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Water Quality Survey of London Docks (June 89)

CHAPTER 1

EXECUTIVE SUMMARY

1.1 Background

Many of the projects undertaken and planned within the area of the LDDC make a feature of the water environment. It is therefore important to ensure that the quality of the water is appropriate for the envisaged use and to ensure that the quality can be maintained.

These objectives form the subject of this study which includes the development of a long-term treatment and management strategy. This is the first dock-wide study to be undertaken, which will investigate the mechanisms that affect the changes in water quality. A mathematical model is to be developed to assist with the management of the docks, and also to predict changes in water quality which may result from developers proposals.

This Stage 1 report describes the result from the one complete initial round of water sampling and analysis. The results have been used to formulate proposals for the second stage of the study.

The report summarises European Community and UK legislation of relevance to the London Docks and discusses national and international initiatives which might have an influence on the quality to be achieved in the docks. For the identified uses the appropriate environmental standards are listed in separate tables.

1.2 Preliminary Survey

A survey of the docks has been undertaken to understand the hydraulic regime of each dock, also to decide sampling sites and procedures, by means of which the quantity and quality of water entering and leaving each dock system can be determined.

To sample water from within all docks, 28 sampling sites have been established at which samples from three depths can be taken. The first monthly sampling round took place in May and samples have been analysed to determine their physical, chemical, microbiological and algological characteristics. Additional weekly monitoring of algae has also been undertaken.

1.3 Observation

In most of the docks the most important inflows are from the river Thames. The exceptions are Canada Water and the Hermitage Basin/Tobacco Dock system, where the inputs are from groundwater and the potable water supply, respectively. The hydraulic residence time in all the docks is long, in some cases being greater than one year.

At the time of the preliminary survey there were measurable salinity and temperature gradients over the depth in all the docks. However, only in Millwall Docks was this gradient so severe that the water column could be considered stratified. This stratification in the Millwall Docks is probably caused by a sill in the communication channel to the West India Docks.

Salinity of the docks water increases with distance downstream from London Bridge, and is seasonally dependent. Surface temperatures and degree of stratification are greater for the smaller docks than with greater surface areas.

Generally, nitrogen and phosphorus concentrations are much higher than concentrations at which they would become limiting to algal growth. In most docks the N : P ratio is low, with phosphorus concentrations exceeding those for nitrogen. In the Isle of Dogs system the reverse is true with much higher concentrations of nitrogen than phosphorus.

At some sites where the N : P is low, the nitrogen concentration is tending to values at which it may become limiting.

In contrast, Canada Water has very low nutrient concentrations and those in Surrey Water are intermediate in value.

The differences in nutrient concentrations are to some extent reflected in the algology of the system. Canada Water is again exceptional in having very low algal populations, and thus very clear water. Large algal populations were observed in all the other docks, but distinct differences in specification were observed. In the Royal Docks the dominant species is Oscillatoria, a blue-green algae which forms filaments, and is capable of moving within the water column by controlling its buoyancy.

In contrast, the dominant species in the West India Docks is Melosira sp, a diatom common in freshwater lakes when the water is turbulent and well-mixed. In the Millwall Docks speciation is again different, and although Melosira sp is present the dominant species is Scenedesmus, a green algae. This difference is speciation within the same dock system may be due to differences in water column stability and turbidity.

Generally, algal growth appears to be light limited, and the degree of light penetration is related to the concentration of algal cells. Growth is therefore controlled by self-shading. The algal are the principal cause of turbidity in the water column, which can exceed the limits defined by the EC Directive on Bathing Water. Their presence also causes discolouration of the water.

On the basis of routine monitoring data provided by LDDC, the bacterial quality of all the docks, except possibly South Dock, was found to comply with EC Directive on Bathing Water requirements during the April to October period. During the winter higher bacterial concentrations occur and only 6 of the 18 docks are acceptable.

1.4 Emergency Treatment System

Viable short-term treatments which warrant more detailed investigations in Stage 2 in case an algal bloom occurs are, amongst others, induced circulation by air diffusion through perforated pipes; application of $CuSO_4$ or other algicide; partial drainage; mechanical aerators; and skimming techniques.

1.5 Mathematical Model

As a result of the preliminary survey and sensitivity tests carried out on possible process descriptions, the key processes and unknowns have been identified. The selected model structure will allow for the physical processes inducing water transfer within the docks as well as the inflows and outflows. These transfers will then be included amongst the processes controlling the chemical and biological interactions.

Principal outputs from the model will be bacterial, dissolved oxygen, and ammonia concentrations. The first four parameters relate directly to EC Bathing Water Directives and the fifth will provide some indication of likely algal problems. The model will be used to evaluate various management strategies, and could be used to predict problem conditions.

1.6 Quality Assurance

Specialists from the Water Research Centre undertook inspections of the main laboratories involved in the survey. In general, analytical techniques were found to be satisfactory. More rigorous audit and quality assurance programmes are being implemented for Phase 2 surveys.

1.7 Proposals for Stage 2

The results of the Stage 1 survey and review of pre-existing data have allowed us to prepare a reduced sampling programme for Stage 2. This reduced programme emphasises the value of a flexible sampling procedure which permits the concentration of sampling and analytical resources in important areas, thus providing better data at often reduced cost. It is proposed to carry out the minimum sampling programme to monitor compliance of this EC Bathing Water Directive in all docks:

- survey all docks and inputs to assess the degree of contamination by toxic substances;
- monitor inputs to all the dock systems;
- study three dock systems in detail (the Royal Docks, Isle of Dogs, and Canada Water/Surrey Water);
- develop a prediction model for all the dock systems, based on the detailed studies in these three systems;
- assess various management techniques for controlling floating debris and surface film, and for maintaining the quality of water satisfactory for bathing and contact sports between April and October.

The proposals for Stage 2 represent a considerable departure from the envisaged in the original Brief. There is now a need for greater effort to be directed towards the assessment of data, and also the ability to consider at short notice aspects that are not provided for in the Brief. It is suggested that this can most readily be achieved by increasing the proportion of time charge work to include all aspects of the study, but subject to an agreed maximum ceiling cost.

CHAPTER 2

INTRODUCTION

Many of the redevelopment projects undertaken and planned within the area of the London Docklands Development Corporation (LDDC) shown on Figure 2.1 make a feature of the water environment that is associated with the docks. It is, therefore, important to ensure not only that the quality of the water is appropriate for the envisaged use but that the quality can be maintained. This requirement has been emphasised by the appearance of extensive algal blooms in several of the dock systems, which have resulted in planned water contact activities being cancelled.

Previously, water quality studies have been undertaken that were either specific to the needs of a particular developer, such as Olympia and York at Canary Wharf, or to consider a particular dock system, as for Hermitage Basin. The only study involving all of the LDDC docks systems has related to quarterly sampling of the dock waters, primarily to assess whether the waters were in compliance with the EEC Bathing Water Directive.

The Corporation recognises the importance of dock water quality in achieving its overall objectives and wishes to undertake an investigation for all of its dock systems. The principal objectives are to provide a water which is:

- of a quality acceptable for use in water contact recreational activities;
- aesthetically pleasing at all times;
- free from noticeable odour, visible algal scum and contamination.

The investigation to achieve these objectives consists of five main elements as listed below:

- Identification of relevant legislation and standards and an assessment of the water quality targets which should be achieved, bearing in mind the end use of each particular dock system.
- Identification and assessment of inputs to and outputs from each dock system.
- Assessment, evaluation and monitoring of water quality and water movement within each dock system, both currently and on a regular basis into the future.
- Identification and evaluation of emergency treatment options for each dock system with recommendations for early warning monitoring and implementation.

- Development of a long-term treatment and management strategy.

In addition, a mathematical model is to be designed to aid in the management of water quality and the prediction of water quality changes resulting from developer's proposals.

To allow for the use of the docks as a heat sink/source for heat pumps to serve buildings alongside the docks, the possible effects of a variation in temperature in the dock waters are to be considered.

This will be the first dockwide study of water quality which will investigate the mechanisms affecting the changes taking place in the water, an understanding of which is necessary for the effective management and control of water quality.

On the 12 April 1989, Mott MacDonald was appointed to undertake the investigation on behalf of the LDDC. The study is to be conducted in two stages. This report refers to the findings of Stage 1 and provides recommendations for Stage 2 of the study.

For Stage 1, existing water quality legislation has been studied, also an identification and assessment made of existing input and output flows to the dock systems. Initial water sampling has been carried out, the analysis of which has been used to formulate the proposal for Stage 2. The basis and framework of the mathematical model has also been identified.

CHAPTER 3

LEGISLATION AND WATER QUALITY STANDARDS

3.1 Introduction

In the UK surface water quality is managed by identifying the use or uses (Environmental Quality Objective) of a particular stretch of river, estuary or coastal water and by setting Environmental Quality Standards (EQS) to protect the identified uses. (An Environmental Quality Objective (EQO) is the requirement that a body of water should be suitable for those uses identified by the controlling water authority ie protection of other (less sensitive) freshwater life such as cyprinid fish. An Environmental Quality Standard (EQS) is that concentration of a substance which must not be exceeded if a specified use of the aquatic environment is to be maintained, for example, the concentration of un-ionised ammonia should not exceed 21 μg N/l for the protection of cyprinid fish. Discharge consents are calculated by the controlling water authority to ensure that the EQS values applicable for the protection of the particular uses are not exceeded, taking into account other inputs including those from diffuse sources.

The European Community (EC) has adopted several use-related Directives which lay down EQS values for selected parameters to protect the specified uses. In addition the EC has adopted the Dangerous Substances Directive (74/464/EEC)[2] to control the discharge of dangerous substances to the aquatic environment. EQS values for individual dangerous substances (List I) are laid down in 'Daughter Directives'. These are not use related although different values may be set for fresh, estuarine and coastal waters. In addition, the UK has set use-related national EQS values for a number of less dangerous substances (List II) in fulfilment of the EC Dangerous Substances Directive which requires national governments to set EQS values for these less dangerous substances.

This chapter reviews briefly the different uses identified for surface waters in the UK, selects those uses likely to be of relevance to the London Docks and provides a listing of the appropriate EQS values to protect these uses.

3.2 Water Uses

The agreed uses identified by Gardiner and Mance[2] for the derivation of EQS values for List II substances are presented in Table 3.1. However, a more comprehensive selection of possible water uses has since been proposed and is still under discussion. Eight estuarine water uses and quality objectives have been proposed (Table 3.2) by the Water Authorities Association (WAA) Estuarine Working Party[3]. These uses may form the basis of future statutory quality objectives for estuaries.

TABLE 3.1

Designated Uses of Water

Use	Freshwater	Saline water
For direct abstraction to potable supply	*	-
For abstraction into impoundment prior to potable supply	*	-
As a source of food for human consumption	*	*
Protection of fish and shellfish	*	*
Protection of other aquatic life and dependent non-aquatic organisms	*	*
Irrigation of crops	*	-
Watering of livestock	*	-
Industrial abstraction	*	*
Bathing and water-contact sports	*	*
Aesthetic considerations	*	*

TABLE 3.2

Identified Uses of Estuaries and Related Environmental Quality Objectives[3]

	Uses	Environmental Quality Objective	Explanatory notes	Examples
1.	Basic amenity	Maintain water quality so as to prevent public nuisance arising from visual and smell problems.	Refers to the minimum general aesthetic acceptability of an estuary to people in close proximity to, but not intimate contact with, the water.	Walking, boating, birdwatching.
2.	General ecosystem conservation		To include fish, shellfish and the protection of other aquatic life and dependent organisms.	Dependent organisms could include oyster catchers where there is a need to protect mussels which are their primary food source.
	a) For estuaries receiving no substantial effluent discharges directly or indirectly.	Maintain water quality so as to protect all aquatic life and dependent non-aquatic organisms such that the ecosystem is typical of an estuary with those physical characteristics and latitude.	It is implicity that objective (a) includes all the subjectives outlined in (b) where applicable.	
	b) For estuaries receiving substantial discharges.	Maintain or improve estuary water quality to such a condition that: (i) it supports a variety of aquatic life and dependent non-aquatic organisms; (ii) where appropriate fish and shellfish are protected: (iii) where appropriate it supports a benthic fauna essential to sustain sea fisheries.		
		NB Specific species and habitats may need more stringent protection on a local basis because of their particular valve as an environmental resource.	This will include SSSIs, RAMSAR sites, Marine Nature Reserves, fisheries and shellfisheries including beds designated under the terms of the EC Shellfish Directive.	

Uses	Environmental Quality Objective
3. Migratory fishery	Maintain water quality so as to protect passage to and from freshwater of all relevant species of migratory fish where this is not prevented by natural physical barriers.
4. Commercial harvesting of fish for public consumption	Maintain water quality such that commercial marine fish quality shall be acceptable for human consumption as determined by the appropriate competent authorities (eg MAFF).
5. Commercial harvesting of shellfish for public consumption.	Maintain water quality such that commercial shellfish quality shall be acceptable for human consumption as determined by the appropriate competent authorities (eg MAFF).
6. Bathing	Maintain water quality so as to protect those engaged in bathing.
7. Other water contact based recreation.	Maintain water quality so as to protect those engaged in water contact related recreation.
8. Other recognised uses which are not incorporated within 1 - 7.	Maintain water quality so as to protect all other recognised uses which are affected directly by water quality and which are not incorporated in other objectives.

TABLE 3.2 (cont)

Explanatory notes	Examples
To include eels but not marine species which use part of estuaries for breeding grounds.	
This objective relates only to suitability for human consumption; the general health of the fish themselves is protected under objective (2) above.	
This objective relates only to suitability for human consumption; the general health of the fish themselves is protected under objective (2) above.	
This should include those activities related to bathing.	
Includes only those activities where there is a risk of intimate contact with the water.	Windsurfing, canoeing, water-skiing, skin-diving.
Includes only those uses affected or or influenced by water quality.	Abstractions, harvesting of edible seaweed, harvesting of gulls eggs.
This objective should only be applied where positive water quality management is practised by a water authority.	

For freshwaters, the Water Quality Survey Group[4], set up by the National Rivers Authority Advisory Committee, has proposed 10 use-related EQO. These are outlined in Table 3.3. The UK has also developed classification systems for rivers, canals and estuaries[18] - freshwaters are classified in four categories from 'good quality' (Classes 1A and 1B) to 'bad quality' (Class 4) as shown in Appendix A, Table 1. The different classes are related to the potential uses of the water and values are assigned to a limited number of chemical parameters, such as dissolved oxygen, ammonia and biochemical oxygen demand, describing the different classes. For estuarine waters the classification is not based on water use but on a combined assessment of the biological and aesthetic status of the water together with minimum dissolved oxygen contents. The scheme is shown in Appendix A, Table 2.

The proposed EQO values, for both fresh and marine waters, relevant to the uses of the London Docks are discussed below.

3.2.1 Basic Amenity

This use requires the maintenance of water quality to prevent public nuisance especially from visual and smell problems and is relevant to both fresh and saline waters. The objective is to provide protection for people in close proximity to the water, eg those engaged in birdwatching, walking, boating etc.

3.2.2 General Ecosystem Conservation

For rivers and estuaries receiving no substantial discharges and which are near to ideal natural conditions, the quality objective requires maintenance of water quality so as to protect all aquatic life and dependent non-aquatic organisms to preserve an ecosystem typical of that particular river or estuary. Where there are substantial inputs or where achievement of pristine conditions is impracticable, the objective becomes more limited and requires the water quality to be capable of supporting a variety of aquatic life relevant to the maintenance of fish populations and, where appropriate, the protection of marine fish and shellfish.

3.2.3 Cyprinid Fishery

This use requires maintenance of water quality so as to sustain a natural, breeding population of non-salmonoid fish appropriate to the characteristics of a river. This objective will normally protect sport fisheries but not necessarily a food source.

TABLE 3.3

Identified Uses of Rivers and Related Environmental Quality Objectives[4]

	Uses	Environmental Quality Objective	Explanatory notes	Examples
1.	Basic amenity	Maintain water quality so as to prevent public nuisance arising from visual and smell problems.	Refers to the minimum general aesthetic acceptability of a river to persons in close proximity to, but not intimate contact with, the water.	Walking, bird watching, boating, sailing, rowing.
2.	General ecosystem		Includes all aquatic flora and fauna and dependent organisms, excluding fish which are covered by objectives 4 and 5.	Dependent organisms includes river birds, otters etc
	(a) For rivers of or near to, pristine conditions	Maintain water quality so as to protect all aquatic life and dependent non-aquatic organisms, such that the ecosystem is typical of a river with those physical characteristics and flow regime.		
		OR		
	(b) For rivers where achievement of pristine conditions is impracticable.	Maintain or improve water quality to such a condition that it can provide a fauna and flora capable of supporting relevant fish populations (see Objectives 4 and 5).	This more limited objective would apply where it was economically or practically not feasible to return a river to its natural state. The level of ecosystem to be achieved would be specified as part of the 'standards'.	
3.	Special conservation value.	Maintain water quality so as to safeguard the special conservation interest for which the river is designated.	Applies only where the rivers contain statutorily designated areas.	NNRs, SSSIs. Requirements will be site specific.
4.	Salmonid fishery.	Maintain water quality so as to sustain a natural population appropriate to the physical characteristics and flow regime of the river where this is not precluded by natural physical barriers.	Supporting a breeding population of salmonids.	) Appropriate water quality standards and/or magnitude of population is specified as a 'standard'. (applies to 4 and 5)
5.	Cyprinol fishery	Maintain water quality so as to sustain a natural cyprinid population appropriate to the physical characteristics and flow regime of the river where this is not precluded by natural physical barriers.	Supporting a breeding population of non-salmonid fish; this will generally be a sport fishery, not a food source.	)

TABLE 3.3 (cont)

	Uses	Environmental Quality Objective	Explanatory notes	Examples
6.	Human consumption of fish	Maintain water quality such that fish are acceptable for human consumption as determined by the appropriate competent authorities (eg MAFF).	This use refers to the use of fish for food by humans, only; the presence of these organisms is safeguarded under Objectives 4 and 5.	
7.	Immersion sports	Maintain water quality so as to protect those engaged in immersion sports.	Includes only those activities where there is a risk of intimate contact with water. Could differentiate between water contact sports by means of the quality standards applied to safeguard them.	Canoeing, sailboarding, but not sailing, rowing. Need to be specific as to which activities these are.
8.	Potable water supply	Maintain water quality and river flow so as to safeguard potable abstractions.	Will need to take into account both quality and quantity considerations.	
9.	Industrial and agricultural use	Maintain water quality and river flow so as to safeguard industrial abstractions and where water is used for agricultural purposes, maintain water quality so as to protect the health and well-being of affected animals, avoid damage to crops and safeguard public health.	Will need to take into account both quality and quantity considerations. Different types of abstraction would be safeguarded by the quality standards which would always be site specific.	Cooling water, industrial abstractions, livestock watering, spray irrigation of crops.
10.	Other recognised uses.	Maintain water quality so as to protect all other recognised uses where they are not covered by Objectives 1-9.	Includes only those uses affected or influenced by environmental quality.	This could include uses such as 'eel fishery' which are relatively rare and site specific.

3.2.4 Commercial Harvesting of Fish and Shellfish for Human Consumption

This quality objective relates to waters used for the rearing of freshwater fish for human consumption and for the commercial harvesting of marine fish and shellfish for public consumption. The water quality must be maintained to ensure that commercial marine fish, shellfish and freshwater fish quality is acceptable for human consumption as determined by competent authorities eg MAFF. The general health of the organisms is protected under the EQO 3.2.2 and 3.2.3.

3.2.5 Immersion Sports, Water Contact Based Recreation and Bathing

This use is related to those activities where there is a risk of intimate human contact with water such as canoeing, sailboarding, water-skiing and bathing.

3.2.6 Industrial and Agricultural Use

This use requires the maintenance of water quality and river flow to safeguard abstractions for industrial and agricultural uses and to protect the well-being of livestock and crops to safeguard public health.

3.2.7 Other Recognised Uses

This use encompasses all other uses that are affected or influenced by water quality, eg harvesting of edible seaweed, eel fishery etc.

3.3 Use-related European Communities Legislation

Several use-related EC Directives have been agreed which might be of relevance to the docks. (The text of the Directives is given in Appendices B to F). Statutory EC standards are generally defined in terms of frequency, location, methodology and statistics of monitoring and hence monitoring programmes can be devised. Mandatory requirements in the water Directives are implemented through the Control of Pollution Act (Part II) 1974. Detailed provisions are issued in administrative circulars by DoE such as Circular 7/89[8] describing implementation of the Dangerous Substances Directive 76/464/EEC[2] and its Daughter Directives.

3.3.1 Quality of Bathing Waters 76/160/EEC[5]

Bathing waters include all running or still freshwater and seawater where bathing is explicitly authorised or identified by the competent authorities of a member state or where bathing is not prohibited and is traditionally practised by a large number of bathers. The Directive applies to designated waters only although the specified standards are being adopted more widely in the UK in the design of new discharge schemes. The Directive is mainly concerned with the bacterial quality of the water to avoid infections which might be transmitted to bathers, for instance, by the discharge of sewage effluent to bathing water.

The Directive lays down standards for faecal coliforms and faecal streptococci but also contains parameters including mineral oils, tarry residues, phenols, pesticides, cyanides and heavy metals such as arsenic, cadmium, lead and mercury. All of these require monitoring.

3.3.2 Protection of Freshwater Fish Life 78/659/EEC[6]

The aim of this Directive is to protect or improve the quality of those running or standing freshwaters which support or which, if pollution were reduced or eliminated, would become capable of supporting fish life. The Directive is particularly directed at protecting the diversity of indigenous species deemed to be desirable for water management purposes by the competent authorities of the member states. Member states must designate the freshwaters to which the Directive is applicable. The Directive lays down mandatory and guide linr values such as dissolved oxygen (DO), temperature and ammonia, important for the maintenance of healthy freshwater fisheries.

3.3.3 Protection of Shellfish Waters 79/923/EEC[7]

This Directive concerns the quality of shellfish waters and applies to those coastal and brackish waters designated by the member states as needing improvement or protection in order tc protect shellfish (bivalve and gastropod molluscs) life and growth. It is also intended to protect the high quality of shellfish products used for human consumption. This Directive lays down mandatory and guide values for a number of parameters including temperature, salinity, DO, petroleum hydrocarbons and heavy metals.

3.4 International Conventions

Several international conventions also have a bearing on the control of pollution in the UK.

3.4.1 Ministerial Conferences on the Protection of the North Sea

The UK agreed, at the Second Ministerial Conference on the Protection of the North Sea[14], to adopt a dual approach to the control of certain dangerous substances. The dual approach consists of applying EQS values and 'best available technology not entailing excessive cost' (batneec)[15], whichever is the more stringent. This more precautionary approach is applied initially to the discharge of the 23 red list substances in Table 3.4. WRc is currently deriving preliminary EQS values for those red list substances for which EQS values have not been adopted.

The UK has also agreed to reduce inputs of red list substances to UK coastal waters in the order of 50% by 1995, based on 1985 levels. This might be achieved for some substances by applying strict EQS and limit values, but will also involve additional control measures, particularly for diffuse inputs, such as restriction in use. The administration of the new system will be shared between Her Majesty's Inspectorate of Pollution (HMIP) and the National Rivers Authority (NRA). Approximately 500 existing discharges to water will be affected.

The third meeting of the Environment Ministers of the North Sea littoral states is planned for 1990 in the Netherlands.

3.4.2 Paris Convention

The Paris Convention deals with pollution of the sea arising from land based/riverine discharges to coastal waters. In the UK the provisions of the Convention are implemented through the Control of Pollution Act 1974.

3.4.3 Oslo Commission

The Oslo Convention deals with the disposal of wastes from ships and aircraft at sea, in particular the North Sea and the north-east Atlantic Ocean. The provisions of the Convention are implemented through the Food and Environmental Protection Act 1985 which requires discharge licences for waste disposal at sea. In England and Wales the licences for the dumping of waste at sea are issued by the Ministry of Agriculture, Fisheries and Food (MAFF).

TABLE 3.4

The UK 'Red List'

	EC Directive adopted (List I status)
Mercury	+
Cadmium	+
gamma - hexachlorocyclohexane (lindane)	+
DDT	+
Pentachlorophenol (PCP)	+
Hexachlorophenol (HCB)	+
Hexachlorobutadiene (HCBD)	+
Aldrin	+
Dieldrin	+
Endrin	+
PCB (polychlorinated biphenyls)	
Tributyltin compounds	
Triphenyltin compounds	
Dichlorvos	
Trifluralin	
1,2 Dichloroethane	
Trichlorobenzene	
Azinphos-methyl	
Fenitrothion	
Malathion	
Endosulfan	
Atrazine	
Simazine	

3.4.4 Organisation for Economic Co-operation and Development

This is an advisory body but its views are influential and can lead to legislation. A State of the Environment report[9] was published which highlighted concern over eutrophication, increasing levels of nitrates, metals and organic contaminants. There is an increasing awareness of the importance of diffuse pollution sources and a call for more comprehensive water management and integration of air, water and waste management policies. The report raised concern about the state of marine waters in the vicinity of bathing beaches or where there are fish farming operations.

3.5 Future Developments

3.5.1 Minimum Quality of Water

Proposals are being prepared by the European Commission to introduce a Directive laying down minimum water quality standards for all surface waters with the objective of eliminating grossly polluted surface waters and ensuring that all waters reach a minimum ecological quality. This may have implications for waters which have no identified use at present and hence for discharges to such waters. Indications are that the EC is considering, as a minimum ecological standard, the maintenance of a healthy coarse fishery which might be expressed as a descriptive target to be reached within a stated time period. However, pressure is being exerted by several countries for the inclusion of numerical parameters in the proposal, for instance, DO, BOD, pH, ammonia and nutrients. It will probably be left up to national governments to prepare plans for meeting the targets if the proposal is adopted.

3.5.2 Dumping of Waste at Sea

This proposed Directive[10], which is given in the Appendices, could be of relevance if the docks are to be dredged regularly and the dredgings are contaminated with any of the substances listed in the Annexes of the Directive. The disposal at sea of dredgings containing compounds listed in Annex I will be prohibited whereas dumping of Annex II compounds will be restricted. The proposal states that no new permits for the dumping of wastes listed in Annex II may be issued and existing authorisations must be reduced by 10% per year over a 5 year period starting from 1990 although this time-scale is now unrealistic as so far little progress has been made in negotiations on the proposed Directive.

3.5.3 Limiting Nutrient Inputs to Surface Waters

The EC has recently published a proposal for limiting the nutrient (specifically nitrate) inputs from diffuse sources, eg agricultural runoff, and sewage discharges to sensitive areas likely to be affected by eutrophication[42]. This proposal might be of relevance to the docks as algal blooms have been experienced.

3.5.4 Control of Pollution Act (Part II) 1974

The Control of Pollution Act 1974 is to be strengthened with the provisions for further legislation to be included in the Water Bill. The major intention is to establish statutory water quality objectives for all surface waters - rivers, lakes and coastal waters. The water quality objectives will be set by the Secretary of State on the advice of the National Rivers Authority (NRA).The quality objectives are likely to be reviewed in 1992 when the results of the 1990 river quality survey should be ready.

3.5.5 Best Practicable Environmental Option and Integrated Pollution Control

The UK Royal Commission on Environmental Pollution put forward in 1976 the need for disposing waste according to the 'best practicable environmental option' (BPEO). This concept was further considered by the Royal Commission in a report published in 1988[11]. In the meantime, HMIP has been created to 'control the disposal of waste in the most efficient and effective way without imposing excessive cost to industry'. The concept of BPEO fostered by the Royal Commission on Environmental Pollution appears to be emerging under the new guise of integrated pollution control (IPC) introduced in a consultative paper by the Department of the Environment[15]. The aim is that restrictions placed to protect one environmental compartment should take into account the effect this might have on the other compartments. It is envisaged that HMIP will be responsible for implementing IPC at least for the most dangerous substances. However, the required legislation has not yet been adopted.

Pressure is mounting within the EC to stop disposal of waste at sea. Thus, although sea disposal may be the best environmental option for dock dredgings this disposal route may be restricted without regard for the overall environmental impact of alternative methods of disposal, particularly if the dredgings are contaminated with substances on the dangerous substances lists.

3.5.6 Revisions to Existing Directives

Discussions in the EC on the harvesting and marketing of shellfish may lead to proposals for extending the scope of the existing Shellfish Directive (79/923/EEC)[7]. At present there are no indications as to what microbiological standards will be set.

The European Institute for Water reviewed the implementation of the EC Bathing Water Directive in November 1987 on behalf of the Commission. There was pressure for a revision of the Directive and for changes to the mandatory biological limits. The proposals included abandoning the total coliform parameter, reducing the faecal coliform limit to 1000/100 ml and making the guideline value for faecal streptococci (100/100 ml) a mandatory limit. Although the justification for these changes was not substantiated, it is likely that more stringent limits than those currently in force will be proposed in any future revision of the Directive. Consideration may also be given to the role of viruses in relation to bathing water quality.

3.6 Water Quality Criteria

The relevant criteria used to assess water quality and their importance for possible water uses of the London Docks are discussed below.

3.6.1 Aesthetic Criteria

Aesthetic acceptability is determined on the basis of visual and olfactory perception. It is appropriate for basic amenity, immersion sports and bathing. There is an element of subjectivity in assessing these parameters and possibility of misinterpretation of evidence by untrained personnel. The EC Directive on bathing water quality[5] includes numerical aesthetic parameters for mineral oils and surface active agents. These are guide values and may be considered too stringent for general application but provide an indication of acceptable concentrations which may be required for setting discharge consents.

3.6.2 Bacteria and Viruses

EQS values for bacteria and viruses are only applicable in terms of public health and therefore to uses involving possible ingestion of water such as immersion sports and bathing. Relevant EQS values are included in the EC Directive on bathing water quality[5]. No freshwaters in the UK have been designated bathing waters but the directive is widely applied in managing coastal waters adjacent to sewage outfalls. In the absence of reliable dose-response data on water borne infections in bathers these EC values can be used as guide values in those situations where people may be in intimate contact with water.

3.6.3 Ammonia

The behaviour of ammonia in water and its toxicity to aquatic organisms has been reviewed by WRc[19] and EQSs appropriate for various water uses have been proposed, expressed as un-ionised ammonia which is the fraction more toxic to aquatic organisms.The EC Freshwater Fish Directive[6] lays down EQS values for both ionised and un-ionised ammonia.The ratio of un-ionised ammonia to total ammonia depends on temperature and pH and, in terms of toxicity, at low temperature and low pH a much higher ammonia concentration can be tolerated.However, it may be necessary to control total ammonia levels in water as high concentrations lead to de-oxygenation and eutrophication.In addition ammonia concentrations can vary widely during the day, particularly if the water receives sewage effluent.Therefore, conditions in individual rivers need to be considered in the management of river water quality in respect of ammonia.

3.6.4 Dissolved Oxygen

Criteria for dissolved oxygen (DO) are included in the National Water Council (NWC) Classification of River Water Quality[18] and the maintenance of aerobic conditions is a requirement for all uses of water.The EC Freshwater Fish Directive[6] includes mandatory and guideline values for DO for salmonid and cyprinid fish and guideline values have also been proposed by the European Inland Fisheries Advisory Commission[16]). Migratory fish also require a minimum DO concentration[17] but this use is not expected to be relevant to the Docks (Table 3.5).

3.6.5 Biological Oxygen Demand

Criteria for biochemical oxygen demand (BOD) are also included in the NWC Classification of River Water Quality[18]. There are no national standards but guidance values are included in the EC Freshwater Fish Directive[6]. BOD affects the DO concentration in the water and DO should therefore be the primary consideration when judging fitness for use.

3.6.6 Dangerous Substances

EC has adopted the Dangerous Substances Directive 76/464/EEC[2] to control pollution of surface waters by dangerous substances.The Directive distinguishes between particularly dangerous substances (List I), for which pollution of the aquatic environment must be eliminated, and less dangerous (List II), for which pollution must be minimised on the basis of national EQS values. The List I and List II substances for which EQS values have been adopted so far are given in Table 3.6. The EC list of 129 potential List I compounds provides the basis for future negotiations[12]. The EC has recently proposed community-wide standards for the List II compound chromium[13]. The

TABLE 3.5

Criteria for Dissolved Oxygen in Freshwaters and in Estuaries Sustaining Migratory Salmonid Fishes

Use/Criteria			Reference
Protection of salmonid freshwater fish			
50% of all values	>9 mg/l	(I)	6
All values	>7 mg/l	(G)	
values <6 mg/l require investigation/action		(I)	
50 percentile	9 mg/l		16
5 percentile	5 mg/l		
Protection of coarse freshwater fish			
50% of all values	>7 mg/l	(I)	6
	>8 mg/l	(G)	
All values	>5 mg/l	(G)	
values <4 mg/l require investigation/action		(I)	
50 percentile	>5 mg/l		16
5 percentile	>2 mg/l		
Protection of shellfish			
Average value	≥70% saturation	(I)	7
Migration of salmonid fish through estuaries			
95 percentile (at site with lowest annual concentrations of oxygen)	≥5 mg/l		17
95 percentile of 3 mg/l would allow establishment of limited fishery with restricted migration			

Note I = mandatory value, G = guide value

TABLE 3.6

Substances for which Environmental Quality Standards have been Agreed or are Under Consideration within List I or II of EC Directive 76/464/EEC

List I

Mercury

Cadmium

Hexachlorocyclohexane (lindane)

Carbon tetrachloride

DDT

Pentachlorophenol

Chloroform

Aldrin, endrin, dieldrin, isodrin

Hexachlorobenzene

Hexachlorobutadiene

Values have been proposed for the following substances:

1.2 Dichloroethane)
Tetrachloroethylene) 1988
Trichloroethylene)
Trichlorobenzene)

Proposals are expected for the following:

Monochloroanilines

Monochloronitrobenzenes

Dichloromethane

Dichloropropane

Trichlorophenols

Organophosphorus pesticides

List II

Chromium

Copper

Zinc

Nickel

Lead

Arsenic

Vanadium

Boron
pH

Organotins

Mothproofing agents

Iron

Sulphides

Inorganic tin
Ammonia

EQS values proposed are more stringent than those adopted by the UK but agreement on this directive (intended as a framework for further List II substances) has been held up as some member states insist on the inclusion of Uniform Limit Values. National EQS values have been published by $DoE_{(8)}$ for a number of List II substances for various uses of water. The UK has adopted EQS values for nine metals, pH, organotin and mothproofing compounds and values for another three compounds have been agreed. A further nine compounds are currently being considered.The most critical uses for most substances are the protection of freshwater and/or saltwater fish and other aquatic organisms.

3.6.7 Other Determinands

Other compounds which also need to be considered are the red list substances not covered by EC legislation (see Section 3.4.1 and Table 3.6), and other determinands such as sulphide, inorganic tin and temperature for which standards have so far not been adopted.

3.7 Identified Uses of London Docks and Appropriate Environmental Quality Standards

Table 3.7 summarises the likely uses (EQOs) of the London Docks and the applicability of environmental quality standards (EQSs) and other criteria to protect the uses. A more detailed description of the applicability of EQS values and other criteria is given in Table 3.8. If several uses are identified for a particular dock the most stringent EQS values must be applied.

In the following Tables 3.9 to 3.14 the EQS values appropriate for each individual use are listed and details are given as to whether the EQS values are expressed as annual averages or 95 percentile concentration and as total or dissolved compound. References to the source documents are also provided.

3.7.1 Basic Amenity

Protection of basic amenity requires that water should be visually acceptable, free of debris and should not cause offensive smell. The EQSs listed in Table 3.9 are therefore primarily aesthetic criteria and are derived from the EC Directive on bathing water quality[5].

3.7.2 General Ecosystem Conservation

Criteria for general ecosystem conservation should be selected from the EQS listed in Table 3.10 having regard to the nature of the ecosystem concerned and the objective selected (see Tables 3.2 and 3.3). Control of List I substances is mandatory under the EC Dangerous Substances Directive[2].

TABLE 3.7

General Applicability of Environmental Quality Criteria

EQO	Aesthetic	Bacteria and viruses	Ammonia	Dissolved oxygen	BOD	Dangerous substances List I	Dangerous substances List II	Other Determinands
Basic amenity	•	•	•	• (plastics)				
General ecosystem conservation	•	•	•	•	•	•	•	•
Cyprinid fishery			•	•	•	•	•	•
Commerical harvesting of fish and shellfish for public consumption	•	•				•	•	•
Immersion sports, water contact based recreation and bathing	•	•		•1			•	•
Industrial and agricultural use	•	•	•	•	•	•	•	•2
Other recognised uses	•	•	•	•	•	•	•	•2

Notes 1. No standard is specified on a statutory basis, but regard should be given to value specified in EC Bathing Water Directive.

2. All as appropriate.

TABLE 3.8

Applicability of Environmental Quality Standards and Other Criteria to Identified EQO for Rivers

EQO		Aesthetic criteria	Bacteria and viruses	Ammonia	Dissolved oxygen	BOD	Dangerous substances List I	Dangerous substances List II	Other determinands
1	Basic amenity	Aesthetic criteria specified in EC Bathing Water Directive. In addition, there should be no recognisable sewage derived debris in marine waters that give rise to substantial complaint (Table 3.9)	NSR EQO relates to public nuisance NOT public health	NSR	Aerobic conditions should be maintained to avoid smell nuisance. No nationally agreed standards	NSR	Includes persistent synthetic floatable substances (no standard adopted)	NSR	NSR
2	General ecosystem conservation	NSR unless special circumstances require site-specific criteria fish Directive	NSR except for shellfish beds designated under EC Shell-	No national standard adopted (Table 3.10)	No national standard adopted (Table 3.10) organisms and sediments (Table 3.10)	No national standard adopted (Table 3.10)	Dangerous Substances and Shellfish Directives values apply to living	National standards adopted primarily to protect fish life (Table 3.10)	Provisional EQSs proposed for red list substances not in List I or II (see Table 3.6)
3	Cyprinid fishery	NSR	NSR standard adopted (Table 3.11) EC Freshwater Fish Directive Standards apply to designated waters	No national standard adopted (Table 3.11) EC Freshwater Fish Directive Standards apply to designated waters	No national standard adopted (Table 3.11) EC Freshwater Fish Directive Standards apply to designated waters	No national living organisms apply (Table 3.11)	EC values for adopted for the protection of other aquatic life (Table 3.11)	National standards for red list substances not on List I and II. EC values for fishing water quality	Provisional EQSs proposed
4(1)	Commercial harvesting of freshwater and marine fish and shellfish for public consumption	NSR	EC Shellfish Directive Standards apply to designated beds. Bacterial quality of non-designated shellfish for human consumption according to MAFF guidelines (Table 3.12)	NSR EC Shellfish Directive standards apply to designated beds	NSR	NSR See MAFF guidelines	EC values for Mercury	EC Shellfish Directive standards apply to designated beds. Lead in food regulations. See MAFF guidelines	As appropriate (eg to prevent taint of fish flesh by oils etc)
5(2)	Bathing, water contact related recreation and immersion sports	EC Directive values for bathing water quality (Table 3.13) Should be no recognisable sewage-derived debris in marine waters that give rise to substantial complaint	EC Directive values for bathing water quality (Table 3.13) Bathing Water Directive	NSR but should have regard to the guidelines specified in EC Directive	NSR but should have regard to the guidelines specified EC Bathing Water	NSR	NSR	EC Directive values for bathing water quality (Table 3.13). Standards specified in WRc Technical Reports 207-212, 253-261	
6	Industrial and agricultural use		Public health criteria applicable in some situations	NSR	NSR	NSR	No EC standards applicable	National standards adopted on the advice of MAFF for spray irrigation and livestock watering (Table 3.14)	
7(3)	Other recognised uses	*	*	*	*	*	*	*	

Notes:
(1) See MAFF Guidelines - Public Health Requirements
(2) EQO restricted to waters identified under 76/160 EEC and other sites considered to require protection for the pursuit of activities involving immersion in water.
(3) Requirements to be determined for any specific uses to be protected.
NSR No standard required.

TABLE 3.9

EQS Values for Basic Amenity

Parameter	Unit	Value	Status*	Reference
Aesthetic Criteria				
Colour	visual inspection	no abnormal change	I	5
Mineral oils	visual inspection	no visible surface film	I	
	olfactory inspection	no odour		
	mg/l after extraction and weighing dried residue	≤0.3	G	
Surface-active substances (methylene-blue active)	visual inspection	no lasting foam	I	
	mg/l as lauryl sulphate	≤0.3	G	
Phenols	olfactory inspection	no specific odour	I	
	mg/l	≤0.05	I	
Transparency	m	1	I	
Tarry residues, solid floating material	visual inspection	absent	G	
Dissolved Oxygen				
Aerobic conditions (≥10% saturation) should be maintained to avoid effects of deoxygenation, particularly production of hydrogen sulphide, ammonia or methane.				18
List I Substance				
Pollution attributable to persisent synthetic floatable substances or to persistent mineral oils should be avoided (cf Aesthetic Criteria)				2

Note: * Status specified in EC Directive (mandatory (I) or guide (G) values based on fortnightly or less frequent sampling) may not be appropriate for this use. The objective is to prevent public nusiance at all times.

TABLE 3.10

EQS Values for General Ecosystem Conservation

Parameter	Unit	Value		Status*	Reference
Ammonia (un-ionised)	µgN/l	15	(based on the value required to protect cyprinid fish)	AA,D	19
		21 780	(un-ionised) (total)	95P,I	6

List I Substances

The EQS values for List I substances are shown in Table 3.15 as they are not use-related.

List II Substances

The freshwater EQSs for general ecosystem conservation for the following List II substances must be at least as stringent as those shown for a cyprinid fishery in Table 3.11.

Arsenic, boron, chromium, copper, lead, mothproofing agents, nickel, triorganotins, vanadium and zinc.

Standards for other determinands for the protection of freshwater life can be found in Directive 78/659/EEC[6].

Additional criteria based on EQSs for particularly sensitive freshwater flora or fauna proposed by WRc should be considered in particular circumstances, eg:

Hydrogen sulphide		µg/l as undissociated H_2S		AA	27
	<15°C		2.0		
	>15°C		1.0		
Lead		µg Pb/l			
	hardness	<50 mg/l as $CaCO_3$	5	AA,D	28
		>75 mg/l as $CaCO_3$	60	AA,D	
Nickel		µg Ni/l			
	hardness	<50 mg/l as $CaCO_3$	8	AA,D	29
		50-100 mg/l as $CaCO_3$	20		
		100-200 mg/l as $CaCO_3$	50		
		>200 mg/l as $CaCO_3$	100		
Tin (inorganic)		µg Sn/l	25	AA,T	30

Note: *AA = annual average, D = dissolved, T = total, 95P = 95 percentile, M = maximum.

TABLE 3.10 (cont)

Parameter	Unit	Value	Status	Reference
List II EQSs for the protection of saltwater life are itemised below, EQSs for the protection of general ecosystem conservation should be at least as stringent.				
Chromium	µg/l	15	AA,D	8
Copper	µg/l	5	AA,D	8
Lead	µg/l	25	AA,D	8
Nickel	µg/l	30	AA,D	8
Zinc	µg/l	40	AA,D	8
Arsenic	µg/l	25	AA,D	8
Vanadium	µg/l	100	AA,T	8
Boron	µg/l	7 000	AA,T	8
Inorganic tin	µg/l	10	AA,D	30
pH		6.0-8.5 (saltwater life)		8
		7.0-8.5 (shellfish)	95P	32
Ammonia (as N)	µg/l	21 (un-ionised)		19
Iron	µg/l	1 000	AA,D	8
Mothproofers:				
PSCDs	µg/l	0.05	95P,T	8
Cyfluthrin	µg/l	0.001	95P,T	8
Sulcofuron	µg/l	25	95P,T	8
Flucofuron	µg/l	1	95P,T	8
Permethrin	µg/l	0.01	95P,T	8
Hydrogen sulphide	µg/l	10 (undissociated)	24 h max	27
Organotins	µg/l TBT	0.002	M,T	8
	µg/l TPT	0.008	M,T	

Standards for other determinands for the protection of saltwater life can be found in Directive 79/927/EEC[7].

Red List Substances

The following provisional EQSs have been proposed by WRc for consideration by DoE:

Parameter	Unit	Value	Status
Malathio	µg/l	0.01	AA
Atrazine	µg/l	2	AA
		10	95P
Simazine	µg/l	2	AA

TABLE 3.11

EQS Values for a Cyprinid Fishery

Parameter	Units	Values	Status*	Reference
Ammonia	μgN/l	21 (un-ionised) 780 (total)	95P,I	6
Dissolved oxygen	mg/l	50% all values >7 50% all values >8 all values >5 values <4 to be investigated	I G G I	6
		50 percentile >5 5 percentile >2		16
BOD	mgO_2/l	≤6	95P,G	6

List I Substances

The standards for List I substances in Table 3.15 apply.

List II Substances

Parameter	Units	Values	Status*	Reference
Arsenic	μg As/l	50	AA,D	8
Boron	μg B/l	2 000	AA,T	8
Inorganic tin	μg Sn/l	25	AA,T	30
Organotins M,T 8 (TBT/TPT)	μg/l	TBT 0.02 TPT 0.02		MT
pH		6.0-9.0	95P	8
Iron	μg Fe/l	1 000	AA,D	8
Mothproofing agents PCSDs Sulcofuran Flucofuron Permethrin Cyfluthrin	μg/l	 0.05 25 1 0.01 0.001	95P,T	8
Residual chlorine	μg HOCl/l	≤ 5 at pH 6	95P,T,I	6
Hydrogen sulphide (undissociated)	$\mu g\ H_2S/l$			27
	<15°C, <5 mg O^2/l	0.5	AA	
	<15°C, <5 mg O^2/l	5.0	(24 h max)	
	<15°C, >5 mg O^2/l	1.0	AA	
	<15°C, >5 mg O^2/l	10.0	(24 h max)	
	>15°C, <5 mg O^2/l	0.25	AA	
	>15°C, <5 mgO^2/l	2.5	(24 h max)	
	>15°C, >5 mgO^2/l	0.5	AA	
	>15°C, >5 mgO^2/l	5.0	(24 h max)	

Note: I = mandatory, G = guide value, AA = annual average, M = maximum, 95P = percentile, 98P = percentile, T = total, D = dissolved

TABLE 3.11 (cont)

The following standards are hardness related:

Parameter	Unit	Value: Hardness (mg/l as $CaCO_3$) <50	50-100	100-150	150-200	200-250	>250	Status*	Reference
Chronium	µg Cr/l	150	175	200	200	250	250	AA,D	8
Copper	µg Cu/l	1	6	10	10	10	28	AA,D	8
		5	22	40	40	40	112	95P,D	
Lead	µg Pb/l	50	125	125	250	250	250	AA,D	8
Nickel	µg Ni/l	50	100	150	150	200	200	AA,D	8
Zinc	µg Zn/l	75	175	250	250	250	500	AA,T	9
		300	700	1 000	1 000	1 000	2 000	95P,T,I	
Vanadium	µg V/l	20	20	20	20	60	60	AA,T	8

Other Determinands

Parameter	Unit	Value	Status*	Reference
Temperature	°C	≤3 above	98P,I	6
		≤28 unaffected water	98P,I	
		≤10 for breeding of coldwater species	98P,I	
Phosphorus (indicative of a need to reduce eutrophication)	mg PO_4/l	0.4	T	6

TABLE 3.12

EQS Values for Human Consumption of Fish and Shellfish

Parameter	Unit	Values	Status*	Reference
List I Substances				
Mercury	mg/kg (wet wt)	0.3 (in a representative sample of fish flesh)	I	20/21
List II Substances				
Arsenic	mg/kg	1 (for most foods but exemptions for fish in which arsenic is naturally present)		33
Lead	mg/kg wet wt	2 fresh fish 10 game, game pate 10 shellfish 1 watercress	M	28
Organotins TBT, TPT		insufficient data on which to base an EQS, although values for protection of aquatic life would probably also protect this use.		
Permethrin	μg/l	0.01	95P,T	34

Water quality requirements for shellfish waters designated under 79/923/EE[7] should be sufficient to contribute to the high quality of shellfish products directly edible by man.

Note: * I = mandatory, M = maximum, 95P = 95 percentile, T = total

TABLE 3.13

EQS Values for Immersion Sports and Bathing

Parameter	Units	Values	Status*	Reference
Aesthetic Criteria				
Colour	visual inspection	no abnormal change	**95P	5
Mineral oils	visual olfactory	no surface film no odour	95P	
Surface-active substances	visual	no lasting foam	95P	
Phenols	olfactory mg $ClOH_5$ OH/l	no specific odour ≤ 0.05	95P	
Transparency	m	1	**95P	
Bacteria and Viruses				
Total coliforms	per 100 ml	10 000	95P	
Faecal coliforms	per 100 ml	2 000	95P	
Salmonella	per litre	0	95P	
Enteroviruses	PFU/10 litres	0	95P	
Other Determinands				
pH		6-9	**95P	32
List I Substances				
Values for List I substances detailed in Table 3.15 apply				
List II Substances				
Lead	µg/l	500	95P	28
Chromium	µg/l	500	95P	35
Zinc	µg/l	50 000	95P	36
Copper	µg/l	500	95P	37
Nickel	µg/l	500	95P	29
Arsenic	µg/l	500	95P	33
Iron	µg/l	3 000	95P	38
Hydrogen sulphide (undissociated H_2S)	µg/l	40	95P	27

Notes: *95P = 95 percentile

**provisions exist for exceeding the limits in the event of exceptional geographical or meteorological conditions

TABLE 3.14

EQS Values for Agricultural Uses

Parameter	Unit	Value: Crop irrigation	Value: Livestock watering	Status*	Reference
List I Substances					
Cadmium	µg/l	20			39
List II Substances					
Arsenic	µg/l	40	200	A,T	33
Boron	µg/l	1 000- 2 000**		A,T	40
Chromium	µg/l	2 000	1 000	A,T	35
Copper	µg/l	500	200	A,T	37
Iron	µg/l	1 000		P,T	38
Lead	µg/l	2 000	100	A,T	28
Mothproofing Agents	µg/l			95P	34
PCSDs		0.05			
Sulcofuron		25			
Flucofuron		1			
Permethrin		0.01			
Molybdneum	µg/l	30		A,T	39
Nickel	µg/l	150	1 000	A,T	29
Organotins	µg/l			95P,T	31
triphenyltin			0.09		
tricyclohextltin			0.10		
pH		5.5-8.5		A	32
Selenium	µg/l	20		A,T	39
Vanadium	µg/l	80		A,T	41
Zinc	µg/l	1 000	25 000	A,T	36

Notes: *A = annual average, T = total, 95P = 95 percentile

** depending on crop sensitivity

TABLE 3.15

EQS Values for List I Substances

Parameter	Unit	Value	Status*	Reference
Mercury	µg Hg/l	1	AA,T	20/21
		0.5 (estuaries)	D	
		0.3 (other coastal waters)	D	
Cadmium	µg Cd/l	5	AA,T	22
		5 (estuaries)		
		2.5 (other coastal waters)	D	
Hexachlorocyclo-hexane	µg HCH/l	0.1	AA,T	23
		0.02 (estuaries and other coastal waters)		
Carbon tetrachloride	µg CCl_4/1	12 (all waters)	AA	24
DDT	µg DDT/l	0.025](all waters)	AA,T	24
	µg p.p-DDT/l	0.01]	AA	
Pentachlorophenol	µg PCP/l	2 (all waters)	AA	24
'Drins'	µg/l	0.03] until	AA,T	25
	µg endrin/l	0.005] 1.1.1994	M	
	µg aldrin/l	0.01]		
	µg dieldrin/l	0.01] after		
	µg endrin/l	0.005] 1.1.1194		
	µg isodrin/l	0.005]		
Hexachlorobenzene	µg HCB/l	0.03 from 1.1.1990 (all waters)	AA	25
Hexachlorobutadiene	µg HCBD/l	0.01 from 1.1.1990 (all waters)	AA	25
Chloroform	µg $CHCl_3$/l	12 from 1.1.1990 (all waters)	AA	25

Proposals have also been published for the following candidate List I substances but these have not so far been adopted:

1,2-Dichloroethane	µg EDC/l	10 (all waters)	AA	26
Trichloroethylene	µg TRI/l	10 (all waters)	AA	
Perchloroethylene	µg PER/l	10 (all waters)	AA	
Trichlorobenzene	µg TCB/l	0.1 (all waters) (total of three isomers)	AA	

The concentrations of the following List I substances in sediments must not increase with time:

Cadmium, hexachlorocyclohexane, mercury

The concentrations of the following List I substances in sediments and/or molluscs and/or fish must not increase significantly with time:

DDT, pentachlorophenol, 'Drins', hexachlorobenzene, hexachlorobutadiene.

Note: *AA = annual average, D = dissolved, T = total, M = maximum.

3.7.3 Cyprinid Fishery

Requirements for the maintenance of a cyprinid fishery are broadly similar to those identified for general ecosystem conservation since the presence of a healthy coarse fishery is often indicative of a satisfactory ecosystem. EQS are listed in Table 3.11.

3.7.4 Commercial Harvesting of Fish and Shellfish for Human Consumption

For this use the objective is the protection of consumers by restricting levels in food derived directly or indirectly from waters. This objective can be attained by stipulating a standard either in terms of an allowable level of contaminant in food or in the water such as to restrict the level in food.The EQSs listed in Table 3.12 do not, however, guarantee the maintenance of the quality during processing.

3.7.5 Immersion Sports, Water Contact Based Recreation and Bathing

Mainly aesthetic and microbiological criteria are applied to maintain water quality and protect people in intimate contact with the water (Table 3.13). Although the EC Directive on bathing water quality[5] applies only to designated bathing waters there is no basis for deriving different bacteriological standards for non-designated areas used for water sports and bathing (see Section 3.6.2).

3.7.6 Industrial and Agricultural Use

It may be necessary to impose EQS values to protect local industrial applications of water, but usually it is expected that special needs would be met by treatment within the industrial plant. Irrigation of crops and watering of livestock are the principal agricultural uses of water with specific quality requirements (Table 3.14).

3.7.7 Other Recognised Uses

Criteria appropriate to any such uses will be determined on a case-by-case basis having regard to local conditions and the specific objective to be met.

3.8 Conclusions

A number of different uses of relevance to the London Docks have been identified and the appropriate standards to protect these different uses have been summarised in separate tables.

The standards have been derived from EC Directives and national UK legislation.

Several EC, national and international initiatives are currently under discussion which might have a bearing on the standards to be achieved for the London Docks.

CHAPTER 4

IDENTIFICATION AND ASSESSMENT OF INPUTS TO AND OUTPUTS FROM THE DOCK SYSTEM

4.1 Identification Desk Study and Survey of All Recorded Inputs and Outputs

A study has been made of old record drawings and development plans to identify possible flows into and out of the docks. In addition a survey of each dock has been undertaken to verify present conditions.

This section describes the situation in each dock system. The method of identification and assessment of inputs and output flows into the docks is described in three stages:

- listing of inputs and outputs and a display of their locations on a schematic map;

- brief description of each input/output, its role in the dock water system and any particular idiosyncrasies;

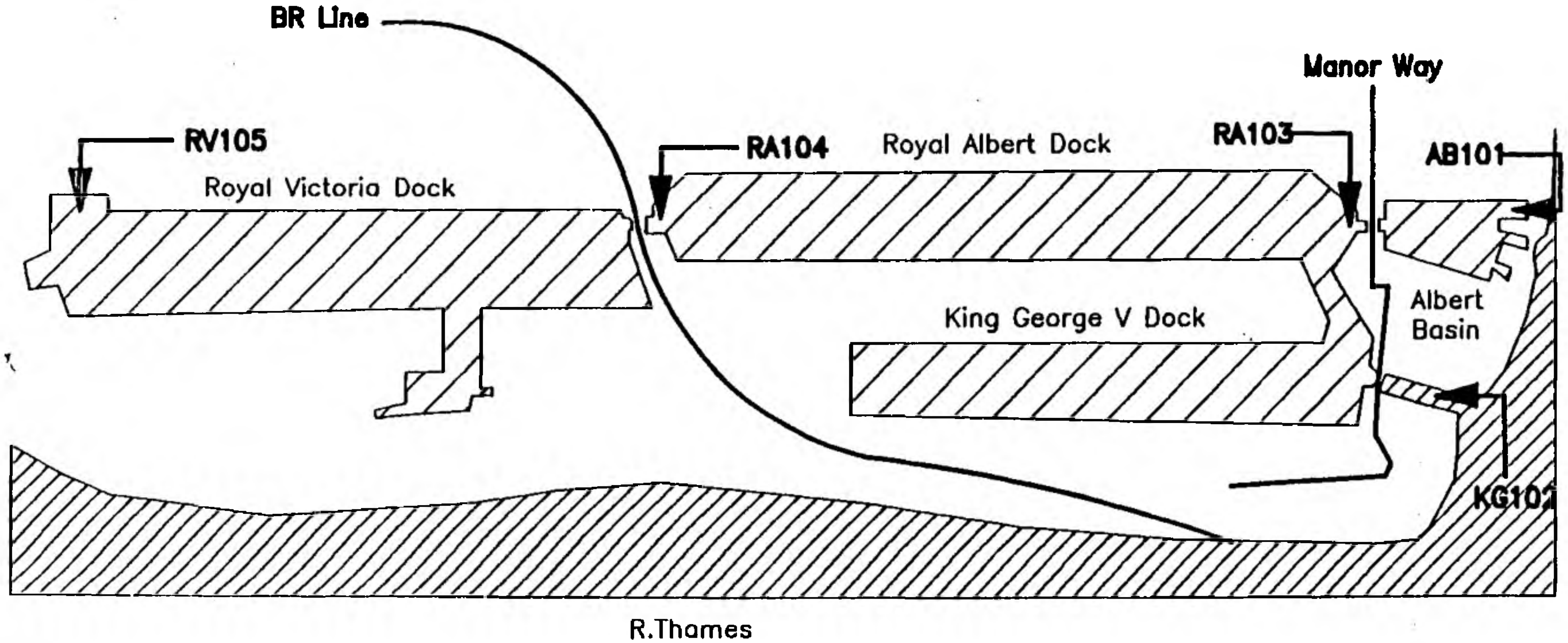
- a method of calculation of the volume and volumetric rate of flow of each input/output to be adopted for future calculation.

4.2 Royal Docks

4.2.1 Introduction

Tables 4.1 and 4.2 list the identified inflows and outflows respectively in the Royal Docks. The principal inflows are shown on Figure 4.1.

At present the main entrance into the docks through the King George V lock is closed while new gates are fitted.



Noto: Rainfall, runoff and evaporation are not shown for clarity

Figure 4.1

Royal Docks: Principal Inflows

TABLE 4.1

Inflows into the Royal Docks

	Site number
Pumping from the river at the eastern end of the Albert Basin	AB 101
Inflow by run-in through the King George V lock gates	KG 102
Groundwater pumping from the diversion of the North Woolwich Rising Main	RA 103
Pumping from the Connaught Rail Tunnel	RA 104
Pumping from the Western Gateway into north-west of Victoria Dock	RA 105
Direct rainfall into the docks	-
Surface runoff from the area immediately surrounding the docks	-
Groundwater pumping from the Rosehaugh Stanhope Development	-

TABLE 4.2

Outflows from the Royal Docks

	Site number
Evaporation from the dock water surface	-
Outflow during operation of the small craft lock	-
Outflow during operation the King George V lock	KG 102
Dredging of the Albert Basin	-
Dredging of other parts of the docks	-
Sluicing through King George V lock after run-in	KG 102
Anti-siltation jetting in the locks and bellmouth entrances	
Leakage into the Connaught Rail Tunnel	RA 104
Seepage loss through the dock walls and floor	-

A brief description of the inflows/outflows is necessary to indicate when a flow from each might occur and their significance in the overall dock water system.

4.2.2 Inflows

(a) Pumping from the River

The impounding station at the eastern end of the Albert Basin is designed to maintain the water level in the dock at the required level. It houses four axial flow pumps each with a nominal capacity of 6 m^3/s.

The intake is positioned next to the Gallions lower lock lead in jetty. At this location the river has a high silt concentration and both the intake and the Albert Basin are prone to siltation. Previously, when the docks were used, regular dredging of the Albert Basin and other parts of the docks took place.

It is feasible to pump for 3 hours either side of high water when the intake is beneath river level, but usually pumping only occurs for 1.5 or 2 hours either side of high water. At present no pumping takes place because the dock is inoperable and no significant amount of water is flowing out of the dock.

(b) Inflow by Run-in through the King George V Lock Gates

Normally when the river level is greater than the impounded level in the docks the mitre gates of the King George V lock open automatically, they are closed when the river level falls below the dock impounded level. When the tide turns, the water level in the docks can be lowered by sluicing through the King George V lock.

Run-in does not occur through the Small Craft lock as it has reverse mitre gates. These are kept in the closed position when the lock is not being used.

(c) Pumping from the Connaught Rail Tunnel

Water leaks into the London Regional Transport (LRT) tunnel and it has been estimated that up to 50% of it is dock water. It is pumped back into the dock at the Albert lock side of the Connaught Crossing. The pump sump fills up half as quickly as it can be pumped out and so pumping occurs for approximately half of the time. Pumping rate is roughly constant.

(d) Direct Rainfall into the Docks

Self explanatory

(e) Surface Water Runoff from the Area Immediately Surrounding the Docks

Historically, the small elevated area immediately adjacent to the docks was designed to drain into the docks. Extensive new sewerage is now being installed to cater for planned new development which will convey surface water away from the docks. The only water draining into the docks is that from roofs and paving that slope toward the docks, these areas of roofs and paving have been determined from site and drawing inspection.

(f) Groundwater Pumping from the Diversion of the North Woolwich Rising Main

Dewatering of an excavation necessitates pumping groundwater into the dock. In excavations of this type, the most likely source of water is groundwater recharge. Net input of water into the dock is likely to be small but there may be a turbidity problem.

(g) Pumping of the Western Gateway into the North West of Victoria Dock

There is no net inflow to the dock - water pumped in is that which has leaked into the excavation from the dock. However, turbidity could again be a problem.

(h) Pumping from the Rosehaugh Stanhope Development

This is scheduled to start in August 1989, the significance of proposed volumes of pumping in relation to other inputs will be assessed later.

(i) Runoff from City Airport

Runoff from the City Airport is collected and pumped into a sewer. Suggestions have been made that in future flows may drain directly into the dock. This could require monitoring particularly in winter when deicing fluids are used on the runway.

4.2.3 Outflows

(a) Evaporation from the Dock Water Surface

Self explanatory

(b) Outflow During Operation of the Small Craft Lock

This is currently functional and outflow occurs as sluicing every time the lock is used. From past records, this lock is used rarely in comparison with the King George V lock.

(c) Outflow during Operation of King George V Lock

Whereas the lock is currently out of operation it is expected to be recommissioned in Autumn 1989. Water is lost from sluicing everytime the lock is used. Loss of water through locking in the King George V lock constitutes the largest water loss from the Royal Dock System.

(d) Dredging of the Albert Basin

The high silt content of pumped water necessitates dredging to keep bed levels in the dock from exceeding manageable levels. Dredging causes a small loss of water but a large loss of nutrients and mixing of the dock water. When the docks were used commercially dredging of the basin was done on a regular basis, future practice is uncertain.

(e) Dredging of Other Parts of the Docks

This principally applies in the vicinity of the King George V lock and the bellmounth entrances to both locks although the latter does not constitute an inflow. Comments from the above section apply here also.

(f) Sluicing through the King George V lock after Run-in

On the turn of the tide after a run-in the lock gates are closed and sluicing occurs to lower the dock water level to design impounded level.

(g) Anti-siltation Jetting in the Locks and Bellmouth Entrances

This is another possible solution to the siltation problem and, if used, will involve a large outflow of water from the docks. However, the process of anti-siltation jetting is not considered environmentally sound by the Port of London Authority and their permission is awaited before if can be used.

(h) Leakage into the Connaught Rail Tunnel

See previous comments under 'inflow' in Section 4.2.2. The net inflow/outflow at this location into the dock system is likely to be small.

(i) Seepage Loss Through the Dock Walls and Floor

This can be estimated as the residual in the water balance. Observation suggests it is small since during the non-operation of the King George V lock and the impounding pumping station the dock water level has been rising slowly due to pumping of groundwater by various engineering works. To offset this water has had to be released to maintain levels, dock water. Since none of these engineering works have large net input into the docks, seepage rate can be assumed to be small.

A method of calculation of the volumetric rate of flow of each input/output to be adopted for future calculation is outlined below.

4.2.4 Calculation of Inflows

(a) Pumping from the River

The impounding station weekly report contains dock water levels before and after pumping. Pumped volume can be calculated from:

[(Water level in dock) - (Water level in dock)] x Area of dock
[(after pumping (m)) (before pumping (m)] (94.8×10^4 m^2)

and a rate can be calculated by considering the total pumped in volume over a chosen period of time.

Dock surface area can be determined accurately, so that any inaccuracy in this method results from errors in measuring dock water levels.

Since levels are measured to the nearest 25 mm and dock levels change during pumping by typically 250 mm the accuracy of the method is ± 10%.

A less accurate estimate can be got from multiplying pumping rate by time of pumping (also in impounding station weekly report), but since pumped capacity is only known approximately, at 6 m^3/s for the design head, and head difference across the pump will vary with river levels, data are insufficient to calculate inflow accurately using this method. Comparison of estimated inflows from the same event as calculated by the two methods show gross errors in calculation using pumping rates.

A typical weekly inflow for 1987 was 200 000 m^3 although this varies throughout the year according to the effect of other inflows and outflows on dock impounded levels.

(b) Run-in Through the Lock Gates

The small craft lock has reverse mitre gates and allows no run-in. The King George V lock, when refurbished, will allow run-in when water level in the river is greater than water level in the dock.

Run-in records are available which give date of run-in, how long gates are open and water levels in the dock before and after run-in occurs.

Volume of run-in can be calculated from:

Run-in volume	= [(Water level in dock) - (Water level in dock)] x [(after run-in (m)) (before run-in(m))]	Area of dock ($94.8 \times 10^4 m^2$)

For a typical run-in water level rises by 25 to 50 mm ie,

$$\text{Typical run-in volume} = 25 \times 10^{-3} \times 94.8 \times 10^4 = 23\,700 \text{ m}^3$$
$$\text{or } 50 \times 10^{-3} \times 94.8 \times 10^4 = 47\,400 \text{ m}^3$$

Between 1 June 1988 and 14 July 1988 there were five run-ins, although this record is too short to be used as typical for any month or year, it does give an estimate of the likely run-in volume of approximately 140 000 m^3/month. Examination of records after the refurbishment of the King George V lock gates will give a more accurate answer. Since levels are read to the nearest 25 mm and water level changes are of a similar size errors of estimate about 100% can occur.

(c) Pumping from the Connaught Tunnel

The pump beneath the Connaught Tunnel is currently pumping against a head of 18.3 m, which stays approximately constant, and pumps at a rate of 2.5 m^3/minute. Actual pumping occurs for approximately half of the time, ie the pump empties the sump twice as quickly as the sump fills hence current pumping rate into the dock is 1.25 m^3/minute. Hence typical monthly pumping rate = 54 000 m^3/month.

Water pumped from the Connaught Tunnel is pumped into the Albert Dock on the east side of the Connaught Bridge.

This is not a net input since the lowering of head in the tunnel by pumping will cause increased seepage from the dock and it is estimated that up to 50% of the pumped water can be dock water.

(d) Direct Rainfall into the Docks

Areas of the docks are as follows:

Royal Albert Dock	28.56 ha
Albert Basin	5.64 ha
King George V Dock	25.25 ha
Royal Victoria Dock and Pontoon Dock	35.35 ha
Total	94.80 ha = 94.8×10^4 m^2

Hence from known rainfall depths volumes of inflow into each dock, parts of dock or the whole dock system, can be calculated.

For example: April to December 1988

Month	Total rainfall, P(m) x 10^3	Total rainfall volume inflow (m^3) = 94.8 x 10^4 x P
April	28.6	27 113
May	32.1	30 431
June	29.9	28 345
July	61.1	57 923
August	47.2	44 746
September	25.5	24 174
October	81.0	48 348
November	20.0	18 960
December	10.9	10 333

Note that 1988 was a dry year and changing climatic patterns will make the use of older historical records to estimate future inflows unsatisfactory. Inspection of current rainfall records will be necessary.

(c) Surface Water Runoff from Land Adjacent to the Docks (not including City Airport)

Each dock will be considered separately for compatibility with individual consideration in the mathematical model.

Royal Victoria Dock:

A 10 m wide strip running along the northern boundary slopes towards the dock in general. Some depression storage will occur between the crane rails so that 100% runoff will not occur. All land further back from the dock on the north side either drains away from the dock or has such great depression storage that negligible runoff will take place.

For the south side of the dock it is the south-east corner where there is a significant area of paved surface. It is assumed that half of the roof area of buildings adjacent to the dock drain into it.

Area of 10 m wide strip	12 000 m^2
Area of other paved areas draining into dock	28 800 m^2
Areas of roofs draining into dock	13 000 m^2
Total area draining into Pontoon and Royal Victoria Docks	53 800 m^2

This is about 15% of the area of the dock itself. For calculating runoff volumes from rainfall depths and contributing areas a runoff coefficient of 0.75 will be used to allow for the effect of depression storage.

Albert Dock:

Dockside buildings are orientated such that the south-facing halves of their roofs drain on to a 17 m wide strip and then into the dock. However, depression of land adjacent to the dock below dockside level by operation of cranes on rails leads to negligible runoff into the docks.

The south side of the Royal Albert Dock is the City Airport and this is considered separately later.

Albert Basin:

There is an approximately 5 m wide strip which drains into the dock for approximately half of the perimeter of the dock, again with large depression storage.

Total area draining into the Albert Basin = 1 000 m^2

A runoff coefficient of 0.75 will be used.

George V Dock:

On the south side of the dockside half of roofs slope towards the dock. West of the buildings a 5 m wide strip with rails slopes away from the dock in general and so there is no input from this strip.

Total area draining into George V Dock = 2 000 m^3

Because of depression storage a 0.75 runoff coefficient will be used.

On the north side of the George V Dock is the City Airport which will be considered later.

(f) Groundwater Pumping from the Diversion of the North Woolwich Rising Main

From the beginning of June dewatering south of the Royal Albert Passageway will pump into the eastern end of the Royal Albert Dock beneath the Manor Way Swing Bridge, as shown in Figure 4.1, until the end of August 1989. Estimates of total pumping for May to August 1989 are 40 900 to 54 600 m^3/month. Since this input could be very turbid, water samples will be taken.

Comments made earlier about increased seepage due to groundwater pumping apply here and so net input will be given the value of the lower limit of 40 900 m^3/month.

(g) Pumping from the Western Gateway into the North West of Victoria Dock

There is no net inflow into the dock. However it has been estimated that a circulation of flow of up to 13 700 m^3/month takes place. Turbidity could be high and sampling is proposed. This pumping is scheduled to finish before August 1989.

(h) Pumping from the Rosehaugh Stanhope Development

This is scheduled to commence in August 1989. It is estimated that circulation of flow will be about 27 300 m^3/month. Previous comments about seepage and net inflows are applicable.

(i) Runoff from the City Airport

Currently this is zero. If runoff was diverted into the dock 60 000 m^2 of concreted area would be drained into the west end of the Royal Albert Dock. Volumes of runoff would be as calculated earlier by multiplying rainfall depth by drained area.

4.2.5 Calculation of Outflows

(a) Evaporation from the Water Surface

From a knowledge of the dock surface areas and evaporated depth, evaporated volume will be calculated using the FAOPEN1 subroutine. Inputs to the FAOPEN1 program are: date, latitude, sunshine hours, temperature, relative humidity, wind speed, day/night wind speed ratio.

Evaporation is of the same order as rainfall, greater in summer but less in winter.

(b) Outflow during Locking

For both locks the water lost is calculated from:

(Water lost in) = [(Impounded) - (River level when)] x (Area of part of lock)
(locking) [(level) (outer gates opened)] (used).

All these data are provided in the log books used by the Harbour Master.

Areas:	Small Craft lock	133 m^2
	Full King George V lock	7 436 m^2
	$^1/_4$ King George V lock	1 889 m^2
	$^3/_4$ King George V lock	5 577 m^2

A typical river level when docking = 4.8 m
A typical dock level when docking = 7.6 m
The quarter lock of the King George V lock is most commonly used.
For a sample month with 15 lockings:

$$\text{Water lost} = (7.6\text{-}4.8) \times 1\,859 = 5\,200 \text{ m}^3 \text{ per locking}$$
$$= 5\,200 \times 15 \text{ m}^3 \text{ for that month}$$
$$= 78\,000 \text{ m}^3/\text{month}$$

The future volume lost in locking will depend on the future activity of the locks. Currently the Small Craft lock is not being used and the King George V lock is not in use and so water loss through locking is zero.

(c) Leakage into the Connaught Tunnel

From the previous estimate of 50% of the pumped volume coming from the dock this results in a loss due to leakage of 0.5 x 54 000 m^3/month = 27 000 m^3/month.

(d) Seepage

As discussed earlier, this is presumed small in comparison with the significant inputs and outputs.

4.3 Isle of Dogs

4.3.1 Introduction

The inflows and outflows for the Isle of Dogs dock system are tabulated in Tables 4.3 and 4.4 respectively. The principal inflows are shown on figure 4.2.

TABLE 4.3

Inflows into the Isle of Dogs Dock System

	Site number
Pumping from the river at the eastern end of West India Main Dock	WI 106
Contractors' discharge	WI 107
Run-in through the lock gates	WI 108
Pumping from the river at the western end of West India Main Dock	-
Direct rainfall into the dock	-
Surface water runoff from the area immediately surrounding the docks	

Figure 4.2

Isle of Dogs: Principal Inflows

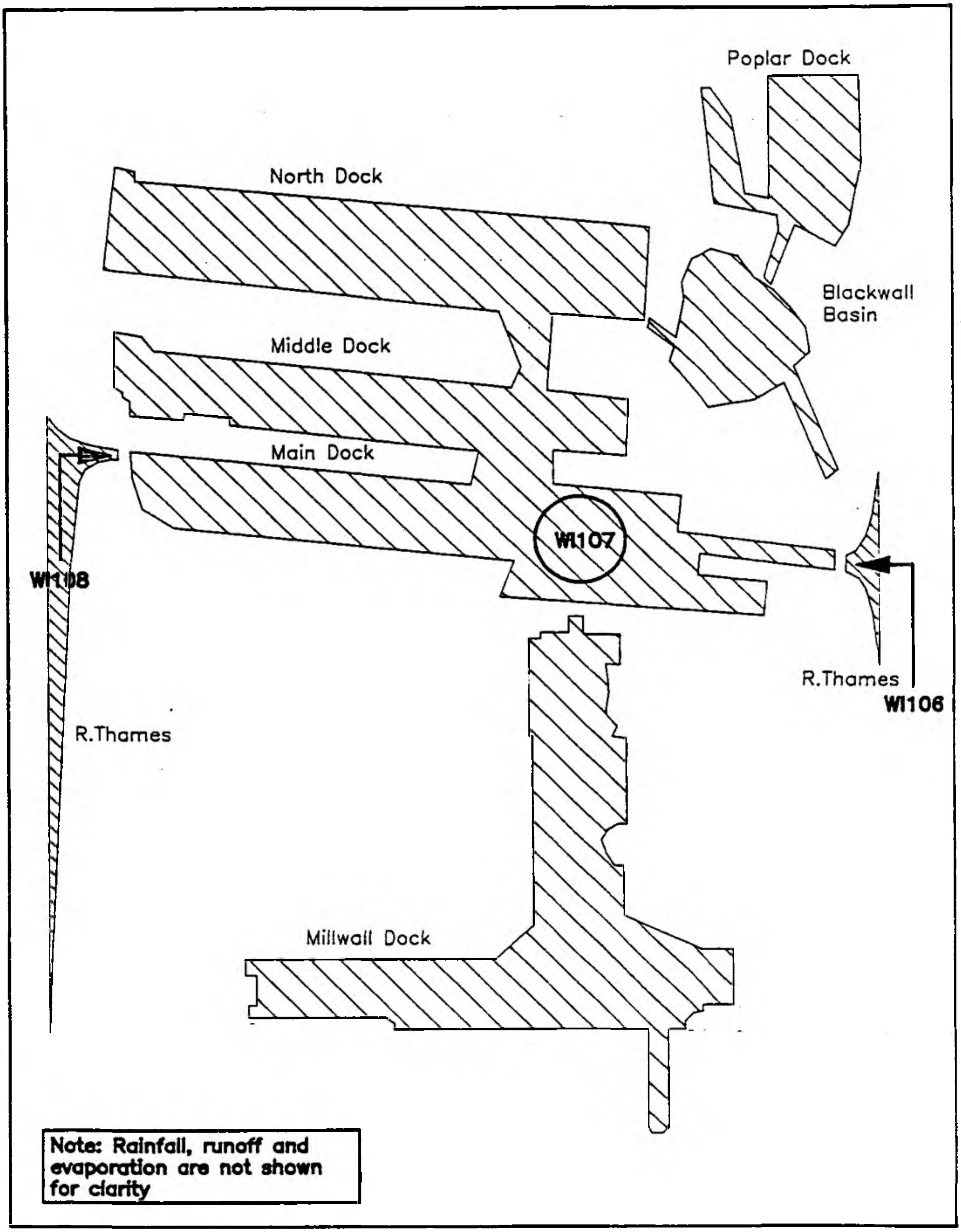


TABLE 4.4

Outflows from the Isle of Dogs Dock System

	Site number
Evaporation from the dock water surface	-
Outflow during operations of the lock	
Seepage losses	WI 106

As for the Royal Docks, a brief description of each inflow/outflow follows to indicate when a flow from each might occur and its function in the overall docks management system.

4.3.2 Inflows

(a) Pumping from the River at the Western End of the West India Main Dock

Four centrifugal pumps operate in this station; water is drawn from the river via a culvert and intake channel adjacent to the Cascades development. The pumping station is being refurbished and is therefore not in use. The impounding pumping station restores the level of the dock water when it is reduced by the outflows.

(b) Pumping from the River at the Eastern End of West India Main Dock

This temporary pumping station is used to maintain impounded dock water level during the time that the pumping station at the west end of the dock is out of action. The capacity of the station is much smaller than the permanent one and it must pump continuously all day to maintain dock water levels. The pumping rate varies with the change in the river water level, and the volume pumped per month can be calculated as the residual in the water balance.

(c) Run-in Through the Lock Gates

The Blackwall Basin lock is now dammed off. This occurs through site WI 106 for similar reasons to those given in Section 4.2.2 (b). Currently run-ins occur more frequently than when the permanent impounding station was in use. This results from the impounded level in the dock being depressed due to low pumping rates of the temporary pump and frequent use of the lock because of construction work. An estimate of typical run-in volumes, input records from when the permanent impounding station was working or future records when it is again working will have to be inspected.

(d) Direct Rainfall onto the Dock Water Surface

Self explantory

(e) Surface Runoff from the Area Immediately Surrounding the Docks

The only surface water draining into the docks is from roofs and paving that slope towards the dock. These areas have been determined from engineering drawings and actual site inspections.

(f) Contractors' Discharges

At present a large amount of engineering work is occurring around the docks. Water flowing into the dock from these works is small compared with pumping, run-in and locking volumes, but it could be qualitatively significant. Hence it is most effective to initially monitor the quality of these inputs.

4.3.3 Outflows

(a) Evaporation form the Dock Surface

As for Section 4.2.3 Outflows (a).

Outflow During Operation of the Lock

Outflow occurs as sluicing every time the lock is used. Currently this lock is in frequent use, resulting in an outflow which the temporary pump finds difficult to balance.

(c) Seepage

This value is small compared with the rapid rate of inflow from pumping 24 hours a day and outflow from frequent use of the lock.

(d) Sluicing in the Blackwall Basin

Previously sluicing took place, but it is understood that this is no longer practised.

Calculation of the volumetric rate of flow of each input/output.

4.3.4 Calculation of Inflows

(a) Pumping from the River at the West End of West India Main Dock

When this pumping station is functioning the impounding station weekly report details heights before and after pumping and times of pumping, hence volume inflow can be obtained from:

Volume pumped = [(water level in dock)] - [(water level in dock)] x Area of docks
[(after pumping)] [(before pumping)]

Water area of the West India and Millwall dock system is 51.56×10^4 m^2. From inspection of recent historical records, a typical weeks pumping involves a water level change of 0.125 m, hence:

Volume pumped in a typical week = $0.125 \times 51.56 \times 10^4$ = 64 450 m^3/week.
Volume pumped per month = 275 000 m^3/month

This figure will vary with the frequency of use of the lock and loss of water in locking, and also with the degree of run-in. Inspection of future records will be necessary to determine this variation.

Measurements of water level are made to the nearest 25 mm, so if a typical weekly pumping resulted in a water level rise of 125 mm, errors can be as high as $\pm$ 20%. See earlier comments made in Section 4.2.2.

(b) Pumping from the River at the East End of West India Main Dock

This temporary pumping station must pump constantly to maintain sufficient water level in the dock after losses due to lock use. The pumping rate varies with the tide level so that pumping capacity cannot be used to calculate inflow rate. Also, since water is being lost through locking and gained through run-in all the time the pump is working, its effect cannot be separated from these outputs and inputs in terms of effect on change in water level. However, locking and run-ins occur for short periods during the month compared with the pumping. Therefore when water level changes occur they can be attributed to run-in or locking with little loss of accuracy. The volume of inflow can be calculated for a range of tidal cycles representative of the tidal cycles it experiences, for any given period of say, a month. This is obtained by means of the water balance for the dock system (in terms of volumes over a month):

Pumped volume + Run-in volume + Rainfall volume + Increase in dock water volume = Locking volume + Evaporation volume + Seepage volume

All terms in the above equation are known except pumped volume and seepage volume. The latter is small in relation to all the other terms hence pumped volume can be calculated.

(c) Direct Rainfall on to the Docks

Areas of the docks are as follows:

North Section	10.63 ha
Blackwall Basin	2.91 ha
Middle Section	9.40 ha
Junction Dock	0.50 ha
Main Section	13.53 ha
South Section	14.59 ha
TOTAL	51.56 ha = 51.56×10^4 m^2

Hence from known rainfall depths it is possible to calculate volume of inflow into each dock, part of dock or the whole dock system

eg April to December 1988

Month	Total rainfall, P(m) x 10^3	Total rainfall volume inflow (m^3) = $51.56 \times 10^4 \times P$
April	28.6	14 746
May	32.1	16 551
June	29.9	15 416
July	61.1	31 503
August	47.2	24 336
September	25.5	13 148
October	81.0	26 296
November	20.0	10 312
December	10.9	5 620

(d) Surface Water Runoff from Land Adjacent to the Docks

Only land directly adjacent to the water and roofs adjacent actually drain into the docks. From a site survey and inspection of drawings, the following drained areas have been estimated for each dock:

Dock	Paved area (m^2)	Roofed area (m^2)	Total area (m^2)
South Section :	12 000	6 600	18 600
Main Section :	6 400	11 900	18 300
Middle Section :	-	12 000	12 000
North Section :	2 500	12 000	14 500
Blackwall Basin:	2 500	1 600	4 100
Total area draining into docks			67 500

The area must be multiplied by rainfall depth and a runoff coefficient of 0.75 as previously described in Section 4.2.4.

(e) Run-in Through the Lock Gates

Similar calculations as detailed in Section 4.2.4 apply here except for the use of a different dock surface area of 51.56×10^4 m^2. Note that run-in volumes calculated before the permanent pumping station is recommissioned will be much greater than those when it is operating because of the current depressed impounded level.

4.3.5 Calculation of Outflows

(a) Evaporation

Use a similar method as outlined in Section 4.2.5 for the Royal Docks.

(b) Outflow during Locking

The method outlined in Section 4.2.5 for the Royal Docks will be employed. The total area of the India and Millwall entrance lock is 4 343.2 m^2 and river datum is +7.59 m above dock datum.

(c) Seepage

As discussed earlier, this is assumed small in comparison to other inputs and outputs.

4.4 East India Dock

4.4.1 Introduction

The inflows and outflows are as listed in Tables 4.5 and 4.6, respectively; principal inflows are shown on Figure 4.3.

TABLE 4.5

Inflows into East India Dock

	Site number
Run-in from the river through a broken lock gate	EI 109
Rainfall directly into the dock surface	-

TABLE 4.6

Outflows from East India Dock

	Site number
Run-out to the river through a broken lock gate	EI 109
Evaporation from the dock surface	-

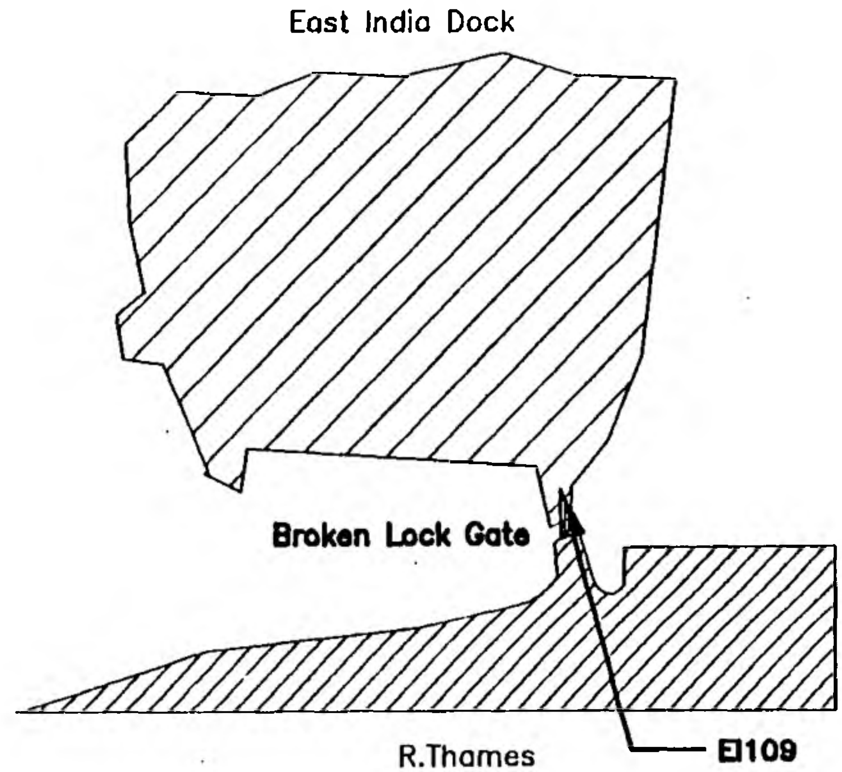
4.4.2 Inflows

(a) Run-in from the River Through a Broken Lock Gate

The old lock has been partially filled with rubble but a water channel exists from the dock through the broken river lock gate, the partially filled lock and through the broken outer lock gate into the river. When the river is higher than the dock water level, water flows in and vice versa. However, there is water retention within the dock, if rising and falling dock levels are more damped than the rising and falling tidal river levels. It is proposed to investigate this aspect in order to estimate a relation between river level, dock level and rate of flow/outflow to calculate flow volumes.

(b) Direct Rainfall on to the Dock Surface

As previously described the area immediately surrounding the dock is either below dock level or has so much depression storage that runoff into the dock is negligible.



Note: Rainfall, runoff and evaporation are not shown for clarity

Figure 4.3 East India Dock: Principal Inflows

(c) Evaporation

As described previously for other dock systems.

4.4.3 Calculations

Calculation of rainfall input and evaporation output will be as detailed previously. Run-in/run-out through the broken lock gate must await the assessment described in (a) before a calculation method can be proposed. Seepage is negligible compared with the tidal input from the river.

4.5 Shadwell Basin

4.5.1 Introduction

Inflows and outflows are listed Tables 4.7 and 4.8; principal inflows are shown on Figure 4.4.

TABLE 4.7

Inflows into Shadwell Basin

	Site number
Sluicing at the dam at the entrance from the river	SB 110
Rainfall directly on to the dock	-
Surface runoff from the area immediately surrounding the dock	-

TABLE 4.8

Outflows from Shadwell Basin

	Site number
Loss over weir overflows	-
Evaporation	-
Seepage	-

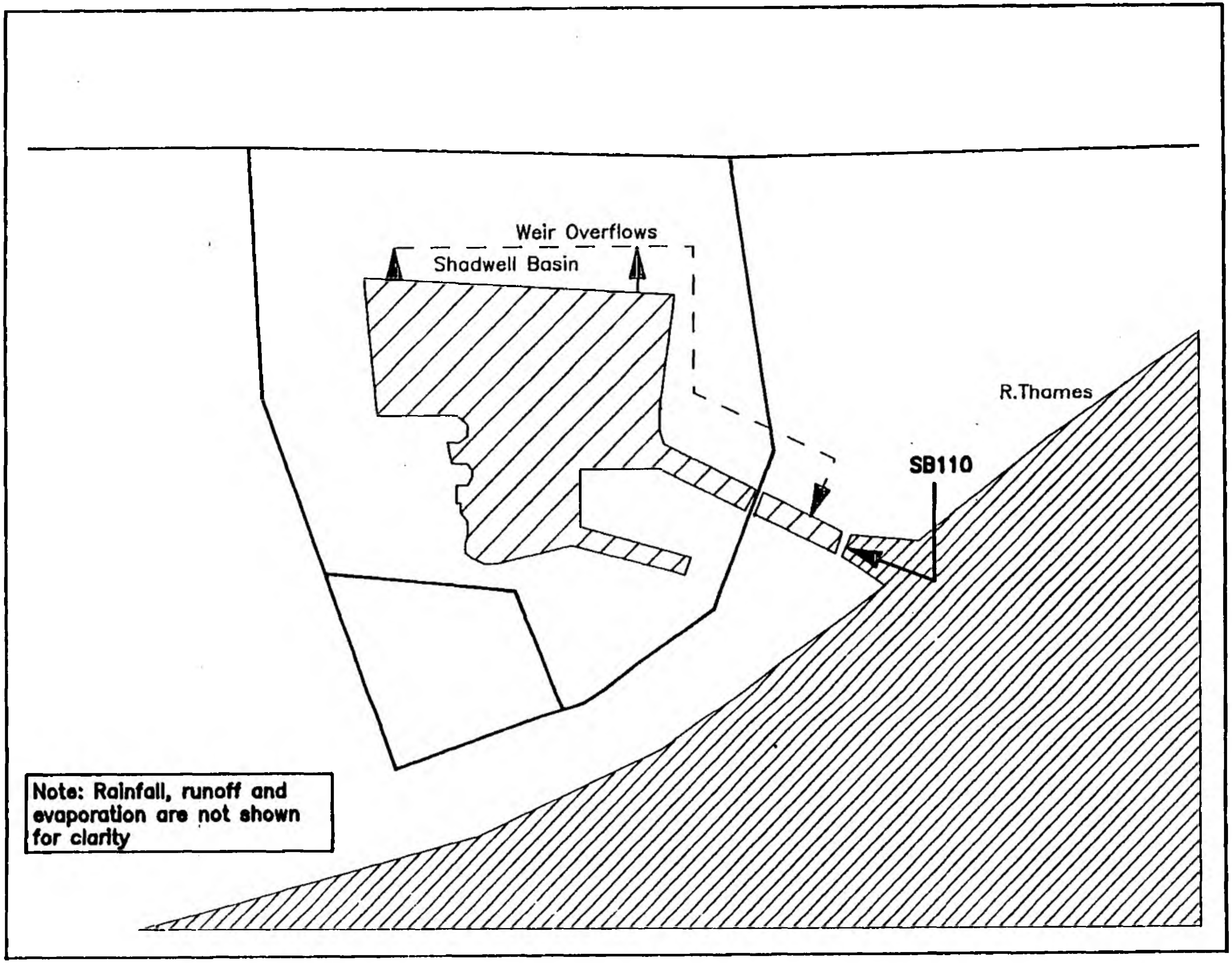


Figure 4.4
Shadwell Basin: Principal Inflows

4.5.2 Inflows

(a) Sluicing through the Dam at the Entrance to the River

Water enters from the river through sluices in the dam which open automatically when the river level is above the level of the weir overflows in the north-western and north-eastern corners of the dock. Water level in the dock then rises with the tide until the peak tide level when the sluices shut and water level in the basin goes down with the tide via the two weirs until the level of the top of the weirs is reached.

(b) Direct Rainfall Input

Self explantory

(c) Surface Water Runoff from the Area Immediately Surrounding the Dock

From inspection of plans and site visits the area draining into the dock and runoff coefficient have been estimated for calculation.

Circulation of water occurs via a small pump in the south-eastern corner of the basin which pumps water from the old lock entrance adjacent to the Glamis road bridge into a small channel at the south-eastern end of the basin. The pump is located in a small sump and operates on a timer for about 12 hours running per day.

4.5.3 Outflows

(a) Loss Over the Weir Overflows

The water flowing over the weirs, described in 4.5.2 (a), discharges into a pipe which runs along the south side of the basin under the Glamis Road and discharges back into the river through an outlet in the north face of the old lock wall.

(b) Evaporation

As described earlier for other dock systems.

(c) Seepage

As described earlier for other dock systems.

Calculation for the Rate of Each Inflow/Outflow

4.5.4 Calculation of Inflows

(a) Sluicing through the Dam at the Entrance to the River

When the tide rises above the level of the two weir overflows the water level in the basin rises with the tide until peak tide level:

Volume of inflow = (Peak tide river level - Weir level) x Area of basin

The area of the basin is approximately 1 900 m^2 as measured from scale drawings.

(b) Direct Rainfall Input

As previously described the basin being approximately 1 900 m^2.

(c) Surface Runoff

As previously, the estimated area draining into the dock being 700 m^2 and the runoff coefficient being 0.8.

4.5.5 Calculation of Outflows

(a) Loss Over Weir Overflows

As with other high-rate, short-time period losses in the docklands, this could coincide with rainfall or evaporation and other long time period, low rate, higher frequency losses. However, the volume of these latter flows is small during the time that the high rate, short period losses occur and so volumes of flow of the latter losses can be reasonably estimated from water level changes in the dock alone with little loss of accuracy. Because of this reasoning we can say:

Loss over weir overflows = Inflow through sluicing

for each input/output time, despite the presence of the other lower rate inflows/outflows.

(b) Evaporation

As described previously, the basin area being approximately 1 900 m^2.

(c) Seepage

As described previously.

4.6 Hermitage Basin, Canals and Tobacco Dock

4.6.1 Introduction

The inflows and outflows are as shown in Tables 4.9 and 4.10 respectively, principal inflows are shown on Figure 4.5.

TABLE 4.9

Inflows to the Hermitage Basin System

	Site number
Inflow from a Thames Water (TW) controlled storage tank	HB 111
Direct rainfall on to the system	-
Surface water runoff from the area immediately surrounding the system	-

TABLE 4.10

Outflows from the Hermitage Basin System

	Site number
Evaporation	-
Seepage	-

Water is introduced into the Hermitage Basin via a ballcock controlled storage tank which is filled direct from the Thames Water drinking supply. Water in the basin falls over a series of weirs under Vaughan Way and then in an easterly direction along Spirit Quay until it reaches the pumping station at the eastern end of Spirit Quay. The water is then pumped via underground pipes back to Hermitage Basin and also to Tobacco Dock. Water arriving in Tobacco Dock flows in an easterly direction along East Quay and then back down to Spirit Quay for circulation by the pump. A further pumping station is provided adjacent to Vaughan Way, at the bottom of the weir system leaving Hermitage Basin, to ensure that water levels in the canals are kept at a pre-set level by pumping direct from the basin to the canals if necessary. It is reported that there are no overflows or points of removal for water in the Hermitage Basin or the canal system.

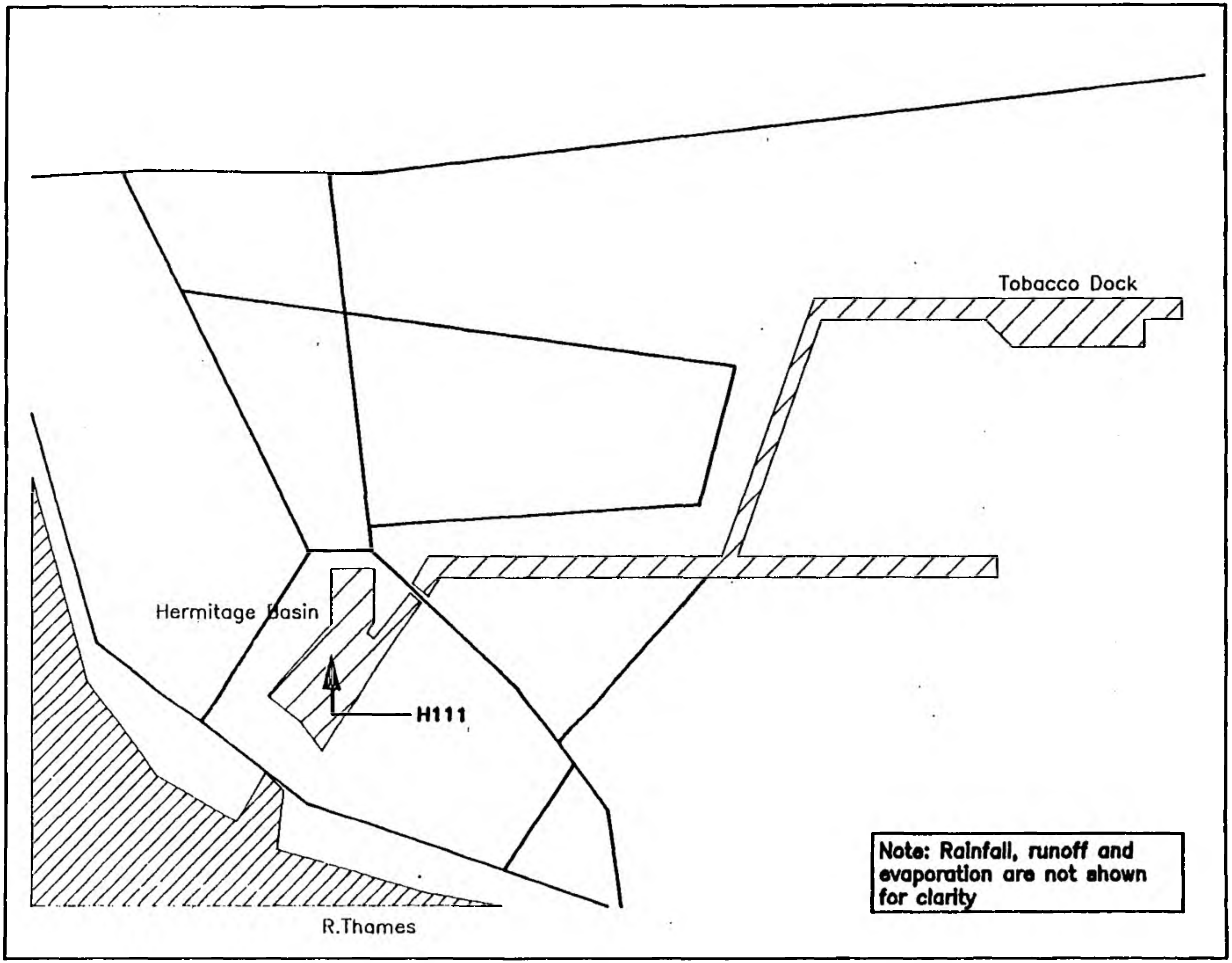


Figure 4.5

Hermitage Basin et al: Principal Inflows

4.6.2 Inflows

(a) Inflows from the Thames Water Controlled Storage Tank

Future use of the input will be to 'top up' the water level in the Hermitage Basin, hence the volume is likely to be small. Previously about 2 700 m^3/quarter were supplied by Thames Water. It is not possible to determine future usage from these figures. Hermitage Basin is currently drained for repair work.

(b) Direct Rainfall Inflow - as earlier.

(c) Surface Water Runoff

As described previously, the only appreciable drained area being adjacent to the canals.

4.6.3 Outflows

(a) Evaporation

As described earlier.

(b) Seepage

As described earlier.

4.6.4 Calculation Methods For Inflow

(a) Inflow from TW Controlled Storage Tank

Volume used in any month can be provided by from Thames Water metered records. This will be small when the Hermitage Basin has been refilled after maintenance work.

(b) Direct Rainfall on to the System

As described earlier, the relevant dock areas, determined from scale drawings are:

Hermitage Basin	3 400 m^2
Canals	2 700 m^2
Tobacco Dock	1 300 m^2

(c) Surface Runoff from the Area Immediately Surrounding the Water

Area draining into canals = 1 800 m^2

Calculated inflow volume as earlier with a runoff coefficient of 0.8.

4.6.5 Calculation of Outflow

(a) Evaporation

As described earlier, the area draining into the system being 1 800 m^2.

(b) Seepage

As described earlier for other dock systems.

4.7 Canada Water, Surrey Water and Albion Canal

4.7.1 Introduction

Inflows and outflows are listed in Tables 4.11 and 4.12, respectively. The principal inflows are shown on Figure 4.6.

TABLE 4.11

Inflows into the Canada Water - Surrey Water System

	Site number
Intake from the river into Surrey Water	SW 112
Pumping water from the local London Transport station into Canada Water	CW 113
Rainfall directly into the water	-
Surface runoff from the area immediately surrounding the system	-

TABLE 4.12

Outflows from the Canada Water - Surrey Water System

	Site number
Outflow to the river from Surrey Water	SW 112
Evaporation	-
Seepage	-

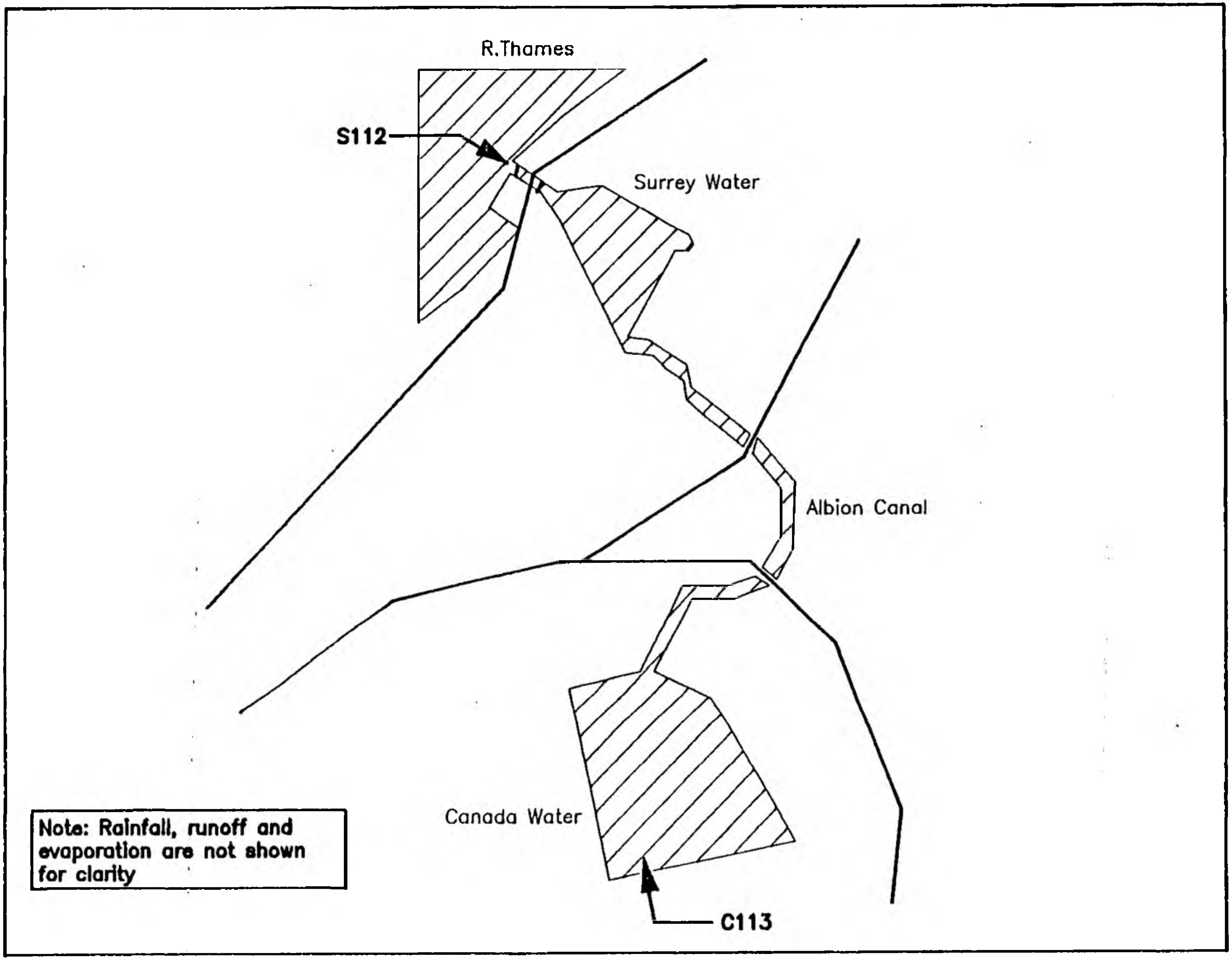


Figure 4.6
Canada Water et al: Principal Inflows

4.7.2 Inflows

(a) Pumping Groundwater from a Local Underground Station into Canada Water

Canada Water is a fresh water system. About 100 000 m^3/year are pumped from the local tube station of which 10 000 m^3/year are pumped into Canada Water. A possible future objective is to pump all the water into Canada Water to provide a net flow from Canada Water to Surrey Water in order that Surrey Water could also become a freshwater system. It is intended to normally maintain the water level in Canada Water at +3.9 m OD (the same level as the Albion Canal) by means of a valved outlet pipe. At present Canada Water level is lowered to allow engineering work to be carried out at the south side of Canada Water, and no water is being pumped from underground station into Canada Water. A weir set at a level of 4.7 m OD ensures that the level in Canada Water cannot exceed 4.7 m. The depth of water in the Albion Canal is maintained at 600 mm by a weir between it and Surrey Water which maintains Albion Canal water level at +3.9 m OD.

(b) Intake from the River into Surrey Water

If Surrey Water falls below 3.5 m OD a float switch detects high tide in the river and automatically opens penstocks until Surrey Water is raised to +3.6 m OD.

(c) Rainfall Directly on to the Water

As described previously.

(d) Surface Water Runoff

As described previously

4.7.3 Outflows

(a) Outflow from the River into Surrey Water

If Surrey Water rises above 3.7 m OD a float switch detects low tide in the river and automatically opens penstocks until Surrey Water level falls to +3.6 m OD.

(b) Evaporation - as described earlier.

(c) Seepage - as described earlier.

4.7.4 Calculation of Inflows

(a) Pumping of Groundwater into Canada Water

Currently 10 000 m^3/year are pumped at a fairly constant rate but this can be increased by LDDC. Records of volumes pumped during any period are available from LDDC.

(b) Intake from the weir into Surrey Water

On every occasion when the intake valves open the water level rises by 0.1 m. The area of Surrey Water is approximately 12 000 m^2, hence 1 200 m^3 of water enter each time the intake valves open. From a knowledge of how often intake valves are opened each month, the volume of inflow per month can be determined. However this will change if inflow from Canada Water is increased and could result in zero inflow.

(c) Rainfall

As decribed previously. Volume of rainfall can be determimed using areas from drawings as scaled:

Canada Water = 17 000 m^2
Albion Water = 3 800 m^2
Surrey Water = 12 000 m^2

(d) Surface Water Runoff

As earlier with the scaled areas for each basin being:

Canada Water = 2 700 m^2
Albion Canal = 9 600 m^2
Surrey Water = 6 200 m^2

and using an estimated runoff coefficient of 0.8.

4.7.5 Calculation of Outflows

(a) Outflow from Surrey Water to the River

A similar situation occurs as in (b) above except in reverse. If Canada Water input is increased to 100 000 m^3/year, outflow rate from Surrey Water will increase to this value plus (rainfall - evaporation).

(b) Evaporation - as described previously, using the dock areas already stated.

(c) Seepage - as described previously.

4.8 Greenland and South Docks

4.8.1 Introduction

The inflows and outflows are as shown in Tables 4.13 and 4.14 respectively, principal inflows are shown on Figure 4.7.

TABLE 4.13

Inflows into Greenland and South Docks

Inflows	Site Nr
Inflow through flap valve system in Greenland Dock from river	G 114
Discharge of local urban runoff into the dock	-
Direct rainfall into the docks	-
Overflow from Norway Dock into Greenland Dock	G 115

TABLE 4.14

Outflows from Greenland and South Docks

Outflows	Site Nr
Outflow through flap valve system in Greenland Dock to river	G 114
Losses in dock entrance	-
Outflow to development at Old Norway Dock	G 115
Evaporation	-
Seepage	-

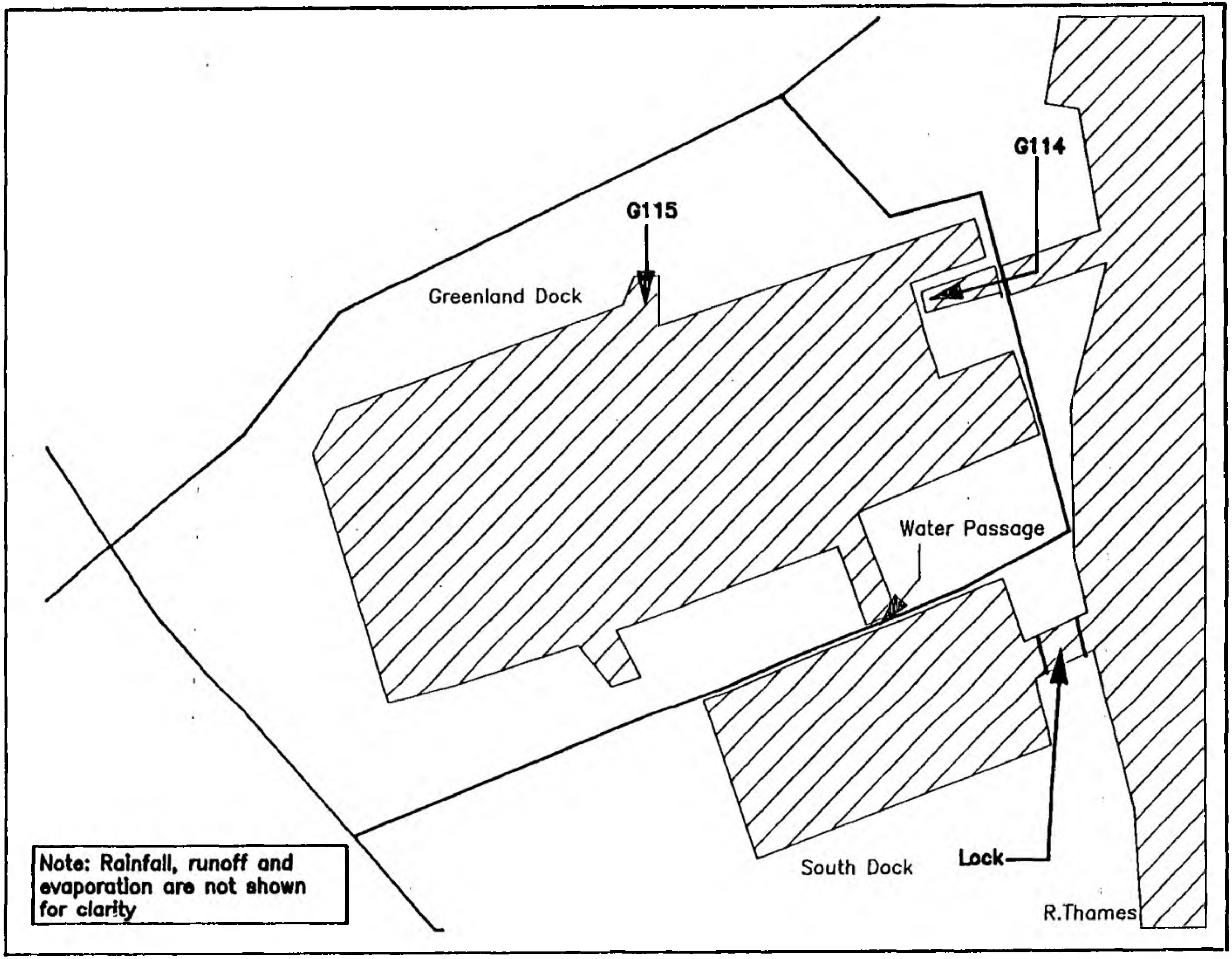


Figure 4.7 Greenland and South Dock: Principal Inflows

4.8.2 Description of Inflows

(a) Inflow through the Flap Valve System in Greenland Dock from the River

The old lock entrance to Greenland Dock has been dammed off and now a flap valve system operates whereby if Greenland Dock water level goes below 2.9 m OD the valve opens and causes the water level in the dock to rise to 3.0 m OD when water level in the river is greater than 2.9 m OD. Outflow is possible when water level in Greenland Dock reaches 3.1 m until dock level is 3.0 m OD, provided river level is less than 3.1 m. This outflow rarley happens because of other water losses.

(b) Discharge of Local Urban Runoff into the Dock

The paved area in the vicinity of the Greenland and South docks is drained into the dock. From the drawings, the contributing area and point of inflow for each drain is known.

(c) Direct Rainfall into the River - as earlier.

(d) Overflow from the Norway Dock into Greenland Dock

A weir overflow from Norway Dock causes flow into Greenland Dock at times of excess rainfall.

4.8.3 Outflows

(a) Outflow through the Flap Valve System in Greenland Dock to the River

As described for the inflows.

(b) Losses in Lock Use.

The lock in South Dock is the major loser of water in this system and it should be noted that the impounded level of 3.6 m in South Dock corresponds to a level of 6.3 m, relative to river datum. The lock gates are hydraulically operated and the minimum river level for lock use is 3.7 m relative to river datum.

(c) Output to Development at Old Norway Dock

An artificial lake has been filled with 10 000 m^3 of water from Greenland Dock. A holding tank between Greenland and Norway Docks is fed by gravity from Greenland Dock by a pipe at an invert level of 2.95 m OD in Greenland Dock. Water is pumped through a treatment plant before entering the lake.

(d) Evaporation - as earlier.

(e) Seepage - as earlier.

4.8.4 Calculation Methods for Inflow

(a) Inflow through the Flap Valve System in Greenland Dock

This can be determined from water balance:

Loss through locking and evaporation = Rainfall + Urban runoff + (Inflow-Outflow) through flap valves

where loss through locking can be determined as shown overleaf and net inflow from Norway Dock and seepage are small in comparison.

(b) Discharge of Local Urban Runoff into the Dock

The contributing areas for the pipes draining into the dock total 10.5 ha.

Hence using a runoff coefficient of 0.75 for each, runoff volumes can be calculated for a rainstorm.

(c) Direct Rainfall on to the Docks

As described earlier. The volume of rainfall being determined using the area of the docks, ie 10 ha.

(d) Overflow from Norway Dock into Greenland Dock

The quality of any discharges from this source will be tested.

4.8.5 Calculation of Outflows

(a) Outflow through the Flap Valve System in Greenland Dock

This occurs together with the inflow through the flap valves and is obtained as a net answer from the water balance detailed earlier.

(b) Losses through Locking

The area of the lock is approximately 220 m^2 hence outflow each time lock is used is:

$$\text{Outflow volume} = \left[\begin{array}{c}(\text{Water level in})\\(\text{dock})\end{array}\right] - \left[\begin{array}{c}(\text{Water level in})\\(\text{river})\end{array}\right] \times \text{Area of lock}$$

Water levels in the dock and river and times of lockings are recorded by the Marina at South Dock.

(c) Output to Development at Old Norway Dock

Now that this lake has been filled this output is negligible over the month compared with other significant flows.

(d) Evaporation

As described earlier.

(e) Seepage

As described for previous dock systems.

4.9 Locations and Sampling of Inflows and Outflows

Sampling is only necessary on flows which make a significant contribution to the dock system. From our assessment these are listed in Table 4.15. After initial sampling it may not be necessary to continue sampling at all of these locations.The circumstances under which inflows occur are also shown.

The principal inflows to six of the dock systems are from the tidal river Thames.

The inflows are spread over a 14.1 km stretch of the river and most only provide flows to the docks at around high water. Some only operate at high water spring tides and one (the temporary pumps for the West India Docks) operates continuously.

All the inflows have variable flow rates depending on the relative levels of water in the relevant dock and the river. Equally, at all the sites except the West India's temporary pumps, the time at which inflow occurs will depend on both the river level and dock water level.

The proposed collection of spot samples at these inflows will not adequately represent the quality of water actually entering the docks because of likely variations in river quality during the period of inflow due to tidal movement in the river. For the river inflows we therefore propose an alternative sampling strategy, as follows.

Samples will be collected at two sites in the river. Suitable sites are probably at West India Docks main entrance locks (WI 106) and at the Albert Basin (AB 101). On the day of sampling, samples will be collected every two hours over the necessary portion of the tidal cycle to ensure that water feeding into all the docks has been sampled. By relating the sampling time to tidal levels it will then be possible to determine the quality of water inflowing to each of the docks.

If the river is sampled at the two sites over a half-tide period (7 hours), a total of 10 samples will be collected for analysis. With the samples from the non-river inflows to the docks this will result in a total of 17 samples of inflows. This procedure will provide considerably more data than that envisaged by the Brief. The sites to be sampled are marked thus* in Table 4.15.

Results from the above sampling routine will be utilised with those from Thames Water's routine monthly water quality survey of the estuary to estimate the quality of the river inflows during the study period.

4.10 Monitoring of Inputs and Outputs

The determination of input and output volumes between sampling periods will be obtained from records which are currently being maintained. This includes records of lock operation and rainfall data. In the case of East India Docks and Surrey Water this approach may need to be reassessed.

TABLE 4.15

Significant Inflow Sites

Dock system	Site code	Description	Distance from London Bridge (km)	Inflow occurrence
Royal Docks	AB 101*	Impounding station	17.1	HW ± 1.5 h
	KG 102	Lock gates	16.6	HW springs
	RA 103*	Groundwater	NA	Random
	RA 104*	Pumping from Connaught Tunnel	NA	Random
	RV 105*	Groundwater	NA	Random
Isle of Dogs	WI 106*	Temporary pumps	10.0	24 hours
		Lock gates	10.0	HW > 6.5 m
	WI 107*	Contractor's discharge	N.A.	Random
	WI 108	Pumping station	4.8	HW ± 1.5 h
East India	EI 109	Broken lock gate	10.9	River level> dock level
Shadwell Basin	SB 110	Lock flap valve	3.1	HW springs
Hermitage	HB 111*	Thames Water potable	NA	Random
Surrey Water	S 112	Lock valves	3.0	HW > 6.8 m
Canada Water	C 113*	Groundwater	NA	Random
Greenland	G 114	Lock valves	5.7	HW > 6.3 m
	G 115*	Overflow from Norway Dock	N.A.	Random

Note : * Inflow to be sampled
NA Not applicable.

CHAPTER 5

ASSESSMENT, EVALUATION AND MONITORING OF WATER QUALITY WITHIN THE DOCK SYSTEM

5.1 Agree and Establish Sampling Sites

Prior to commencing the first round of sampling, the position of 28 sites within the docks from which samples were to be taken was agreed as shown on Figure 5.1.

Limehouse Basin no longer forms part of the study and the site that would have been sampled there has been replaced by a site in Tobacco Dock. The latter is part of the Hermitage Dock system.

Listing of sample sites between the dock systems is shown in Table 5.1. A sample numbering system has been established to provide for samples being taken at three depths (top, middle and bottom) at any one site. In addition to the main monthly sampling rounds, the numbering system allows for the weekly sampling rounds by Queen Mary College for the algology. Typical numbering of a sample is shown below.

Dock abbreviation - Royal Albert
Sampling site number
Sample position, A surface, B mid-depth, C bottom
Monthly sample round number
Weekly sample round by QMC

RA / 4 / B / 2 / 1

5.2 Sampling of Dock Waters and Field Measurement of Physical Determinants

The study has been established to allow for water samples to be taken from all sites at monthly intervals. In addition at times of peak algal activity, monitoring of algal growth is to be undertaken on a weekly basis.

This Stage I report is based upon the results of one monthly round of sampling, with algal monitoring of three periods.

Sampling commenced on the 16 May. Water samples have been generally taken from all sites at three depths, except for Hermitage Basin, which was being cleaned out. The site in Tobacco Dock is too shallow to allow three samples to be taken. Additional surface water samples were taken using sterilised bottles to allow bacteriological analysis.

TABLE 5.1

Dock Water Sampling Sites and Sample Numbering System

Dock abbreviation	Site Nr	Dock	
RV	1	Royal Victoria Dock	)
RV	2	Royal Victoria Dock	)
RA	3	Royal Albert Dock	)
RA	4	Royal Albert Dock	)Royal Docks
RA	5	Royal Albert Dock	)
AB	6	Albert Basin	)
KG	7	King George V Dock	)
KG	8	King George V Dock	)
WI	9	West India Dock	)
WI	10	West India Dock	)
WI	11	West India Dock	)
WI	12	West India Dock	)
WI	13	West India Dock	)Isle of Dogs
WI	14	West India Dock	)
P	15	Poplar Dock	)
B	16	Blackwall Basin	)
M	17	Millwall Docks	)
M	18	Millwall Docks	)
M	19	Millwall Docks	)
EI	20	East India Dock Basin	
SB	21	Shadwell Basin	)
H	22	Hermitage Basin	)Wapping
H	23	Hermitage Basin	)
S	24	Surrey Water	)
C	25	Canada Water	)Surrey Docks
G	26	Greenland Dock	)
G	27	Greenland Dock	)
SD	28	South Dock	)

At the time of sampling, on site measurements of physical determinants in the water column have been made using portable electronic instruments, to avoid any changes in their values resulting from exposure to atmosphere or ambient conditions. Measurements include

- temperature
- pH
- dissolved oxygen concentration
- electrical conductivity.

5.3 Pretreatment of Water Samples Prior to Analysis

After the water samples have been taken they have been preserved or pretreated prior to analysis. Before despatching samples to the specialist sub-contract laboratory, Associated Laboratory Services for detailed analysis, Mott MacDonald staff have carried out the determination of:

- turbidity
- sulphate
- chloride
- acidity/alkalinity.

A local laboratory has been established at the Beckton sewage works of Thames Water. This allows the above analyses to be carried out shortly after the samples have been taken.

5.4 Analysis of Dock Water Samples

Samples have been ~~tested~~ analysed as listed in Table 5.2. The results of which are discussed in Chapter ~~7~~ 6.
Details of materials and methods for the algology are described in Appendix C.

5.5 Additional Monitoring Tests

In addition to the sampling and analysis described in Section 5.4 the following additional monitoring tests have been carried out during the weekly algae sampling. Details of materials and test methods are given in Appendix G. The results are discussed in Chapter 6.

5.5.1 Photosynthesis/Light Flux Measurements

During weekly sample rounds 1 and 2, surface samples were taken from each site and concentrated by centrifugation. The algae were exposed to alternating periods of light and dark, of differing light intensities. Oxygen evolution and uptake rates were measured and P/I curves produced.

TABLE 5.2

Stage 1 Samples and Tests

Determinant	Sites/Occasions/Depths
Temperature	(26 x 1 x 3) + (1 x 1 x 1) = 79
Dissolved oxygen	(26 x 1 x 3) + (1 x 1 x 1) = 79
pH	(26 x 1 x 1) + (1 x 1 x 1) = 27
EC	(26 x 1 x 1) + (1 x 1 x 1) = 27
Turbidity	(26 x 1 x 1) + (1 x 1 x 1) = 27
Colour	Nil Nil
Sulphate	(26 x 1 x 1) + (1 x 1 x 1) = 27
Chloride	(26 x 1 x 1) + (1 x 1 x 1) = 27
Total phosphorus	(26 x 1 x 1) + (1 x 1 x 1) = 27
Orthophosphate	(26 x 1 x 3) + (1 x 1 x 1) = 79
Nitrate nitrogen	(26 x 1 x 3) + (1 x 1 x 1) = 79
Nitrite nitrogen	(26 x 1 x 3) + (1 x 1 x 1) = 79
Ammoniacal nitrogen	(26 x 1 x 3) + (1 x 1 x 1) = 79
Organic nitrogen	(26 x 1 x 1) + (1 x 1 x 1) = 27
Organic carbon	(26 x 1 x 3) + (1 x 1 x 1) = 79
Alkalinity/acidity	(26 x 1 x 3) + (1 x 1 x 1) = 79
Reactive silica	(26 x 1 x 3) + (1 x 1 x 1) = 79
Sodium	(26 x 1 x 1) + (1 x 1 x 1) = 27
Potassium	(26 x 1 x 1) + (1 x 1 x 1) = 27
Magnesium	(26 x 1 x 3) + (1 x 1 x 1) = 79
Calcium	(26 x 1 x 3) + (1 x 1 x 1) = 79
Iron	(26 x 1 x 3) + (1 x 1 x 1) = 79
Sulphide	(26 x 1 x 3) + (1 x 1 x 1) = 79
Total algal count	(26 x 1 x 1) + (1 x 1 x 1) = 27
Major algae speciation	(26 x 1 x 1) + (1 x 1 x 1) = 27
Chlorophyll a	(26 x 1 x 3) + (1 x 1 x 1) = 79
Faecal coliforms	(26 x 1 x 1) + (1 x 1 x 1) = 27
Total coliforms	(26 x 1 x 1) + (1 x 1 x 1) = 27
Faecal streptococci	(26 x 1 x 1) + (1 x 1 x 1) = 27
Salmonella	(26 x 1 x 1) + (1 x 1 x 1) = 27

5.5.2 Light Depth Measurement

(i) Secchi Disc Measurements

A 25 cm diameter steel disc painted in black and white quadrants was lowered into the water at each sampling site on all occasions and the depth at which the disc disappeared from view was recorded. The Secchi depth gives a rather crude but extremely useful estimate of the opacity of the water. Secchi depths in the order of 50 cm are indicators of highly eutrophic conditions.

(ii) Photon Flux Density Measurements

During the third weekly sampling round photon flux density was measured at the surface and at 0.5 m depth intervals. This was continued until the limit of net photosynthesis was reached, obtained from the P/I curves.

5.3.3 Chlorophyll/Light/Depth Relationships

Water samples were taken at all sites during the third weekly sampling round at metre intervals from the surface to the bottom.

5.5.4 Zooplankton in the Water Column

Zooplankton samples were collected at all sites using a 250 μm mesh net, by vertical haul from just above the bottom sediment to the water surface.

The total number of individuals was determined and also the species composition using a monocular microscope.

CHAPTER 6

DISCUSSION OF RESULTS

6.1 Introduction

Following one round of monthly sampling and additional weekly monitoring of the biology, the results do not permit the development of a long term treatment and management strategy. Nevertheless it is possible for initial observations to be made taking note of previous survey results, and to establish the format of the next stage of the study.

The detailed results of the sample analysis are shown in Appendix H, at the time of writing the results from all the algological measurements have not been completed.

6.2 Variations in Water Quality

6.2.1 Temperature and Electrical Conductivity

Only three previous surveys have investigated the variation in water quality with depth, one in the Royal Docks and the other two around Canary Wharf. The two earliest surveys covered very short periods of less than one month, and consequently provide little information about variation in water quality at depth during the year. The information available from these surveys as well as that from the present preliminary work is discussed for each dock system in turn.

(a) Royal Docks

A previous study, undertaken in July 1987, detected temperature differences between the surface and water at 8 m depth of about 2.4°C. At the same time electrical conductivity varied over the depth by about 0.27 $mS.cm^{-1}$.

In the routine sampling, observed surface water conductivity values ranged from 2.2 $mS.cm^{-1}$ in January up to 8.550 $mS.cm^{-1}$ in August.

The depth variations in temperature and electrical conductivity observed during the present survey exceed those noted above. The differences between surface and bottom waters being around 6°C and 0.32 $mS.cm^{-1}$ respectively. The electrical conductivity of the water is now also much higher than observed previously, being about 10.3 $mS.cm^{-1}$.

The higher conductivities in the dock during the summer are likely to be related to greater saline intrusion during periods of low flow in the river. This year rainfall has been low and has probably contributed to unseasonal low-flows. The larger temperature gradients observed this year result from the high temperatures during May.

In neither the historic data, nor data from present survey, is there evidence of a discontinuity in the temperature or conductivity profiles. The water is therefore not stratified, but the downward transmission of heat due to mixing is occurring at a much slower rate than that at which changes in heat and salt are taking place.

(b) Isle of Dogs

Considerable differences were observed between the depth profiles in the West India and the Millwall docks. They are therefore dealt with separately here.

West India Docks

Previous studies investigating the variation in water quality with depth in the West India Docks were only carried out around the Canary Wharf development. These studies took place in July 1986, and between May and September 1988. Both studies revealed little variation in temperature with depth. The average difference between surface and bottom temperatures being 2.5°C in the 1986 survey and 0.46 °C in August and September 1988. No information was reported about the variation in conductivity or salt concentration with depth.

During the present study, temperature variation down the water column was found to be somewhat greater.

In the three main West India basins the average temperature difference between surface and bottom water was 3.0°C. The temperature profiles do not indicate stratification. However, in Blackwall Basin and Poplar Dock surface water temperatures were about 3°C higher than in the three main basins, although the temperatures of the deeper waters were similar.

Variations in electrical conductivity with depth were small, the difference between surface and bottom waters being less than 0.2 $mS.cm^{-1}$.

The rate of vertical mixing in the Blackwall Basin and Poplar Dock is therefore less than in the three main basins.

Millwall Docks

No previous data exist for water quality profiles in Millwall Dock. The present survey detected a very distinct thermocline and halocline. However, the exact form of the temperature and conductivity depth profiles cannot be determined from the limited data available. The depth profiles are compared with those from the West India Docks in Figure 6.1. These show the presence of cold, more saline deep waters underlying warm fresher water. The average temperature difference between surface and bottom waters is 12.6°C, and the difference in electrical conductivity is on average 2.68 $mS.cm^{-1}$.

The cold, saline water is probably trapped in the Millwall Docks by the sill in the interconnecting channel between these and the West India Docks. This sill is approximately 6.8 m above the bottom of the docks.

The limited vertical mixing in the Millwall Docks, due to the stratification, has resulted in a more rapid rise in surface temperatures, which exceed those in the West India Docks.

(c) Other Dock Systems

There are no historic data for the other docks with which to compare results from the present survey. The observed differences in temperature and conductivity with depth are summarised in Table 6.1.

No stratification like that in Millwall Docks was found in the other dock systems. In general, the smaller, shallower docks had higher surface temperatures, and steeper temperature depth profiles. In addition the electrical conductivity of the impounded waters increases with distance of the intake below London Bridge.

TABLE 6.1

Summary of Surface Temperatures and Conductivities and Differences in these Parameters between Surface and Bottom Waters

	Surface		Depth difference	
	Temperature (° C)	Conductivity ($mS.cm^{-1}$)	Temperature (° C)	Conductivity ($mS.cm^{-1}$)
East India Docks	18.6	8.26	1.3	-0.30
Shadwell Basin	20.4	2.68	8.5	-0.21
Hermitage Basin	-	-	-	-
Tobacco Dock	24.1	0.39	-	-
Surrey Water	21.2	2.41	4.0	+0.02
Canada Dock	19.9	1.97	6.4	-0.05
Greenland Dock	19.2	4.31	7.6	-0.91
South Dock	19.9	4.38	7.8	-0.02

6.2.2 Nutrients

A preliminary evaluation of the chemical aspects of dock water quality reveals some surprising differences, since the main inputs for most of the systems is the Thames. There are, in most cases, high concentrations of inorganic nitrogen and inorganic phosphorus in the water column but the total and the relative amounts vary from dock to dock. The fact that any residual plant nutrients at all remain is an indication of the absence of nitrogen or phosphorus limitation, given the very high chlorophyll concentrations present in most of the dock waters.

In the Royal Docks the phosphate concentrations in the water, unusually, exceed the inorganic nitrogen concentrations. At 1.0 mg l^{-1} or more, there is no likelihood of P limitation. Although less nitrate remains there is still enough to generate another 40 $\mu g\ l^{-1}$ of chlorophyll if other factors necessary for growth were present in excess. It is our view that this 'spare' nitrogen and phosphorus are prevented from being utilised by light limitation. In the Royal Docks the site-to-site variation in N and P concentrations is rather small and there are no obvious plant nutrient gradients either horizontally between sites or vertically through the water column at each site. There is a preponderance of NO_3-N values at about 0.2 mg l^{-1} at many of the Royal Dock sites. It seems that this is the lower limit of detection of the technique used and at some sites, eg AB6, RA5, RA4, RA3, nitrogen may be approaching limiting levels. NH_4-N sometimes reaches rather high values, eg RA5 A1, 0.44 mg l^{-1}, RA4, 0.62 mg l^{-1} A1, 0.28 mg l^{-1} B1.

Ammoniacal nitrogen is readily used by algae and these patchy high concentrations are unusual. The most likely causes are zooplankton excretion or decomposition in the water column.

The situation in the West India Docks is quite different with respect to nitrogen. NO_3-N concentrations are about 20 times higher than those in the Royal Docks. PO_4-P concentrations are similar to those in the Royal Docks and so neither major nutrient even approaches limiting concentrations.

In the East India Docks, nitrate concentrations are also below the detection limit and phosphate values are around the 1.0 to 1.5 mg l^{-1} level, so in this respect the water quality resembles that in the Royal Victoria Docks.

Nitrate-nitrogen in Shadwell Basin shows a surface layer depletion of 0.4 mg l^{-1} with 1.9 and 1.5 mg l^{-1} at mid depth and in the bottom water. Orthophosphate too shows a vertical difference. It is possible that this surface depletion was due to algal uptake but surface chlorophyll concentrations are rather low. Without baseline data from last winter it is difficult to make firm conclusions. Winter nutrient concentrations are useful because they provide an indication of the potential productivity of the water in summer. Measurements made in the growing season suffer from the problem of distinguishing cause from effect, ie. are low nutrients in surface waters of Shadwell Basin the result or the cause of the chlorophyll values?

Nitrate-nitrogen and orthophosphate are present in a ratio of about 2 : 1 so phosphorus is in relative excess in terms of algal requirements. However, about 1 mg l^{-1} of NO_3-N in the water column indicates clearly that neither nutrient is limiting.

Canada Water's water quality data shows that this basin is distinctly different from other dock systems. The analytical techniques used are insufficiently sensitive to estimate concentrations of orthophosphate, nitrate-nitrogen, nitrite-nitrogen and organic nitrogen. Clearly concentrations of these variables are low in comparison with other basins, presumably because Canada Water is supplied from groundwater. The very low chlorophyll concentrations reflect the paucity of nutrients and it is the one dock system analysed in this study in which algal growth is limited by nutrients.

The Greenland Basin and South Dock are reasonably rich in nutrients. Again, there is more orthophosphate that nitrate-nitrogen both in absolute terms and in terms of algal requirements. If the low N : P ratio in the Royal Victoria Docks water is one cause of the dominance of Oscillatoria, it would suggest that this organism could also appear in Greenland Basin and South Dock.

6.2.3 Other Chemical Constituents

Only limited interpretation of data for the other chemical parameters is possible as these parameters have the little application in interpreting the processes affecting water quality.

The determinant of most interest is sulphide. However, none was detected during the present survey. Previous studies have not measured this parameter. Similarly, iron concentrations were low, the maximum observed concentration being 0.1 mg/l.

Calcium, sodium and potassium concentrations are as would be expected in waters of these salinities.

6.2.4 Algology

(a) Chlorophyll Concentration

In almost all the dock systems sampled, the algal biomass estimated as chlorophyll concentration is extremely high. On this basis, the Royal Docks, East India Dock and the West India Docks would be termed hyper-eutrophic and Greenland Dock, South Dock and Hermitage Basin, eutrophic. Shadwell Basin seems to have a lower algal biomass than most other sites. The only water bodies included in this study where algal crops are low are Canada Water and Tobacco Dock (H23).

(i) Variations in Chlorophyll Concentration with Depth

The results so far show that although high chlorophyll concentrations are present in the surface waters of the docks, in some systems, notably the West India Docks, very large populations are also found in the bottom waters. Light penetration at these depths is quite insufficient to allow net photosynthesis and hence growth, to occur.

The presence of this biomass at depth means either that the water column is mixing extremely rapidly, so that algae are transferred from the dark depths to the illuminated surface layers for a significant fraction of their life cycles; or, these populations are producing a large net drain on the oxygen budget of the docks.

In the Royal Docks, the variation of chlorophyll with depth is particularly large, with obvious surface blooms (eg RA4 A1(2)) or large sinking populations (eg RV2 C1(1)).

(ii) Variation in Chlorophyll Concentration with Time

No seasonal trends are evident from just two data sets. There does seem to be however, a very large week to week variation at virtually all sites and all depths. For example, the bottom water at AB6 in week 1 contained 24 $\mu g\ l^{-1}$ chlorophyll and in week 2, 152 $\mu g\ l^{-1}$, RV2, on the other hand, had a bottom chlorophyll concentration of 228 $\mu g\ l^{-1}$ in week 1 and only 13 $\mu g\ l^{-1}$ in week 2.

In the West India Docks at sites WI9, WI10, WI11, WI12, WI13 and WI14, the surface populations fell to about half their density from week 1 to week 2. Bottom water populations did not become higher in week 2, so it does not appear that this can be explained by sinking of the very dense dominant diatom Melosira.

In conclusion, algal crops in these dock systems vary, sometimes by an order of magnitude, frequently by a factor of two.

- from site to site
- with depth
- with time

Such short-term fluctuations often characterise nutrient-rich systems. Changes in algal biomass are likely to be caused by variations in the light climate, directly via the weather or indirectly via changes in water turbulence (inflow pumping, boat traffic, wind-mixing, etc).

Such a noisy algal baseline influences the modelling of the primary production system. [redacted]

Variability does not seem to extend to species composition, although this may change as the season progresses. At present, one of the most consistent features of the systems so far investigated is the species composition of the dominant algae. A classification of basins could be achieved on this basis. This is discussed in the following section.

(b) Algal Species Composition and Cell Density (Counts)

Spatial Variation

The most significant point to emerge from the first two sampling rounds is the difference in the dominant algae in each dock system.

In the Royal Docks (stations RV1, RV2, A3, RA4, RA5, KG7, KG8) the dominant, and often the only alga present, was Oscillatoria at cell densities of 155 to 100 000 100 μm units ml^{-1}. This was also true for Albert Basin (AB6) during the first week of sampling, but during the second week, a mixed population of Oscillatoria and the brown diatom Melosira was dominant.

The preponderance of the cyanobacterial (blue green algal) genus Oscillatoria is not a new phenomen. Previous results from an August 1988 survey by Bostock, Hill and Rigby showed Oscillatoria tenuis to be dominant. Further evidence is provided by the LDDC publicity leaflets, in which aerial photographs show clearly the characteristic dense blue-green colouration present throughout the Royal Dock system. This contrasts markedly with the colour of Thames water and other dock systems.

The brown chain-forming diatom, Melosira sp. produced extremely high cell densities in the survey to date. Melosira is an interesting genus in that it is normally common in lakes in early spring when the water column is turbulent and well-mixed. Its growth can be limited by silica deficiency, but this is clearly not a problem in Dock waters (see chemical analysis results). In lakes, the principal reason for the cessation of Melosira growth is the onset of thermal stratification and the increased vertical stability of the water column.

Melosira is also extremely abundant in parts of the West India Dock system, especially at stations WI9, WI10, WI11, WI12, WI13 and WI14, P15 and B16, with concentrations reaching 2 000 cells ml^{-1}

There is little Melosira in the Millwall Docks which are hydrographically isolated from the northern basin, with M17 (the nearest to the West India basins) containing only 1 to 3 cells ml^{-1}. The southern parts of the Millwall Docks (M18 and M19) contain a quite different algal flora with green algae such as Scenedesmus predominating.

The algal species composition and cell density in the northern basins of the West India Docks in 1989 is also different from that at similar sites in May 1988[(2)]. At that time, the sparse net plankton consisted of green algae, total algal biomass being dominated by picoplankton (<2 mm diameter). The change to Melosira dominance, which is evident at the western end of the northern basins where the piling activity for the Canary Wharf development is currently intense, is likely to be a result of this disturbance. Melosira is also dominant at the eastern ends of the West India Docks.

At present the normal pumping station close to the Cascades development is not operational and since early 1989 pumping has been carried out continuously from the eastern end of the docks.

Both of these observations suggest that Melosira is an indicator of turbulent water, and that blooms of this diatom may be expected at sites of frequent input or where water column stability is low.

(c) Secchi Depth

Table 6.2 shows the results of Secchi disc depths and photon flux density attenuation with depth for samples taken during week 3. Secchi depths for weeks 1 and 2 are given in Appendix H.

All sites with the exception of C25 have Secchi depths in the order of a metre or less, indicating highly turbid water. In general, the light penetration in the Royal Victoria Dock system is poorer than at other sites. This is due to the dominant alga Oscillatoria which contains gas vesicles. These are highly refractile bodies which enable the organism to float to the surface in stable water columns and which, incidentally, scatter light.

TABLE 6.2

Light/Depth Relationships

Weather	Site	Date	Secchi	Depth (m)	Surface	0.5	1.0	1.5 (metres)	2.0	2.5	3.0	3.5
					μmol m^{-2} m^{-1}							
Overcast	RV1	06.06.89	50 cm	7.5	180	127	30	11	<5	-	-	-
Sunny	RV2	06.06.89	50 cm	7.5	438	192	89	<5	-	-	-	-
Sunny	RA3	06.06.89	50 cm	9	95	55	12	<5	-	-	-	-
Overcast and raining	RA4	06.06.89	40 cm	9	67	18	5	<5	-	-	-	-
Sunny	RA5	05.06.89	40 cm	9	468	159	10	<5	-	-	-	-
Sunny	AB6	05.06.89	50 cm	7	392	75	7	<5	-	-	-	-
Overcast	KG7	05.06.89	40 cm	10	224	17	5	<5	-	-	-	-
Overcast	KG8	05.06.89	40 cm	10	247	100	10	<5	-	-	-	-
Overcast	WI9	08.06.89	120 cm	8	344	190	87	43	28	<5	-	-
Overcast	WI10	08.06.89	110 cm	8	571	244	95	45	22	<5	-	-
Overcast	WI11	08.06.89	80 cm	5	371	194	63	23	12	<5	-	-
Overcast	WI12	08.06.89	80 cm	7	314	170	72	32	13	-	-	-
Overcast	WI13	09.06.89	70 cm	7	192	89	35	16	<5	-	-	-
Sunny	WI14	09.06.89	70 cm	8	688	400	207	80	15	<5	-	-
Sunny	P15	09.06.89	70 cm	3	900	421	200	100	40	15	8	<5
Sunny	B16	09.06.89	50 cm	3	1 249	312	195	60	35	<5	-	-
Sunny	M17	09.06.89	60 cm	9	1 165	529	187	66	15	<5	-	-
Overcast and raining	E120	06.06.89	70 cm	3.5	128	37	10	<5	-	-	-	-
Sunny	M19	09.06.89	50 cm	7	267	137	32	<5	-	-	-	-
Overcast and raining	E120	06.06.89	50 cm	3.5	172	107	23	<5	-	-	-	-
Overcast	SH21	08.06.80	90 cm	7	279	124	58	32	13	<5	-	-
Very sunny	H22	07.06.89	70 cm	1	66	32	-	-	-	-	-	-
Very sunny	H23	07.06.89	>30 cm	0.3	233	-	-	-	-	-	-	-
Dull	S24	07.06.89	90 cm	4	107	66	43	18	7	<5	-	-
Very sunny	C25	07.06.89	>6 m	6	379	397	312	268	203	168	100	<5
Overcast	G26	07.06.89	50 cm	7	469	78	20	<5	-	-	-	-
Very dark	G27	07.06.89	50 cm	7	153	43	7	<5	-	-	-	-
Overcast	SD28	07.06.89	20 cm	7	232	92	8	<5	-	-	-	-

The low Secchi measurements are supported by the light flux data which show that the photic zone is only about 1.0 to 1.5 m deep.

The results from the West India Docks show that light penetration is better than in the Royal Victoria Dock, but that the water is still extremely opaque. The dominant alga in weeks 1 and 2 was Melosira which colours the water brown and does not have the light-scattering properties of Oscillatoria. Hence the algal crops are not so visible in the West India Docks and the poor light penetration not so obvious as that in the Royal Victoria Dock. The photic zone in the West India Docks extends to a depth of between 2.0 and 2.5 m. Shadwell Basin is similar.

Of the remaining sites, Greenland Dock and South Dock and the East India Dock have the least clear water. Hermitage Basin and Tobacco Dock are being drained at present, and thus are in an atypical condition.

The water clarity of Canada Water is much greater than any other dock system, due no doubt to its being fed from groundwater. The Secchi disc was visible at the bottom and thus the photic zone is likely to occupy most of the dock's depth. The water clarity is reflected in the virtual absence of phytoplankton (chlorophyll c 2 $\mu g\ l^{-1}$).

The light extinction measurements have been used in development of the mathematical model.

(d) P/I Curves

Photosynthesis/light experiments on samples of algal populations at 26 of the 28 sites are now complete. The algal populations at Sites C25 and H23 were so sparse that insufficient material was available. In any event, light limitation is, by definition, unlikely where the summer algal biomass is low.

The results from some sites (mainly the Royal Docks) have been analysed in order to provide inputs to the mathematical model. The importance of making P/I and light/depth and chlorophyll/depth measurements is becoming increasingly evident. The model currently being developed (see Chapter 8) requires these data. Normally in the early stages of model development, generalised coefficients and parameter values have to be extracted from the literature. In this study it is possible to provide detailed, site-specific photosynthetic parameters and light extinction relationships for the dock systems in question. Outputs from the model therefore will be based on the real situation pertaining at the time instead of extrapolation from measurements made at other times elsewhere.

Eight P/I relationships from sites in the Royal Dock system are shown in Figures 6.2 to 6.9.

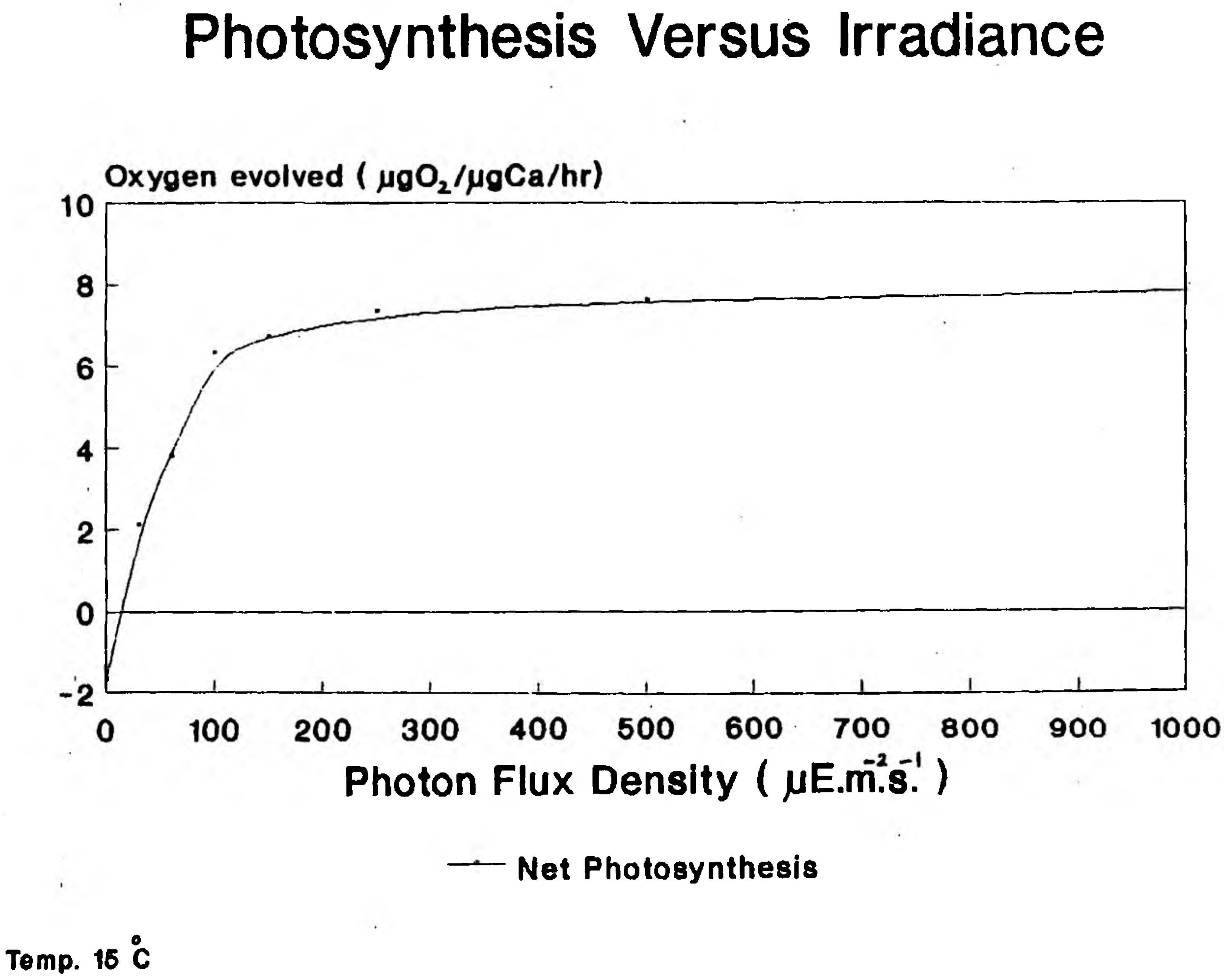
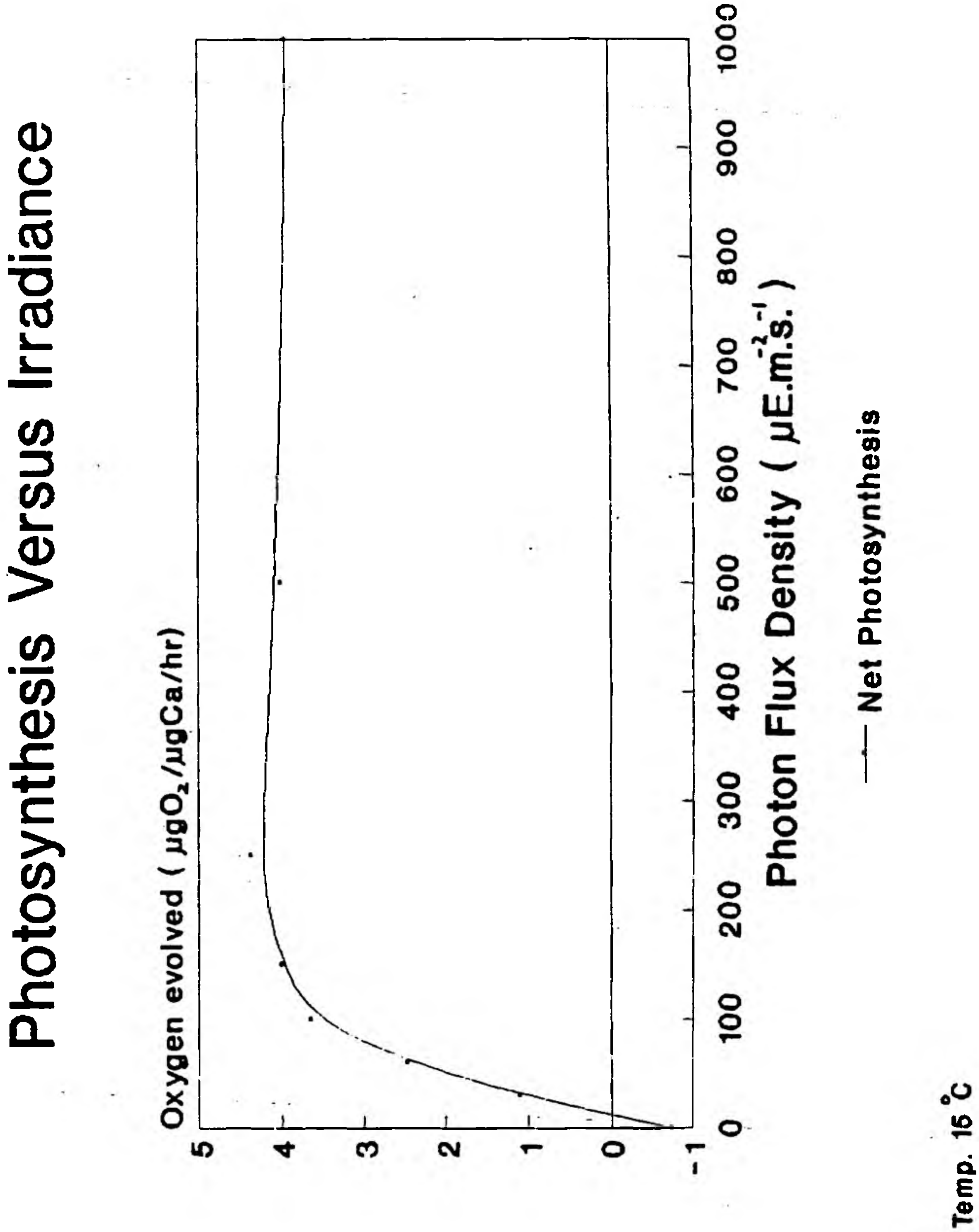


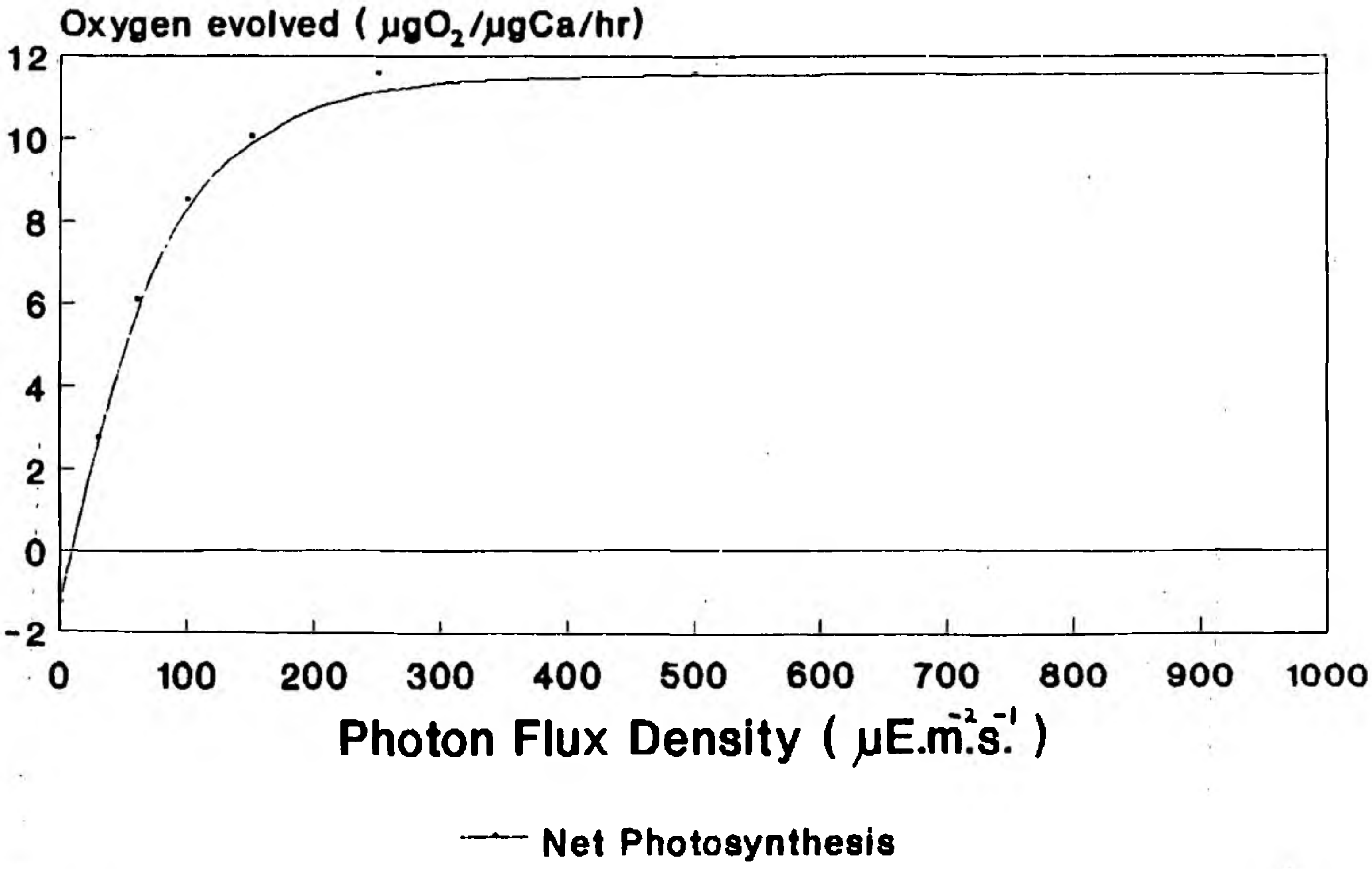
Figure 6.2 P/I CURVE. ROYAL VICTORIA DOCK. SITE RV1

Figure 6.3

P/I CURVE. ROYAL VICTORIA DOCK. SITE RV2



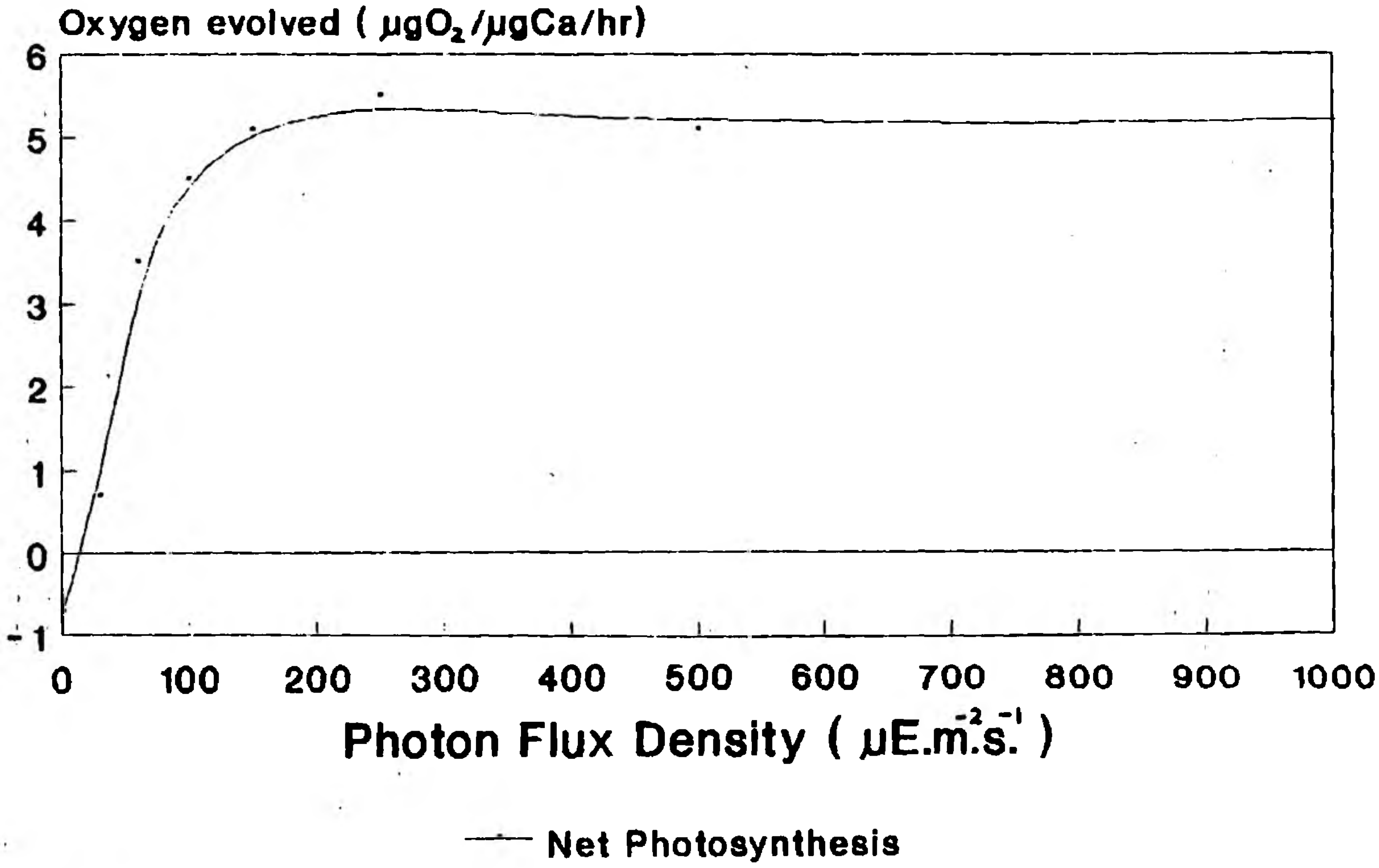
Photosynthesis Versus Irradiance



Temp. 15 °C

Figure 6.4
P/I CURVE. ROYAL ALBERT DOCK. SITE RA3

Photosynthesis Versus Irradiance



Temp. 15 °C

P/I CURVE. ROYAL ALBERT DOCK. SITE RA4

Figure 6.5

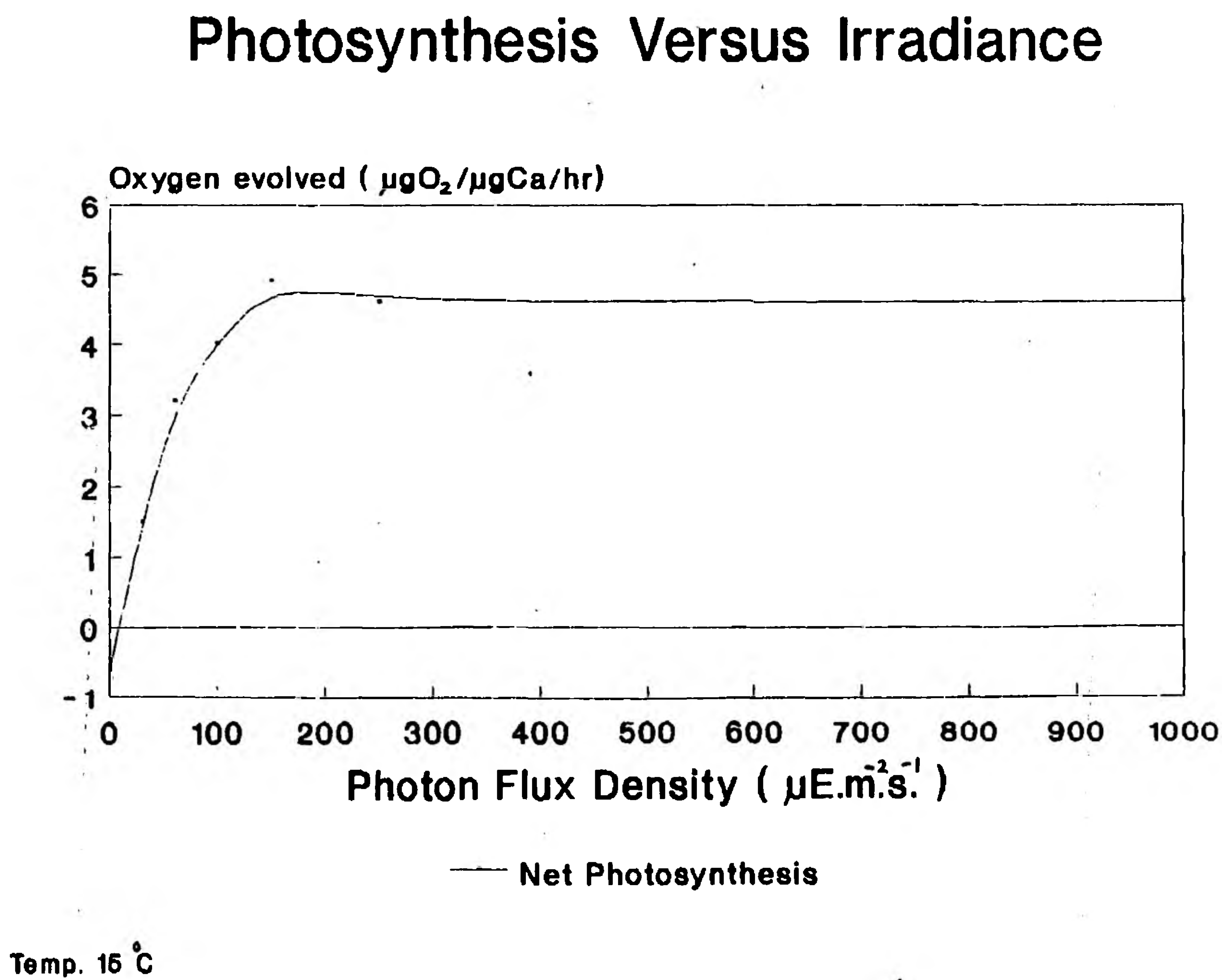
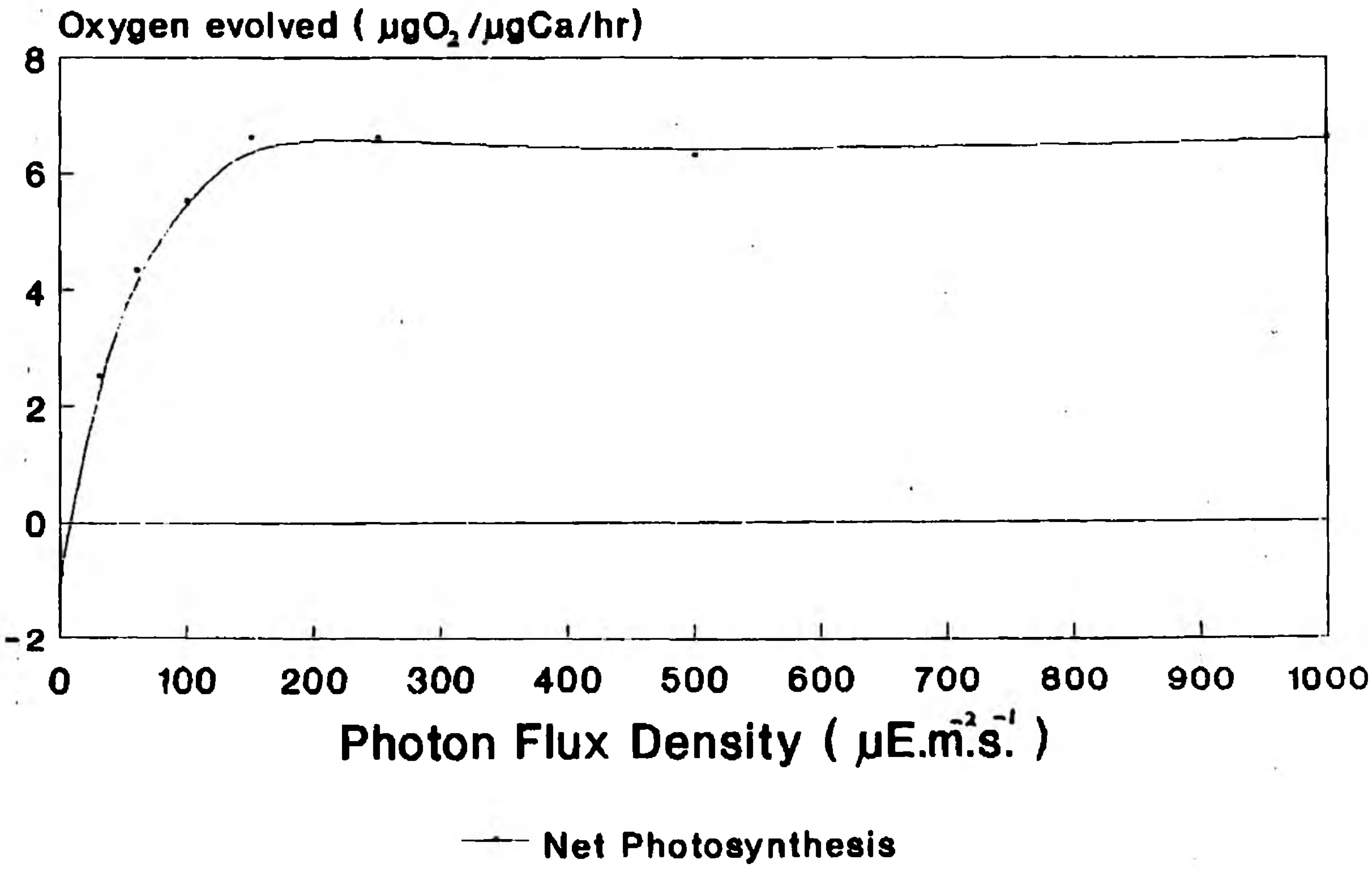


Figure 6.6

P/I CURVE. ROYAL ALBERT DOCK. SITE RA5

Photosynthesis Versus Irradiance

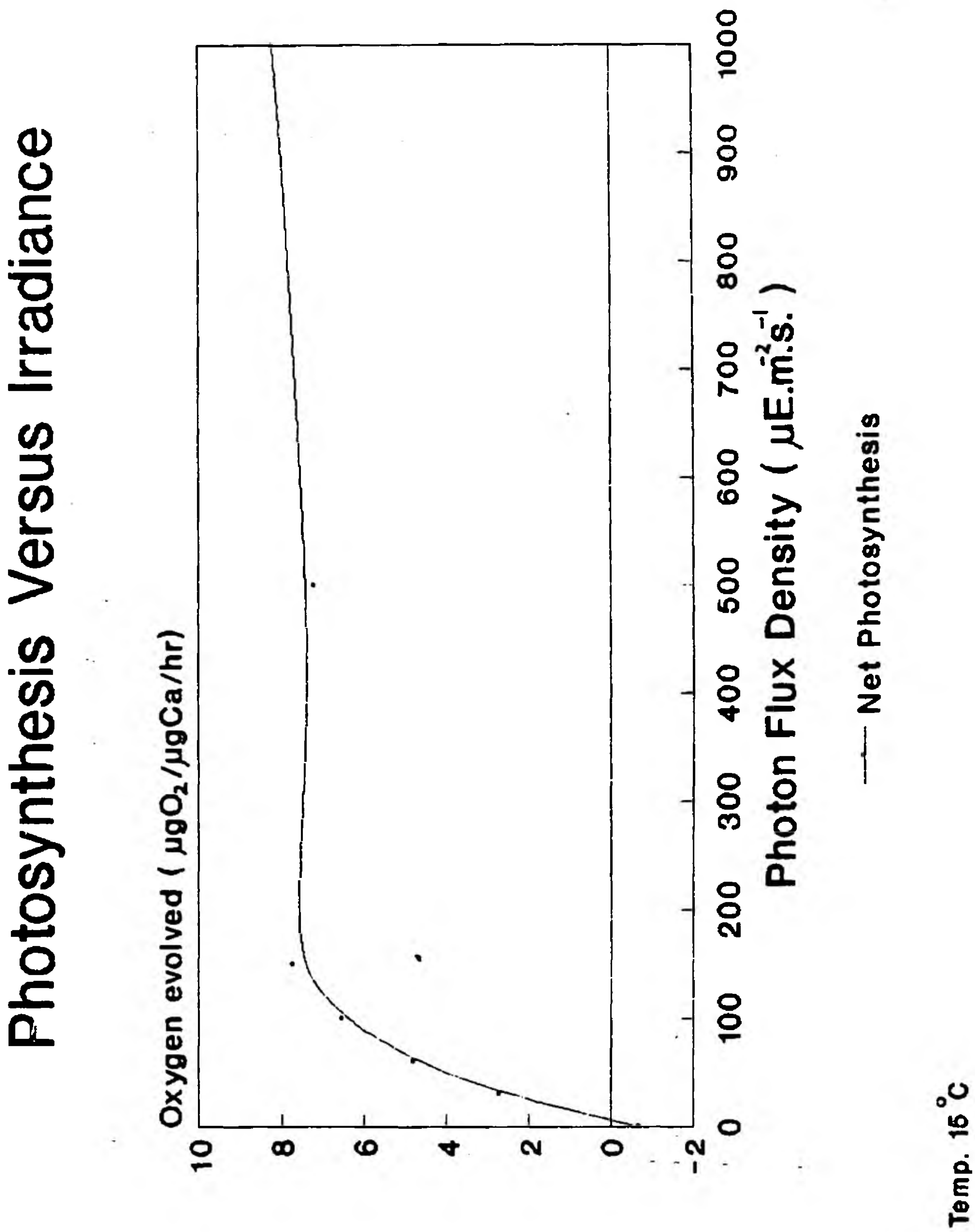


Temp. 15 °C

Figure 6.7 P/I CURVE. ALBERT BASIN. SITE AB6

Figure 6.8

P/I CURVE. KING GEORGE DOCK. SITE KG7



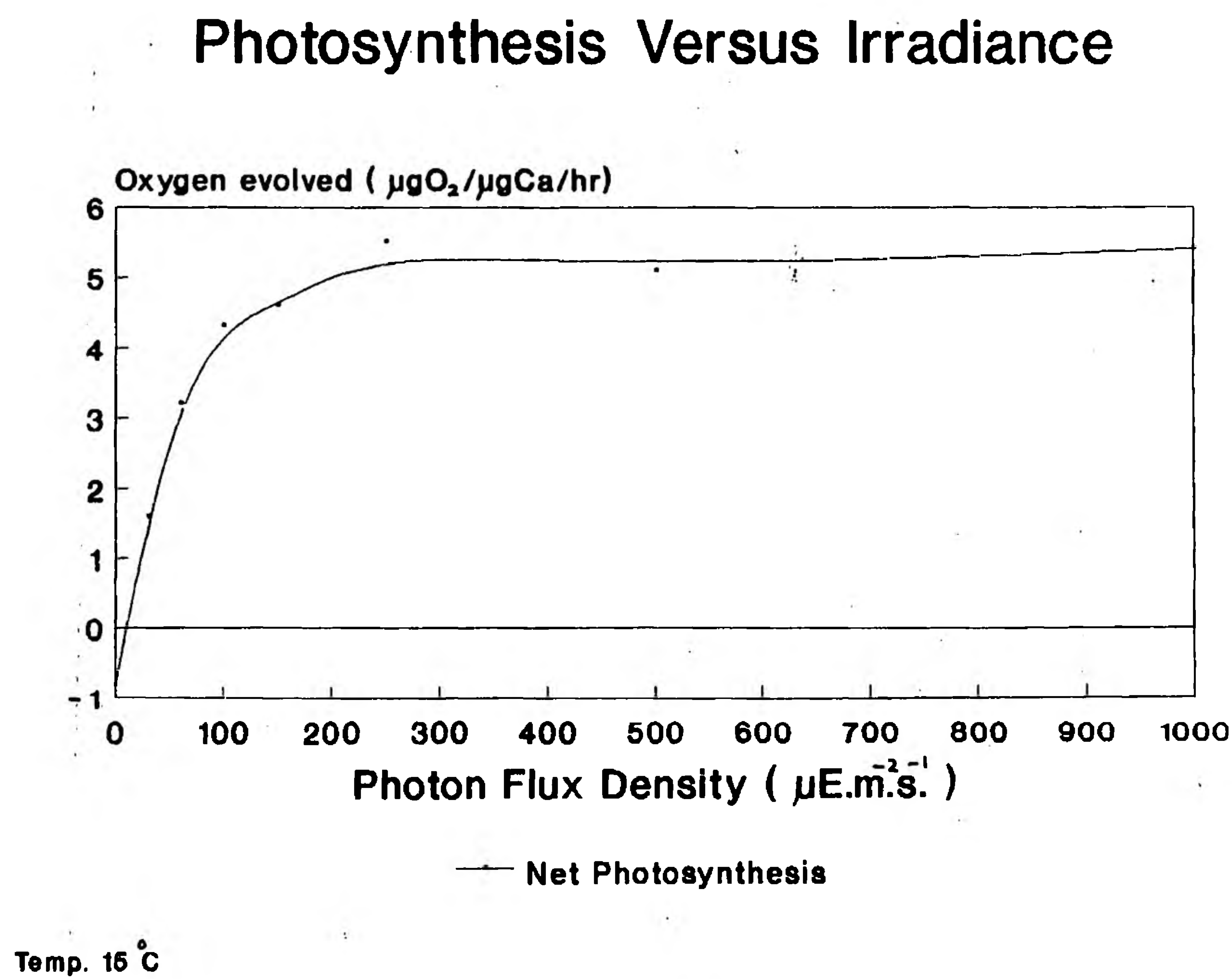


Figure 6.9 P/I CURVE. KING GEORGE DOCK. SITE KG8

The most immediately relevant point to note is that the compensation point (the photon flux density at which net photosynthesis is just balanced by algal respiration) is in the order of 10 to 20 μmol m^{-2} s^{-1}. Light penetration measurements and Secchi depths (Table 6.2) indicate that in the field, this amount of light penetrates only to 1 or 1.5 m.

In the previous section it was noted that considerable algal biomass is usually present below the mid-depth. This means, not only that algae below 1.5 m are severely light limited, but that they are net consumers of oxygen.

The second important conclusion to be drawn from the P/I data is that saturation of photosynthetic rate occurs at rather low photon flux densities and that P_{max} is achieved at about 1/10th bright surface daylight (2 000 μmol m^{-2} s^{-1}. This means that the algae at the surface in the Royal Docks are photosynthesising at maximum capacity. But Table 6.2 shows that P_{max} can only be achieved in the top few centimetres of water, and that it is the algae themselves which are the main preventers of light penetration to greater depths. (The chlorophyll/depth samples currently being analysed will give a more detailed picture of this effect.)

(e) Zooplankton

The zooplankton samples for weeks 1 and 2 are still being examined. The samples from the Royal Docks (RV1 to KG8) have been analysed for both weeks, and for the West India Docks for week 1.

(i) Estimates of Zooplankton Numbers

The results for estimates of zooplankton numbers (Table 6.3) show that numbers in the Royal Docks complex ranged from 7 to 56 l^{-1} in Week 1 and from 7 to 94 l^{-1} in week 2. Site RV1 had the highest number of individuals on both occasions. Numbers at site KG8 were low (7 and 9 zooplankton/litre). The week 1 results for sites in the Isle of Dogs Dock complex ranged from 16 to 93 individuals l^{-1}. Numbers were generally higher in the West India Docks than in the Royal Docks complex (with the exception of site RV1).

It is difficult to distinguish trends from these initial results. It is well known that zooplankton is patchy in distribution[1] which makes it difficult to obtain a true representation of numbers without an extensive sampling effort. Zooplankton exhibit diurnal vertical migration through the water column. They are furthest from the surface at midday and nearest the surface at midnight. Zooplankton also migrate horizontally to form aggregations as a result of such factors as behavioural responses or advective effects. Species observed to exhibit patchiness include Cyclops vicinus, Daphnia hyalina and Bosmina longirostris (George, 1981); all three were recorded from sites in the Isle of Dogs complex (Table 6.4).

TABLE 6.3

Estimates of the Number of Zooplankton Individuals per litre for each Sampling Site
(250 μm net samples)

Site	Number of zooplankton/l	
	Week 1	Week 2
RV1	56	94
RV2	10	37
RA3	*15	19
RA4	7	14
RA5	12	13
AB6	31	*11
KG7	16	16
KG8	9	7
WI9	36	
WI10	16	
WI11	47	
WI12	19	
WI13	16	
WI14	34	
P15	93	
B16	89	
M17	50	
M18	79	
M19	**	

Note: * Sample contained dense population of Oscillatoria sp.
** No estimate could be made, the sample was full of debris.

TABLE 6.4

Zooplankton Results - Percentage of Crustacea Found at each Sampling Site (250 μm net samples)

Royal Dock Complex

Species	Site RV1	RV2	RA3	RA4	RA5	AB6	KG7	KG8
Week 1:								
Eurytemora affinis	96	94	99	99	95	97	98	41
Cyclops sp. 1	4	6	1	1	5	3	2	59
Number of species	2	2	2	2	2	2	2	2
Week 2:								
Eurytemora affinis	92	81	93	98	98	96	92	83
Cyclops sp.1	8	19	7	2	2	4	8	17
Number of species	2	2	2	2	2	2	2	2

West India Docks Complex

Species	Site WI9	WI10	WI11	WI12	WI13	WI14	P15	B16	M17	M18	M19
Cyclops vicinus	96	94	96	97	85	88	91	95	75	98	*
Eurytemora velox	-	-	-	-	9	7	5	-	-	-	
Bosmina longirostris	1	2	-	-	2	-	1	2	-	1	
Daphnia hyalina	2	4	1	1	3	2	2	2	3	-	
Chydorus sphaericus	1	-	2	2	1	3	1	1	22	1	
Number of species	4	3	3	3	5	4	5	4	3	3	

Note: * Percentage composition could not be assessed - sample full of debris.

(ii) Species Composition

The results in Table 6.4 show that each dock complex has its own distinctive crustacean species composition. Crustacean species diversity is greater in the West India Docks than in the Royal Docks, with more species being found per site. The predominant group for all sites was the Copepoda (Eurytemora spp and Cyclops spp). Cladocera (Bosmina longirostris, Daphnia hyalina and Chydorus sphaericus were only found in the West India Docks. Zooplankton communities dominated by copepods, rotifers and small Cladocera such as Bosmina spp and Chydorus spp, graze less efficiently than communities dominated by large Cladocera such as Daphnia magna.

Two calanoid copepods were recorded. Eurytemora spp. are characteristic estuarine species; E velox is a euryhaline species, tolerating a wide range of salinity while E affinis is widely distributed in brackish waters. Cyclops vicinus (a cyclopoid copepod) is the commonest planktonic species of Cyclops and is chiefly a summer form.[2]

The Cladoceran Daphnia hyalina persists in lakes throughout the year. Bosmina longirostris is common in South and East England and is planktonic in ponds and lakes. Chydorus sphaericus is the commonest and most widely distributed of all Cladocera and is found on the bottom and among weeds.[3]

6.2.5 Microbiological Constituents

(a) Method of Assessment

The EC Directive on Bathing Water Quality is not applicable to the London Docks as they are not 'designated bathing waters'. However, the requirements of the Directive have been adopted as a guideline in assessing the bacteriological conditions of the docks.

The Directive sets guideline and mandatory values for the concentration of total coliforms, faecal coliforms, faecal streptococci, salmonella and enteroviruses. The water meets the requirements of the Directive if more than 90% of samples collected during the bathing season meet the guideline value, and 95% meet the mandatory value. Only 80% of faecal coliform and total coliform samples need to meet the guideline value.

It is important to note that the Directive does not require 100% compliance with the guideline or mandatory levels and that sampling need only to be carried out during the bathing season.

(b) Comparison of Available Data with EC Directive Values

As a single sample is insufficient to assess compliance with the Directive, previously collected data provided by the Client have been utilised on the assumption that sampling and analysis were carried out in accordance with the requirements of the Directive. Although it is clear that the specified fortnightly sampling frequency has not been complied with.

The percentage of samples meeting the EC Directive requirements are summarised in Table 6.5. The results indicate that the water at only six of the sampling sites meets the standard for bathing water. These are the Docklands Canal, Millwall Inner Basin, Millwall Outer Basin, Surrey Water, Canada Water and the Royal Victoria Dock.

The historic data indicate that most samples which exceed the maximum levels specified in the Directive have been collected between November and February.

If this period could be expected to be outside the 'bathing season' then the data from all except South Dock would comply with the Directive. However, this conclusion needs to be confirmed by the routine collection of statistically significant data, at a sampling frequency which meets the requirements of the Directive. In addition, the reasons for the failure to meet the standards between November and February should be investigated in order to improve water quality during that period and to predict likely deterioration in water quality during the rest of the year.

6.3 Initial Findings and Possible Mechanisms Influencing the Water Quality

6.3.1 Temperature and Electrical Conductivity

These two parameters are of primary importance in determining the hydrological processes occurring within the docks. By relating the temperature distribution through the water column to the heat inputs from incident solar radiation and influents to the system, it will be possible to determine rates of vertical mixing. Similar balances can be carried out using salt inputs (determined from the conductivity results) from the river influents to confirm the results.

The salt concentrations in the docks with river inflows are related to those in the river. Docks located further downstream are more saline. There is also a seasonal effect. During periods of low river flow which generally occur during the summer, salt water intrudes further up the estuary and correspondingly raises the salt concentrations in the docks. There will, of course, be a lag between increases in salt concentration in the river and that observed in docks because of the limited rates of exchange.

TABLE 6.5

Percentage of Samples Meeting the Bathing Water Directive Requirements

Location	Total coliforms Guideline	Total coliforms Mandatory	Faecal coliforms Guideline	Faecal coliforms Mandatory	Faecal Streptococci	Salmonella	Notes
Royal Victoria Dock	100	100	89	100	100	100	Complies
Royal Albert Dock	67	89	89	100	89	100	-
Albert Basin	71	100	100	100	100	100	-
King George V Dock	75	100	100	100	71	100	-
West India Dock	72	100	100	100	100	100	-
West India Dock South	72	100	86	100	100	100	-
South Dock	72	100	86	100	100	100	-
Poplar Dock	72	100	100	100	100	100	-
Blackwall Basin	72	100	86	100	100	100	-
Millwall Inner Dock	86	100	100	100	100	100	Complies
Millwall Outer Dock	100	100	100	100	100	100	Complies
East India Dock	43	86	57	86	72	100	-
Shadwell Basin	86	86	100	100	86	100	-
Hermitage Basin/Canal	100	100	100	100	86	100	Complies
Surrey Water	100	100	86	100	100	100	Complies
Canada Water	100	100	100	100	100	100	Complies
Greenland Dock	80	90	80	100	90	100	-
South Dock	86	86	86	100	100	100	-

Note: Only a limited number of samples were collected for enterovirus and rotavirus enumeration. None were detected.

Secondly, temperature and salt concentration influence the density of the water. Large differences over the water column can result in stratification and reduced vertical mixing. Deeper layers may then become devoid of oxygen and this may lead to release of hydrogen sulphide. At the same time surface layers may support high algal populations and the subsequent settling of algal cells may remove nutrients from the surface layer.

In addition, oxygen solubility and algal speciation depend on temperature and salt concentration. Thus, they can influence the oxygen balance in the docks and may influence the type of dominant algae.

6.3.2 Algology

Algal crops, as estimated by chlorophyll concentration, are large or extremely large in all dock systems except in Canada Water, Tobacco Dock and Hermitage Basin.

Nuisance algae are present in quantity only in the Royal Docks. Here, high concentrations of the potential surface-scum-forming blue-green alga Oscillatoria are present at all eight sites in the Royal Dock system.

Few surface accumulations of algae have been evident so far during this growing season. The degree of physical mixing in the water column is critical for the formation of surface scums. Fortunately, the Royal Docks surface waters are wind mixed for much of the time. During periods of hot, calm weather, surface scums may develop, particularly at the eastern ends of the Royal Docks basins.

This point has important implications for development strategy. In the envisaged plans for the Royal Victoria Dock, (New Civil Engineer 18 May 1989) the wind stirring will be much reduced in the proposed semi-enclosed small basins and surface scums of nuisance algae are very likely to develop.

In the last round of sampling, for which a detailed analysis is not yet available, the preliminary results indicate that the incidence of Oscillatoria is increasing in the West India Docks. It is now appearing in the East India Docks. Clearly, it is important to monitor the incidence of potential nuisance bloom formers in all dock systems at least for the remainder of this growing season.

The two most significant problems arising from algal growth are:

(i) Surface Scum Formation

This could adversely affect the development potential of the water body in question because surface scums are aesthetically unpleasant and after sinking and decay can cause noxious smells.

(ii) Deoxygenation of Water Below the Thermocline

On occasions when the dissolved oxygen concentration reaches 2 mgl^{-1} or less, fish and other oxygen-breathing organisms are stressed and if the deoxygenation continues, they die. This happens in circumstances of extreme eutrophication coupled with water column stability and accumulation of decaying algal biomass in the bottom water. This situation is dependent on climatic conditions in the season concerned in systems where the algae are light limited. Hot, calm sunny summers will cause:

- higher algal growth rates
- reduced wind mixing
- reduced re-aeration at the surface
- fast deoxygenation rates in the bottom water

No indent

At the moment the summer 1989 seems to be an excellent time to monitor these effects since it has been the warmest and brightest for some years.

We recommend that detailed monitoring of the algae continues until the autumn overturn when the thermocline breakdown occurs and the water column again becomes fully mixed.

Subsequent frequency of monitoring should be determined at that stage, probably during September/October.

There is anecdotal evidence of skin irritation problems being caused by algal blooms in the docks. High concentrations of algae are inevitably associated with high concentrations of bacteria, protozoa and other micro-organisms. We are not aware that the specific algae identified so far in this study are known to be skin irritants. Such a problem could be caused by a multiplicity of factors, including the susceptibility of the individual to allergic reactions. The brief does not specifically address this issue and the question and the approach to investigating it needs to be decided in Stage 2.

6.4 References:

1. eg George, D G (1981) Zooplankton patchiness. Rep Freshwater Biol Ass. 49, 32-44.

2. Harding, J P and Smith W A (1974) A Key to the British Freshwater Cyclopoid and Colanoid Copepods. Scientific Publications Nr 19. Freshwater Biological Assoiction 56 pp.

3. Scourfield, D J and Harding J P (1966) A Key to the British Freshwater Cladocera. Scientific Publications Nr 5 Freshwater Biological Association 55 pp.

CHAPTER 7

IDENTIFICATION AND EVALUATION OF AN EMERGENCY TREATMENT SYSTEM

7.1 Introduction

On the basis of the data from the first sampling round, which is discussed in Chapter 7, algal production in the dock systems appears to be unlimited by nutrient supply but limited by light availability. At the same time, most algal production is in the upper 1 m of the water column.

Short-term control of an algal bloom by attempting to restrict the nutrient supply will therefore probably be unproductive. Possible alternatives include:

- restricting the available light reaching the algal cells;
- disrupting the algal cells;
- removing the algal crop.

These three options are discussed in more detail below. In addition to these options, additional treatment will be required to alleviate the immediate deleterious effects of a bloom.

7.2 Possible Treatment Option

7.2.1 Restriction of Light Reaching the Algal Cells

Light availability may be reduced by increasing the turbidity of the near surface water or by inducing sufficient circulation so that the algal cells are removed from the photosynthetic zone.

(a) Powdered Activated Carbon

This has been used to increase the near surface turbidity of natural waters. Regular application is required to maintain a high turbidity, and during its use the water colour and clarity will be affected. However, little capital cost is required and the method can be used at short notice.

(b) Inducing Circulation

Circulation within the docks could be increased by a variety of methods. All have been used previously and the choice of system will depend on mixing capacity, capital costs and likely running costs. The mixing capacity has to be sufficient to overcome the algal depth regulatory system.

Possible methods are:

- air diffusion through perforated pipes;
- air diffusion through diffuser domes;
- mechanical pumping of deep water to the surface;
- air-lift pumping of deep water to the surface;
- jet-induced circulation by mechanical pumping;
- mechanical surface aerators.

Of these methods the first two are probably the most practical and cost effective.

7.2.2 Disruption of the Algal Cells

The normal biochemical processes of the algal cells may be disrupted by a variety of chemical, biological and physical techniques. Of these the most common are:

- application of copper sulphate;
- application of proprietary algicides;
- application of potassium permanganate;
- chlorination;
- liming;
- viral control;
- ultrasonic disruption of gas vacuoles

(a) Chemical Application

The most ecologically sound product for chemical control of algae is probably copper sulphate, given its extensive use in potable water reservoirs. It is known that most of the applied copper will precipitate under the conditions found in the docks. However, this normally occurs in most natural freshwater environments and its use is still likely to be effective.

Regular application of such an algicide is likely to be required, and this may result in limitations being imposed on the longer-term use of the method to avoid problems of toxic accumulation.

(b) Alternative Methods

Viral control and ultrasonic disruption of the gas vacuoles will require more extensive preparation than other methods. They are still experimental, and are unlikely to be recommended in the short-term.

7.2.3 Removal of Algal Crop

In the smaller docks a possible technique will be to remove the algal crop if it is concentrated in the upper layers of the water column by selective drawdown of the dock; releasing only near surface water, with subsequent replacement with river water at the following high water. Such a technique will not be effective if the algal population is distributed throughout the water column, unless complete drainage of a dock could be considered.

To minimise the aesthetic drawbacks of such a method, drainage could be carried out at night. Due consideration of navigational requirements will also be necessary.

7.2.4 Additional Treatment

Control of a bloom by disruption of the growing process will result in two side effects; deoxygenation due to cell decay; and the possible production of foam and algal mats caused by water recirculation.

Deoxygenation can be countered by the use of floating aerators, such as that used on the river Thames; and a method of collection for floating algal products, such as skimmers or booms, may be required. Present procedures for the removal of floating debris may also be suitable for the removal of floating algal products.

7.3 Conclusion

Of these alternative methods the following will be assessed in more detail during the next phase of the study, when more survey data become available and as part of a long-term treatment strategy:

- activated carbon
- induced circulation through perforated pipes;
- application of copper sulphate, or a proprietary algicide;
- removal of the algal crop by drainage;
- aertors;
- skimming techniques.

CHAPTER 8

MATHEMATICAL MODELLING

8.1 Introduction

The effective management of the water quality in the Docklands requires the ability to:

- predict any change in the water quality;
- define, examine and compare alternative management options and to test for the consequences of implementing these various actions.

In an attempt to meet these largely qualitative criteria it is helpful to have recourse to some form of quantitative water quality model.

There are two basic forms of model which may be employed to represent the prototype system in such studies:

- physical (scale) models;
- mathematical models.

A mathematical model is to be developed for this project.

Mathematical modelling has advanced rapidly in recent years with the development of high speed computers, algorithms and graphics. The artificial environment offered by a computer has become the ideal medium in which to perform modelling exercises and the models being produced are generally more flexible, adaptable and economic than their physical counterparts.

Mathematical modelling is based upon the representation of a system in a mathematical form. This representation may be via inductive (usually statistical) or deductive (theoretical) methods. By formulating the equations which describe the system's behaviour and then solving them on a computer the model can be used to simulate the prototype's behaviour. In general an empirically based model (predominantly stochastic) requires a large amount of data for calibration and its validity outside the data range may be suspect, whilst a process based model (predominantly deterministic) requires little field data but may be inaccurate if the fundamental process is not well understood. The specific form of the model equations (ie degree of empiricism) have to be determined so that the most appropriate interconnection between the experimentally gathered data and theoretical concepts can be made.

The identification of the processes which are dominant in the prototype system and hence require modelling is important if the mathematical model is to adequately simulate reality. When identified the model can be built and a sensitivity analysis carried out using prototype data to determine the relative importance of each subcomponent in the system, as shown in Figure 8.1. This procedure provides some feedback on the preliminary model identification; leading to an improvement in the model as well as providing a wider understanding of the behaviour of the eco-system in the docks.

Following the sensitivity analysis sub-cycle of the model development procedure, the model can then be set up to simulate the system. This requires calibration from a dataset. If the model can be adequately verified it can then be used for simulation

A simulation model will form the core of a computer-aided management system.

8.2 Modelling the Physical Processes

8.2.1 Background

A mathematical model of the physical processes will be composed of mathematical expressions which attempt to quantify the physical laws of:

- conservation of mass;
- conservation of momentum;
- conservation of energy.

All three laws can be applied in the form of a budget or balance over a volume of fluid.

The physical processes can be described by functions of the four independent variables; the spatial (x, y, z) and temporal (t) dimensions (see Figure 8.2). The relationship between a function expressing the conserved quantity and the rate at which it changes with respect to any of the independent variables will lead to a partial differential equation.

The partial differential equation which expresses mass conservation assumes that the difference between the mass entering and leaving a body of water is being stored within the water body by a change in volume.

The momentum equation is a vector relationship which considers that the change in momentum of a body of water is caused by forces acting on the water body. The forces considered are assumed to be acting uniformly over the body of water and on its boundary.

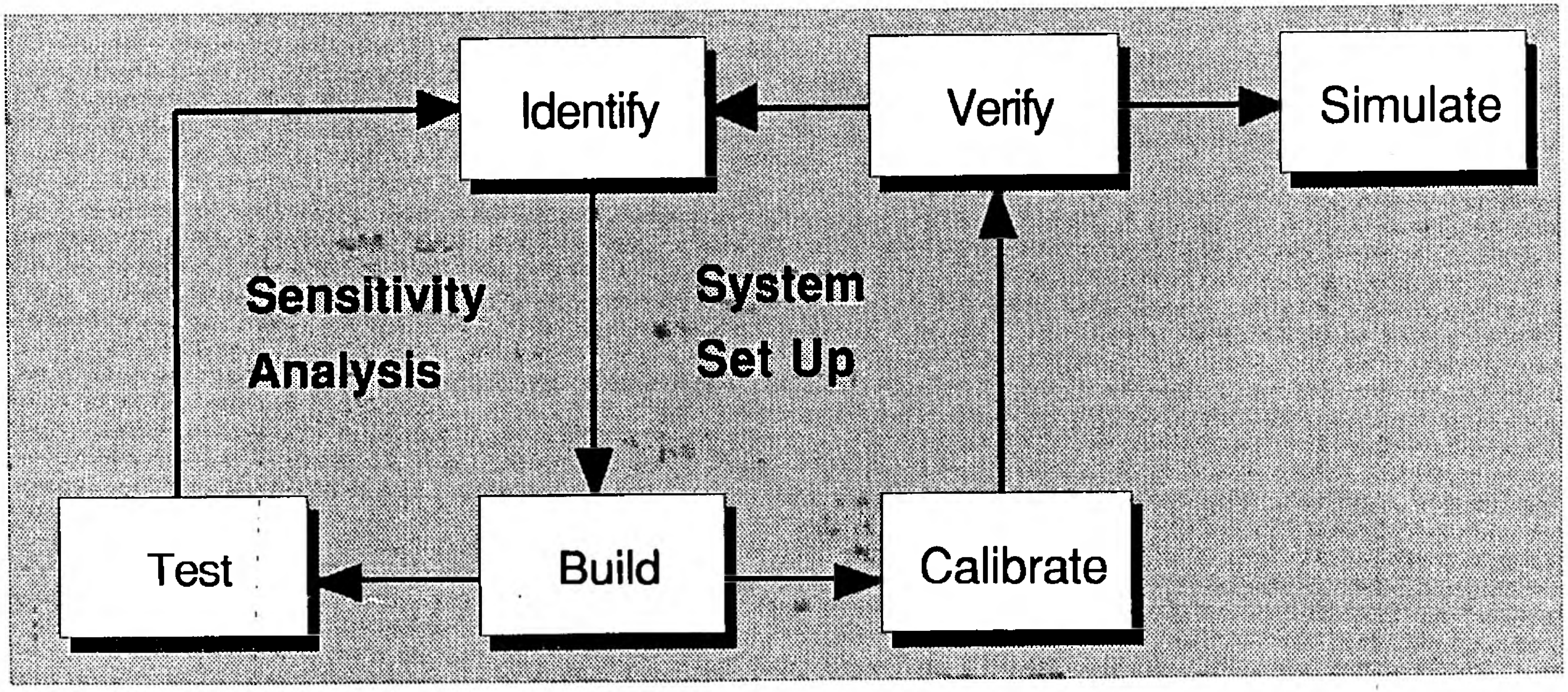
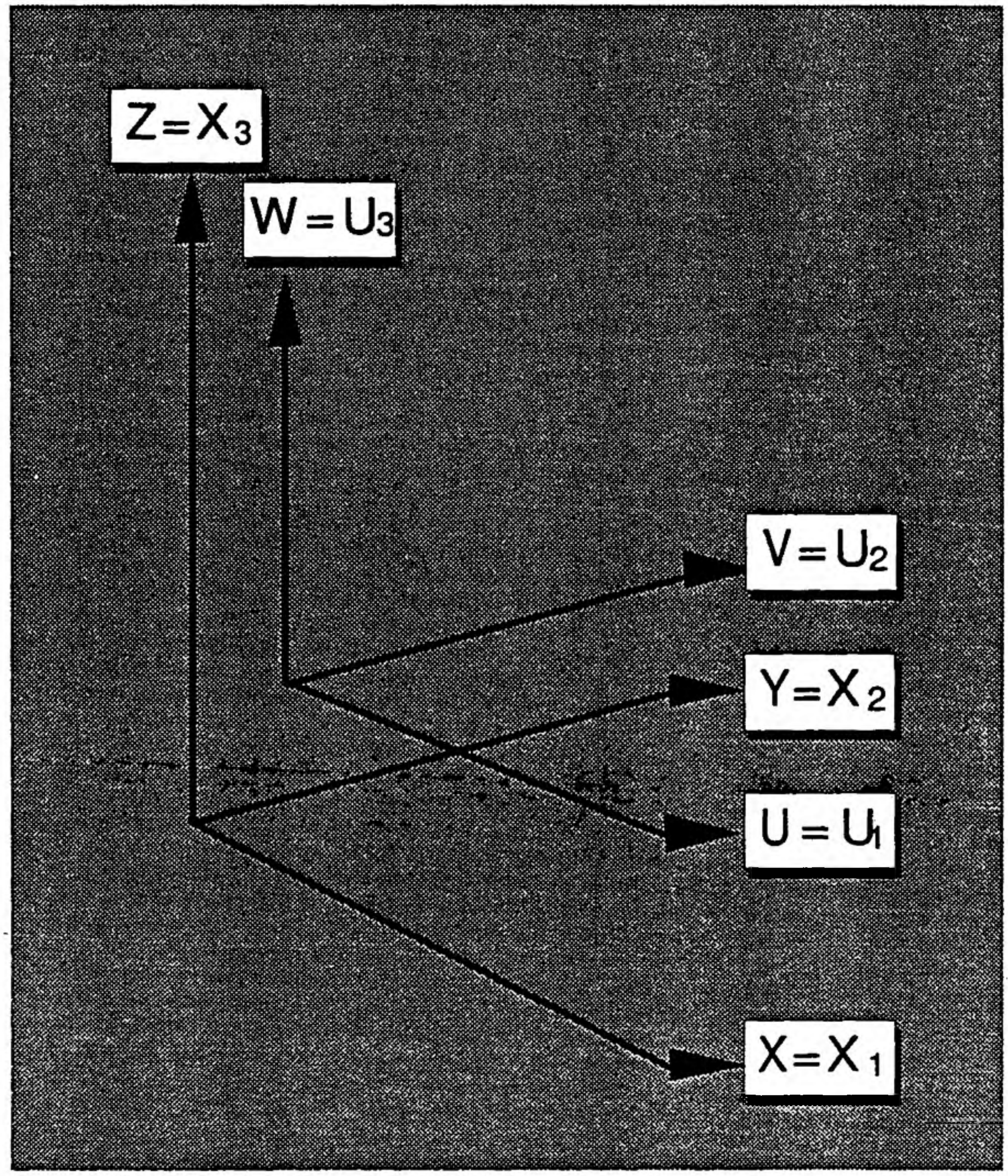


Figure 8.1
Model Development Cycles

Figure 8.2

Co-ordinate System



The energy equation uses a scalar relationship which considers the interchange between potential and kinetic energy. This requires knowledge not only of the work done by the external forces on the water body and the energy transfers into and out of the water body, but also the sources and sinks of energy within the body of water.

In the case of the equations which express the conservation of momentum and energy, they cannot be solved in their purest form; assumptions and simplifications have to be made by the judicious use of empirical data.

8.2.2 Fluid Flow

The equations which govern the motion of a fluid can be best obtained by coupling the equations expressing conservation of mass with the conservation of linear momentum.

Using the shorthand tensor notation (eg $x_1 = x$, $x_2 = y$, $x_3 = z$ and referring to the co-ordinate system of Figure 8.2, the equations for a unit volume of fluid can be written as:

(a) Conservation of Mass

$$\frac{\partial \rho}{\partial t} + \frac{(\rho U_i)}{\partial x_i} = 0 \qquad (8.1)$$

(i) (ii) (for i = 1, 2 and 3)

where the rate of change of density, with time (term (i)) and the net change in mass flow rate (ρU_i) over the volume (term (ii)) are balanced.

(b) Conservation of Momentum

$$\frac{\partial (\rho U_i)}{\partial t} = F_i - \frac{\partial (U_j(\rho U_i))}{\partial x_j} - \frac{\partial P}{\partial x_i} + \frac{\partial \tau_{ij}}{\partial x_j} \qquad (8.2)$$

(i) (ii) (iii) (iv) (v) (for i = 1, 2, 3 and j = 1, 2, 3)

where the rate of change of the mass flow rate with time (momentum) is equal to the body force (F_i) plus the net transport provided by mean flow advection (term(iii)), the pressure (p) gradient over the volume (term(iv)) and the nett diffusion by turbulent and viscous stresses (τ_{ij}) over the volume (term(v)).

The system of four equations which are represented above requires a fifth equation to express the relationship between pressure (p) and density (ρ) of fluid (this is provided by the equation of state - which depends additionally on temperature) and a model of the diffusion by turbulent and viscous stresses (τ_{ij}). Upon application of the relevant boundary conditions the system of equations can be solved.

Even with the current generation of computers the computational requirements for solving this complete system of equations will be excessive and some simplifications have to be made.

The first option is to reduce the number of dependent variables by:

- assuming the density does not change rapidly with time ($\partial\rho/\partial t = 0$)

- assuming a steady flow in an axial direction (U_i = constant).

The second option is to reduce the number of terms in the equations by an order of magnitude argument.

The third option is to reduce the number of independent variables (and thence the number of equations) by averaging the equations over:

- a layer of water
- the depth of water
- the breadth of water
- the area of water
- the volume of water (no flow)
- time (steady state)

Obviously the validity and appropriateness of these assumptions will depend upon the nature of the flow field which is identified in the dock system.

8.2.3 Contaminant Transport

The concentration of a contaminant at a particular point in the dock system will depend not only upon the chemical and biological processes but on the physical transport processes of advection and diffusion. If the contaminant is conservative its concentration at any point will be determined solely by transport phenomena. Assuming that the flux of contaminant mass (q_c) passing through a unit area in a unit time can be expressed by:

$$(q_c)_j = U_j.C - D_j \frac{\partial C}{\partial x_j} \qquad (8.3)$$

(i) (ii)

where the flux of contaminant of concentration, C is given by the sum of advective transport (term(i)) and diffusive transport (term (ii)) through the jth face.

The diffusive transport is assumed to be proportional to the gradient of the contaminant concentration (ie Fickian transport) with the constant of proportionality defined by the diffusion co-efficient (D_j).

By applying the principle of mass conservation to equation 8.3 the contaminant transport equation becomes:

$$\frac{\partial C}{\partial t} + \frac{\partial (U_j C)}{\partial x_j} - \frac{\partial \left(D_j \frac{\partial C}{\partial x_j}\right)}{\partial x_j} = S \qquad (8.4)$$

where S represents the rate of sources/sinks in contaminant concentration due to the internal chemical, biological and physical (ie sedimentation) processes. This equation can be simplified in a similar manner to the fluid flow equations (8.1 and 8.2) depending upon the conditions identified in each dock system.

The contaminant transport equation (8.4) provides the inter-relationship between the contaminant loads being carried into and out of a body of water by the fluid motion and the 'internal' mechanisms which cause changes in the concentration. With a knowledge of the fluid flow, this will allow the determination of contaminant concentrations over the dock system and as such is one of the fundamental building blocks of a water quality model.

The contaminant modelled in this manner may be any transportable quantity such as heat, salinity, BOD, NH_3N or algae. If the transported quantity affects the fluid motion (ie heat or salinity affect the density) then the relevant transport equations are coupled to the fluid flow equations.

8.2.4 Energy Transfer

The energy transferred into the system comes from two distinct sources;

- radiation (heat and light);

- local external sources (heat).

The primary source of radiation at the earth's surface is the sun. Most of this radiation is in the short wave band (0.3 to 3 μm). The incoming radiation is modified by absorption (atmospheric gases) and scattering (atmospheric particles). The total incoming shortwave radiation (S_t) can be expressed as:

$$S_t = \underset{(i)}{S_d} + \underset{(ii)}{S_s} \tag{8.5}$$

The diffuse solar radiation (term(i)) is a background level which will increase with cloud cover, whilst the direct solar radiation (term(ii)) depends upon the inclination of the surface to the sun and will decrease with overcast conditions.

When the incoming shortwave radiation reaches the earth's surface it is partially reflected. The fraction which is reflected (the albedo) varies with the inclination of the sun and type of surface it encounters. The albedo for water is 3 to 7%. The remaining shortwave radiation is absorbed by the (water) body.

Radiant energy is also exchanged between the earth's surface and the atmosphere as longwave radiation. The precise longwave energy transfers are difficult to express mathematically and so empirical data will be required.

The net radiation being received by a body can be expressed as;

$$R_n = \underset{(i)}{(1 - \alpha)S_r} + \underset{(ii)}{(L_d - L_u)} \tag{8.6}$$

where the net radiation, R_n, is evaluated by the balance between the incident and reflected shortwave radiation (term(i)) and the difference between the net long wave radiation received from the atmosphere and that emitted from the body (term(ii)).

The transfer of energy across the air/water interface can be considered in an energy budget formulation. There are three mechanisms which are generally considered;

- the nett radiation input, R_n;
- the energy utilised by evaporation, E_v;
- the energy advected to or from the body of water, C_v.

The combined influence of the mechanisms can be represented as a net heat exchange, H, across the air/water interface;

$$H = R_n - E_v + C_v \qquad (8.7)$$

These flux relations can be calculated within the model from semi-empirical and empirical relationships and basic meteorological data. The net heat flux, H, can then be converted into a volumetric source/sink term for a body of water.

An external source of energy (eg a thermal outfall) can be represented as a source/sink term directly.

The transfer of heat within the system can then be modelled by use of the contaminant transport equation (8.4), with heat as the contaminant. If the model is not depth averaged then the net external heat flux can only be applied to the topmost layer.

The net short wave radiation component, $(1 - \alpha)S_t$, can penetrate the water column and will therefore affect the energy levels below the surface. The amount of shortwave radiation which reaches a point below the surface is measured in terms of light intensity.

The light intensity-depth relationship is usually expressed in terms of an 'extinction' co-efficient, K_e, and the incident shortwave radiation, S_t. Empirical fits are usually made to the distribution of these variables.

8.3 Modelling The Chemical Processes

8.3.1 Background

An understanding of the major chemical processes occurring in aquatic ecosystems is essential for the modelling of the ecological effects that can result from surpluses or deficiencies of the chemical components concerned.

Simple inorganic forms of carbon, nitrogen and phosphorus are the major nutrients for the algae, which produce oxygen as a waste product of their photosynthetic activity. This process may be symbolised as follows:

$$CO_2 + 2H_2O \xrightarrow[\text{Algae}]{\text{Light}} \text{'}CH_2O\text{'} + O_2 + H_2O$$

The oxygen is in turn consumed in the process of respiration (partly by the plant life but also by animal communities) which releases energy for growth or other cellular activities. Respiration is in effect the reverse of photosynthesis, where the nutrients are now complex organic chemicals (symbolised above by 'CH_2O') which are consumed, with the recycling of carbon dioxide and water.

8.3.2 Carbon Cycle

Carbon (C) is the basic building block and energy source of all life forms. Its cycle in water is especially important because it is interrelated with the cycles of all other elements. A diagrammatic description of this cycle is presented in Figure 8.3.

In a closed, well oxygenated system carbon alternates between its inorganic dissolved gaseous form, CO_2, and its organic forms in the living and dead animal and plant tissue. In a system deficient in oxygen, the main product of bacterial decomposition will be methane, CH_4. In such a system ecological richness and diversity is very much reduced due to the lack of CO_2, which is necessary for photosynthesis, and the lack of oxygen required for plant and animal respiration.

In a real system which is open to the environment, the exchange of CO_2 and organic carbon is possible by the physical processes of gaseous exchange and sedimentation. In flowing water the sediments and dissolved CO_2 may be transferred into and out of the system.

Figure 8.3

Typical Nutrient Cycle

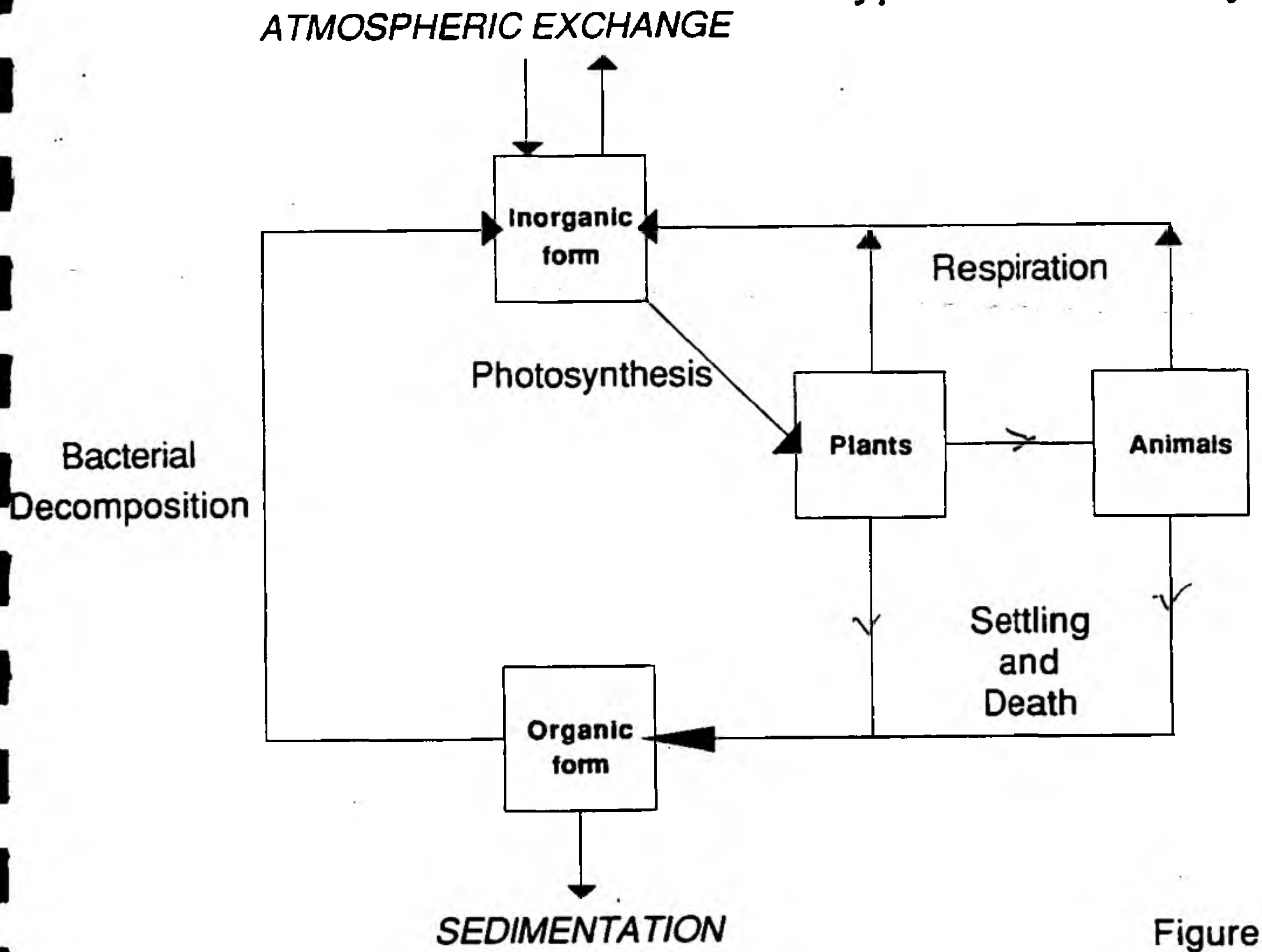
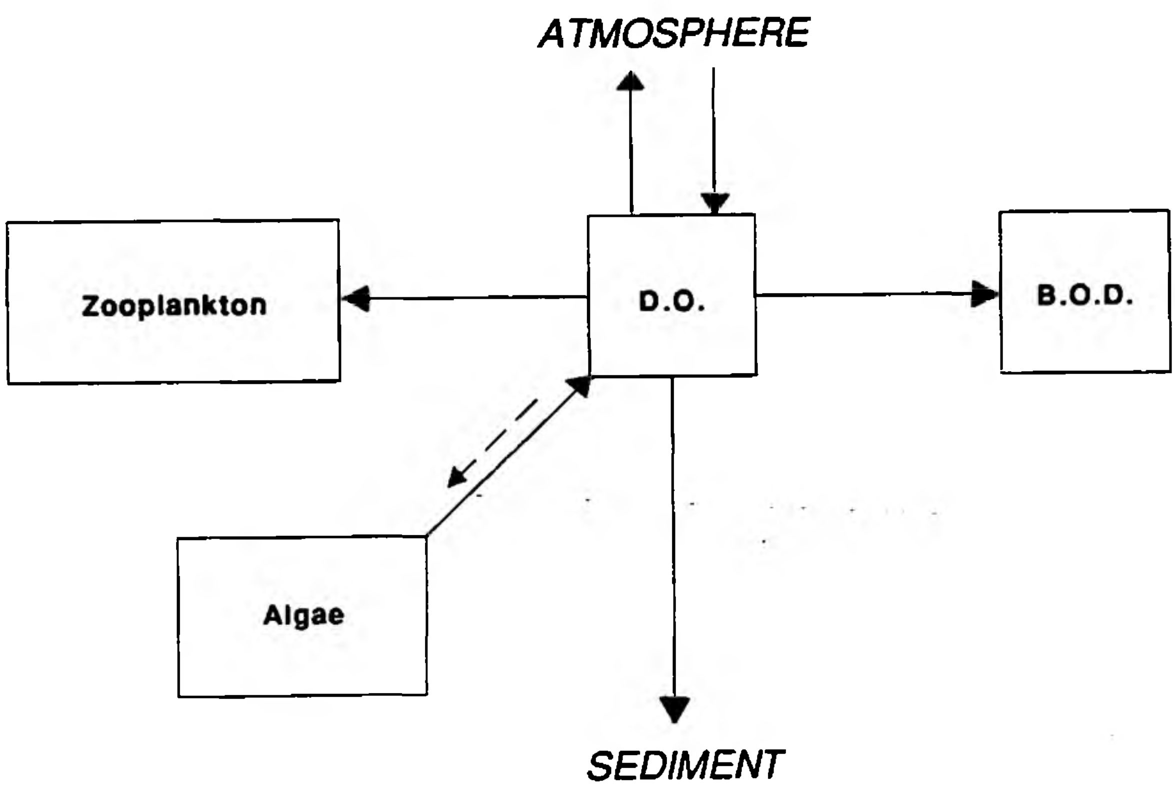


Figure 8.4

The Oxygen Cycle



8.3.3 Phosphorus Cycle

The phosphorus (P) cycle operates like the carbon cycle in many respects, (Figure 8.3). Organic and inorganic phosphorus can be divided into two fractions, particulate and dissolved. A fraction of the phosphorus released during respiration and death is in the inorganic form and will be readily available for algal uptake, (approximately 50%). The remaining phosphorus must undergo mineralisation (bacterial decomposition) into inorganic phosphorus before utilisation.

In order to model the phosphorus cycle it is necessary to identify the processes responsible for its release to and uptake from the aqueous system. The internal processes which are generally assumed to affect the concentrations of phosphorus in its various forms are the algal growth rate (uptake), algal and zooplankton death rate (release), loss to the sediments by absorption, settling and precipitation and the release from the benthal deposits and bacterial regeneration.

A set of formulations which represents the phosphorus system is given by Lorenzen et al. (1974). In this approach the phosphorus cycle is modelled by;

$$dP_1/dt = \underset{(i)}{G_pPA_{pp}} + \underset{(ii)}{I_2P_2} - \underset{(iii)}{I_1P_1} + \underset{(iv)}{I_3P_3} \qquad (8.8)$$

Where the rate of change in the dissolved inorganic phosphorus, PO_4-P, concentration is a function of the uptake from algae (term (i)), the release from benthal deposits (term (ii)), the loss to the sediments (term (iii)) and the release from organic phosphorus in the water column (term (iv)).

$$dP_3/dt = \underset{(i)}{D_pPA_{pp}} + \underset{(ii)}{D_zZA_{pz}} - \underset{(iii)}{I_1P_3} - \underset{(iv)}{I_3P_3} \qquad (8.9)$$

Where the rate of change in the organic phosphorus in the water column is a function of the release from algae (term(i)), the release from zooplankton (term (ii)), the loss to sediments (term (iii)), and the conversion to soluble inorganic phosphorus (term (iv)).

$$dP_2/dt = \underset{(i)}{I_1P_1} - \underset{(ii)}{I_2P_2} + \underset{(iii)}{I_4P_3} \qquad (8.10)$$

The rate of change in the total sediment phosphorus is a function of the gain from soluble inorganic phosphorus deposition (term (i)), the release of phosphorus from the sediment (term (ii)) and the gain from organic phosphorus deposition (term (iii)).

where

P_1 =	soluble inorganic phosphorus, mg/l
P_2 =	total sediment phosphorus, mg/l
P_3 =	organic phosphorus in water volume, mg/l
P =	phytoplankton carbon concentration, mg/l
Z =	zooplantation carbon concentration, mg/l
A_{pp} =	phosphorus to carbon ratio in phytoplankton
A_{pz} =	phosphorus to carbon ratio in zooplankton
I_1 =	rate constant for loss to sediments by sorption and precipitation, d^{-1}
I_2 =	sediment release (desorption; solvation) rate constant, d^{-1}
I_3 =	rate constant for release of soluble inorganic phosphorus from organic phosphorus, d^{-1}
I_4 =	rate constant for loss of inorganic phosphate to sediments, d^{-1}
D_p =	specific death rate of phytoplankton, d^{-1}
D_z =	specific death rate of zooplantation, d^{-1}
G_p =	specific growth rate of algae, d^{-1}

8.3.4 Nitrogen Cycle

Nitrogen (N) is an element essential for the formation of the proteins which are present in plants but more particularly the proteins in animals, which form the basis of their structural framework. As with carbon and phosphorus, nitrogen is present in organic and inorganic forms in water and like these it is cycled through the aquatic biosphere (Figure 8.3). Unlike them however nitrogen is present in three principal inorganic forms, ammoniacal nitrogen, NH_3-N, nitrate NO_3-N, and nitrite nitrogen, NO_2-N.

Depending on the conditions of pH, aeration and the species of bacteria present, either NH_3-N or NO_3-N will be produced from the bacterial decomposition of organic nitrogen. The algae can feed on either of these forms, although there may be a preference for the NH_3 form. If the NH_3 is not consumed it is converted (by Nitrosomonas bacteria) to nitrite and then (by Nitrobacter bacteria) to nitrate. The process of nitrate production from organic nitrogen is termed nitrification.

During algal respiration and death a fraction (about 50%) of the cellular N is returned to the inorganic pool in the form of NH_3-N; the remainder enters the organic pool where it undergoes bacterial decomposition to form NH_3-N. Under anaerobic conditions, often prevailing in bottom sediments, the reverse of the nitrification process, (denitrification) can occur. The end product is gaseous nitrogen which can be lost to the atmosphere by gaseous exchange. Conversely nitrogen dissolved in water from the atmosphere can be 'fixed' into the system by certain bacteria, being used in place of oxygen for their respiration.

Using the symbols N_1, N_2, N_3 and N_4 to symbolise NH_3-N, NO_2-N NO_3-N and organic nitrogen respectively, the nitrogen cycle may be modelled in a manner analogous to that of phosphorus (Lorenzen et al 1974).

$$dN_1/dt = \underbrace{-J_1N_1}_{(i)} \underbrace{- PG_p\, A_{np}(N_1/(N_1 + N_3)}_{(ii)} \underbrace{+ J_4N_4}_{(iii)} \qquad (8.11)$$

The rate of change in the ammoniacal nitrogen concentration is a function of the oxidation of the ammoniacal nitrogen (term (i)), the uptake from algae (term (ii)), and the conversion from organic nitrogen (term (iii)).

$$dN_2/dt = \underbrace{J_1N_1}_{(i)} \underbrace{- J_2N_2}_{(ii)} \qquad (8.12)$$

The rate of change in the nitrite nitrogen concentration is a function of the conversion from ammoniacal nitrogen during nitrification (term (i)) and the oxidation of the nitrite form (term (ii)).

$$dN_3/dt = \underbrace{J_2N_2}_{(i)} \underbrace{- PG_p\, A_{np}(N_3/(N_1 + N_3))}_{(ii)} \underbrace{-J_3N_3}_{(iii)} \qquad (8.13)$$

The rate of change in the nitrate nitrogen concentration is a function of the conversion from nitrite nitrogen during nitrification (term (i)), the uptake from algae (term (ii)) and the denitrification of nitrate nitrogen (term (iii)).

$$dN_4/dt = \underbrace{-J_4N_4}_{(i)} \underbrace{+ D_pPA_{np}}_{(ii)} \underbrace{+ D_zZA_{nz}}_{(iii)} \qquad (8.14)$$

The rate of change in the organic nitrogen concentration is a function of the release of ammonical nitrogen from organic nitrogen (term (i)), the release from algal death (term (ii)) and the release from zooplankton death (term (iii)).

where N_1, N_2, N_3, N_4 = concentrations of the relevant nitrogen form, mg/l

J_1	=	rate constant for ammonia oxidation, d^{-1}
J_2	=	rate constant for nitrite oxidation, d^{-1}
J_3	=	denitrification rate constant, d^{-1}
J_4	=	rate constant for organic nitrogen oxidation; d^{-1}
A_{np}	=	ratio of nitrogen to carbon in algal cells
A_{nz}	=	ratio of nitrogen to carbon for zooplankton

D_p, D_z, Z, P, G_p - as for the phosphorus model.

8.3.5 Oxygen Cycle

The oxygen balance in an aquatic ecosystem depends on the capacity of the system to reaerate itself, a function primarily of the physical processes of advection and diffusion occurring within the system and secondly of the internal oxygen sources and sinks. The major sources of oxygen, in addition to atmospheric reaeration, are photosynthetic oxygen production and the oxygen contained in incoming flow. The sinks of dissolved oxygen include biochemical oxidation of carbonaceous and nitrogenous organic matter, benthal oxygen demand and the oxygen demand of respiring organisms. Available oxygen is required for many of the chemical and biological reactions occurring in the ecosystem. These major processes are outlined in Figure 8.4.

Biological oxygen demand is the demand for dissolved oxygen produced by the respiratory requirements of bacteria feeding on carbonaceous organic matter and its nitrogenous byproducts, (principally NH_3-N). Benthal oxygen demand is produced by organic matter being added to the water column from the benthos (sediment floor).

A typical source/sink formulation for dissolved oxygen used in current water quality models is (Bacca and Arnett, 1976):

$$dDO/dt = K_1 L \quad - \quad x_1 J_1 N_1 \quad - \quad x_2 J_3 N_2 \quad - L_b/\Delta Z$$

Carbonaceous BOD | Ammonia oxidation | Nitrate oxidation | Benthic uptake

$$+ K_r (DOs - DO) + x_3 (G_p - D_p) P \qquad (8.15)$$

Reaeration | Algal productivity

where

DO	=	dissolved oxygen concentration, mg/l
DOs	=	dissolved oxygen saturation concentration, mg/l
L	=	carbonaceous BOD, mg/l
L_b	=	benthic O_2 uptake rate, g m^{-2} d^{-1}
x_1, x_2, x_3	=	stoichiometric constants, unitless
Kr	=	reaeration coefficients, d^{-1}
ΔZ	=	bottom layer thickness, m.

The saturated oxygen concentration, DO_s, is mainly a function of temperature and to a lesser degree a function of salinity and barometric pressure. It is usually sufficient to obtain the saturated oxygen values by means of an empirical formulation. Henry's law can also be used to estimate the solubility of dissolved oxygen, usually to within 1 to 3% of the correct value. Henry's law is expressed as:

$$DOs = \frac{K_H . pO_2 M}{R.T} \qquad (8.16)$$

where

K_H	=	coefficient of absorption, (a function of temperature)
pO_2	=	partial pressure of oxygen, atmospheres
M	=	molecular weight of oxygen, 32
R	=	universal gas constant, 0.082055 l atm K^{-1}
T	=	absolute temperature (°K) at which K_H is calculated.

Reaeration can be visualised as a three stage process. Beginning in the vapour phase, oxygen travels through a gas film on the vapour side of the gas-liquid interface, it then passes through a liquid film on the liquid side of the interface, and is finally dispersed throughout the bulk solution.

For oxygen, or any sparingly soluble gas, the rate limiting step is passage through the liquid film. Assuming the concentration gradient to be linear through the film this transport can be described by Fick's first law as

$$q = AD_m \frac{(DOs - DO)}{\delta} \qquad (8.17)$$

where

q	=	rate of transport of oxygen through a surface, mg min^{-1}
D_m	=	molecular diffusivity of oxygen in water, cm^2 min^{-1}
δ	=	film thickness, cm
DOs, DO		as already defined, mg ml^{-1}
A	=	surface area, cm^2

Letting $K_L = DM/\delta$,

$$q = AK_L (DOs - DO) \qquad (8.18)$$

where K_L is known as the oxygen transfer coefficient.

If however, the water body is assumed to be well-mixed vertically, so that a homogeneous DO concentration exists over the depth d, the rate of accumulation of dissolved oxygen due to reaeration can be expressed as

$$\delta DO/\delta t = \frac{K_L}{d} (DOs - DO) \qquad (8.19)$$

where the quantity K_L/d is usually expressed as the single reaeration coefficient K_r.

An expression for a transfer coefficient applicable to lakes was developed by Kanwisher (1963) and is given by

$$K_L = D_m \,/(200 - 60 \quad V_w)\, 10^{-6} \qquad (8.20)$$

where D_m = molecular diffusivity of oxygen, $m^2\ s^{-1}$

V_w = wind speed, $m\ s^{-1}$

Dissolved oxygen is very important in water quality models because it affects and controls the rates of change and concentration of a significant number of other system constituents.

8.4 Modelling The Biological Processes

8.4.1 Background

As previously discussed, the organisms of the aquatic environment interact with its chemistry via the two major biochemical mechanisms of photosynthesis and respiration. A diagrammatic summary of the interactions of all the nutrient cycles as they affect algal biomass is presented in Figure 8.5. In photosynthesis light energy is converted to energy stored in chemical form in the plants concerned (the primary producers). This stored energy is then released by the process of respiration either in the plant itself or in animals which have ingested that plant tissue.

Thus, if respiration is considered as the reverse of photosynthesis, the following represents the primary interaction between the aqueous chemistry and the algal protoplasm:

$$106\ CO_2 + 16\ NO_3 + HPO_4 + 122\ H_2O + 18\ H + \text{energy} + \text{trace elements}$$

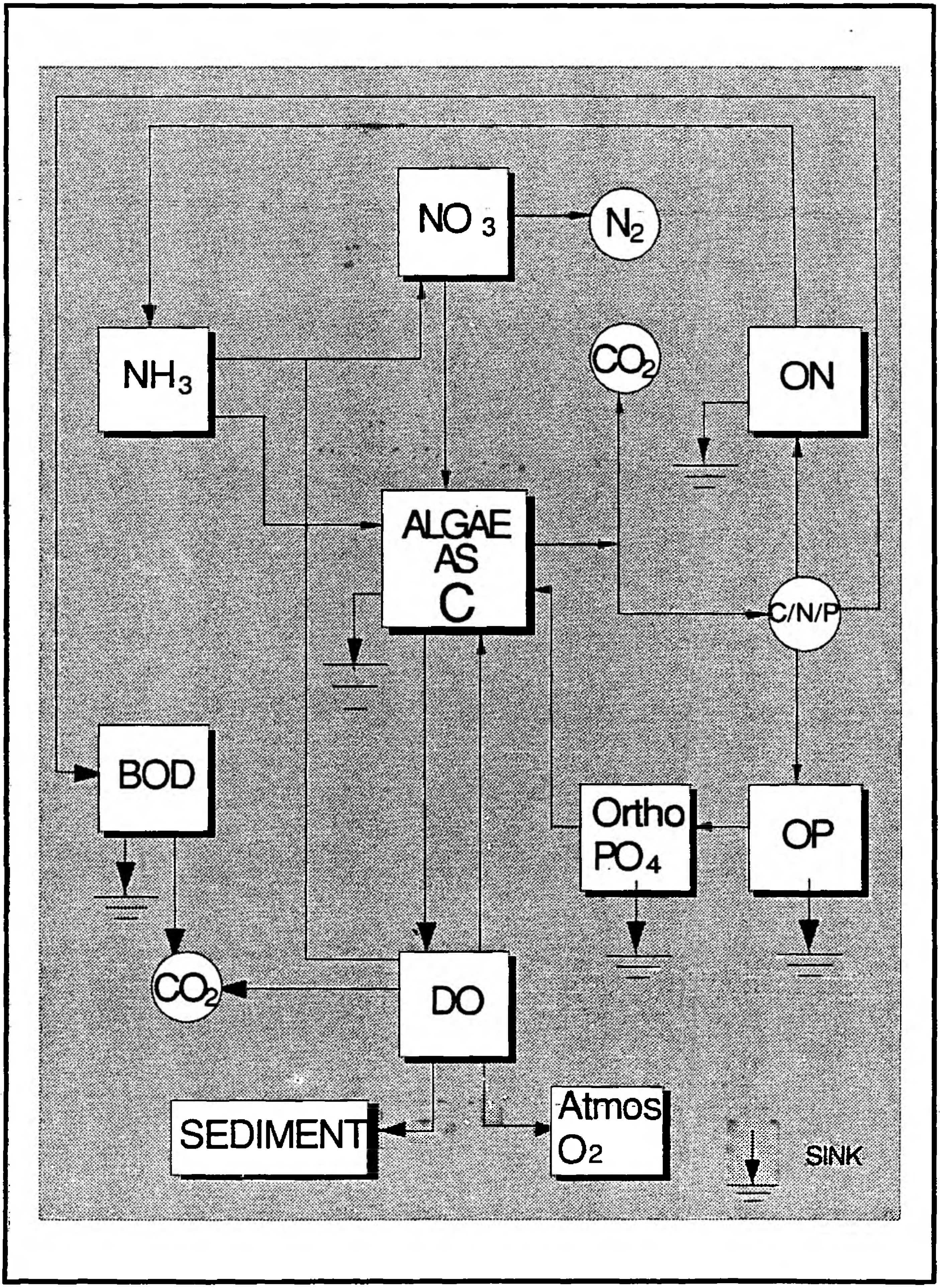
$$P \downarrow \quad \uparrow R \qquad (8.21)$$

$$C_{106}\ H_{263}\ O_{110}\ N_{16}\ P_1 + 138 O_2$$

P = photosynthetic production
R = rate of destruction

Figure 8.5

Simplified Model Of C:N:P Cycles In An Aquatic System



The balance between P and R is necessary to maintain water in a non-polluted and aesthetically pleasing condition. When P is approximately equal to R the organic material is decomposed by respiratory activity as fast as it is produced photosynthetically. Just as a balance between P and R is a prerequisite for the maintenance of a constant chemical composition of the water (chemostasis), the chemostasis is a prerequisite for the maintenance of a relatively constant population of organisms (homeostasis). As chemostasis depends on the coexistence of a sufficient number of phases, homeostasis depends on a sufficiently large heterogeneity of the population structure.

Temporally or spatially localised disturbance of the stationary state between photosynthesis and respiration leads to chemical and biological changes reflecting pollution. Pollution may be interpreted as a departure from P-R balance. For example, if a water body receives an excess of organic bacterial nutrients then $R > P$ and the dissolved oxygen may be used up (biochemical oxygen demand). Ultimately NO_3, SO_4 and CO_2 may become reduced to N_2, NH_4, H_2S and CH_4. Under such conditions all higher plants and most algae are excluded and aquatic fauna are restricted mainly to large populations of anaerobic bacteria (sewage sludge).

The condition $P > R$ is characterised by a progressive accumulation of chemical nutrients and energy which ultimately leads to an organic overloading of the receiving water, a situation commonly termed eutrophication. This results from an excessive input to the system of one of the factors controlling algal growth, whether it be nutrients, light or temperature. The eutrophication of a lake is a natural ageing process that can lead eventually to the filling up of the lake with sediments. Man can accelerate this process by altering the natural patterns in our environment; discharge of domestic wastes and agricultural drainage has recently accelerated the nutrient enrichment of many lakes.

The P-R balance may also be disturbed by a physical separation of the P and R organisms. In a stratified body of water a vertical separation results from the fact that algae remain photosynthetically active only in the euphotic upper layers. Algae that have settled under the influence of gravitation serve as food for the R-organisms in the deeper layers of the water body. Organic algal material that has been synthesised with excessive CO_2 in the upper layers becomes biochemically oxidised in the deeper layers; thus most of the photosynthetic oxygen escapes to the atmosphere and does not become available in the deeper layers. An excessive production on the surface of the water body ($P >> R$) is paralleled by anaerobic conditions at the bottom ($R >> P$).

8.4.2 Eutrophication

Although the maximum possible production can be estimated quite reliably by the stoichiometry of equation 8.21 no such simple correlation exists between biomass and productivity. In circumstances where neither nitrogen or phosphorus are in limiting supply then it will be environmental factors such as light intensity, temperature, turbulence and predator populations which determine the algal population levels.

Under circumstances where environmental conditions are optimal the biochemistry of the organism determines the rate of growth and replication and this rate is the maximum or saturated growth rate, Gp_{max}. In natural systems, non-optimal levels of one or more of the factors or substances required for growth may cause the rate to be less than Gp_{max}. The principal factors affecting the rate of phytoplankton growth are availability of the principal nutrients, temperature and light. However, under some circumstances the supply of carbon dioxide and trace elements (Mo, Mn and Si) can limit productivity.

The dependence of enzyme catalysed reaction rate on temperature can be expressed as:

$$K_T = T_{Tr}\ \Theta^{(T-Tr)} \qquad (8.22)$$

where

T	=	ambient temperature, °C
Tr	=	reference temperature, °C
K_T	=	enzyme catalysed reaction rate at temperature T, d^{-1}
K_{Tr}	=	enzyme catalysed reaction rate at the reference temperature, T_r, d^{-1}
Θ	=	characteristic constant, 1.01 to 1.18.

In view of the role of light in cellular energetics and biochemical synthesis, substantial changes in light levels may have a very major effect on algal cell function in general and growth rates in particular. A plot of photosynthetic production as a function of light intensity (the P(I) curve) shows a strongly linear relationship up to a certain light intensity, whereafter growth increases at a decreasing rate with increased illuminance until at higher levels photo-inhibition can occur. Since light intensity is a function of depth algal growth is also a depth dependent function.

The basic approach to simulating the change in phytoplankton population in most models is based upon the expression:

$$dP/dt = (Gp - Dp)P \tag{8.23}$$

where

Gp = specific growth rate, d^{-1}
Dp = specific death rate, d^{-1}
P = phytoplankton concentration, mg C/litre

This fundamental equation is usually expanded to account for the effects of growth limiting conditions, respiration, predation and settling. In order to incorporate the effects of growth limiting conditions, the maximum specific growth rate is modified to:

$$Gp = Gp_{max}\ (T).\ r\ (I_s, K_e)\ \ (C_i/K_m,i + C_i) \tag{8.24}$$

(The Michaelis - Menten formulation)

where

$K(T)$	=	Temperature dependent maximum specific growth rate, d^{-1}
$r\ (I_s, K_e)$	=	Light reduction term due to non-optimal incident light on a function of saturated light intensity, I_s, and extinction coefficient K_e, unitless.
$K_{m,i}$	=	the with Michaelis-Menten constant
C_i	=	the with nutrient concentration.

This Michaelis-Menten approach is widely adopted and used in many models which simulate algal population dynamics. Its typical form is

$$Gp = Gp_{max}\ (S/(S+K)) \tag{8.25}$$

where S is the limited nutrient concentraiton or sub-optimal light level. The Michaelis-Menten constant, K, is also known as the half-satuartion constant. In physical terms it represents the concentration of nutrient (or light level) at which Gp is half its maximal rate, Gp_{max}.

The multiplier (S/(K+S)) therefore ranges from zero to one depending on the value of S. K is determined experimentally by measuring specific growth rate as a function of the nutrient or light level. An example of such a relationship is provided in the present context by the P(I) curves derived for the dock's waters by the Centre of Research into Aquatic Biology.

Another procedure (Lambardo, 1972) is to treat the algal uptake of each nutrient separately and then determine which uptake rate causes the smallest algal growth rate in each time period. The method assumes that a nutrient is limiting for each time period, although the nutrient's identify might change over successive time periods.

for example: for phosphate uptake

$$G_{pp} = VMAXP\ (PO_4/(CMMP + PO_4)).\ (NO_3/(CMMN + NO_3)) \qquad ....(8.26)$$

VMAXP = maximal PO_4 uptake rate, typically 0.3/hour

CMMP = Michaelis constant for phosphorus, (~0.0303 mg/l)
CMMN = Michaelis constant for nitrogen, (~0.0284 mg/l)
PO_4, NO_3 - concentrations, mg/l

PO_4 uptake rate, G_{pp}, may be converted to algal biomass production using Equation 8.21.

The expression for N-limited growth is

$$G_{pn} = VMAXN\ (No_3/(CMMN + No_3)) \qquad (8.27)$$

where

VMAXN = max NO_3 uptake rate, typically 0.7 h^{-1}

Assuming neither light not nutrients are in short supply Lambardo gives G_p as

$$G_p = 0.006T - 0.035 \text{ for: } 28 > T > 6°C \qquad (8.28)$$

where

T = water temperature, °C

Under light limited growth conditions Lambardo's expression is

$$G_{PL} = VMAXL\ (ZT\ /(VLT + ZI)) \tag{8.29}$$

where

G_{PL}	=	nitrate uptake rate, h^{-1}
CLT	=	Michaelis constant for light, ~0.033 Langleys/minute
ZI	=	light intensity, Langley/minute
YMAXL	=	maximum NO_3 uptake rate under light limiting conditions, 0.3 h^{-1}

Lehman et al (1975) cite a function for photosynthesis reported by Steele:

$$P(I) = P_{max}\ (I/I_{opt})\ \exp\ (1-(I/I_{opt})) \tag{8.30}$$

where

P_{max} = max photosynthetic rate, any productivity units

P(I) = the photosynthetic rate at light intensity I, same units

I_{opt} = light intensity for saturated photosynthetic rate, cal cm^{-2} min^{-1}

To describe growth rate, Gp, in terms of light intensity and associated parameters Smith (1980) developed another of Steele's models to produce:

$$Gp = \frac{Gp_{max}\, e}{K_e\, Z_m} \left[\exp\left(- \frac{\phi_{max} K^c I_o}{Gp_{max}\, \Theta\, \exp\,(1+Z_m)} \right) - \exp\left(- \frac{\phi_{max} K_c I_o}{Gp_{max}\, \Theta\, e} \right) \right]$$

where

K_e	=	total light extinction coefficient, m^{-1}.
Z_m	=	mixed layer depth, m.
Θ	=	carbon to chlorophyll ratio, (mg/mg).
K_c	=	light absorption coefficient per unit of chlorophyll, (m^2 mg^{-1}).
I_o	=	surface light intensity, Einstein m^{-2}.
ϕmax	=	maximum quantum yield, mg C $Einst.^{-1}$
e	=	2.718

The corresponding expression for integral gross production in the mixed layer (ΣP, carbon biomass per unit area per unit time) is given by the product of phytoplankton biomass, mean specific growth rate and depth of the layer. Since biomass is generally measured as chlorophyll concentration, the production equation is most usefully expressed as:

$$\Sigma P = Ca\ \Theta\ Gp_{max}\ e/K_e \qquad (8.32)$$

Ca = chlorophyll-a concentration, mg m^{-3}.

Estimates of nutrient unlimited phytoplankton growth and production rates can then be based solely on these constants, K_e and the free variables light, temperature and chlorophyll concentration.

The death rate expression, D_p, can also be expanded to account for the sinks for the algal biomass. These sinks include the endogenous respiration rate, grazing by zooplankton and other herbivores, settling, parasitisation and stress induced death. Death rate can be simply expressed:

$$D_p = R_p + S_p + F_p \qquad (8.33)$$

where

R_p = respiration rate, d^{-1}
S_p = settling rate, d^{-1}
F_p = predation rate, d^{-1}

The endogenous respiration rate (the rate of algal biomass conversion back to CO_2) is considered as partial death of the cell since biomass is consumed. Death rate can be formulated more fully in the following description

$$Dp = R + CgZ\ (k_{mp}/(k_{mp} + P)) - W/Z \qquad (8.33)$$

where

R = endogenous respiration rate of phytoplankton, (a function of temperature), d^{-1}
C_g = grazing rate of herbivorous zooplankton ld^{-1} - mg zooplankton carbon
Z = zooplantation carbon concentration, mgl^{-1}
K_{mp} = Michaelis constant for zooplankton grazing on phytoplankton, mg/a
P = phytoplankton concentration, mgl^{-1}
Z = depth of settling out, m
W = settling velocity, md^{-1}

Endogenous respiration rate can be expressed as a function of temperature:

$$R = K_2\Theta^{T-20}$$

where

K_2 = endogenous respiration rate, d^{-1} (typically 0.1)

Θ = 1.08

8.4.3 Coliform Bacteria

The presence of coliform bacteria is evidence of faecal contamination and implies a potential health risk from pathogenic bacteria.

The usual approach to modelling coliform bacteria is to simulate their population levels as a function of initial loading and die-off rate, itself a function of time or distance from the source. Traditionally coliform modelling has only taken into account die-off and a simple first order kinetics approach has been used.

$$dC/dt = KC \qquad (8.34)$$

C = coliform concentration mgl^{-1}

K = die off rate constant, d^{-1}

Physical, physicochemical and biological factors can affect the coliform population in water, resulting in an apparent increase or decrease in coliform die-off rate. Of the physical factors solar radiation is the most important, being able to cause more than a tenfold increase in die-off rate. Adsorption, coagulation and flocculation may affect die-off rates although their effects are difficult to quantify. Sedimentation, the settling out of these bacterial particles and aggregates, is important with regard to water column coliform levels, espcially under low vertical mixing conditions.

Physicochemical factors such as pH and salinity may have significant effects on die-off rates. Escherichia coli survive longer in low salinity solutions of pH<8 than under more saline and alkaline conditions. Major biological effects include predation by bacteria and amoebae and poisoning by toxic substances produced by some algae. Algal blooms also increase the alkalinity to above pH 8. It is therefore important to model light intensity both for its direct effects on the bacteria and its indirect actions as mediated through the phytoplankton.

Such effects can be modelled using a depth averaged, light-dependent die-off rate. (A we. water body is assumed so that sedimentation can be ignored).

$$dC/dt = \overline{K}C \qquad (8.35)$$

where

$\overline{K} = K_i\overline{I}$

$\overline{I} = I_o(1 - e^{-xz})/xZ$

$\overline{I}$ = depth averaged light intensity, calcm^{-2} h^{-1}

I_o = light intensity at surface, calcm^{-2} h^{-1}

K_i = algal specific proportionality constant, cm^2 cal^{-1}

x = light attenuation coefficient per unit depth

Z = depth in units consistent with x

No growth terms are normally included in the model since regrowth is generally considered unimportant.

8.5 Preliminary Model Identification

8.5.1 Introduction

The process of model identification, whereby the conceptual basis of the model is determined for each dock system, is essentially a pragmatic exercise. In developing the description of the eco-system in the dock water three major issues must be addressed:

(i) What spatial representation is required to simulate the conditions in the prototype system?

(ii) Over what time scale do significant changes occur in the prototype system?

(iii) What is the nature of the significant forcing or driving conditions which need to be applied by the boundaries of the model system?

These considerations are interdependent and cannot be viewed in isolation.

The spatial representation of the dock system under study should be determined by discretising (sub-dividing) the water body into a finite number of cells, such that all the quantities under consideration are approximately homogeneous over each sub-volume. The fluid flow and the advective and diffusive transport of contaminants are then permitted between the cells and the chemical and biological processes, which are represented as sources and sinks in the contaminant transport equation, are simulated inside each cell. The resulting spatial discretisation is invariably a compromise between the accuracy of the spatial approximation required to describe the system and the computational cost.

The temporal representation of the dock system under study depends on the responsiveness of the ecosystem to change. Models with a 'long' time step generally require simplified equations (to prevent instabilities) and a coarse geometric representation. This type of model is useful in predicting problems which develop in the ecosystem over a long period. Models with a 'short' time step are more useful in determining water quality behaviour in the case of acute problems.

A further temporal representation is to use an infinite time step and to assume that quantities are essentially invariant with time throughout the system. This assumption will only be valid if the boundary conditions, which determine the state of the system, are reasonably constant (ie a stationary system).

8.5.2 Water Physics

One of the most important questions which must be addressed when identifying the physics of the water body is the rigour with which the fundamental fluid flow and contaminant transport processes must be represented in the model. This decision has to be made in conjunction with the most suitable geometrical representation of the system, the temporal scale required and the nature of the model inputs.

The factors which may affect the movement of water in the dock system can be listed as:

- the plan geometry;
- the bed levels and bed material;
- the location and magnitude of flows entering and leaving the system;
- the tidal conditions in the river Thames (which may affect inflows/outflows);
- the temperature and salinity of inflows;
- the local wind direction and speed;

- the energy being transferred into the system from radiation;

- the energy leaving the system from evaporation;

- the volume of water leaving the system by evaporation;

- the volume of water entering the system from precipitation;

- the use of internal water moving equipment.

The overall geometry of the study area depends upon the water elevation. This, in turn, depends on the volume of water entering and leaving the dock system and on tidal conditions when the docks are subjected to tidal influences. From examining the available plans and charts of the docks and from visiting the site it was judged that the plan geometry of the dock systems will be reasonably invariant with time; with the exception of Canada Water where local engineering works on the south-west edge of the docks has resulted in a sloping bank.

The bathometry and bed material will be influenced by the natural processes of scour and deposition and by dredging. The rate of deposition will depend upon the sediment load entering the dock system. In general, the bathymetrey will only change appreciably on an annual basis, although it is noted that concern has been expressed as to the rate of siltation in the Albert Basin. Dredging of the dock system occurs infrequently. In terms of modelling the flow field and resulting mass transport the bed level and roughness can be assumed invariant with time and reasonably constant over each dock.

The location, size and nature of inflows into the dock systems have been discussed in Chapter 4. There were four types of inflow identified:

- stormwater drainage (infrequent);

- pumping from engineering works (intermittent);

- impounding pumping stations (depends on the state of tide and impounding level);

- run in from the river (depends on the state of tide and impounding level).

These inflows can all change on an hourly basis. The detail of the representation of this movement of water through the system will depend upon the scale at which the model discretisation is employed to describe the geometry and bathometry.

The temperature and salinity of the inflows and the net heat transfer into the system via the water surface will determine the horizontal and vertical density distributions. A density differential generates a buoyancy-driven circulation, except in the vertical direction when a top layer is less dense than the lower layer. This circulation tendency will be counteracted by the difference in weight (ie gravitational forces) and the water body will become stratified.

From examining the first round of data it can be seen that there are distinct variations in temperature and electrical conductivity (salinity) over the depth in all of the docks, particularly in the Millwall Docks where complete stratification can be said to have occurred. The representation of the hydrodynamics in these systems requires a vertical discretisation of the water body.

The net radiation energy being received by the water body, which varies with position on the earth's surface, changes on both a daily and a seasonal basis. These variations are in the form of a distorted sine curve. Daily totals can be estimated from descriptions of cloud cover and the number of sunshine hours and then redistributed at a finer time interval by use of a sine curve.

The wind direction and speed are likely to be significant factors in the movement of water in a dock system; especially in reducing the degree of stratification by ensuring some vertical mixing. Wind speeds and directions will vary on a very short time basis and their local conditions will be affected by the surrounding environment. Mean daily wind speed and direction data are commonly used (available from the Meteorological Office).

The volume of water leaving the system by evaporation will depend upon the temperature of the air and water, the net radiation, the wind speed and the saturated and actual vapour pressure. Although these factors vary throughout a day it is more usual to express the evaporation as total volume over the day. Similarly, the volume of water entering the system by precipitation is also expressed in terms of a daily total (available from the Meteorological Office). Once again this can be redistributed at a finer time interval by application of a sine factor.

The use of internal water moving equipment, possibly part of a future management strategy, will require a small scale grid in order to pick up the detailed features of the water movement. The length of time step required by the model will be a function of the accuracy required and the operating rules for the particular equipment.

Bearing in mind the ultimate objectives of the mathematical model (to predict detrimental water quality and to investigate management options) it would appear most appropriate to have a two pronged attack in order to simulate physical conditions in the dock systems:

- Discretising the dock systems into a number of sub-volumes, which are then further discretised vertically. This model could then be run on a daily time-step to predict daily flow rates and mass transfers between sub-volumes in the horizontal and vertical directions.

- Further discretising the layered sub-volumes in to a regular sized grid in order to simulate the detailed flow field on an hourly time basis. This would be a quasi-three dimensional model.

These simulation models could then be interlinked in order to facilitate data transfer.

8.5.3 Water Chemistry

The concentration of a chemical in a body of water will depend upon;

- the nature of the flow field in the water body;
- the chemical load entering and leaving the body of water;
- its interaction with other chemicals which are present in the system;
- its interaction with the biological processes in the system;
- the energy being transferred into the system.

The nature of the flow field in the dock system can be determined by the physics of the flow field. The transport of chemicals through the system from an external chemical loading can be determined by use of the contaminant transport equation. These physical factors will be uniquely responsible for the concentration of a conservative chemical species at any position in a body of water.

A non-conservative chemical will also inter-react with other chemicals which are present in the system and with the living organisms. The rate of these reactions will be controlled by the energy which is available in the system for reaction and the availability of chemical and biological reactants. The energy inputs, as discussed previously vary hourly but are expressed daily but can be redistributed over the day by application of a sine function.

Three types of models can be defined which depict the chemical processes in a system:

- equilibrium models;
- dynamic equilibrium models;
- fully dynamic models.

The equilibrium models treat the system as being closed (ie no net external loading) and estimate the concentrations required for the system to reach a chemical equilibrium (chemostasis). The validity of such an approach is restricted to very large water bodies and as such will be inappropriate for use in the dockland system.

Dynamic equilibrium models can be applied to open systems which are stationary (ie invariant inflow loading) and can be used to estimate the concentrations required for the system to reach equilibrium.

Fully dynamic models can be applied to non-stationary (dynamic) systems where the inputs are constantly changing. This type of model can then be used to predict the instantaneous changes in concentration after a given time interval, before an equilibrium condition is reached, as well as the long-term changes.

From examining the initial set of data and the data gathered from previous studies it can be seen that there are spatial variations of certain chemicals within individual dock systems and variations between the dock systems. For example, the preliminary measurements of dissolved oxygen (DO) show a general decrease with depth, except in some instances when the DO is much lower at the surface. This apparent anomaly could be explained by the interaction between algae and DO (during the day algae produce oxygen, but at night they consume oxygen). Thus, as it is the minimum DO level which is important an hourly time level would appear to be necessary in order to determine the critical DO conditions.

The spatial variation in concentration requires that the dock systems are discretised both horizontally and vertically. From the view of transferring data between the physical component of the water quality model and the chemical process model it would appear to be most efficient to use the same discretisation for each dock system. By using this approach the chemical process model can be used to represent the source/sink of each chemical constituent in the transport equation.

In terms of meeting the water quality requirements, the chemical which is of most concern in the dock system and therefore should receive the most attention is the dissolved oxygen. The nutrient (primarily the nitrogen and phosphorus) concentrations may affect the production of algae and as such their cycles should also be represented in the model. Concern has also been expressed as to the phenol, poly-aromatic hydrocarbon (PAH) and naphthalene concentrations (amongst others) in the dock systems. These chemicals are not highly reactive with the other chemicals in the dock system, but will decay as a result of bacterial action and sedimentation. The model could be extended to cover these chemicals at a later date.

8.5.4 Water Biology

The biological population in a body of water will depend upon:

- the nature of the flow field in the water body;
- the biological load entering and leaving the water body;
- its interaction with other biological populations;

- its interaction with the chemical processes in the system;
- the energy being transferred into the system.

The identification of these processes needs to be carried out in a similar manner to the identification of the water chemistry in a dock system so that the appropriate biochemical interactions can take place.

From examining the initial sets of data it can be seen that there are spatial variations in the chlorophyll concentration over both the vertical and horizontal directions. Considerable variation in the chlorophyll concentrations have also been observed over the weeklong period between the data collection rounds.

The specific algal species which are most significant in each dock system have been identified during the sampling rounds. This identification also shows that the dominant algae in each dock system may change with time. All algal species should thus be modelled.

The qualitative differences between the different algal species were outlined by Bierman (1976) and are produced in Table 8.1.

TABLE 8.1

Qualitative Differences between Phytoplankton Types

Characteristic property	Phytoplankton Type: Diatoms	Greens	Blue-green (N-fixing)	Blue-green (non-N-fixing)
Nutrient requirements	P, N, Si	P, N	P, N	P
Relative growth rates (optimum at 25°C)	High	High	Low	Low
Phosphorus uptake affinity	Low	Low	High	High
Sinking rate	High	High	Low	Low
Grazing pressure	High	High	None	None

In the general modelling approach, the rates of algal growth (source of phytoplankton biomass) may change between species as the maximum growth rate (Gp_{max}) is species dependent and the death rate (Dp) will depend upon particular species respiration, settling and predation rates.

The initial survey for coliform bacteria showed that in some dock systems the level is extremely low, whilst in others the level is high. Coliform bacteria should also be included in the model in order to evaluate the compliance of the dock water with the appropriate water quality standards.

8.6 Sensitivity Analysis

8.6.1 Introduction

Having attempted a preliminary identification of a water quality model of the dock systems, some of the components were built for testing.

The tests were in the form of a sensitivity analysis, using literature values for constants and the collected data, when available. By varying these model inputs in a systematic manner, the relative importance of each factor can be ascertained. This procedure provides a better understanding into the behaviour of the ecosystem and provides some feedback into the model identification process.

Initial interest has been focused on the factors which affect the algal population and the concentration of dissolved oxygen.

8.6.2 Nutrients and Algal Growth

It is appreciated that the effects of nutrient concentrations on algal growth rates are more complex than the simple multiplicative description given by Michaelis-Menten growth kinetics. In practice, acceptable results have been obtained using such an approach which has therefore been applied in the present circumstances to model the effects of phosphorus and nitrogen concentrations on algal growth.

If dissolved inorganic nitrogen (DIN) can be considered as the sum of NO_3-N and NH_3-N, on which the algae feed, then a simple expression for the growth limitation due only to nitrogen is given by:

$$Gp = Gp_{max} \frac{(DIN)}{(CMMN + DIN)}$$

Using a typical value for CMMN of 0.025 mg/l the model predicts that for DIN values above 0.22 mg/l the growth rate, Gp, is equal to Gp_{max} and dissolved inorganic nitrogen concentration will not limit algal growth. Below this threshold value there is a gradual decline in Gp, while below the concentration equal to CMMN there is a rapid linear decline in specific growth rate.

For growth limitation by dissolved inorganic phosphorus (DIP), a similar Michaelis-Menten expression can be used for modelling purposes. For phosphorus however a typical value of K_{MP} is 0.001 mg/l. Using this value the model shows that phosphorus availability is only limiting to algal growth when DIP concentrations are less than 0.09 mg/l. Severe limitation on algal growth therefore only occurs when DIP falls below K_{MP}.

In an aquatic ecosystem where either nutrient is potentially limiting to algal growth rate the value of Gp will be governed by the smaller of the two growth rate expressions.

Results from the first stage sampling round show that in all docks the phosphorus levels are well above the rate limiting threshold of about 0.09 mg/l. Typical DIP concentrations are 10 to 20 times, this limiting value at all depths. Most of the dock waters are also nutrient-rich with respect to nitrogen but there are specific areas in some docks where the DIN value falls below the threshold value. (These docks include the Queen Victoria, Albert Basin, East India and Canada Water.) In the future modelling of algal growth the nutrient levels should be considered, especially DIN in those docks mentioned above.

8.6.3 Temperature and Algal Growth

The effect of temperature is modelled via its effect of Gp_{max}, as described by the following equations:

$$Gp_{max}(T) = Gp_{max(15)}\theta^{T-15}$$

where T = temperature °C
15 = reference temperature °C

Using a value of 1.068 for the temperature coefficient Θ, and a temperature range of 5 to 25°C the model predicts a doubling of growth rate with every 10°C change in temperature.

This result emphasises the importance of the model's ability to predict water temperature from the available meteorological data and flow inputs.

8.6.4 Light and Algal Growth

From examining equation (8.30) it is apparent that the important variables controlling algal growth rate due to light levels are the following: chlorophyll concentration, maximum specific growth rate, extinction coefficient, light intensity, maximum photosynthetic yield, depth of the mixed layer, the extinction coefficient per mg of chlorophyll and the carbon to chlorophyll ratio.

By employing typical values of these variables sensitivity tests were applied to the model. This involved varying each component within its natural range while maintaining the others at their mean values to discover how large an influence each parameter had on algal biomass production. When all the variables were constrained to their mean values the daily biomass production was 24 mg C m^{-2} day^{-1}. Table 8.2 shows the typical ranges of the variables concerned and the effect of introducing their maximum and minimum values into the model.

From these results it is apparent that neither Θ, the carbon to chlorophyll ratio, nor Gp_{max}, the temperature dependent maximum specific growth rate, appear to have a significant effect on total algal biomass production (ΣP). Changing mixed layer depth within its limits, could change ΣP by as much as 25%. The influence of the value of Kc (chosen from literature) and that of ϕ max (derived from P(I) curves) are more significant as they are capable of producing a 25 to 50% change in ΣP.

The most striking effects on ΣP are produced, not surprisingly, by light intensity, I_o, and the extent to which this surface intensity is attenuated with depth, as measured by Θ, the extinction coefficient. When low values of Σ (characteristic of some freshwater lakes) are introduced into the model ΣP approaches values comparable to the literature values of such lake systems (hundreds of milligrams of C^{-2} m day^{-1}). A plot of ΣP versus extinction coefficient for a typical dock system is shown in Figure 8.6. The high values of the extinction coefficient, typical of many of the docks, are a result of the high algal concentrations at the surface (which shade out the other algae in the layers below). This is particularly the case in docks populated with bouyant phytoplankton which are not prone to settling from this surface euphotic layer. As the extinction coefficient is thus largely a function of algal concentration it should be possible to relate chlorophyll a concentration to K_e. Such a relationship would be useful in the further model development stage, obviating the need for the many light/depth relationships necessary to calculate K_e.

8.6.5 Death Rate and Algal Growth

The death rate expression used in this model includes terms to describe settling rate, predation and endogenous respiration rate. The algal species used for study in this sensitivity analysis is one of the bouyant species which is less prone to grazing. For this present modelling exercise settling and predation could be ignored and death rate (loss of algal biomass) could be expressed simply as a function of endogenous respiration rate. This was determined from a selection of the docks, P(I) curves and ranged between 1×10^{-4} -1×10^{-3} day^{-1}. Although not a high rate in absolute terms this respiration rate could be significant when specific growth rate is low (for example when K_e is high). Under such circumstances specific respiration rate could be as high as one tenth of specific growth rate. The model therefore shows that, especially in more turbid waters, endogenous respiration and death rate cannot be ignored when predicting changes in phytoplankton biomass production. This will be even more the case for some algal species where settling and predation are significant factors in the death rate expression.

8.6.6 Dissolved Oxygen

When modelling the changes in dissolved oxygen concentration the same method of sensitivity analysis was employed as that used to analyse Smith's algal growth rate expression. The variables concerned, their typical range and their effects on dissolved oxygen concentration (DO) charges

Figure 8.6

Algal Production v Extinction Coeff

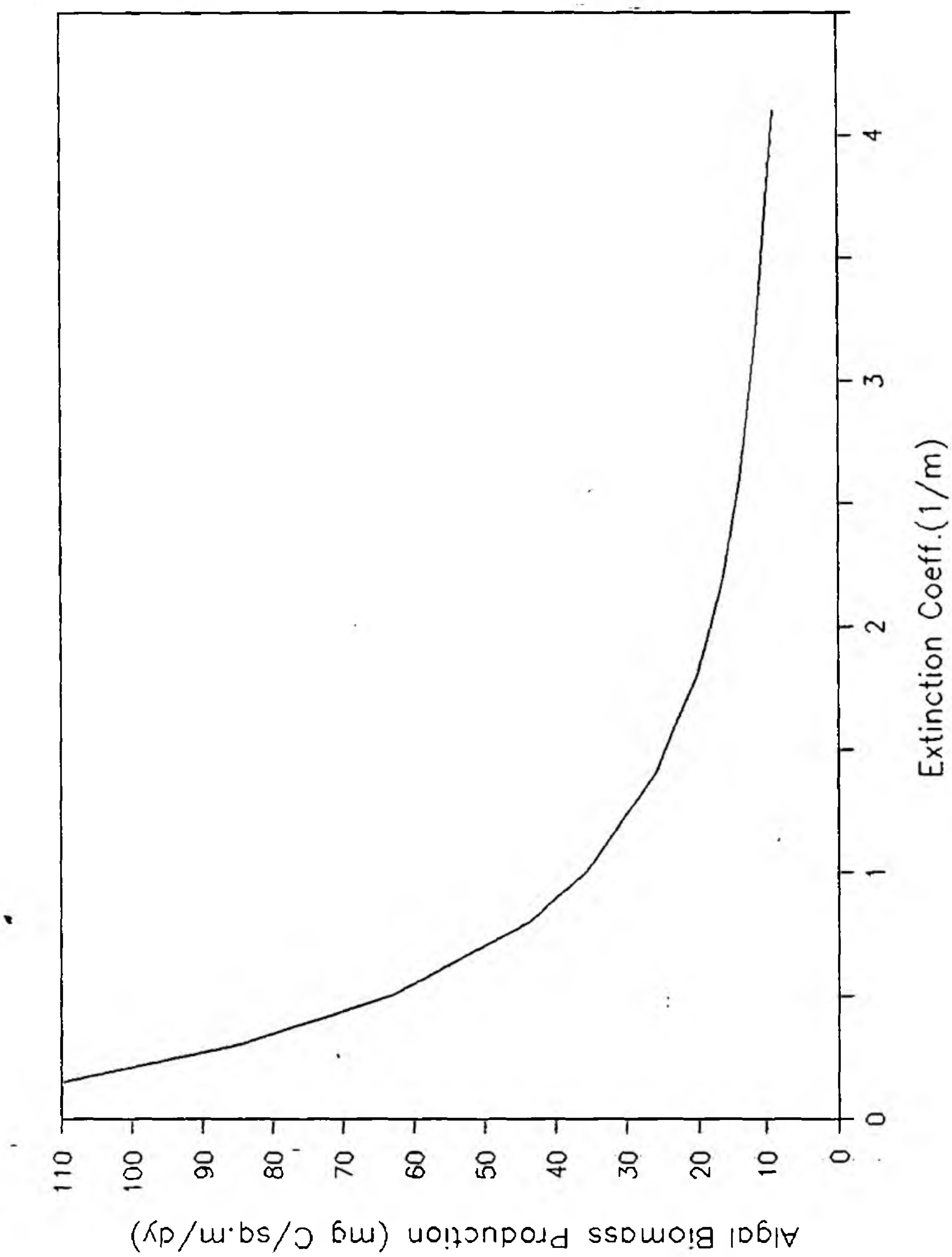


TABLE 8.2

Sensitivity of Gross Algal Biomass Production to Light Equation Parameters

Variable (V)	Unit	Range	ΣP (mg carbon m^{-2} d^{-1}) High Value	Low Value
Chlorophyll-a	mg m^{-3}	40 - 126	40.0	12.8
θ		20 - 100	24.2	24.2
Gp_{max}	d^{-1}	0.25 - 1.50	24.1	24.2
K_e	m^{-1}	0.15 - 4.10	8.9	109.0
K_c	m^2 mg^{-1}	0.01 - 0.02	30.0	15.2
I_o	Einst m^{-2} d^{-1}	8 - 120	4.0	48.0
ϕ_{max}	mgC $Einst^{-1}$	0.25 - 0.72	12.0	35.0
Z_m	m	1 - 10	18.0	30.0

TABLE 8.3

Sensitivity of Rate Changes in DO to Factors Affecting its Concentration

Variable (V)	Unit	Range	d DO/dt mg l^{-1} d^{-1} High value	Low value
N_1	mg/l	0.16-0.70	-0.93	-0.37
N_2	mg/l	0.00-0.29	-0.69	-0.52
J_2	d^{-1}	0.10-0.50	-0.83	-0.32
J_3	d^{-1}	0.00-0.10	-0.64	-0.52
DO_s	mg/l	7.80-12.16	-2.41	-0.96
DO	mg/l	5.00-10.00	-1.05	-0.30
Gp	d^{-1}	0.02-0.70	+2.60	-4.50
Dp	d^{-1}	4×10^{-4}-12×10^{-4}	-0.58	-0.58
P	mgC/l	2.40-8.00	+0.27	-2.80
Z	m	0.10-1.00	+1.72	-20.00
K_r	d^{-1}	0.05-0.35	-0.23	+0.90
K_d	d^{-1}	0.10-0.60	-1.10	+0.08
BOD	mg/l	0.00-5.00	+0.22	-1.30

are listed in Table 8.3. Using typical mid-range values from the literature for the rate constants and mean values from the docks for the chemical and biological parameters the model predicted a daily DO change of -0.58 mg/l.

The model showed that DO is fairly insensitive to the concentrations of ammonia and nitrite and their respective coefficients of oxidation. Dissolved oxygen saturation and DO had rather more significant effects while the BOD value and the magnitude of its rate constant, Kd, were more significant still. Changes in BOD could produce a 200 to 300% change in the DO value. The value chosen for the reaeration coefficient, K_r, could also make the difference between the water body being a net daily producer or consumer of oxygen. In a still body of water this value depends mainly on wind speed, and any realistic prediction of K_r will therefore require reliable local estimates of wind speed (which, in an urban environment, can differ markedly from the mean values).

Other than reaeration the other major source of dissolved oxygen is algal photosynthesis. With regard to the algal production term, Gp, specific growth rate is observed to have the largest effect on DO. When Gp is constrained to its lowest extreme the oxygen sink terms dominate the DO equation and there is a net daily deficit of 4.5 mg/l. At its higher values, however, the water becomes a net oxygen producer. In contrast death rate does not have a significant effect and can be ignored for the purposes of modelling DO. Phytoplankton concentration, however, is significant, being able to produce between a 100% increase and a 400% decrease in DO over its range of values employed in the model.

Of all the factors which have been investigated, the DO model is most sensitive to ΔZ, the thickness of the water layer in contact with the benthic sediments. The model assumed a value of 0.5 m for ΔZ and and increase to 1.0 m increases the daily DO change to 1.72 mg m^{-2} from -0.58 mg m^{-2}.

In a water body which is well mixed over the depth, the value of ΔZ becomes equal to this depth and benthic uptake can become a relatively small sink term in the DO equation. In water bodies where this is not the case (ie there is a division between the well mixed upper layers and the stiller, lower layers) the benthal sink term can be ignored in the well mixed layer while it is extremely important in the lower layers, where anaerobic conditions often predominate as a result.

8.7 Conclusions and Recommendations

The proposed mathematical model would comprise a series of linked sub-models to simulate the:

- water physics;
- water chemistry;
- water biology.

A schematic showing the model framework and the interrelationship between components is shown in Figure 8.7.

Once the model has been set up for each dock system it would be driven by entering hydrological and meteorological data. The data requirements for each dock system would be:

- inflow rates, temperatures and the chemical and biological loadings;
- outflow rates;
- wind direction and speed;
- precipitation;
- relative humidity;
- number of sunshine hours.

It is envisaged that the model output would be in the form of a colour coded system. The colour scale would be related to the water quality standards for each of the pertinent water quality indicators. The best medium for displaying this information would be a graphical post-processor.

The model being designed for the dock systems will be as process dependent as possible. By simulating fundamental laws the model is then applicable to a wide variety of circumstances and can be easily altered to suit the particular requirements of each dock system. Changes to a dock system (eg development) can be included with minimal alterations to the model.

The initial sensitivity analysis which was performed on some components of the water chemistry and water biology models has aided in identifying which parameters need to be most accurately determined for the simulation of algal populations and dissolved oxygen concentrations.

In modelling the sensitivity of algal growth to the nutrient levels the model has underlined the importance of the accurate determination of the phosphorus and nitrogen concentrations when they are present in low concentration. This is particularly pertinent in the case of nitrogen, which may be controlling the production of some algal species in the docks.

When the nutrients are no longer limiting the algal growth the model will require reliable measurements of the daily light intensity. This energy input is not only crucial in terms of algal growth but it also determines the water temperature and hence the chemical and biochemical reaction rates.

The importance of wind speed and direction on the dock system can be inferred by examining the influence of aeration and mixed layer depth on the model. The former is crucial in terms of dissolved oxygen entering the system, whilst the latter will affect the extinction coefficient (by maintaining a more uniform concentration of chlorophyll with depth) and also the bottom layer thickness, from which oxygen may be absorbed by the sediments.

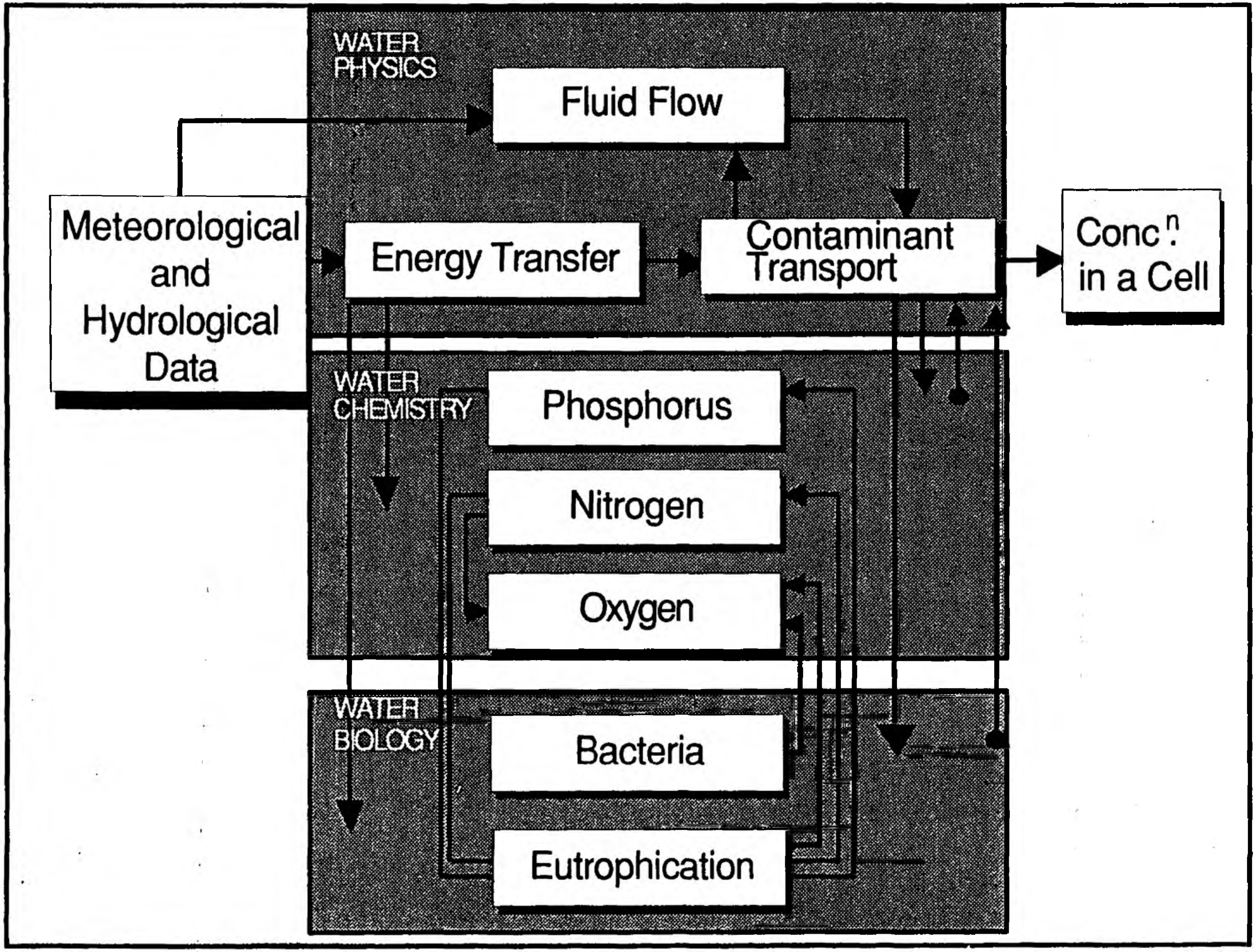


Figure 8.7

Model Framework

Possible developments to the model would be to establish a relationship between the extinction coefficient, mixed layer depth and chlorophyll concentration. Furthermore, the wind speeds in built-up areas are complex and variable and may not be adequately described in terms of a mean daily wind speed and direction. If this proves to be the case then more data will be required to relate the localised air flow patterns to the mean wind speed and direction over the dock system.

In order to simulate the vertical flow patterns, with a high degree of confidence, it will be necessary to establish a more accurate temperature/salinity and depth relationship.

The vertical distribution of dissolved oxygen would also be useful in order to better calibrate the DO model. To this end, values of the biochemical oxygen demand (BOD) and its rate coefficient are essential for the successful modelling of DO.

In view of the increased data requirements it is felt that it would be better initially to concentrate all the modelling effort on a single dock system. The model, as discussed earlier, can then be transferred to the other dock systems.

CHAPTER 9

DEVELOPMENT OF A POSSIBLE LONG TERM Treatment AND MANAGEMENT STRATEGY

9.1 Introduction

In this chapter various options are considered with a view to meeting the Corporation principal objectives of providing a water which is:

- of a quality acceptable for use in water contact recreational activities;
- aesthetically pleasing at all levels;
- free from noticeable odour, visible algae, scum and contaminants.

The management strategies to be investigated must include methods to:

- control and remove floating algal mats and other debris;
- control and remove oil film;
- control and reduce turbidity;
- maintain adequate oxygen concentrations to avoid production of noxious odours;
- control and reduce microbiological contamination;
- control and reduce toxic organic contaminants.

The latter two objectives relate only to the requirements for bathing water and water contact sports.

The possible strategies must take account of algal growth which is a factor in the control of floating material, turbidity and oxygen concentration. In addition the influence of stratification and mixing processes are important for the control of algal populations, oxygen concentrations and microbiological contamination.

9.2 Floating Solids

The accumulation of discarded litter will occur in the docks and might be expected to increase with increasing usage. Mechanical methods for collection of such material will need to be assessed.

9.3 Oil Films

Oil may be expected to enter the dock systems from inflows, shipping and accidental spillage. In the protected conditions of the dock surface film may not be broken up by natural water turbulence. Collection and treatment methods will require investigation.

These will include:

- provision of booms and removal equipment;
- chemical dispersion;
- physical break up of surface film;
- removal of surface water by preferential discharge.

9.4 Algal Populations

Long-term measures to control algae will include those mentioned in Chapter 7, on emergency treatment. In addition, means of limiting algal populations by restricting nutrient supply to the photosynthetic zone will be considered. Possible methods to be investigated will include:

- artificial stratification to prevent recirculation of nutrients from bottom waters;
- chemical precipitation of phosphate by dosing of products such as aluminium sulphate;
- replacement of dockwater by groundwater.

The reduction in nitrate concentration by chemical treatment will not be considered because of the likely cost and the possibility of encouraging the growth of nitrogen-fixing blue-green algae in a phosphate rich environment.

9.5 Control of Oxygen Concentration

The mathematical model will be used to predict conditions under which low oxygen concentrations are likely to occur. The management strategy will then be to avoid those particular conditions. However, if it proves impossible to prevent such conditions occurring then compressed air and mechanical aeration will be investigated as previously described in Chapter 7.

9.6 Control of Stratification

Stratification has been observed in Millwall Docks. If heat pumps are used to any great extent a degree of stratification may occur in other docks. At the same time, the encouragement of stratification may prove useful for the control of algal populations.

The effect of heat pump usage and other causes of stratification will be studied using the model to identify the likely advantages and disadvantages. Control methods such as those noted in Chapter 7 will be considered if de-stratification proves necessary.

9.7 Control of Microbiological Contamination

The principal factors influencing coliform concentrations are rates of inflow to the docks and their subsequent decay. The decay rates are light and temperature related. Model simulation will permit investigation of the likely effects of various development alternatives on these rates. In particular, we will consider the effect of shading due to the Canary Wharf development and the effect of additional contamination from marinas and contact sport activities.

9.8 Control of Toxic Contaminations

Previous studies have identified the existence of high levels of toxic organic compounds in the West India Docks. These may be related to contamination of the sediments. To meet bathing water standards these would need to be reduced. Possible strategies include:

- flushing of the dock system;
- removal of the sediments;
- reducing further migration of the compounds from the sediments.

The first two options in combination are probably most viable. The methods for carrying out the work will need to be assessed.

CHAPTER 10

PROPOSALS FOR STAGE 2

10.1 Introduction

The work carried out during the first phase has demonstrated that in general the dock waters are capable of meeting the requirements of the EC Directives on bathing water quality, requirements which may also be applied to waters used for water contact sports. However, previous surveys indicate that at some times of the year the water quality does not meet these standards, due to bacterial contamination, turbidity resulting from algal growth, oxygen concentrations, floating debris and oil films.

In the West India Docks unacceptable concentrations of trace organics have also previously been detected in the water column. Not all the docks have yet been surveyed for these trace organics nor for other toxic trace compounds specified in the Directive.

In our proposal for Stage 2 we have been conscious of the need to avoid undue expenditure by the Corporation and have balanced this against the requirement to satisfactorily fulfil the objectives of the study. Proposals in this chapter are designed to yield sufficient information for the following specific purposes:

- to monitor the quality of the dock water to ascertain its compliance with the EC Directive on bathing water;

- to determine the processes controlling microbacteriological contamination, algal growth and the oxygen balance in the docks, so that both short-term and long-term management strategies can be defined; (to assist with this procedure a computer model is to be developed)

- to evaluate other management options.

Finally, we propose specific detection limits and precisions for the various analyses to be carried out in this second phase.

10.2 Compliance with the EC Directive on Bathing Water

The Directive on Bathing Water is discussed in detail in Chapter 3 of this report, and is summarised here. The Directive requires routine sampling at a minimum fortnightly interval during the bathing season to determine the concentrations of total coliform and coliform bacteria as well as the measurement of turbidity (measured by Secchi disc). Subjective observations of floatables, surface films, foam, water colour and odour are also required. Other determinations are only required if specific contamination is suspected. Compliance is not determined on a single sample, but a certain percentage of collected samples must be less than the specified limits.

If the Corporation wishes to demonstrate compliance with the terms of the EC Directive then a minimum fortnightly sampling of these parameters would be required, as described in Section 10.1.1. In addition, as the dock systems are likely to have been contaminated by industrial products in the past we suggest in Section 10.1.2 a limited survey to determine the extent to which this has effected the present water quality. Section 10.1.3 describes a similar limited bacterial and viral enumeration survey.

10.2.1 Fortnightly Routine Sampling

(a) Microbiological Enumeration

If the bathing season may be considered to extend from April to October, then we recommend that routine monitoring should be carried out fortnightly during this period to ensure compliance.

Sampling could be carried out from the dockside, ensuring that the sample is taken at least 1 m from the dock wall.

Analysis of the samples should be restricted to the enumeration of total coliforms and faecal coliforms only, but visual inspections as noted below would also be required.

(b) On-site Inspection

Inspections include observations of colour, surface film, foam, phenolic odour, Secchi depth and tarry residues and floating material. Routine inspections would normally be carried out at the same time as the routine monitoring for microbiological enumeration.

We propose that these on-site inspections should be included in the fortnightly sampling surveys.

10.2.2 Assessment of Contamination by Toxic Substances

As the toxic constituents noted in the Directive are relatively conservative in the environment and as the residence times in the dock are long, little variation in the concentrations of these substances is expected with time.

We therefore propose to undertake a complete initial survey in June. If the results of this survey, in combination with the results of the previous surveys, do not detect unsatisfactory concentrations in a particular dock then we propose to exclude that dock from further tests for these constituents. Instead resources should be concentrated on determining the extent of the problem in the docks, such as the West India, which are found to be contaminated.

The parameters to be measured in these surveys are mineral oils, surface-active substances, phenols, pesticides (parathion, HCH, dieldrin) total As, total Cd, total Cr (VI), total Pb, total Hg and cyanide. We recommend that Zn, total Cu and total Ni are also included.

10.2.3 Assessment of Contamination by Virus and Non-coliform Bacteria

The project provides for sampling and analysis for rotavirus and enterovirus on three separate occasions. However, the two previous surveys of viral concentration did not detect their presence. We therefore propose to carry out the first viral survey in July, and if no virus are detected from that survey we recommend that no further sampling for virus enumeration is carried out during the current bathing season.

Similar arguments apply to Salmonella determination, no organisms having been detected in the docks during previous surveys. However, we do propose to continue with routine monthly determinations of faecal streptococci as enumeration of this organism may be required under the EC Directive in the future.

10.3 Quantifying the Processes Controlling Microbial Contamination, Algal Growth and the Oxygen Balance

Further determinations of some of the water quality parameters specified in the original brief are no longer required, as sufficient information has now been collected. These parameters are specified in Section 10.3.1 Reductions in sample numbers are also suggested and as a result of our initial work, we have identified some additional measurements which should be made as they will provide a key insight into the important processes.

10.3.1 Analyses No Longer Required

- The chemical analyses no longer required either for dock-water samples or inflow samples are the major ions (alkalinity, sulphate, sodium, potassium, magnesium, calcium and iron), physical parameters (colour and turbidity), and dissolved total organic carbon.

- Zooplankton do not appear to be an important factor in the control of the algal population in the docks. We therefore feel that only a reduced monthly sampling for zooplankton is warranted.

- In three basins the number of sample sites can be reduced as no significant difference in water quality is noted between the alternative sampling positions.

  The sampling stations to be combined are 9 with 10, 11 with 12, and 26 with 27.

- Little information is being provided by the inclusion of a mid-depth sample for chemical parameters. We therefore propose eliminating mid-depth sampling at all sites. The upper sample will be collected at 0.2 m depth, and the lower sample will be collected at about 1 to 2 m above the bottom. The exact depth of this latter sample should be selected by observation of the temperature and conductivity profile, and will be recorded.

10.3.2 Additional Measurements Required

(a) Vertical Profiles of Conductivity, Temperature and Dissolved Oxygen

The specified three depth measurement of these variables does not provide sufficient information about the vertical structure of the water column. As noted in Chapter 8 on modelling this is the most important factor in controlling bacteriological die-off, algal growth and oxygen depletion.

A preferred method is to measure these three variables in situ at numerous depths at each station. The exact number of depths being selected at the time of sampling depending on the vertical variations observed.

(b) Biochemical Oxygen Demand (BOD)

After the parameters mentioned above, the most influential factor in providing an oxygen deficit in the water column is the BOD. We therefore propose that this should be included in the routine analyses.

(c) Light Extinction

Light extinction is an important parameter for controlling algal production and bacterial decay. This should be measured at frequent intervals, and should be related to concurrent chlorophyll concentrations.

We therefore propose to measure Secchi depth at all sample points wherever and whenever chlorophyll concentrations are measured.

(d) Chlorophyll Distributions

The algal populations vary markedly throughout the water column and with time. The limited data provided by a three depth weekly sample is insufficient to describe these changes. So as additional costs are not incurred, we propose to carry out the same number of determinations but in a different manner. Under our proposal samples for chlorophyll analysis would be collected weekly from near-surface at all sites, and once a month these data will be supplemented by sampling from eight depths at each site.

(e) C:P:N Ratio

The C:P:N ratio of the algal population relates the algal biomass to the P and N cycles. Total carbon, total phosphorus and total nitrogen analyses of the particulates in all water column samples will provide these data.

(f) Sampling of River Inflows

See Section 4.3, where this is described in detail.

10.4 Other Investigations

10.4.1 Silt

The silt is being sampled and analysed with the objective of determining its likely influence on water quality and possible constraints on its disposal due to the toxic contaminant content. As the chemical content of the silt is unlikely to change significantly with time we suggest that the three required sampling surveys are not carried out.

Instead we propose to carry out the June survey as required. However, to account for spatial variability samples should be collected at various sites within each particular dock and then thoroughly mixed before analysis.

If contaminated sediments are identified in a particular dock system, then future sampling efforts should be concentrated in that system to identify the degree of contamination more precisely. In addition, two alterations are proposed to the analytical procedures; and two analyses (as indicated in Section 10.5.3) are not required.

(a) Solids Content

Measurement of organic content of the silts is being carried out. We recommend that total solids content (on a wet weight basis) is also calculated. No additional laboratory measurements or costs are implied.

(b) Metals Content

To minimise risk of loss of volatile constituents such as mercury and arsenic during sample drying, we recommend that digestion of wet, homogeneous samples is carried out.

The final determination of metals and similar trace constituents could then be made by atomic absorption spectrophotometry.

The analysis should be carried out in accordance with the approved DOE SCA method.

10.4.2 Nuisance Algae

As stated in Section 6.3.2, there is anecdotal evidence of skin irritations resulting from contact with algae. Should the Corporation wish to consider this phenomenon we suggest that an appropriate level of investigation would be to carry out a survey of available literature. This would be additional the present work.

10.4.3 Fisheries

All the docks appear to contain or are likely to contain fish populations. In some of the docks angling occurs at the moment and, given greater public access, this may be a legitimate future use of the docks.

The objectives of the present study do not include fisheries as a possible use of the dock and the sampling and analytical techniques do not provide sufficient information to provide a satisfactory investigation of their use as a fishery, although the management strategies will aim at ensuring sufficient oxygen concentrations in the water to prevent catastrophic fish-kills.

If the Corporation considers that angling and fisheries, which in other areas are significant revenue earners, is an aspect which should be investigated then significant increases in costs could be expected.

10.5 Analytical Requirements

10.5.1 Water Chemistry

	Determinand	Unit	Detection limit	Precision	Comments
(a)	In-situ measurements:				
	Temperature	deg C	4.0	0.2	-
	Electrical conducitivty	$mS.cm^{-1}$	0.04	0.02	<4.0
	Dissolved oxygen	$mg\ l^{-1}$	-	0.2	≥4.0
	Secchi depth	m	0.1	0.1 - 0.5	-
	pH	-	4.0	0.2	-
(b)	On-site analysis:				
	Turbidity	NTU	2	2	not required
	Colour -	-	-		not required
	Sulphate	$mg\ l^{-1}$	5	4	not required
	Chloride	$mg\ l^{-1}$	100	100	-
	Alkalinity	$mg\ l^{-1}$	40	20	not required
(c)	Laboratory analyses:				
	Dissolved constituents:				
	Total phosphorus	$mg\ l^{-1}$	0.1	0.1	(1)
	Orthophosphate	$mgl\ l^{-1}$	0.02/0.5	0.01/0.1	<0.5/>0.5
	Nitrate nitrogen	$mgN\ l^{-1}$	0.02/0.5	0.01/0.1	<0.5/>0.5
	Nitrite nitrogen	$mgN\ l^{-1}$	0.02	0.01	-
	Ammoniacal/nitrogen	$mgN\ l^{-1}$	0.02	0.01	-
	Organic nitrogen	$mgN\ l^{-1}$	0.2	0.1	(1)
	Organic carbon	$mgC\ l^{-1}$	0.2	0.1	(1)
	Reactive silica	$mgSiO_2\ l^{-1}$	0.05/0.5	0.01/0.1	<0.5/>0.5
	Sodium	$mg\ l^{-1}$	50	10	not required
	Potassium	$mg\ l^{-1}$	10	2	not required
	Magnesium	$mg\ l^{-1}$	10	2	not required
	Calcium	$mg\ l^{-1}$	20	5	not required
	Iron	$mgFe\ l^{-1}$	1.0	0.1	not required
	Sulphide	$mgS\ l^{-1}$	0.2	0.1	Total ($H_2S + HS^-$)
	Chlorophylls	$\mu g\ l^{-1}$	5	2	-
(d)	Whole sample:				
	BOD	$mgO_2\ l^{-1}$	0.2	0.1	no seed, no dilution with ATU (1)
(e)	Trace constituents				
	Total arsenic	$mgAs\ l^{-1}$	0.4	0.1	-
	Total cadmium	$mgCd\ l^{-1}$	1.0	0.2	-
	Total lead	$mgPb\ l^{-1}$	0.4	0.1	-
	Total chromium	$mgCr\ l^{-1}$	0.4	0.1	-
	Total mercury	$mgHg\ l^{-1}$	0.15	0.1	-
	Total cyanide	$mgCN\ l^{-1}$	0.05	0.01	-
	Total phenol	$mg\ l^{-1}$	2.0	0.5	As C_6H_5OH
	Anionic detergents	$mg\ l^{-1}$	0.1	0.1	As lauryl sulphate
	Total zinc	$mgZn\ l^{-1}$	25	5	Recommended for analysis
	Total copper	$mgCu\ l^{-1}$	0.4	0.1	Recommended for analysis

Note: (1) on unfiltered sample

Determinand	Unit	Detection limit	Precision	Comments
Total nickel	mgNi/l	0.4	0.1	Recommended for analysis
Mineral oils	mg/l	0.2	0.1	-
Phenols	mg/l	0.002	0.001	As C_6H_5OH
PAH				
Fluoranthene	mg/l	5	1	-
Benzo(B)fluoranthene	mg/l	2	0.5	-
Benzo(K)fluoranthene	mg/l	2	0.5	-
Benzo(A)pyrene	mg/l	2	0.5	-
Benzo(GHI)perylene	mg/l	3	0.5	-
Indeno(123CD)pyrene	mg/l	2	0.5	-
Total	mg/l	20	4	-
Pesticide Screen				
Hexachlorobutadiene	mg/l	0.010	0.002	-
Tecnazene	mg/l	0.010	0.002	-
[Tetrachloroaniline]	mg/l	-	-	-
Alpha-BHC	mg/l	0.001	0.0002	-
Hexachlorobenzene	mg/l	0.001	0.0002	-
Gamma BHC	mg/l	0.001	0.0002	-
Aldrin	mg/l	0.001	0.0002	-
Isodrin	mg/l	0.002	0.0004	-
Dieldrin	mg/l	0.002	0.0004	-
DDE(PP)	mg/l	0.005	0.001	-
Endrin	mg/l	0.005	0.001	-
TDE(PP)	mg/l	0.005	0.001	-
DDT(PP)	mg/l	0.005	0.001	-
Trifluoraline	mg/l	0.010	0.002	-
Parathion	mg/l	0.040	0.008	-

10.5.2 Microbiology

Numerical enumeration should be provided for concentrations between the industrial upper and lower centration to permit comparison with the EC Directive Bathing Water.

Determinand	Unit	Detection limit	Precision	Comments
Faecal coliforms	MPN/100 ml	10	3 000	-
Total coliforms	MPN/100 ml	50	15 000	-
Faecal streptococci	MPN/100 ml	10	150	-
Salmonella	MPN/l	0	10	-
Enterovirus	MPN/10 l	0	10	-
Rotavirus	MPN/10 l	0	10	-

10.5.3 Silt Samples

Determinand	Unit	Detection limit	Precision	Comments
Density	g/ml	-	0.1	-
pH	-	4.0	0.2	-
Solids content	% m/m	5.0	1.0	wet weight basis
Organic content	% m/m	1.0	0.5	-
Total nitrogen	mgN/kg	500	50	-
Available nitrogen	-	-	-	not required
Total phosphorus	mgP/g	500	50	-
Orthophosphate	mgP/kg	500	50	-
Available phorphorus	-	-	-	not required
Sulphide	mgS/kg	20	5	total
Total arsenic	mgAs/kg	4	1	(2)
Total cadmium	mCd/kg	1	0.2	(2)
Total chromium	mgCr/kg	20	5	Cr(VI)+CR(III)
Total copper	mgCu/kg	20	5	(2)
Total lead	mgPb/kg	50	5	(2)
Total mercury	mgHg/kg	0.1	0.01	(2)
Total nickel	mgNi/kg	50	5	(2)
Total tin	mgSn/kg	1	0.2	(2)
Total zinc	mgZn/kg	50	5	(2)

Note: (1) All analyses to be expressed on a dry weight basis on homogenised sample.
(2) After digestion with concentrated HNO_3/HCl

10.5.4 Sample Collection and Preparation

The details of the methods of sample collection and preparation are summarised below.

Determinand	Container material	Washing/preservation	Sample volume required
Ammoniacal N Organic N Organic C Total phenol*	Glass	Wash with chromic acid Preserve: (10 ml 5M H_2SO_4) Analar/litre	1 litre
Copper * Arsenic * Cadmium* Lead * Hexavalent chromium* Nickel Zinc Calcium Magnesium	LDPE	Wash: 24 h nitric acid soak DI clean Preserve: 10 ml 10M HCl/litre or 4 ml conc HCl/litre (WRC)	2 litres
Cyanide * Total phosphorous Orthophosphate		Wash: Detergent	
Nitrate Nitrite Silica Iron Sodium Potassium Anionic surfactants	Polythene	Store at 4°C	1 litre

Determinand	Container material	Washing/preservation	Sample volume required
Sulphide	Polythene	Wash: Detergent Preserve: 4 drops 2 N zinc acetate (Analar) + NaOH (Analar)/litre	250 ml
Mercury*	Glass	Wash: 24 h nitric acid soak DI clean Preserve: Acidic dichromate sol	1 litre
Bacteriology	Glass	Sterile	min 500 ml

Notes: (1) * Analysis on surface (A) samples only

(2) All preservation conducted by Mott MacDonald on site.

(3) 2 ml/l 20% w/v $K_2Cr_2O_7$ solution prepared in 1 + 1 HNO_3

10.6 Conclusions

A summary of the proposed sampling programme as described above, at the frequency envisaged in the original brief and with dock water sampling sites reduced to 25, is presented in Table 10.1. It is clear from the table that a very large amount of data will be generated, much of which will not be of specific use in developing the management strategy.

It is therefore proposed that the programme of sampling and analysis is concentrated much more on specific areas and greater allowance is made for time to assess data. Table 10.2 shows a summary of a proposed reduced sampling programme and allows for:

- monitoring of all docks to assess compliance with the EC Bathing Water Directive;
- survey of all docks for toxic viral contamination;
- monitoring inputs to all dock systems;
- carrying out detailed surveys of the main docks in the Isle of Dogs, the Royal Docks and the Canada Water/Surrey Water system. This detailed data will allow development of the management model that will be designed to suit all of the dock systems.

At the same time techniques for controlling floating debris and surface films will be assessed and the best methods will be selected and recommendations made.

At the end of the growing season it is suggested that a further report will be produced to review progress. Issues that will need to be considered include, the need to continue with the study during the winter months, and provisions to be made for the study starting later in the growing season than originally envisaged.

The suggested programme for Stage 2 is considerably different from the Brief and it is very likely that this will change as more data become available. In a similar way the time and associated cost for data assessment has and will change. This study has a large investigative component and the ability to be flexible and maximise our resources at short notice is very important. This includes being able to carry out additional tests or determine critical reaction rates, which were not specified in the original brief, as the need arises.

The format of the present contract does not facilitate this easily. The original Brief allows for certain parts of the study to be carried out on a time basis. It is now evident from the way that the project is developing that it should all be carried out in this manner. It is proposed that there should be an agreed ceiling cost for expenditure and monthly records of time and expenditure incurred submitted to the Client for monitoring, as the study progresses.

TABLE 10.1

Summary of Proposed Phase 2 Sampling in All Dock Systems

Description	Sample sites per survey	Sample depths per site	Number of* surveys	Total number of samples
Dock water sampling:				
EC monitoring (Section 10.1.1)	25	1	10	250
Contamination by toxic substances (10.1.2)	25	1	10	250
Contamination by viruses and bacteria (10.1.3)	25	1	3	75
Zooplankton (10.2.1b)	25	(haul)	10	250
General chemical/bacterial (10.2.1 & 10.2.2b&c)	25	2	10	500
EC/T/DO profiles (10.2.2a)	25	8	10	2 000
Secchi depth/light profiles (10.2.2c)	25	1	44	1 100
Chlorophyll (10.2.2.d)	25	8	10	2 000
	25	1	44	1 100
C:P:N in particulates (10.2.2e)	25	1-2	10	500
Inflow sampling:				
General chemical/microbiological (10.2.2f)	17	1	10	170
Toxic substances (10.1.2)	17	1	10	170
Virus/bacteria (10.1.2)	17	1	3	51
Silt:	25	1	3	75

Note: * assuming 10 monthly sampling rounds

TABLE 10.2

Summary of Proposed Reduced Phase 2 Sampling

Description	Sample sites per survey	Sample depths per site	Number of surveys	Total number of samples
Water sampling:				
EC monitoring (Section 10.1.1)	25	1	10	250
Contamination by toxic substances (10.1.2)	25	1	1	250
Contamination by virus and bacteria (10.1.3)	25	1	3	75
Zooplankton (10.2.1.b)	16	(haul)	10	160
General chemical/bacterial (10.2.1 +10.2.2b & c)	16	2	10	320
EC/T/DO profiles (10.2.2a)	16	8	10	1 280
Secchi Depth /tight profiles (10.2.2c)	16	1	44	704
Chlorophyll (10.2.2.d)	16	8	10	1 280
	16	1	44	704
C:P:N in particular (10.2.2e)	16	2	10	320
Inflow Sampling:				
General chemical/microbiological (10.2.2f)	17	1	10	170
Toxic substances (10.1.2)	17	1	10	170
Virus/bacteria (10.1.2)	17	1	3	51
Silt	25	1	3	75

CHAPTER 11

QUALITY ASSURANCE

11.1 Introduction

During this first survey phase quality assurance methods appropriate to the preliminary nature of the investigation have been adopted. The full quality assurance procedures for the chemical analyses can only be implemented after appropriate detection limits are specified and samples are being analysed routinely. Appropriate detection limits for the various determinations have been proposed in Chapter 10 based on the results received from the Phase 1 survey.

Inspections have been made by Water Research Centre specialists of the principal laboratories carrying out the analyses. These inspections had the primary objective of assessing the methods and procedures in use, and to ensure that satisfactory documentation will enable auditing to be carried out during future surveys. The observations made during the inspections are presented below.

11.2 Sampling

11.2.1 Procedure Adopted

A satisfactory sample numbering system has been adopted, as noted in Chapter 5, each bottle being marked with the appropriate number in indelible marker ink. Sample bottles have received the minimum necessary preparation for general analyses and have been rinsed on-site with the water to be sampled. Given the general nature of the determinations to be made, sample preservation was limited to refrigeration or storage in insulated boxes until delivered to the laboratory.

11.2.2 Recommendations for Future Surveys

(a) Labelling written directly on bottles may be erased in transit. Although this did not occur during this survey future labelling will be by indelible marker ink on waterproof labels fixed to the bottles.

(b) During future surveys samples will be collected for many different determinands requiring various methods of preservation and sample bottle material. These will be provided as detailed in Chapter 10.

(c) Sample bottle cleaning procedures should be documented. In future surveys different determinands require different bottle cleaning techniques. The procedures to be adopted are also noted in Chapter 10.

(d) Information about the samples, in addition to that included in the sample numbers, will be provided by the sampling team to the laboratories on delivery of the samples. This will include such information as time of sampling, electrical conductivity and dissolved oxygen concentrations.

11.3 Analytical Chemistry

11.3.1 Procedures Adopted

Analytical procedures adopted by the Associated Laboratory Services are suitable for the preliminary nature of this survey, although some changes will be required in light of the results obtained. No internal analytical quality control was carried out during this first survey, but suitable procedures for both internal and external quality control were agreed between the laboratory and WRc. Quality control inspections of field analyses have not yet been carried out.

11.3.2 Recommendations for Future Surveys

(a) A nitrate determination technique will be made available for use if saline or very low concentration samples are collected.

(b) Analytical techniques appropriate to the detection levels given in Chapter 10 will be used.

(c) Internal analytical quality control procedures as agreed with WRc will be adopted.

(d) WRc will provide external control by provision of Aquacheck samples and will closely monitor the results of these exercises so any necessary remedial action can be taken immediately.

11.4 Bacteriology

Total coliform, faecal coliform and faecal streptococci examinations are made by Braintree District Council laboratory. Salmonella assays are carried out by Berridge Environmental Laboratories. The former was inspected by WRc.

11.4.1 Procedure Adopted

The analyses carried out at the laboratory are of a satisfactory standard. However, larger volume samples are required to determine low numbers of organisms.

Samples for bacteriological specimens are collected directly into the bottle, with suitable precautions to avoid contamination of the sample.

11.4.2 Recommendations for Future Surveys

Sample volumes wil be increased to 600 ml.

11.5 Algology and Zooplankton

Queen Mary College undertakes the algal and zooplankton determinations. The laboratory is very satisfactory and the staff carrying out the work are well experienced in the assays required.

Zooplankton sampling and counting procedures are satisfactory.

Chlorophyll determinations are carried out using a novel mixed solvent technique. This is to be compared with the older technique using boiling methanol, a reagent which is teratogenic and not now considered suitable for routine use.

Algal identification following concentration of cells in a 55 micron plankton net is to be confirmed by comparison with an alternative method designed to capture all algae by sedimentation after iodine treatment.

APPENDIX A

UK RIVER AND ESTUARY QUALITY CLASSIFICATION SCHEME

APPENDIX B

COUNCIL DIRECTIVE CONCERNING THE QUALITY OF BATHING WATER

APPENDIX C

COUNCIL DIRECTIVE ON THE QUALITY OF FRESHWATERS NEEDING PROTECTION OR IMPROVEMENT IN ORDER TO SUPPORT FISH LIFE

APPENDIX D

COUNCIL DIRECTIVE ON THE QUALITY REQUIRED OF SHELLFISH WATERS

APPENDIX E

COUNCIL DIRECTIVE ON POLLUTION CAUSED BY CERTAIN DANGEROUS SUBSTANCES DISCHARGED INTO THE AQUATIC ENVIRONMENT OF THE COMMUNITY

APPENDIX F

PROPOSAL FOR A COUNCIL DIRECTIVE ON THE DUMPING OF WASTE AT SEA

Appendix G

Algology and Zooplankton

Test Materials and Methods

APPENDIX G

ALGOLOGY AND ZOOPLANKTON TEST MATERIALS AND METHODS

G.1 Algae

G.1.1 Chlorophyll Concentration

(i) Collection

Water samples at all sites were collected at the surface, mid-depth and bottom of the water column in 1 or 2 l Ruttner sampling vessels. Closure at the appropriate depth was effected with a brass messenger sent down the sampling line.

(ii) Extraction and Measurement

Appropriate volumes (usually 250 ml to 1 000 ml) were filtered through 0.8 μm pore size cellulose acetate filters. Suction was provided by a series of vacuum pumps. Samples were filtered on the day of collection, and dried under vacuum in a desiccator at 4°C for 48 hours.

Pigment extraction and filter dissolution was achieved by overnight incubation in sealed and darkened tubes containing 5 ml 90% acetone.

Extracted samples were then centrifuged at 4 000 rpm for 10 minutes. The supernatant absorbance was measured with a Pye Unicam SP6-550 spectrophotometer in a 1 cm path length glass cuvette at 750, 664, 647 and 630 nm.

Chlorophyll a, b and c concentrations were calculated using the method of Parsons et al (1984)[1].

G.1.2 Algal Counts and Species Composition

(i) Sample Collection

Surface water samples, 10 l in volume, were filtered through a 55 μm mesh plankton net and resuspended in 30 ml water. A further 10 l sample, filtered in the same way was preserved in 30 ml 5% formalin.

(ii) Measurement and Identification

Counts and identifications were made using a Nikon stereoscopic SM2 microscope fitted with a 355 EFM camera.

Quantitative estimations were made in one of three ways depending on cell density and species composition.

(a) with a haemacytometer of 1/16 mm^2 x 0.2 mm minimum grid volume.
(b) with a 1 ml volume Sedgewick-Rafter cell.
(c) by curvimeter measurements of filament length using black/white photography of a 1 mm^2 area of haemacytometer field. Eukaryotic filaments in which individual cells could be discerned were measured in this way and then cell numbers per ml calculated. Prokaryotic filaments in which individual cells were not discernible are given as 100 μm units.

G.2 Additional Monitoring Tests

G.2.1 P/I Measurements

Surface samples from each site were taken during sampling rounds 1 and 2 and were concentrated by centrifugation to a suitable cell density. Aliquots 5 ml in volume were then placed in the chamber of a Clarke-type oxygen electrode. Temperature was controlled at 15°C. The algae were exposed to alternating light/dark periods of 5 to 10 minutes each. Differing photon flux densities were provided by halogen filament bulbs at varying distances from the electrode.

Oxygen evolution and uptake rates were recorded on a BBC chart recorder.

G.2.2 Light/Depth Measurements

(i) Secchi Disc Measurements

A 25 cm diameter steel disc painted in black and white quadrants was lowered into the water at each sampling site on all occasions and the depth at which the disc disappeared from view was recorded. The Secchi depth gives a rather crude but extremely useful estimate of the opacity of the water. Secchi depths in the order of 50 cm are indicators of highly eutrophic conditions.

(ii) Photon Flux Density Measurements

During the third round of sampling photon flux density was measured at the surface and at 0.5 m depth intervals with a Delta-T Devices Ltd quantum sensor with a 15 m cable, connected to a battery driven Delta-T microvolt integrator.

Light influx was measured for a period of 1 minute at each position. Results were expressed as $\mu mol\ m^{-2}\ s^{-1}$. A cut-off point below which no further measurements were made was set at 5 counts per minute, equivalent to c. 10 $\mu mol\ m^{-2}\ s^{-1}$. This value was used since the P/I curves demonstrated this to be the limit of net photosynthesis (compensation point) in the algae tested.

G.2.3 Chlorophyll/Depth

Water samples at all sites during the third sampling round were taken with a 2 l Ruttner sampler at metre intervals from surface to bottom.

Chlorophyll concentrations were measured as described in Section G.1.1.

G.3 Zooplankton

G.3.1 Collection

Zooplankton samples were collected at all sites using a 250 μm mesh zooplankton net with an opening diameter of 0.25 m. Collection was by vertical haul from just above the bottom sediment to the water surface. The water depth was noted. Samples were then transferred to 30 ml Sterilin tubes and preserved in 25 ml 10% formalin.

G.3.2 Zooplankton Counts and Species Composition

(i) Counts

Subsamples of known volume (usually 1 or 2 ml) were transferred to a petri dish marked with a 5 mm grid and the total number of individuals counted under a monocular microscope. An estimate of the number of zooplankton per litre for each site could then be calculated by relating the number of individuals in the subsamples to the volume of water sampled on site.

(ii) Species Composition

The different species of Crustacea comprising each subsample were identified using a monocular microscope, counted and the percentage composition calculated.

References

(1) Parsons, T R, Maita, Y and Lalli, C M (1984) A Manual of Chemical and Biological Methods for Seawater Analysis. Pergamon Press, Oxford, 173 pp.