.

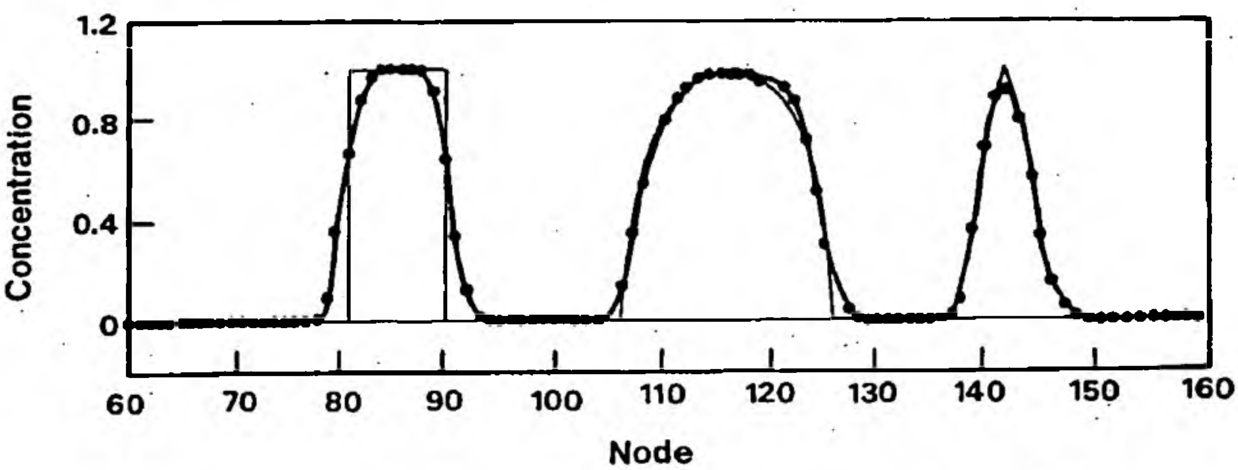


Fig. 6. – Predicted concentration distributions for test cases using sixth-order accurate scheme with a TVD filter.

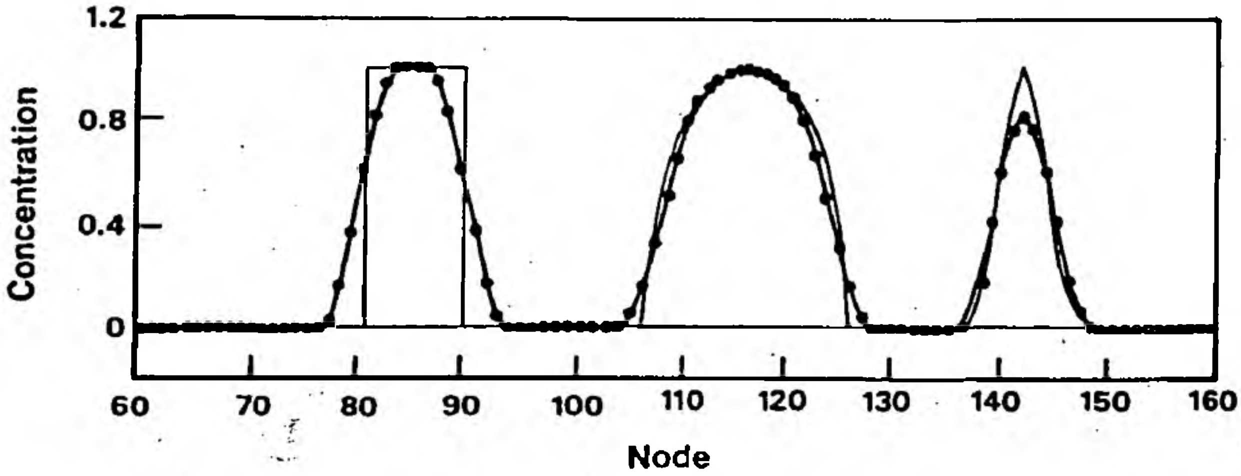


Fig. 7. – Predicted concentration distributions for test cases using QUICKEST scheme with a TVD filter.

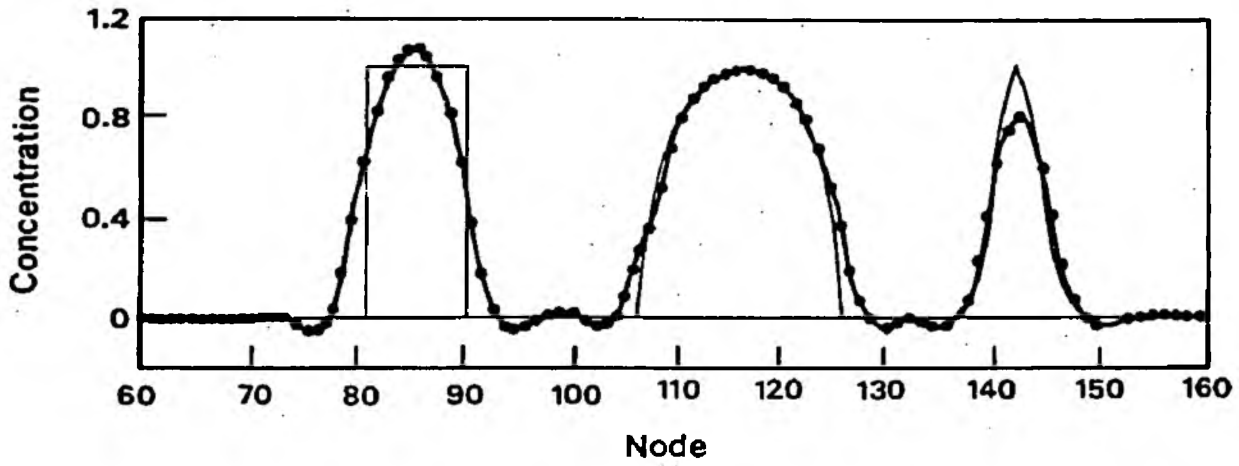


Fig. 8. – Predicted concentration distributions for test cases using QUICKEST scheme with no filter.

Although the spurious waves across the plane can be removed by adding artificial diffusion, this additional diffusion also affects the predicted column source and reduces the peak concentration considerably. Figs. 11 and 12 respectively show the predicted column source distributions after half a rotation for the QUICKEST scheme, extended directly from the 1-D version given by Leonard (1988) and the full 2-D version obtained by including all of the cross product terms of the Taylor series (see Chen and Falconer, 1992). This comparison shows the importance of considering fully all of the terms of the Taylor series when extending any finite difference scheme from one to two dimensions.

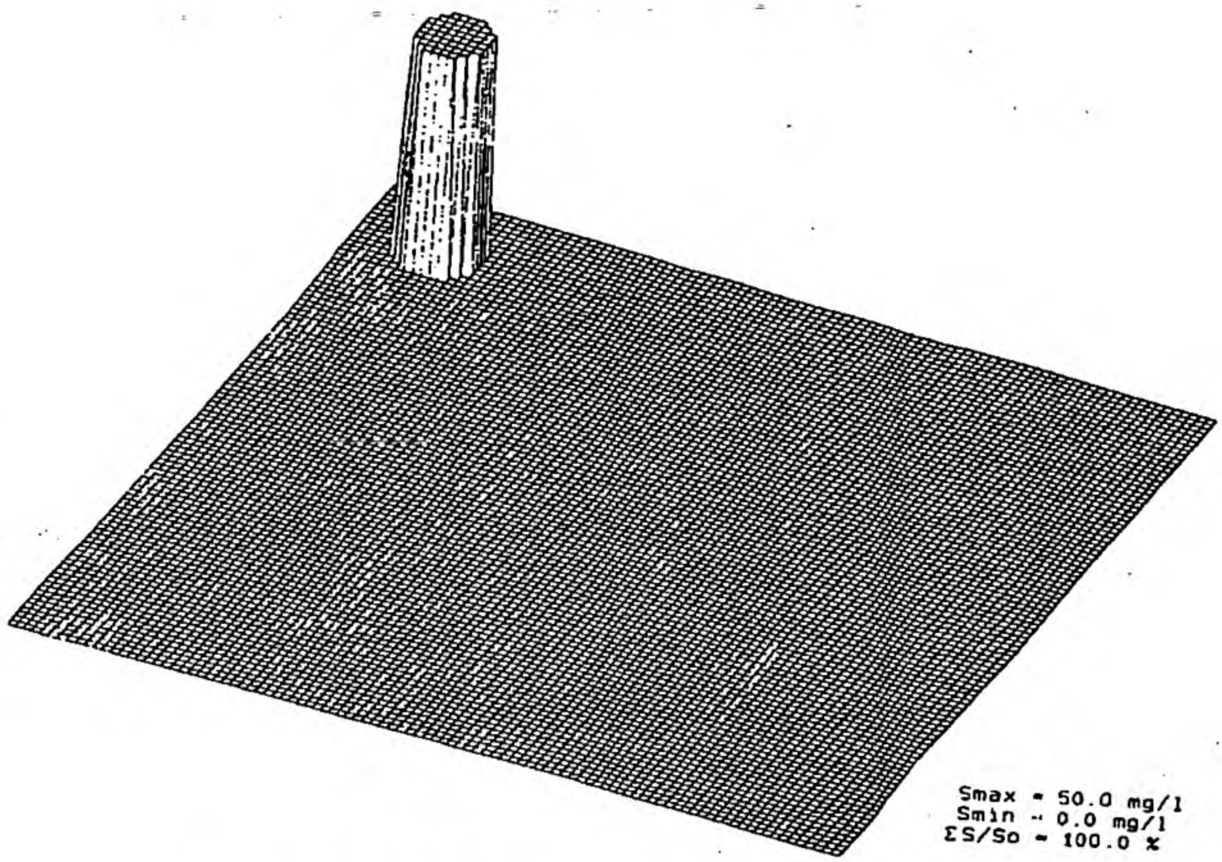


Fig. 9. – Initial solute distribution for 2-D test case.

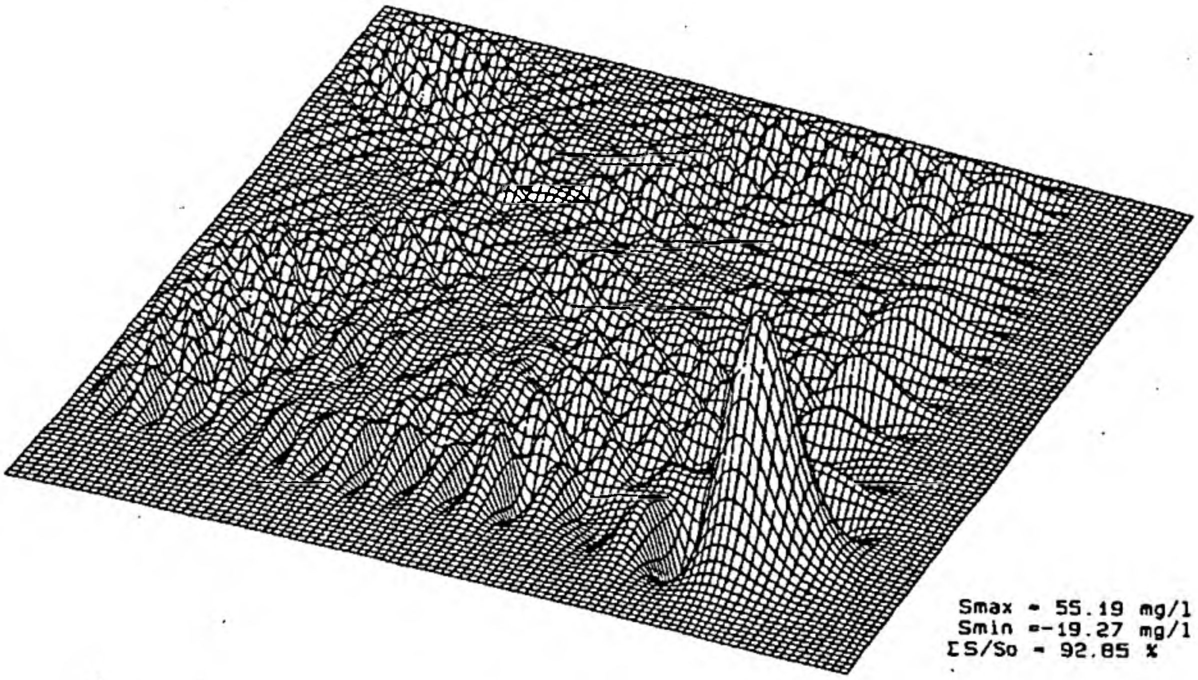


Fig. 10. – Solution distribution for second order central difference scheme.

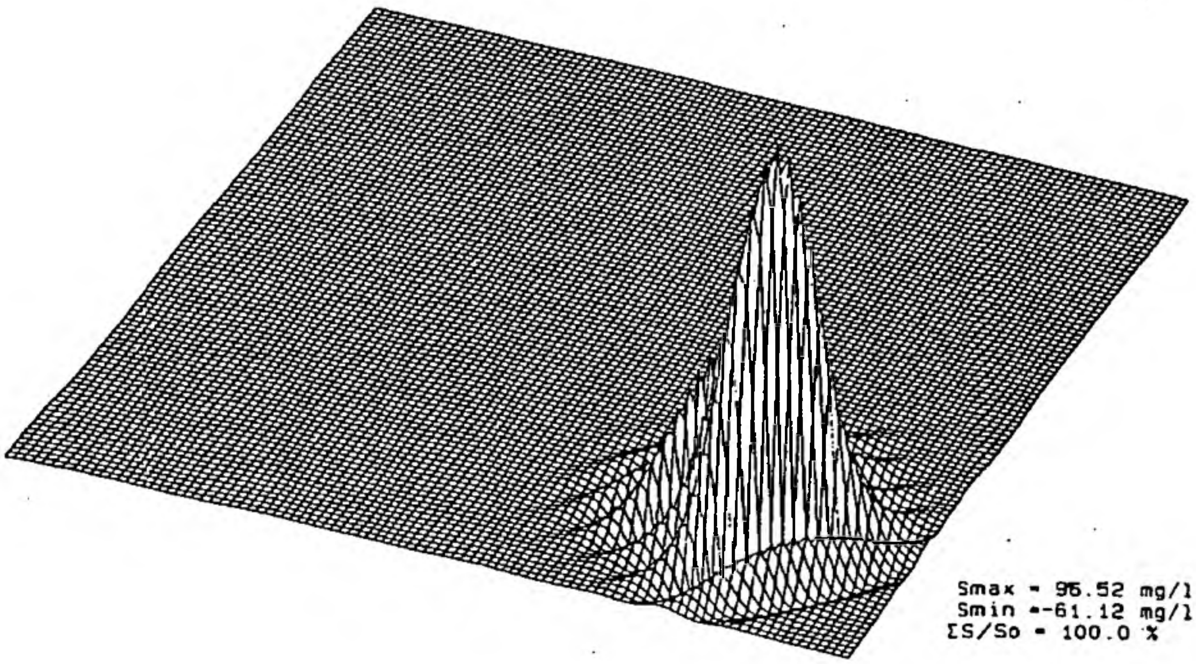


Fig. 11. – Unstable solute distribution for 2-D QUICKEST scheme extended directly from 1-D version.

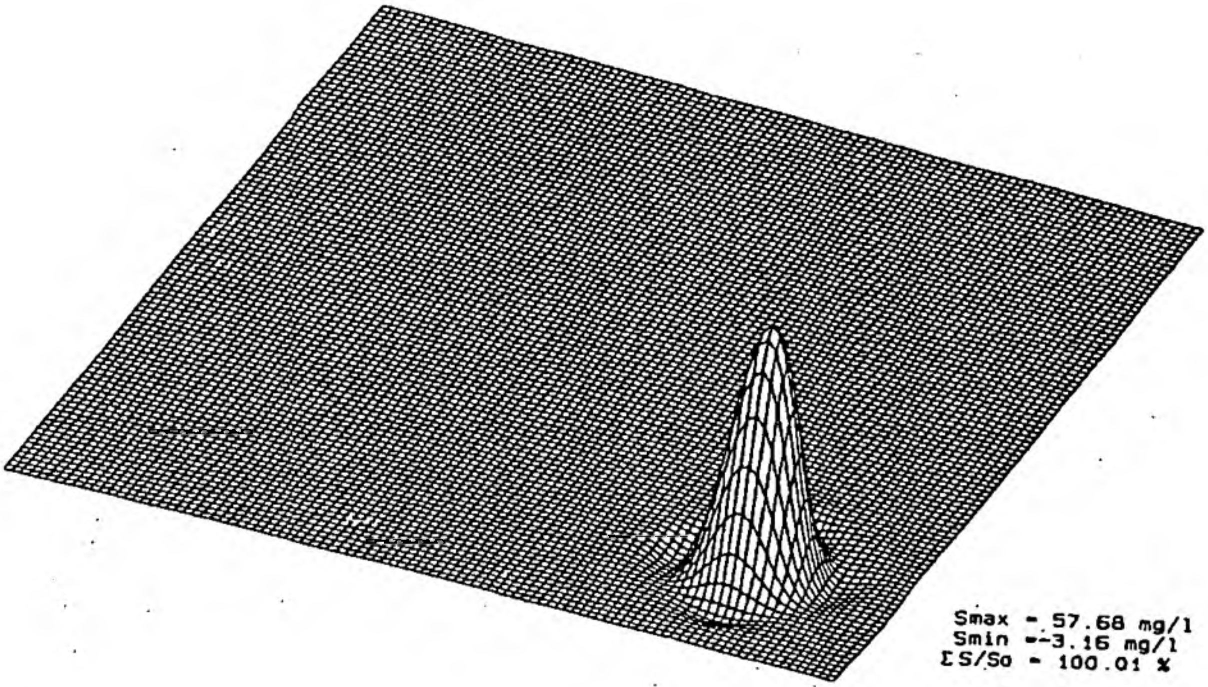


Fig. 12. – Stable solute distribution for full 2-D version of QUICKEST scheme.

Finally, the solute distribution is shown in Fig. 13 for the SMART scheme, which appears to be highly accurate and relatively efficient for modelling the advection process. These schemes are now being tested against extensive field data provided by Yorkshire Water plc and the National Rivers Authority (Wessex Region), for faecal coliform levels from Bridlington long sea outfall along the north east coast of England and nitrate and phosphate levels in Poole Harbour along the south coast of England.

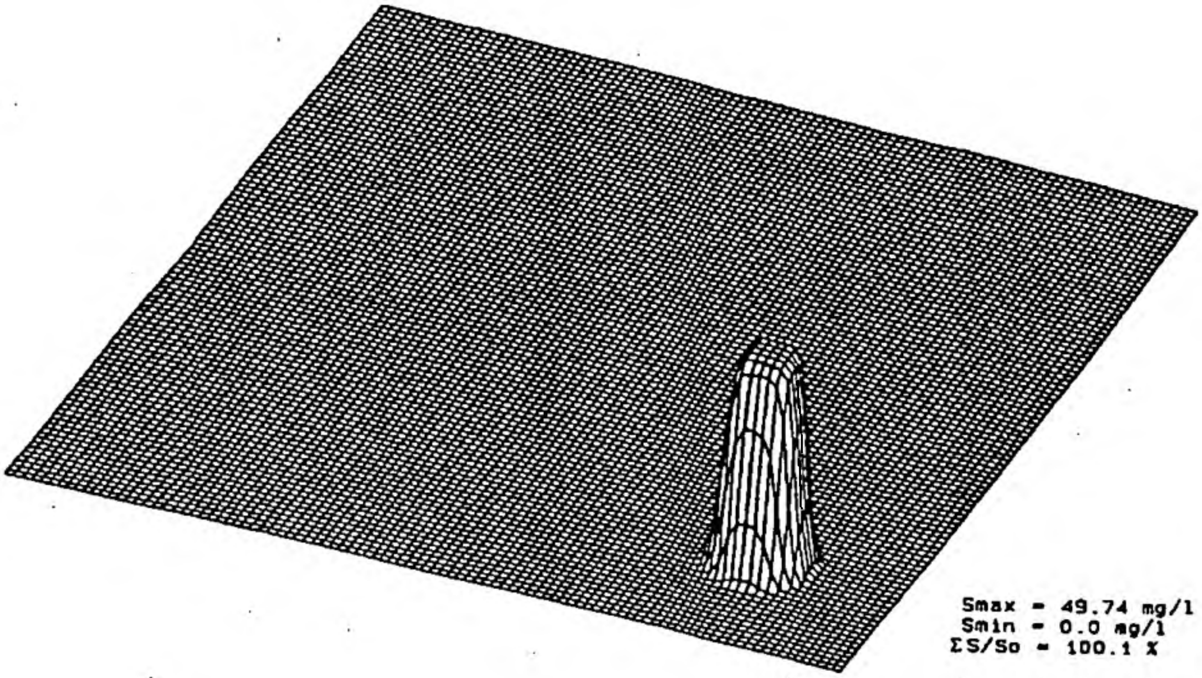


Fig. 13. – Solute distributions for the 2-D SMART scheme.

4 Conclusions

In recent years there has been a significant increase in public awareness of a wide range of environmental issues, particularly with regard to the quality of coastal and inland waters. This increase in public awareness has led to an increasing involvement of hydraulic engineers in environmental impact assessment studies and a corresponding increase in the use of numerical hydraulic models, both by specialist and non-specialist engineers. Such numerical models have several advantages over physical models for water quality studies, but it is also important to appreciate that numerical models also have limitations in terms of the representation of: the fluid mechanics, the physical processes, the chemical and biological processes, the numerical methods and the boundary conditions. Numerical models can provide valuable and extensive information for engineers and planners involved in water quality studies in coastal and inland waters, but they can also provide misleading and erroneous data in the hands of inexperienced engineers, scientists or planners with little or no knowledge of fluid mechanics or hydraulics and numerical modelling techniques.

Two current research studies being supervised by the author have been outlined in the paper, with the first of these studies being a comparison of nested and patched modelling techniques. The results showed that for certain types of flow fields non-dynamically linked (or nested) modelling techniques can give inaccurate and sometimes spurious velocity field predictions. However, before modelling water quality indicators in any study it is essential that accurate flow field predictions are produced and non-dynamically linked models therefore have to be used with caution.

In the second study reported herein, a summary was given of an extensive comparison of 36 schemes for modelling high solute concentration gradients. Although the accuracy of the schemes improved with the order of accuracy and with the inclusion of filters, modified versions of schemes such as QUICKEST and SMART were found to be computationally efficient and easier to apply to practical problems where difficulties often arise with irregular boundaries and flooding and drying etc.

Finally, the numerical model referred to in the paper is based on the solution of Newton's second law of motion (developed in 1687), using the Taylor-Maclaurin infinite series (developed in 1715) and including the Darcy friction factor (developed in 1889) and Prandtl's turbulence theory (developed in 1925). Many of these equations and experimental observations - together with others not included in this example list - had little relevance at the time, and certainly no obvious relevance to water quality modelling. However, numerical models similar to the model referred to in the paper are now used worldwide by practicing consulting hydraulic engineers for water quality studies varying from the hydro-ecological design of small marinas to comprehensive hydro-ecological and environmental studies of large seas. As more and more research funders, both nationally and internationally, place increasing emphasis on the application of the research before funding can be provided, it is of fundamental importance that within the hydraulics research fraternity and funding organisations the potential value of basic original research should never be forgotten.

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9 R&D DISCUSSION

The discussion focused on what participants felt should be incorporated into R&D planning for the 2001/2002 financial year, however many issues will need to be addressed in the 2000/2001 financial year as well.

9.1 Strategic level

- Need to be efficient and make the best use of legislative opportunities
- Feed into CIS/IT Business Needs strategy
- WQ have already identified the future areas of work – use this as a guide to identify modelling requirements, and make sure it is embedded within the R&D strategy

9.2 Modelling Strategy Project

- Many felt that there was a wide variation in ability / experience in modelling in different parts of the Agency / National Centres / Regions. This partly reflected historic differences in the Water Authorities. Modellers are skilled and there was concern that some Regions did not recognise modelling and were consequently losing modelling skills. The strategy should include the requirement for modelling skills (i.e. modellers) to be in place in all regions.
- A Code of Practice for modellers was partially developed and it should be completed.
- The Agency be proactive in terms of environmental modelling

9.2.1 Communication Issues

- The idea of a "Virtual National Centre" was supported. This would be an internal grouping which could include:

    1. Discussion group, identifying successes and failures
    2. Key modelling staff within the Agency identified with their specialisms recognised (eg UPM modelling, coastal modelling) and time allowed for them to assist other Regions with difficult modelling scenarios. This would need to be formally agreed and arranged between Regions.
    3. Information on where to get informal modelling advice both within and outside the Agency.
    4. Models should be consistently reviewed and updated models made available as required – the model database being developed could be an important tool in this. It should be informative rather than prescriptive

Linkages between different modelling communities should be made.

For example:-

- Link the groundwater modelling with surface water modelling (e.g. strategies, implications, and contaminant transport). There has been work consulting the regions to identify problems etc. There should be a united approach to solving difficulties.
- Link the Flood Defence Hydrodynamic model acquisition to water quality requirements

9.2.2 Staff Requirements

- Identify the training needs of those involved
- Identify the staffing requirements for modelling in each region
- Identify the software requirements for modelling and ensure adequate IS support – a key area of difficulty for many modelling staff.

9.3 Suggested Further Development Work

- GIS integration, catchment scale models
- Develop automated data formatting tool for the main models used by the Agency
- Bridging the gap between chemical standards and ecological response
- How to address model uncertainty and design risk
- Marine modelling, particularly in view of the large numbers of audits of marine models which the Agency must carry out.
- Develop a route for the funding of model development which is not radical enough to be considered research.

10 ATTENDANCE LIST

Danielle Ashton	-	EA – (NCEHS)
Norman Babbedge	-	EA – South West Region
Simon Bingham	-	EA-Midlands Region
David Boorman	-	CEH, Wallingford
Brian Cox	-	AERC, Reading University
John Davys	-	EA – NGCLC
Paul Dempsey	-	WRc
Emma Devonshire	-	EA Southern Region
Rachel Dils	-	EA - NCEHS
Chris Extence	-	EA – Anglian Region
Prof. Roger Falconer	-	Cardiff University
Rachel Fleming	-	EA – Head Office (R&D)
Andy Fraser	-	Soil Survey and Land Research Centre
Dr Ian Guymer	-	University of Sheffield
Mark Hallard	-	SEPA
John Harris	-	Plymouth Marine Laboratory
Andrew Hartland	-	EA – North West Region
Sally Heslop	-	University of Bristol
Ashley Holt	-	EA – Head Office
Rachel Hudson	-	EA – Anglian Region
Jimi Irwin	-	EA – NCRAOA
Julia Jarvis	-	EA – North East Region
Elfled Jones	-	H.R Wallingford
John Kupicc	-	EA – NCEHS
Gary Lane	-	EA Southern Region
Graham Leeks	-	EA – Wallingford
Matthew Lees	-	Imperial College
Brenda Mace	-	EA Anglian Region
Jackie Maskell	-	Hydraulics Research Institute – Wallingford
Ruth Medlar	-	EA – Anglian Region
Bob Moore	-	University of Wales
Dr Neil Murdoch	-	EA – South West Region
Jacqui Murphy		EA – Anglian Region
Andrjez Nowosielski	-	EA – Thames Region
Geoff Phillips	-	EA - NCRAOA
Linda Pope	-	EA – NCRAOA
Toby Sherwin	-	University of Wales Bangor
John Siddorn	-	Plymouth Marine Laboratory
Peter Singleton	-	SEPA
Russell Smith	-	Imperial College, London
Sheila Sowerby	-	EA – North West Region
Juliane Struve	-	EA – Thames Region
Dr Alan Tappin	-	CCMS Plymouth Marine Laboratory
Andrew Wade	-	AERC, Reading University

Tony Warn	-	EA – Head Office
Mike Weston	-	EA – North West Region
Robert Willows		EA - NCRAOA
Emma Wrige	-	EA – NCEHS

Glossary

EA Environment Agency

Environment Agency National Centres

NCRAOA	National Centre for Risk Analysis and Options Appraisal
NCEHS	National Centre for Ectoxicology and Hazardous Substances
NGCLC	National Groundwater and Contaminated Land Centre
SEPA	Scottish Environment Protection Agency
CEH	Centre for Ecology and Hydrology